High Consequence Scenarios for North Korean Atmospheric Nuclear Tests

with Policy Recommendations for the U.S. Government

Working Paper of the Foundation for Resilient Societies

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Cover Image: The debris fireball and aurora created by the Starfish Prime test, as seen from a KC-135 aircraft at 3 minutes after detonation at 09:00:09 UTC on July 9, 1962. Note tail of observation aircraft is visible in lower right of image. Photograph taken by U.S. Air Force 1352nd Photographic Group, image and caption courtesy of Defense Threat Reduction Agency.

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Introduction

On August 8, 2017, North Korea threatened the U.S. territory of Guam with a "ring of fire." On September 3, 2017, North Korea conducted an underground test of a high-yield nuclear device claimed to be a hydrogen bomb. This device, if weaponized, could be carried on an intercontinental ballistic missile (ICBM)—such as the missile tested on July 18, 2017—and detonated at high altitude to execute an electromagnetic pulse (EMP) attack. On September 3, coincident with its bomb test, North Korea declared a "super-powerful EMP attack" capability to be a "strategic goal." On September 22, 2017, Ri Yong Ho, Foreign Minister of North Korea, spoke of a potential atmospheric nuclear test. On October 13, 2017, North Korea state media published a threat to "take counteractions for self-defense, including a salvo of missiles into waters near the US territory of Guam."[1] In a CNN interview aired on October 25, 2017, a senior North Korean official repeated a threat of an atmospheric nuclear test.[2] We expect this pattern of North Korean threats to continue.

On September 20, 2017, U.S. Air Force General John E. Hyten validated in public that EMP attack is "a very dangerous threat." As commander of U.S. Strategic Command, General Hyten has the responsibility for assuring the viability of America's nuclear deterrent. General Hyten also stated, "Our nation as a whole has not looked at EMP, we have not looked at the critical infrastructure that could be damaged by EMP, and we need to take a step back and look at that entire threat because it is a realistic threat."[3]

The Congressional EMP Commission likewise concluded in 2004 that EMP is "one of a small number of threats that has the potential to hold our society at risk and might result in defeat of our military forces."[4] In short, multiple credible authorities have concluded that EMP attack by North Korea poses an existential threat to America.

In this working paper, we provide a brief appraisal of the nature of the EMP effects and how technical experts might proactively prepare for atmospheric nuclear tests. To aid government policymakers, we consider five atmospheric test scenarios conducted via ballistic missile that North Korea might pursue, taking into account potential trajectories, detonation altitudes, and impacts on humans and critical infrastructure.

We found that all atmospheric nuclear test options in the Pacific cause significant risk for both humans and critical infrastructure.

We urge the U.S. Government to immediately prepare for North Korean atmospheric nuclear tests. Moreover, the U.S. Government should rapidly assess the implications of such tests if they occur—and prepare in advance appropriate diplomatic, political, military, and technical responses.

Optimistically, U.S. actions, diplomatic and otherwise, will forestall such atmospheric tests. Nonetheless, the United States, in concert with its allies, should proactively install EMP instrumentation and recording devices in the Pacific region.

Executive Summary

On September 3, 2017, the Korean Central News Agency of the Democratic People's Republic of Korea stated that the capability to conduct high-altitude electromagnetic pulse (EMP) attack is a strategic goal of the regime. On September 22, 2017, the North Korean foreign minister remarked to reporters in New York that his country may conduct an atmospheric hydrogen bomb test above the Pacific Ocean. Multiple commentators have speculated that a North Korean atmospheric test in the Pacific could have the purpose of demonstrating an EMP attack capability.[5] [6]

In order to deter attack or regime change, North Korea must threaten severe consequences on the United States. The former technical director of the Defense Nuclear Agency, George W. Ullrich, has stated, "The single, most effective use of a nuclear weapon by a Third World country would be a high-altitude detonation to debilitate sophisticated electronics technologies…"[7] High-altitude EMP may ultimately be North Korea's strongest deterrent, holding the American population under threat of sustained and widespread disruption of U.S. critical infrastructure with only a small number of nuclear weapons. However, because EMP tests by the U.S. and Soviet Union five decades ago were inadequately instrumented by current day standards, and because the limited test results have been withheld as classified information, North Korea currently lacks technical data to definitively make an EMP attack on the United States a credible threat.

Authoritative sources such as the congressionally authorized Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack ("Congressional EMP Commission") have concluded that EMP is a severe and even existential threat to America. Nonetheless, other analysts routinely discount the EMP threat, undermining its deterrent value to North Korea.[8] An atmospheric test of EMP could end this debate by demonstrating widespread debilitation of modern infrastructures dependent on miniaturized electronics, undersea telecommunication cables, space satellites, and associated ground stations.

The Foundation for Resilient Societies has postulated a variety of scenarios for both high-altitude EMP tests and low-altitude non-EMP nuclear tests to aid in determining potentially advantageous locations for pre-positioning instrumentation. We took into consideration potential missile trajectories, detonation altitudes, and impacts on critical infrastructure and human populations. We found that the vast expanses of the Pacific Ocean provide a wide range of test options, but that all possible trajectories and detonation altitudes pose significant risks to human populations and critical infrastructures.

Based on our assessment, we recommend that the U.S. Government move quickly to pre-position measurement instruments at several locations. The large geographic footprint of EMP effects—up to 5,000 kilometers across— reduces the number of needed instrumentation locations and greatly increases the likelihood of data capture. Data collected from any EMP tests would increase scientific understanding of these phenomena, aid public and private sector investments in critical infrastructure protection, inform strategic responses, and provide insights respecting North Korean nuclear weapons designs.

Some candidate locations for North Korea EMP tests in the Pacific Ocean might result in disrupted global trade, impaired intercontinental communications, and damage to critical infrastructures in Hawaii and other U.S territories, Russia, China, South Korea, Japan, and other nations. Accordingly, through concerted regional diplomacy, the U.S. should redouble efforts to discourage high-altitude EMP testing that can be anticipated to harm many nations. In parallel, the United States should prepare for "anticipatory self-defense" campaigns, including attempts to prevent launches—and to enable ballistic missile interceptions were launches to occur.[9]

North Korean Statements and Actions on Nuclear Program Goals

On August 8, 2017, in an official statement, North Korea threated the U.S. territory of Guam:[10]

> *The KPA Strategic Force is now carefully examining the operational plan for making an enveloping fire at the areas around Guam with medium-to-long-range strategic ballistic rocket Hwasong-12 in order to contain the U.S. major military bases on Guam including the Anderson Air Force Base in which the U.S. strategic bombers, which get on the nerves of the DPRK and threaten and blackmail it through their frequent visits to the sky above south Korea, are stationed and to send a serious warning signal to the U.S.*

On September 3, 2017, North Korea conducted an underground test of a high-yield nuclear weapon. Seismic readings indicated that the yield was consistent with a small hydrogen bomb or boosted fission device.[11] In an official statement, North Korea claimed that a hydrogen bomb had been tested:[12]

> *Scientists in the nuclear field of the DPRK successfully carried out a test of H-bomb for ICBM in the northern nuclear test ground of the DPRK at 12:00 on September 3, true to the Workers' Party of Korea's plan for building a strategic nuclear force.*

Just hours before the September 3, 2017 bomb test, the Korean Central News Agency released a statement with the headline "North Korean leader Kim Jong-un gives guidance to nuclear weaponization of ICBM." Communist party Chair Kim Jong-un declared EMP attack capability is a strategic goal of his regime:[13]

> *The H-bomb, the explosive power of which is adjustable from tens kiloton to hundreds kiloton, is a multi-functional thermonuclear nuke with great destructive power which can be detonated even at high altitudes for super-powerful EMP attack according to strategic goals.*

On September 19, 2017, President Donald Trump made a speech to the United Nations General Assembly, saying:[14]

> *North Korea's reckless pursuit of nuclear weapons and ballistic missiles threatens the entire world with unthinkable loss of human life…The United States has great strength and patience, but if it is forced to defend itself or its allies, we will have no choice but to totally destroy North Korea. Rocket Man is on a suicide mission for himself and for his regime.*

In response to President Trump's United Nations speech, Kim Jong-un made a televised statement on September 22, 2017:[15]

> *Now that Trump has denied the existence of and insulted me and my country in front of the eyes of the world and made the most ferocious declaration of war in history that he would destroy the DPRK, we will consider with seriousness taking a corresponding, highest level of hard-line countermeasure in history.*

Only hours after Kim Jong-un's September 22, 2017 threat against the U.S., Ri Yong Ho, Foreign Minister of North Korea, spoke to reporters in New York, stating: [16]

> *In my opinion, perhaps we might consider a historic aboveground test of a hydrogen bomb over the Pacific Ocean.*

On October 13, 2017, North Korean state media published a renewed threat to launch missiles on a trajectory terminating near the U.S. territory of Guam. The media release quoted Kim Kwang Hak, a researcher at the Institute for American Studies of the North Korean Foreign Ministry:[17]

> *We have already warned several times that we will take counteractions for self-defense, including a salvo of missiles into waters near the US territory of Guam…the US military action hardens our determination that the US should be tamed with fire and lets us take our hand closer to the 'trigger' for taking the toughest countermeasure.*

On Wednesday, October 25, 2017, a senior North Korean official, Ri Yong Pil, repeated foreign minister Ri Yong Ho's threat of an atmospheric nuclear test:[18]

> *The foreign minister is very well aware of the intentions of our supreme leader, so I think you should take his words literally.*

Electromagnetic Pulse Capability as a "Strategic Goal"

North Korea has declared "super-powerful EMP attack" capability as a "strategic goal" of its nuclear weapons program. To conduct a high-altitude EMP attack, a nuclear weapon is detonated at an altitude of approximately 40 kilometers to 400 kilometers. Ionizing radiation from the detonation interacts with the earth's magnetic field and electrons in the thin atmosphere to produce a series of electromagnetic pulses radiating downward within line-of-sight of the burst. The first pulse (E1) can debilitate electrical and electronic equipment. Electronic communication and control equipment is particularly vulnerable, precipitating failure of critical infrastructure including the electric grid, telecommunications, the Internet, transportation, oil and chemical refineries, drinking water supplies, sewage pumping and treatment, banking and finance, and a host of other critical infrastructures. A subsequent pulse (E3) can damage or destroy high-voltage transformers essential for long-distance transmission of electricity and also debilitate both land and undersea telecommunications systems. For a detonation at 40 kilometers altitude, the diameter of the line-of-sight area on the ground is approximately 1,400 kilometers. For a detonation at 400 kilometers altitude, the diameter of the line-of sight-area on the ground is approximately 4,400 kilometers.

Why would EMP be a preferred means of nuclear attack by North Korea, a higher strategic priority than ground-level attack causing shock, blast, fallout, and ground-level radiation? We propose that the North Korean incentives fall into three basic categories. First, to achieve an EMP attack capability, North Korea would have fewer technical obstacles than for ground-level attack. Second, a high-altitude burst EMP attack is wide-area threat—with one or a few nuclear warheads mounted on missiles for EMP attack, North Korea can credibly threaten the vast majority of U.S. infrastructure, whereas a surface-burst attack on a few cities would not have the same widespread impact. Third, an EMP attack will not directly cause human fatalities, although wide-area critical infrastructure failure in the aftermath will certainly result in economic disruption and long-term loss of life. However, without immediate loss of life, the international community may lack consensus that an EMP attack justifies retaliation using nuclear weapons, perhaps decreasing the risk of escalation.

Achieving Electromagnetic Pulse Attack Capability

The technical pathway to achieving a high-altitude EMP attack has far fewer obstacles than a ground-level blast and shock attack. Fundamentally, lightweight EMP devices, with a much wider area of impact, are easier to deliver than higher yield weapons designed to produce localized ground-level damage.

For ground-level attack, the warhead must be delivered over a long distance, necessitating a fleet of long-range bombers (including aircraft carriers and/or air refueling capability), submarines or ships capable of crossing oceans undetected, or intercontinental ballistic missiles (ICBM) with inertial guidance systems. If ICBMs are to be the delivery mechanism, the warhead must survive the heat and vibration of reentry. Ground-level blast and shock effects vary with the cube root of the yield of the warhead. Effective ground-level attack with small warheads requires accurate delivery or the use of multiple reentry vehicles.

The technical requirements to execute an EMP attack are more easily surmounted. The warhead must be lofted to an altitude of at least 40 kilometers; this altitude can be attained with a crude missile launched from a ship or submarine. An accurate inertial guidance system is not required—detonation dozens or even hundreds of kilometers off-course will still cause EMP over a wide area—the line-of-sight effects coverage has diameter hundreds or even thousands of kilometers across. EMP detonation at altitude 100 kilometers or greater avoids the challenges of designing a reentry vehicle. Detonation over the ocean, well outside national borders, can expose areas hundreds of miles inland.

EMP effects do not vary proportionately with yield of the warhead—a low-yield device detonated at an optimal altitude can produce EMP effects of approximately the same magnitude as a high-yield device. While nuclear blast and shock effects diminish rapidly with distance from the detonation, the most-damaging EMP effects are remarkably uniform within line-of-sight of the detonation. Because only a small amount of the energy released by the detonation is needed to produce EMP effects, there is opportunity to design and test small low-yield, high-efficiency EMP weapons—or "super-powerful EMP" devices in the parlance of North Korea.

Electromagnetic Pulse as an Asymmetric Threat to Large Nations

Large, industrialized nations such as the United States are dependent on critical infrastructure such as electric grids, telecommunication networks, and computer-controlled water treatment systems for daily survival. All critical infrastructures depend on electric grids. Electric grids, in turn, depend on microprocessor-based control systems that are highly vulnerable to electromagnetic pulse. Hard-to-replace high voltage transformers are another key EMP vulnerability of electric grids.[19]

The Congressional EMP Commission concluded:[20]

> *The high-altitude nuclear weapon-generated electromagnetic pulse (EMP) is one of a small number of threats that has the potential to hold our society seriously at risk and might result in defeat of our military forces.*

More recently, on September 20, 2017, General John E. Hyten, the commander of United States Strategic Command, addressed the EMP threat in public remarks to the 2017 Air Force Association conference:[21]

> *An EMP is a very dangerous threat and it's a realistic threat. It's something that would basically—if you're not nuclear hardened—it will basically shut down any digital computer that is operating in the range of the EMP…The most likely way to create EMP is with a nuclear weapon and you don't actually have to kill anyone directly with a nuclear weapon to create that horrible EMP pulse.*

Without functioning electric grids, and the functioning of dependent infrastructures, industrialized nations cannot support their dense, urbanized populations. It is not an overstatement to say that an effectively executed electromagnetic pulse attack could be existential threat to a large nation.

In contrast, North Korea is far less dependent on its electric grid and other modern infrastructure, as this NASA nighttime photograph of the Korean Peninsula shows:

Figure 1. NASA Photograph of Korean Peninsula at Night in 2014

Therefore, it is not surprising that the small nation of North Korea has ambitions to exploit EMP as an asymmetric threat against the much larger and more industrialized U.S.

International Perceptions of Electromagnetic Pulse Attack

Because an EMP attack would be against critical infrastructure, and would only indirectly cause human casualties, near-term international consensus that retaliation with nuclear weapons is justified may not exist. The technical phenomena of EMP can be unfamiliar to heads of state and their diplomats, while all nations understand the effects of ground-level nuclear attack on human populations. Were an EMP attack to be launched from a ship or submarine, the source of the attack might not be immediately traceable.[22] The impact zone for EMP is large—up to 5,000 kilometers across. The wide-area effect of EMP would allow an attacker to detonate EMP devices above international waters and still expose large inland geographies, causing massive debilitation of land-based infrastructure.

The International Legal Regime: Atmospheric Testing Opportunities

Treaties Restricting Atmospheric Nuclear Tests

The legal regime affecting high-altitude testing of nuclear weapons by North Korea is unfavorable, but probably not sufficient in itself to deter North Korean atmospheric testing. An international consensus developed during the atmospheric testing in the 1950s and early 1960s, resulting in the Limited Test Ban Treaty (LTBT) of 1963.[a] The LTBT treaty allows testing underground, but not in the atmosphere, outer space, or underwater. North Korea is not a party to this treaty. Other nations have refrained from joining this treaty and later tested in the atmosphere, without direct military response against these nuclear testing nations.

North Korea is, however, a state party to the Environmental Modification Convention of 1977 ("the ENMOD"), which entered into force in October 1978. The ENMOD treaty limits purposeful manipulation of the earth's environment that causes widespread, severe, or long-lasting harm to other state parties. An EMP-enhanced nuclear weapon or multiple weapons detonated in the upper atmosphere could cause widespread, severe, or long-lasting harm to critical infrastructures, through the electromagnetic modification of the earth's environment. Such intentional action could be a "material breach" of the ENMOD Convention.

Because this Convention directs initiatives for remedial action to the U.N. Security Council, an imprudent design feature of the treaty,[23] North Korea might seek shelter from China, Russia, or both—each a permanent member with veto power in the Security Council. Even were a veto to be exercised to shield North Korea from enforcement actions under Chapter VII of the United Nations Charter, member states suffering damage to critical infrastructure and possibly extensive loss of life could invoke their superior rights under Article 103 of the Charter to exercise mutual obligations for self-defense under Article 51.[24]

Moreover, technical constraints in the design of the high-altitude EMP event or events might reduce the geographic reach or the prompt damage from a high-altitude EMP attack, so that apologists for North Korean misconduct might argue that sanctions should not be extended beyond those already imposed by the United Nations in September 2017.

Testing Opportunities Nearby North Korea

North Korea may consider detonating an atmospheric hydrogen bomb test in the Sea of Japan, within its Pyongyang (ZKKP) Flight Information Region (FIR).[25] The Pyongyang FIR was established by international agreement through the International Civil Aviation Organization (ICAO) of the United Nations. This FIR and the region immediately to its east has been a common testing ground for unarmed missiles, despite danger to aircraft transiting commonly traveled airline routes.

[a] See the Treaty Documents and UN Resolutions section of this paper for a click-through hyperlink to the text, list of signatory states, and state parties for treaties.

Most nations that have tested nuclear weapons above the land or ocean surfaces have done so within their national territory, within colonies, or within trust territories under their jurisdiction. North Korea has no such proprietary test regions. One alternative that North Korea might consider is a test within their restricted air defense zone and/or Pyongyang FIR in the Sea of Japan, eastward of North Korea as shown in Figure 2 below.

We consider an atmospheric nuclear test by North Korea in the Sea of Japan to be possible, but unlikely. An atmospheric test in the Sea of Japan without Notices to Airmen and Notices to Mariners would be an extremely provocative act. However, if North Korea were to provide proper notice of a test, there is the risk that a missile delivery system would be shot down by Terminal High Altitude Area Defense (THAAD) systems in South Korea or Aegis ballistic missile systems onboard U.S. Navy ships. Likewise, aircraft or ships used as delivery systems by North Korea could be intercepted.

For the line-of-sight of the nuclear fireball to stay within the area of the Pyongyang FIR shown in Figure 2 below, the test would require an altitude limitation of approximately 1 kilometer.[a] Such a choice would preclude North Korea from demonstrating a high-altitude EMP weapon and from assessing electromagnetic effects (E1, E2, and E3) of such a weapon. To test even minimal E1 and E3 effects, it would be necessary for North Korea to detonate a device at an altitude of at least 40 kilometers—and EMP effects would undoubtedly spill over the territory of other nations.[26]

Policymakers should take note that North Korea has threatened missile launches terminating in the Pacific Ocean near Guam and also threatened an atmospheric nuclear test — these statements are consistent with intent to conduct a high-altitude EMP test. If North Korea's objective is to demonstrate high-altitude "super EMP" capability, as previously stated by Party officials, such a test cannot occur in the Sea of Japan without significant damage to infrastructure of other countries. Any test in the Sea of Japan capable of producing high-altitude EMP effects would damage land based critical infrastructure in Vladivostok, portions of China, much of South Korea and Japan, as well as North Korea itself.

[a] We recognize that within "line-of-sight" of the detonation point is a somewhat arbitrary benchmark for direct nuclear effects, including visual impacts. However, we employ this measure for an atmospheric nuclear test within the Pyongyang FIR to show that the FIR region is so small that tests without impact to other nations would be extremely difficult.

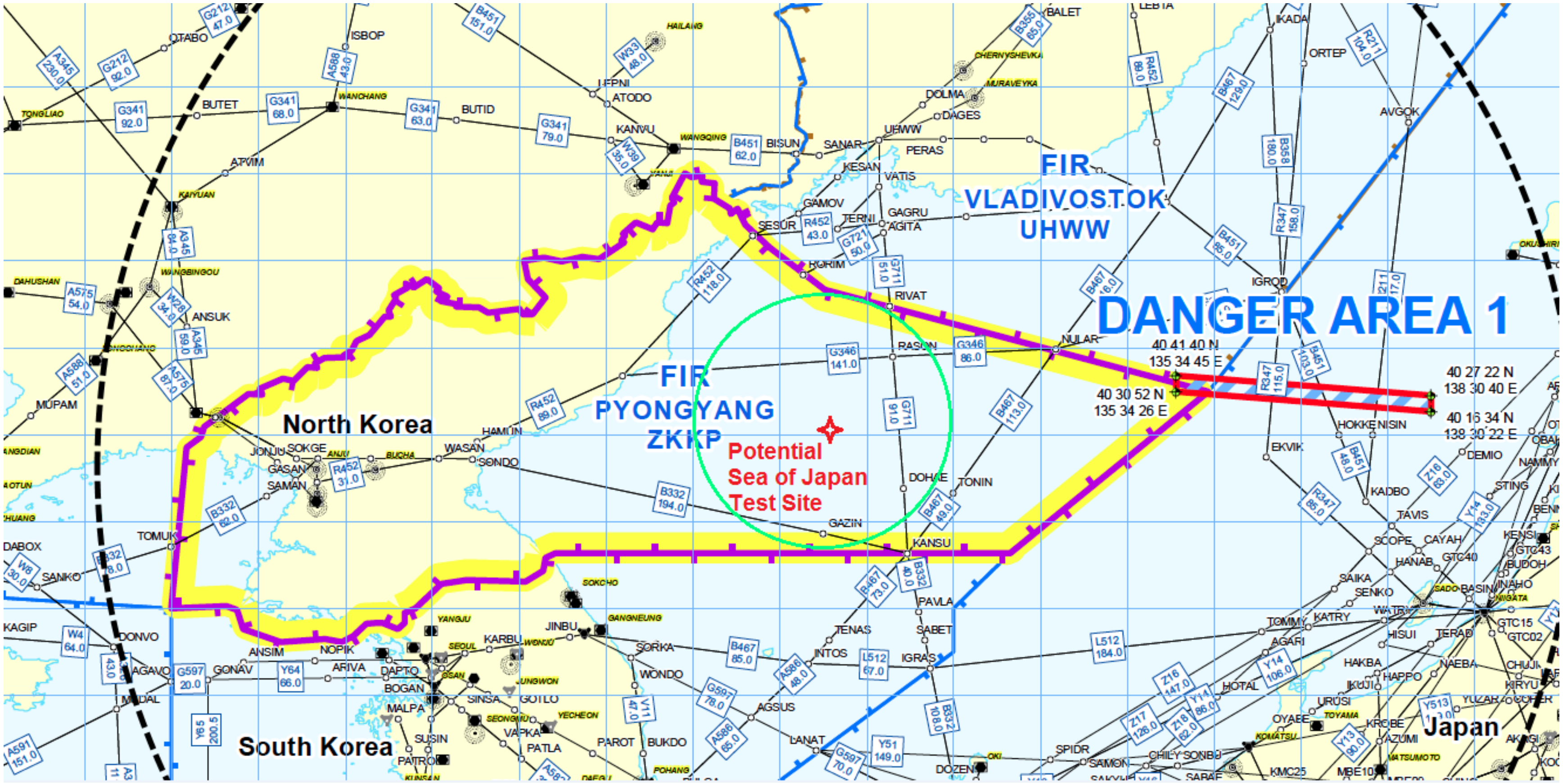

Image Source: ICAO map annotated by Foundation for Resilient Societies to show potential test site and line-of-sight radii

Figure 2. Potential Atmospheric Test Site in Sea of Japan within Pyongyang (ZKKP) Flight Information Region

The line-of-sight from a detonation at one kilometer burst height could be contained within North Korean airspace, as shown by the green circle in Figure 2. However, lower-altitude bursts to demonstrate non-EMP aspects of a weapon, such as definitive hydrogen bomb capability, miniaturization and pairing with a missile, or reentry capabilities, also entail substantial risk. The fireball from a surface burst or very low-altitude airburst would reach the ocean, causing severe localized fallout that would spread in a direction determined by prevailing winds. The black dashed line in Figure 2 shows the line-of-sight extent of an atmospheric test at an altitude of 40 kilometers; the electromagnetic pulse from such a test would reach South Korea, China, Japan, and Vladivostok, Russia.

Testing Opportunities in the South Pacific

North Korea is not a state party to the Treaty of Rarotonga, by which South Pacific nations and others agree to refrain from nuclear testing in that region. Due to a South Pacific-wide treaty to prohibit atmospheric testing of nuclear weapons, North Korea might conclude it was prudent to exclude the French Polynesian or other South Pacific regions from options for high-altitude nuclear testing areas.[27]

Potential Financial Liabilities from Atmospheric Nuclear Tests

Beyond military or sanctions vulnerabilities, would the government of North Korea be financially liable for the intentional design and conduct of atmospheric nuclear tests that result in severe, widespread, or long-lasting damage to critical infrastructures? Would North Korea be financially vulnerable, for example, to consortium-financed owners of submarine fiber optic cable systems deployed throughout the Pacific Rim region? Or to investors in financial products or markets that collapse in the absence of reliable intercontinental telecommunications?

A Canadian case provides insight as to the standards for financial liability, applying common law principles. A fishing vessel master, with nets tangled via a submarine fiber optic cable line, willfully cut the cable to recover his nets. A Canadian court determined that the damage was intentional and the harm foreseeable. As a consequence, the court determined that the 1976 Convention on Limitation of Liability for Maritime Claims and its 1996 Protocol should not limit the scope of financial damages for which the Ship Master and vessel owner should be responsible. In the *Telus* case, the Court determined to waive the $500,000 damage limit because "the loss was committed with the intent to cause such loss, or recklessly and with the knowledge that such loss would probably result."[28]

While North Korea might, theoretically, be liable for massive financial damages through the willful or reckless damage to submarine cable networks resulting from high-altitude EMP testing, in practical terms North Korea may be nearly judgment-proof. Consider the broad scope of sanctions already in force, through the unanimous decision of the United Nations Security Council via Security Council Resolution 2375 (September 2017). [a]

Altogether, the political and legal regime governing atmospheric nuclear testing is unfavorable for nations seeking to engage in atmospheric nuclear testing. Since North Korea is already in many respects a pariah state with limited financial resources, the legal regime may be insufficient to deter atmospheric nuclear testing if the demonstration of capability is seen as a sufficient prize by North Korea and other test sponsors.

Might more prosperous nation states that have aided and abetted North Korea's development of ballistic missiles, indigenous rocket fuel production, fissionable materials for nuclear weapons, and other weapons technologies be determined to be financially responsible for third

[a] See the Treaty Documents and UN Resolutions section of this paper for a click-through hyperlink to the text of this resolution.

party loss of life and infrastructure damage? A substantial and growing literature on "complicity" in international law may ultimately result in financial liability for intentional violation of export controls and sanctions regimes.[29] However, nations that merely train or financially aid other nations may not be determined to be legally responsible for the tortious acts of other nations.[30]

Technical Considerations for and against High-Altitude EMP Tests

While an EMP attack would cover a much wider area than a ground-level blast and shock attack, and an EMP attack would likely have a more pervasive impact on critical infrastructure, this means of attack has been far less tested. To date, there have been approximately 2,500 nuclear tests worldwide, including approximately 500 in the atmosphere. The United States conducted 1,054 nuclear tests, including 216 aboveground. Of the aboveground U.S. tests, less than a dozen have been at high enough altitudes to generate significant EMP effects. Tests included Operation Hardtack I in 1958 (Yucca, Teak, and Orange shots); three shots during Operation Argus in 1958-59; and Operation Dominic in 1962 (Fishbowl Series including Starfish Prime, Checkmate, Bluegill, and Kingfish). The U.S. tests were inadequately instrumented for EMP measurement, because the severity of high-altitude EMP effects was unanticipated due to incomplete theory that underestimated electromagnetic field strengths. Most of the data collected remains classified. Publicly available data on the handful of USSR high-altitude tests is likewise sparse.

In 1963, the Limited Test Ban Treaty took effect, bringing U.S. and USSR atmospheric tests to an end. Moreover, even if the U.S. and Soviet atmospheric tests had been better instrumented in the early 1960s, they could not have provided high confidence in assessing vulnerability, operability, and recovery of 21st century critical infrastructures in the present era of ubiquitous use of miniaturized electronics, digital communications and control circuitry, and the Internet.

A high-altitude EMP test might be viewed as an act of war, or at minimum a material breach of the ENMOD of 1977. Nonetheless, North Korea could have high strategic payoff to developing a better understanding of optimal techniques for EMP attack. (Various EMP attack parameters include altitude, latitude, time of day, location to maximize critical infrastructure damage, etc.). And an important step in enhancing a nuclear EMP deterrent would be demonstrating to adversaries that EMP attack could have wide-area effects on modern critical infrastructures and the global economy.

North Korea also has disincentives for a high-altitude EMP test. Their EMP test may turn out to be executed at a non-optimal altitude and location, producing minimal effects. Alternatively, an EMP test might damage critical infrastructure of multiple countries—especially, the widespread networks of undersea telecom cables and landing stations in the Pacific region.[31] After an EMP test, depending upon the altitude of detonation, a large fraction of satellites in medium and low-earth orbit could fail from radiation exposure. An EMP test with resulting damage to telecommunications and satellite infrastructure may profoundly harm the economy of China, North Korea's critical trading partner.

An EMP test that had foreseeable effects upon military facilities or critical infrastructures in U.S. territories, or within a U.S. allied nation, might be deemed to be an attack on the United States, thereby authorizing individual or collective self-defense under Article 51 of the United Nations Charter. Hence, a North Korean EMP test might invite a nuclear response, or in the alternative, execution of "anticipatory defense" actions targeting of North Korean military strike capabilities with conventional forces.[32] Non-military response to an EMP test may include further trade, travel, transportation interdiction, and other sanctions consistent with the United Nations Security Council sanctions unanimously approved in September 2017.[a]

Potential North Korean Test of Fractional Orbital Bombardment System

For use as a Fractional Orbital Bombardment System (FOBS), a satellite with a nuclear device onboard is launched into low earth orbit, where it can remain ready for attack commands for hours, days, months, or years. Shortly preceding the time of attack, the orbital velocity of the satellite is decreased with thrusters, causing the satellite to de-orbit and reach the desired altitude and location for nuclear device detonation. There is the possibility that North Korea could use the FOBS technique for an atmospheric nuclear test.

The United States has been vulnerable to FOBS attacks coming toward its southern border—especially as a satellite approaches U.S. territory in its first orbit. However, as U.S. ballistic missile defense (BMD) systems have improved, their inherent capability to counter FOBS attack has increased.

The U.S. might counter any North Korean test using the FOBS technique. In addition to several U.S. and Japanese Aegis BMD destroyers and cruisers in the vicinity of North Korea, the United States deployed in October 2017 three aircraft carrier strike groups, including their associated cruisers and destroyers. Thus, there are several BMD ships that could shoot down such satellite launches, depending on the satellite launch site, the BMD ship locations and the crew training, and preparations and intercept authorization to engage in a timely way.[b]

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[a] See the Treaty Documents and UN Resolutions section of this paper for a click-through hyperlink to the text of this resolution.

[b] The U.S. capability to shoot down satellites was demonstrated in 2008, when the USS Lake Erie shot down a dying satellite above the atmosphere. See the U.S. Navy's mission video at https://www.youtube.com/watch?v=pDqNjnUNUl8 and the lengthy Wikipedia description https://en.wikipedia.org/wiki/Operation_Burnt_Frost Operation Burnt Frost was a major feat, given the then embryonic state of U.S. sensor tracking systems. Today, 35 Aegis BMD ships of the U.S. Navy have improved intercept capabilities and substantially improved tracking capabilities. These capabilities could also provide data for the U.S. ground-based homeland BMD system, especially at Vandenberg AFB in California. Also, the THAAD site in South Korea has a TPY-2 X-Band radar which will improve tracking capability. A remaining issue is whether the crews are trained and ready—and whether they are authorized to engage in a timely way.

Previous North Korean Missile and Satellite Launches

Since May 2017, North Korea has conducted five intermediate range and intercontinental ballistic missile tests that show capability for atmospheric tests over the Pacific Ocean.[33] [34] [35] The locations and altitudes of these tests inform possible scenarios for future North Korean tests:

> **May 14, 2017**: North Korea launched a Hwasong-12 missile from a site near Kusong into the Sea of Japan. Distance covered was 700 kilometers in 30 minutes, maximum altitude was 2,000 kilometers. Had the trajectory been shallower, the missile range would have been 4,500 kilometers, potentially reaching the U.S. territory of Guam in the Pacific.
>
> **July 3, 2017:** North Korea launched a Hwasong-14 missile from the Panghyon Aircraft Factory into the Sea of Japan. Distance covered was 930 kilometers in 37 minutes, maximum altitude was 2,802 kilometers. Had the trajectory been shallower, the missile range would have been 6,700 kilometers, potentially reaching Alaska or Hawaii.
>
> **July 28, 2017**: North Korea launched a Hwasong-14 missile from the Chagang Province into the Sea of Japan. Distance covered was 1,000 kilometers in 45 minutes, maximum altitude was 3,700 kilometers. Had the trajectory been shallower, the missile range would have been around 10,000 kilometers, potentially reaching Los Angeles, Denver, or Chicago.
>
> **August 27, 2017**: North Korea launched a Hwasong-12 missile from Sunan launch site, near Pyongyang International Airport, transiting over the Japanese island of Hokkaido and into the Pacific Ocean. Distance covered was 2,700 kilometers in 15 minutes, maximum altitude was 550 kilometers. At a more optimal trajectory, the range might have been 4,800 kilometers.
>
> **September 14, 2017**: North Korea launched a Hwasong-12 missile from a site near the Pyongyang airport, transiting over the Japanese island of Hokkaido and into the Pacific Ocean. Distance covered was 3,700 kilometers in 17 minutes, maximum altitude was 770 kilometers. This was the longest range North Korean missile test to date.

North Korea has successfully launched two satellites into polar orbits.[36] The rockets and trajectories used for these launches could also be used for atmospheric tests and demonstration of the fractional orbital bombardment technique:

> **December 12, 2012**: North Korea launched a satellite on an Unha-3 rocket from the Sohae Space Centre in North Phyongan Province southward into a polar orbit. The launch path passed over the Philippine Sea, east of the island of Luzon.
>
> **February 6, 2016**: North Korea launched a satellite on an Unha-3 rocket along approximately the same trajectory as the December 2012 launch.

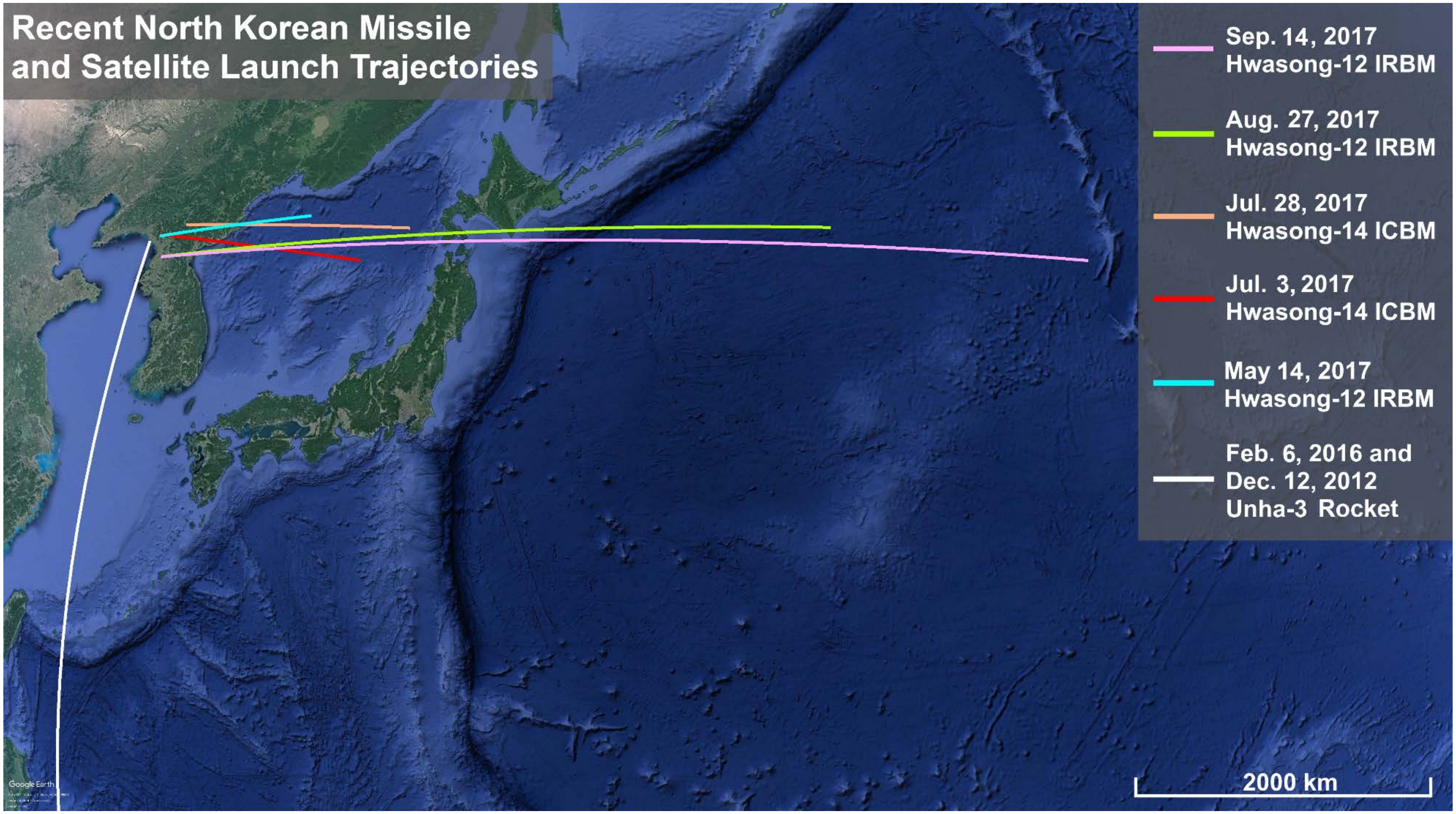


Figure 3. Approximate Trajectories of Recent North Korean Missile and Satellite Tests

Recent North Korean long-range missile tests have flown eastward trajectories, landing in the Sea of Japan on lofted trajectories or overflying the less densely populated Japanese island of Hokkaido. Trajectories for launches of North Korean satellites have overflown the Philippine Sea east of the island of Taiwan, narrowly avoiding the densely populated Philippine island of Luzon. The eastward and southern trajectories may be likely paths for missiles used for future North Korean atmospheric tests.

High-Yield Underground Bomb Test

At 03:30 UTC on September 3, 2017 North Korea conducted an underground nuclear test at the Punggye-ri Nuclear Test Facility. Yield estimates ranged from 60 kilotons to in excess of 300 kilotons.[37] This range of yields would be consistent with a small hydrogen bomb or a boosted yield fission device. Either design can produce optimized EMP effects.

High-Altitude Electromagnetic Pulse Environments

The 1962 Starfish Prime test demonstrated that a nuclear weapon detonated in the upper atmosphere will produce a series of electromagnetic pulses radiating downward within line-of-sight (LOS) of the blast, termed high-altitude EMP or "HEMP" effects.

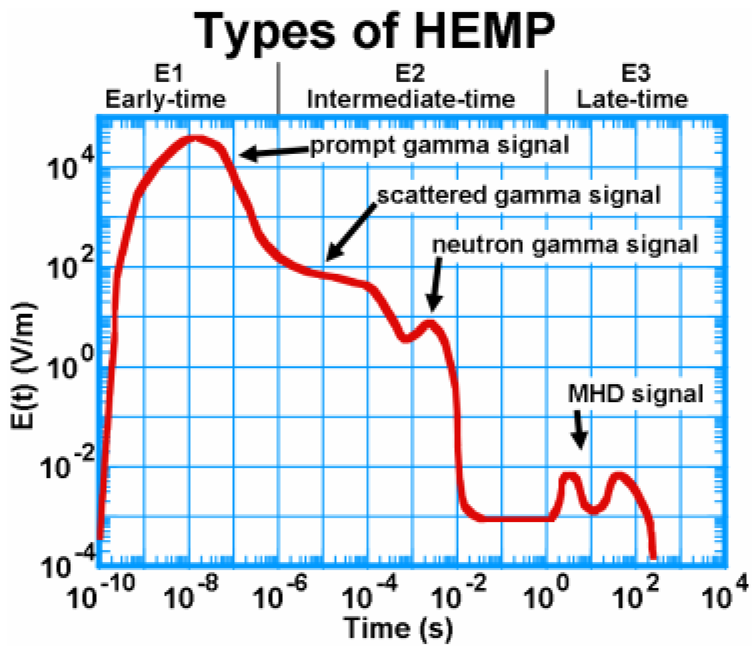


Figure 4. Types of HEMP; Notional Waveform[38]

- The E1 "early time" pulse has a high amplitude of thousands of volts per meter, with the peak lasting about 200 nanoseconds. The E1 pulse induces high voltages in conductors of approximately 0.3 meters of length or more; these conductors act like radio antennas. When electronic equipment is exposed to E1 pulse voltages, transistor junctions can change polarity or break down, causing temporary upset or permanent damage. Also, E1 voltages can cause arcing and damage of large power transformers used for high-voltage electricity transmission.
- The E2 "intermediate time" pulse is similar to nearby lighting strikes. Ground-based equipment protected against lightning is similarly protected against E2.
- The E3 "late-time" pulses, also termed magnetohydrodynamic (MHD) pulses, are low frequency waves lasting tens of seconds. The E3 pulse, as illustrated above, has two components that occur in sequence. The E3A pulse is caused by distortion of the Earth's

magnetic field caused by the expanding fireball. The E3B pulse, or "heave" effect, is caused by rising plasmas in the ionosphere. Both E3A and E3B can induce dozens of volts per kilometer in long conductors such as high voltage transmission lines and undersea communication cables; resulting currents in long power and communication lines can reach 1,000 amperes.

E1 Pulse

The E1 pulse is produced by nuclear detonations at altitudes ranging from 40 kilometers to 400 kilometers. The peak E1 fields are only weakly dependent on weapon yield. A factor of one thousand change in yield results in a factor of four change in peak field. It is a misconception that only high-yield devices can produce damaging E1 electric fields.

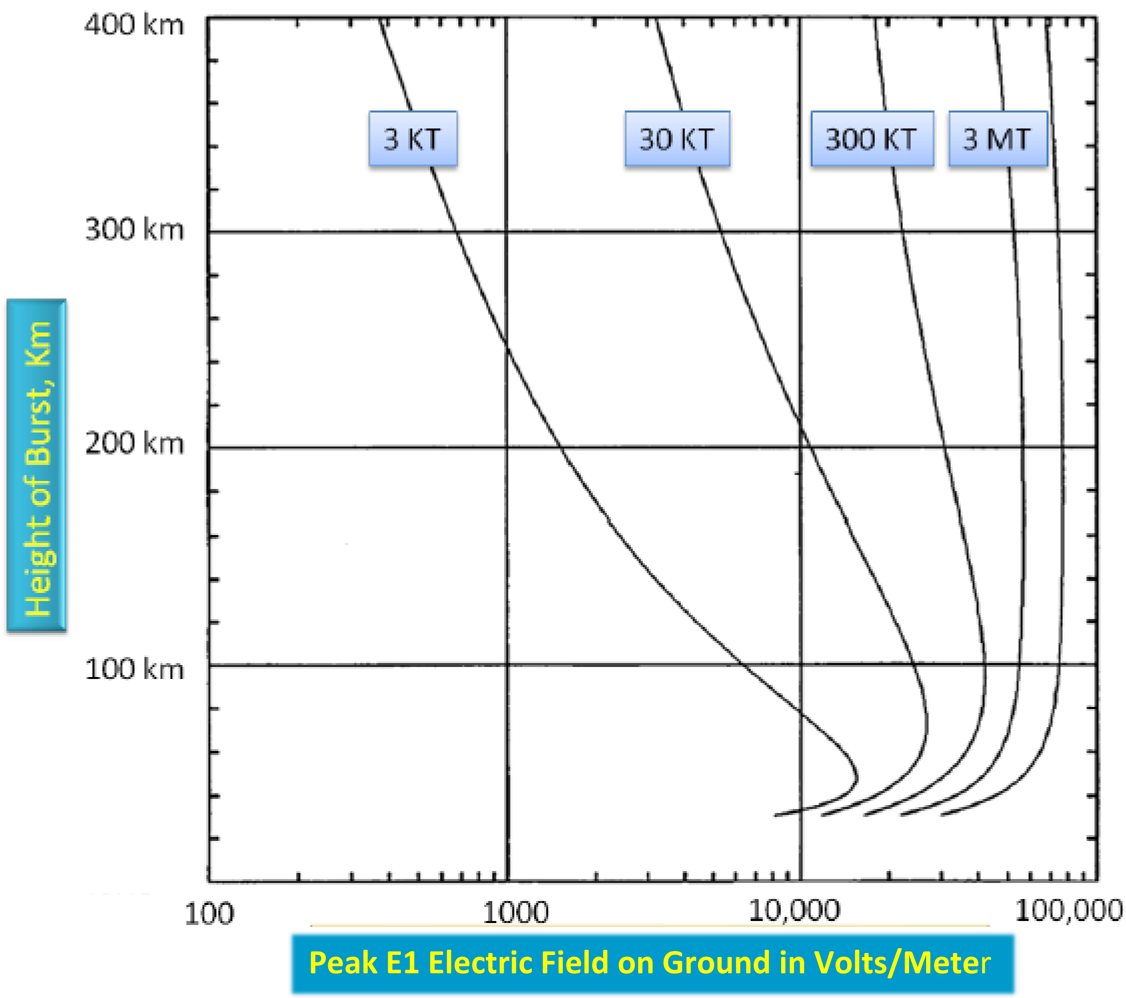


Figure 5. Illustration of Peak E1 Field on Ground by Detonation Altitude and Device Yield[39]

For a 300 kiloton yield device, at the upper end of yield estimates for the September 3, 2017 North Korean underground test, the peak E1 field max could be in the range of 20,000 volts/meter at a detonation altitude of 40 kilometers. At a detonation altitude of 400 kilometers, the peak E1 field could likewise be approximately 20,000 volts/meter. At an intermediate altitude of 80 kilometers, a slightly higher peak E1 field of approximately 25,000 volts/meter could be produced. Bomb designs that more efficiently produce gamma radiation may produce higher amplitude electric fields.

E3A Pulse

The E3A pulse can be produced by nuclear detonations at altitudes starting at 200 kilometers. The peak value of the E3A pulse scales nearly linearly with bomb yield over a wide range of yields from 10 kilotons to 1 megaton.[40]

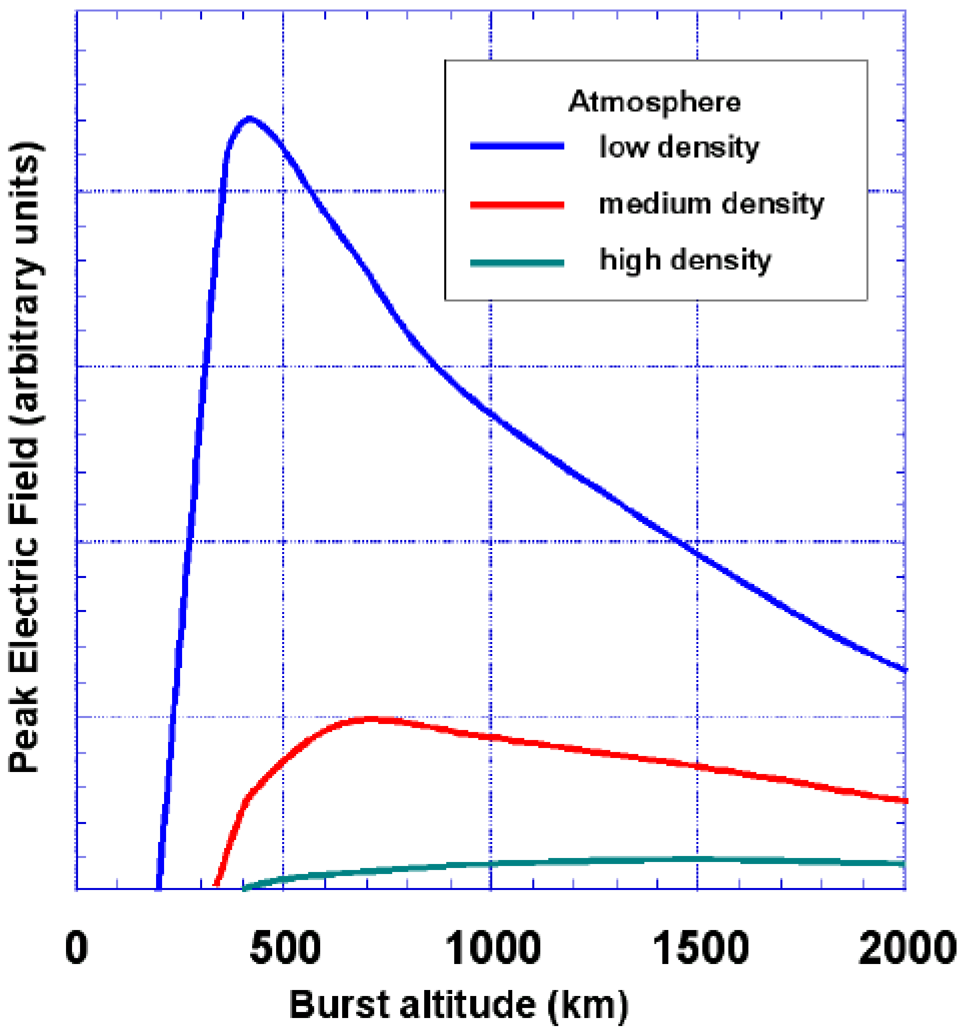


Figure 6. Burst Height and Atmosphere Scaling for Peak E3A Electric Field[41]

The E3A pulse amplitude peaks at detonation altitude of approximately 400 kilometers in a low density atmosphere. The amplitude of the E3A electric field is greatly affected by the density of the atmosphere, with a “high density” atmosphere reducing the signal by a factor of 20 or more. “Low density” refers to nighttime at the minimum of the solar cycle, “medium density” refers to daytime at solar minimum or nighttime at solar maximum and “high density” refers to daytime at solar maximum. In year 2017, the sun is nearing the minimum of the 11 year solar cycle.

E3B Pulse

The amplitude of the E3B pulse rapidly increases after a detonation altitude of 100 kilometers, peaking at a detonation altitude of approximately 140 kilometers and then diminishing by an order of magnitude at 400 kilometers.

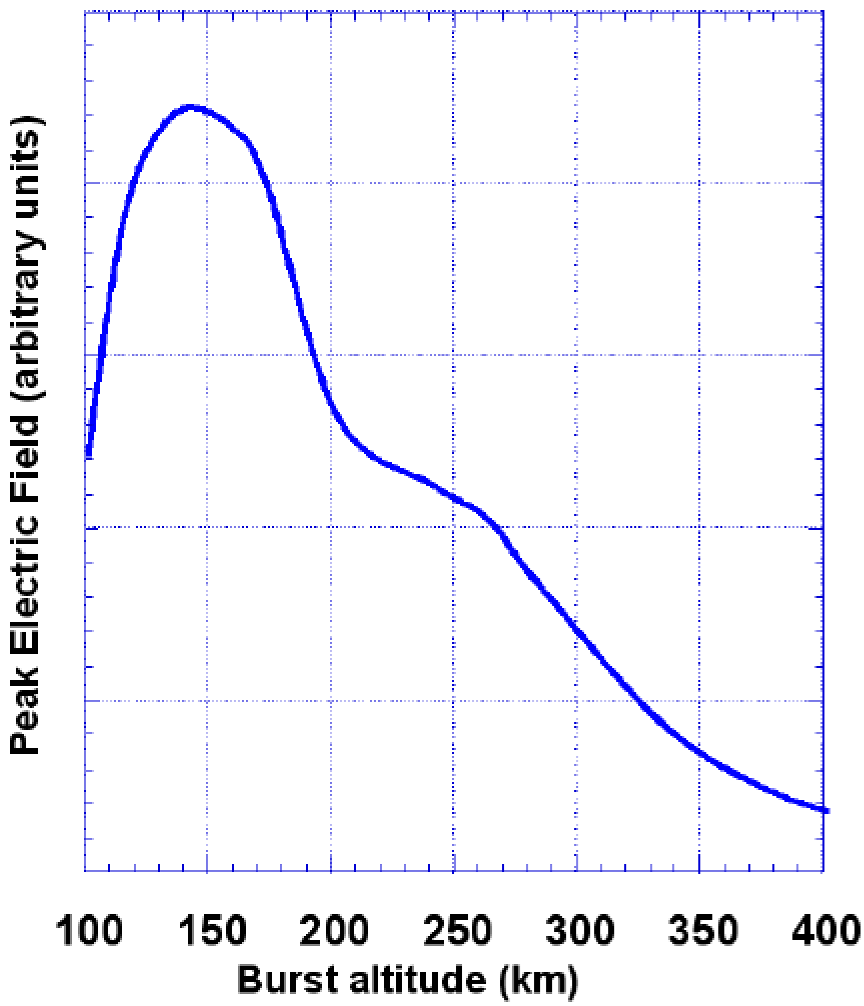


Figure 7. Burst height scaling for Peak E3B electric field[42]

It is notable that the E3A and E3B electric fields have significantly different peak amplitudes as a function of altitude—400 kilometers and 140 kilometers, respectively.[43] [44]Therefore, it is impossible to maximize both E3A and E3B effects with a single detonation.

High-Altitude Electromagnetic Pulse Effects

Land-Based Critical Infrastructure

The E1 pulse will impact land-based electrical infrastructure connected to conductors of approximately 0.3 meters length or more, such as antennas, coaxial cables, twisted pair conductors, power cords, Ethernet patch cords, etc. Particularly affected will be any connected equipment with integrated circuits, such as computers, internet routers, and industrial control systems. Self-contained devices with no connected cords, such as handheld cell phones, are less likely to be impacted.

The E3 pulse will impact land-based electrical infrastructure connected to long conductors running several kilometers or more. Induced currents of up to 1,000 amperes can cause overload and premature failure. Examples of vulnerable equipment include power transformers at the ends of high voltage transmission lines, line driver cards at the ends of long metallic communication landlines, and repeaters necessary for the operation of long fiber optic lines.

Undersea Cables

The E3 pulse penetrates deep into ocean waters and has the potential to impact undersea telecommunications cables. [45] While modern undersea cables transmit their signals using non-conductive fiber optics, repeaters are required approximately every 100 kilometers to boost the optical signal. Currents induced in the repeater power leads from the E3 pulse can be in the thousands of amps[46]; if the circuitry is not protected, overload and immediate burnout can occur.

The E1 pulses will not affect submarine cables, but may damage electronic components within aboveground unprotected cable landing sites.[47]

Aircraft

During high-altitude nuclear tests Kingfish (95 kilometers altitude), Bluegill (48 kilometers altitude), and Checkmate (147 kilometers altitude), instrumentation aircraft experienced electronic upsets, proving that the E1 pulse from EMP can impact airplanes. (All aircraft were able to land safely). The aluminum enclosures of aircraft provide limited shielding as partial Faraday cages. Today's avionics are commonly shielded against electromagnetic interference from lightning, radios, radars, passenger cell phones, etc. Nonetheless, because of widespread adoption of digital "fly by wire" controls, modern aircraft are vastly more dependent on electronic circuits than military aircraft used during the 1960's Operation Fishbowl tests.[48] Without placing commercial airframes in EMP test trestles, it is not possible to rule out the possibility that EMP can "cause airplanes to fall from the sky."

Satellites

Due to x-rays released by low-yield nuclear detonations above the stratosphere, unhardened commercial satellites within 1,000 kilometers of the burst will suffer immediate damage to their semiconductor-based circuits. For a burst at 120 kilometers, about 10% of LEO satellites will fail from direct radiation exposure. In addition, long-term damage to satellites will result from the injection of ionizing radiation into the Van Allen belts. The Van Allen belts trap free electrons that can persist in orbit for years, colliding with satellites. This lingering “trapped electron” effect dramatically reduces the operational life of satellites, sometimes to just weeks. The free electron issue is most acute for satellites in Low Earth Orbit (LEO)—160 kilometers altitude to 2,000 kilometers. After the 1962 Starfish Prime EMP test, one-third of all satellites in LEO failed due to cumulative radiation effects.[49]

While many military satellites are now hardened against nuclear radiation, commercial satellites generally are not. Applications for commercial and military satellites in LEO include earth observation and spy satellites, satellite phones (Iridium and GlobalStar), and broadband digital communications (Teledesic). A high-altitude EMP test will cause extensive damage to LEO satellites.

Humans

Direct and immediate impacts of EMP on humans are likely to be minimal. For people directly gazing skyward at the fireball, temporary blindness or even permanent retinal damage may occur, depending on distance, detonation altitude, and meteorological conditions.[50] EMP would cause no blast and shock effects at ground level. Likewise, immediate radiation at ground level would be minimal. However, nuclear debris from EMP detonations above the troposphere would descend over a period of months to years and be carried around the earth by winds in the stratosphere.

Duties to Notify Airmen and Mariners

Under the Chicago Convention on International Civil Aviation, which entered into force on April 4, 1947 and to which North Korea is a party, nations that anticipate a hazard to civil aviation have an obligation to provide Notices to Airmen (NOTAMs) of an impending test or closure area. Pursuant to the law of the sea, coastal states are obligated to provide comparable Notices to Mariners (NOTMARs). Failure to provide timely and reliable notice in advance of missile or nuclear weapons tests increases risks to public safety and public health, including risks of retinal burns and potential blindness, and radioactive debris contamination. North Korea has not reliably issued NOTAMs or NOTMARs for past tests. To conduct an atmospheric nuclear test without appropriate advance warnings would be wrongful under international law, and a needless harm. North Korea, acting as a pariah state, has not reliably provided advance notices to the International Civil Aviation Organization or to aircraft operators in its vicinity.[51] These failures to provide warning of test hazards suggest that in the design of test monitoring capabilities, the United States and its allies should not depend upon mandatory notices as “tip offs” to prepare for test monitoring.

Atmospheric Test Scenarios

Taking into account demonstrated North Korean missile capabilities and past trajectories, statements and threats by North Korea, and potential impacts on critical infrastructure and human population, we constructed five potential North Korean atmospheric test scenarios. Each test scenario has three basic characteristics:

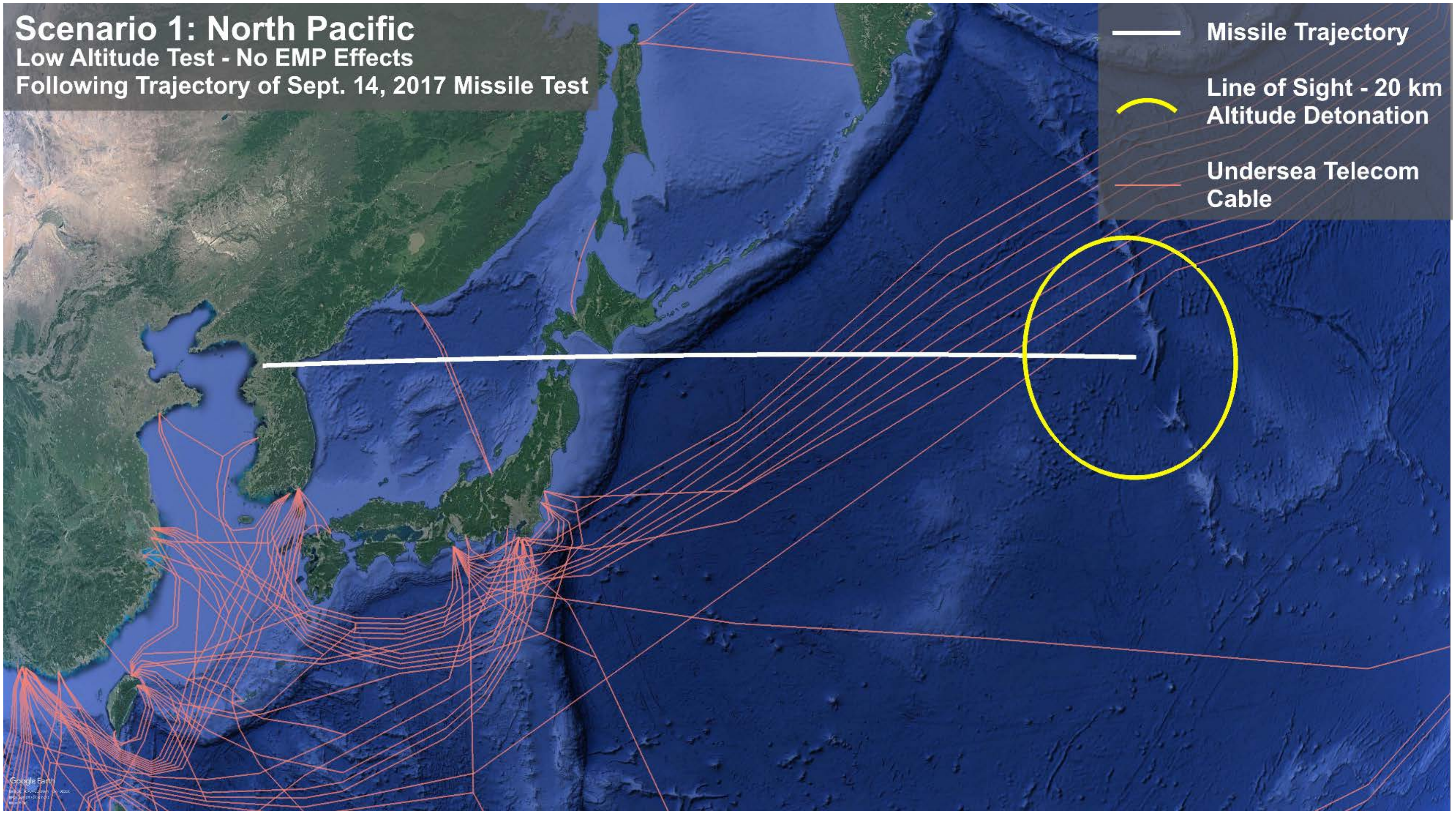
1. Path and terminus of trajectory: following previously observed missile trajectories or not, over ocean only, over landmasses and populations other than North Korea's, etc.
2. Purpose of the scenario: demonstration of integration of missile and warhead, reentry capability, E1 effects, E3 effects, impacts on critical infrastructures, etc.
3. Altitude of detonation.

Importantly, we believe that all five postulated test scenarios are within current North Korean technical capabilities. These scenarios consider live tests of ballistic missiles armed with nuclear warheads. Because of risks associated with fuzing malfunction, launch failure, and guidance errors, nations have rarely tested nuclear warheads mounted on ballistic missiles. However, if North Korea were to conduct an atmospheric test in the Pacific, we believe delivery via an armed missile is most probable given the risks of localized fallout from a surface burst in nearby waters and also the risk of interception of any naval vessel or aircraft used as a delivery mechanism.

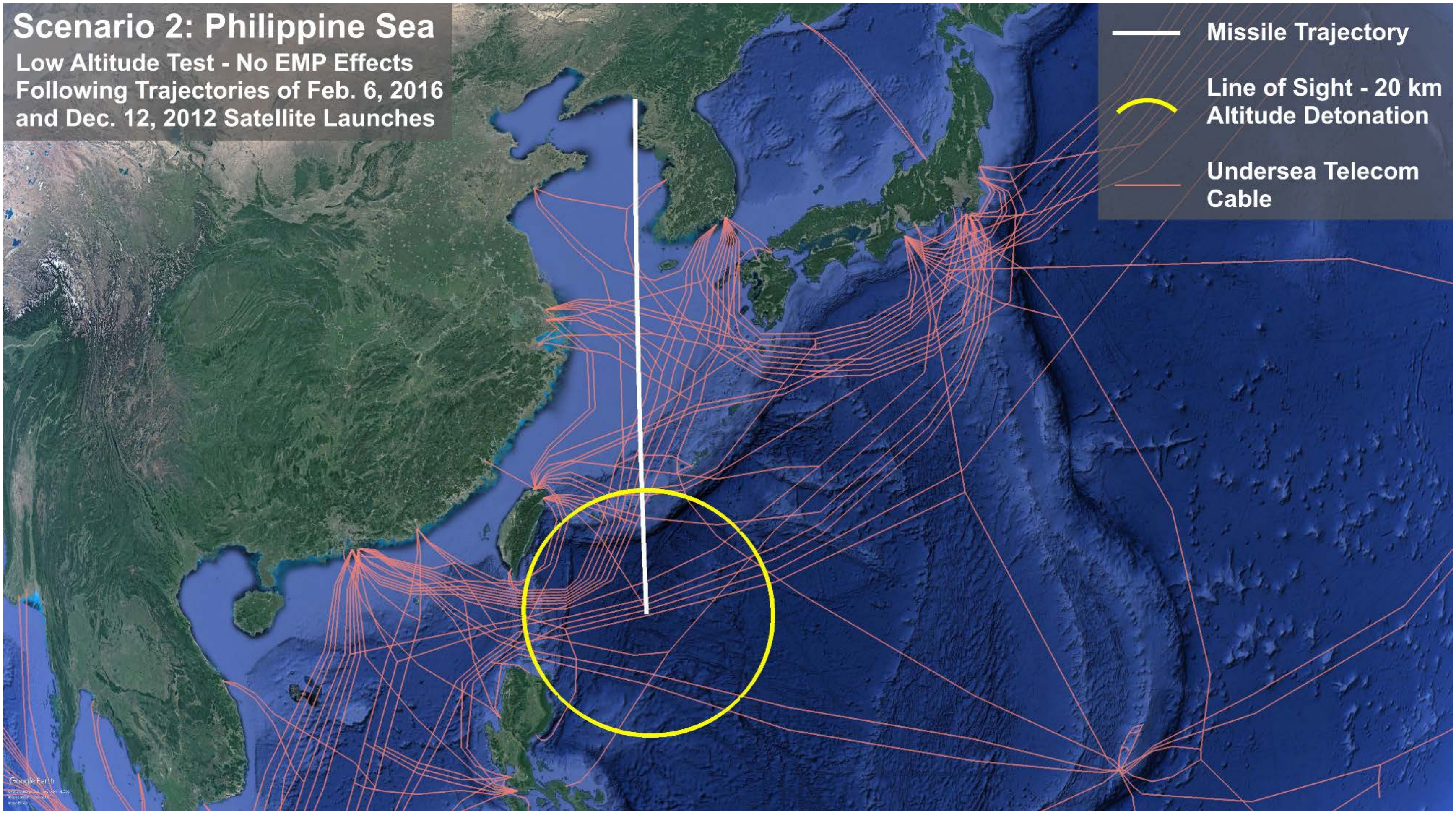
We present the atmospheric test scenarios in rough order of risk and level of provocation. For example, a "North Pacific" test over the ocean at 20 kilometer altitude will not produce appreciable EMP effects or harm satellites, but will demonstrate miniaturization and capability for high-altitude fuzing of a missile and warhead system. In contrast, a 150 kilometer altitude test slightly north of Guam could demonstrate both E1 and E3 impacts on critical infrastructure, including debilitation of undersea telecommunications cables and large numbers of satellites.

Our five test scenarios are illustrative, but not exhaustive. We believe our scenarios are more likely than others because they minimize the risk of international sanctions by limiting collateral damage or, alternatively, demonstrating E1 and E3 effects on less infrastructure. Nonetheless, because of the very few pathways for missile trajectories that avoid overflight of human populations, the extensive network of undersea telecom cables in the Pacific,[52] [a] EMP effects on LEO satellites regardless of test location, and the potential for globally distributed fallout, there are no safe scenarios for atmospheric EMP tests by North Korea.

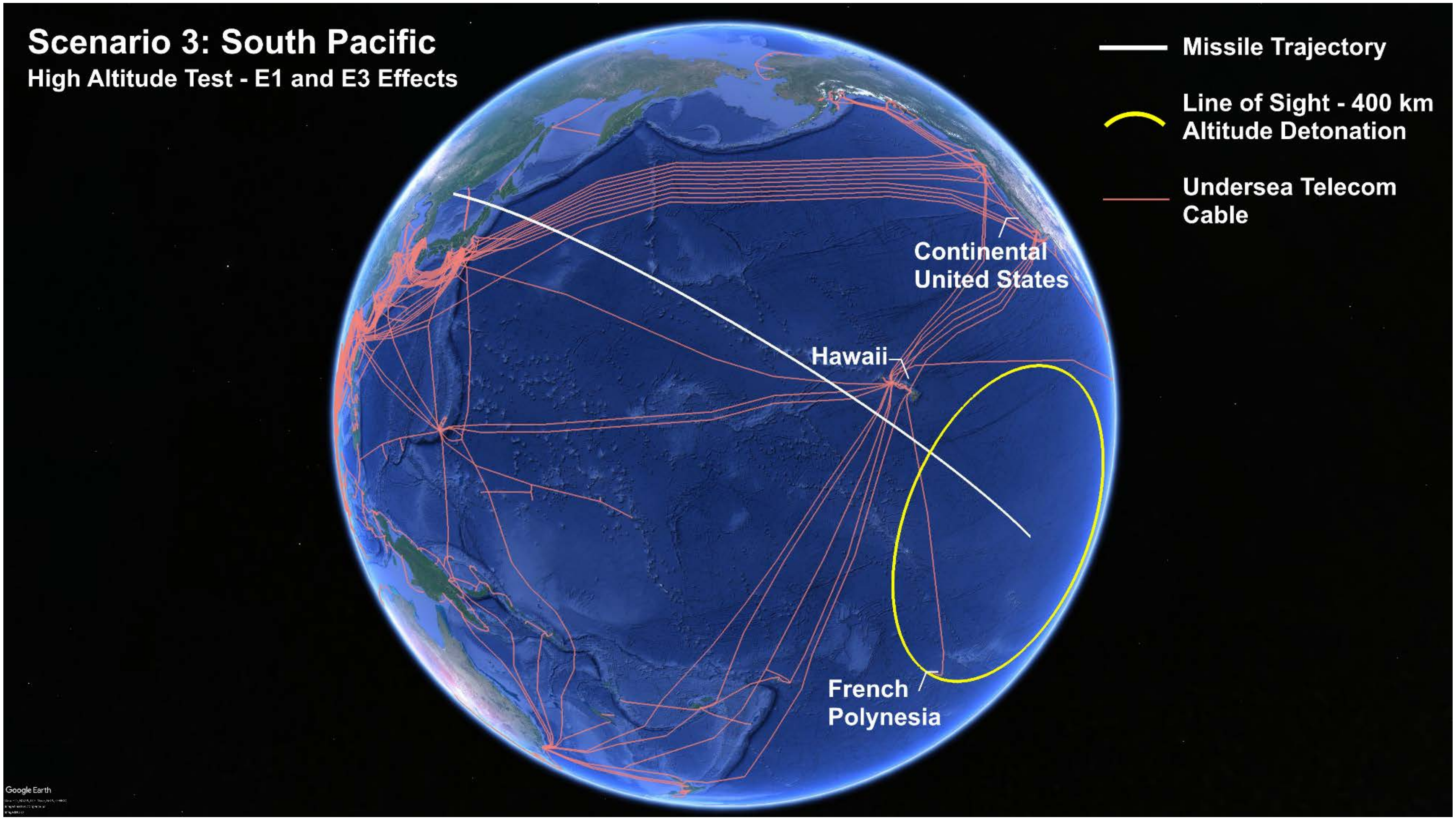
[a] Paths of undersea cables in the following scenario illustrations are indicative of general location and path, and should not be interpreted as precise locations.



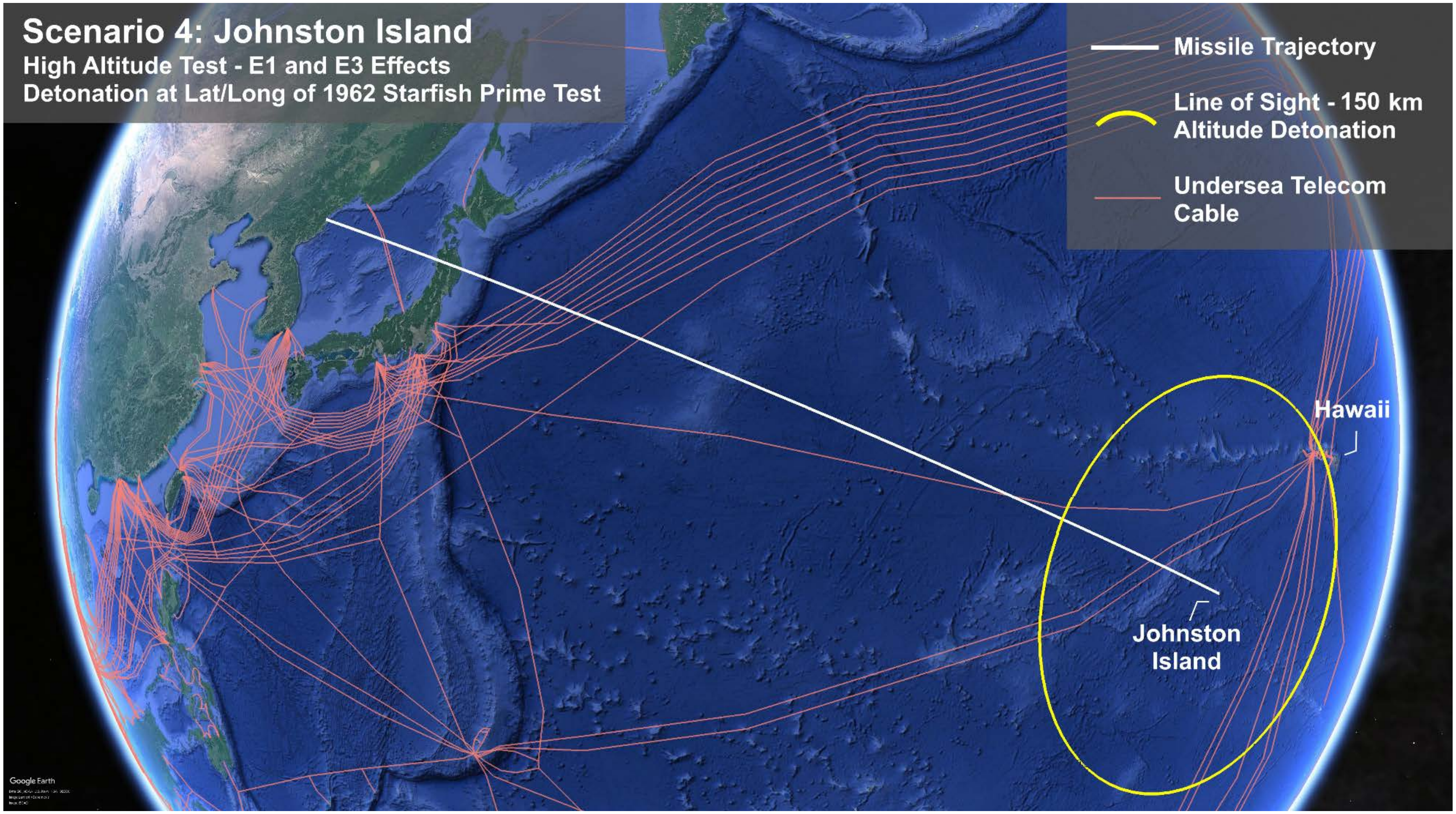
Scenario 1, “North Pacific,” could demonstrate the capability to deliver and detonate a warhead mounted on an ICBM. The trajectory could roughly follow the path of the September 15, 2017 launch, passing over the southern tip of less densely populated Japanese island of Hokkaido and terminating in an empty area of the Pacific Ocean. The 20 kilometers detonation altitude would not produce ground-level blast and shock effects or appreciable EMP effects. Because the detonation would be at low-altitude, satellites would be shielded from radiation effects by the intervening atmosphere. Nearby aircraft may be at risk from blast. At a detonation altitude of 20 kilometers, no debris from the earth’s surface would be irradiated and lofted, so local fallout would be minimal.



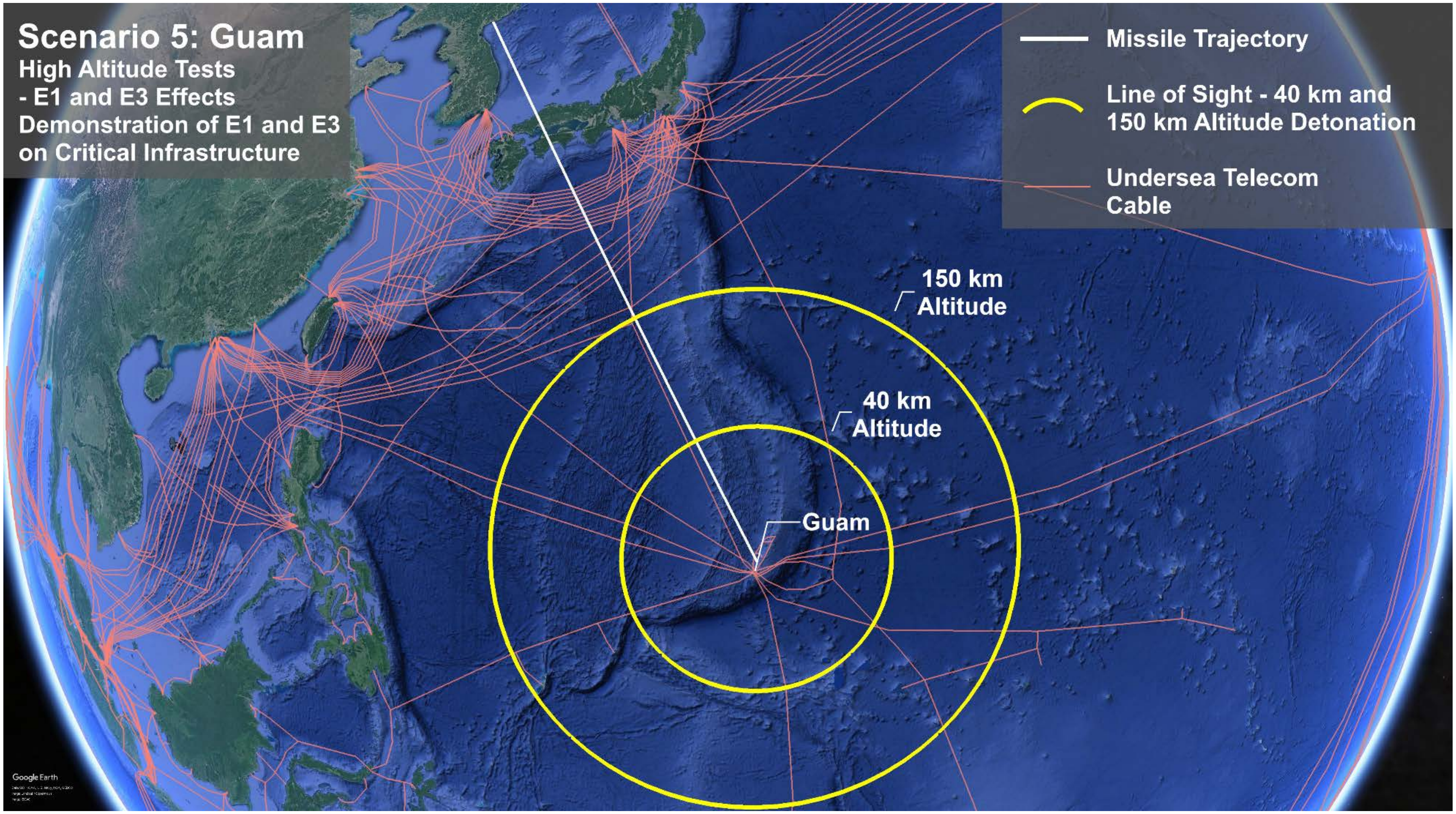
Scenario 2, "Philippine Sea," could have the purpose of demonstrating integrated missile and warhead capability while avoiding overflight of populated areas. The trajectory of the missile would roughly follow the paths of North Korea's December 12, 2012 and February 7, 2016 satellite launches, but would descend toward the Philippine Sea, east of Taiwan, instead of achieving orbit. The 20 kilometer burst altitude should be high enough to avoid radiation exposure and hearing loss for mariners in heavily transited sea lanes. Retinal burns are possible if the burst is directly in the field of view. There would be no EMP effects. Nearby airplanes may be at risk from blast. Were a missile guidance system error to occur, the population of Taiwan could be at risk.



Scenario 3, "South Pacific," could demonstrate both E1 and E3 EMP effects. The missile's path would take it over the Japanese islands, terminating in a vast and mostly unpopulated expanse of the South Pacific. The 400 kilometers burst altitude would produce both E1 and E3 effects. This region of the Pacific Ocean, including French Polynesia, is subject to the Treaty of Rarotonga, an in-force treaty banning atmospheric nuclear testing. To avoid E1 effects on the most populous areas of French Polynesia, the detonation altitude therefore might be adjusted downward. Areas of French Polynesia closer to and south of the center detonation point, such as Nuku Hiva, would be well-situated for EMP observation and instrumentation.



Scenario 4, "Johnston Island," could have the purpose of demonstrating both E1 and E3 EMP effects. The missile trajectory would pass over the northern tip of the Japan's Honshu Island and terminate 150 kilometers above Johnston Island, identical to the latitude and longitude location of the 1962 Starfish Prime test—for potential symbolic effect. A 150 kilometer altitude detonation would produce both E1 and E3 effects. Electrical equipment in the Hawaiian Islands would be impacted by the edge of the EMP field footprint. The E3 pulse might impact electric transmission lines on the big island of Hawaii. Undersea telecom cables running west and south from Hawaii would likely be affected. To avoid E1 impact on Hawaii's infrastructure, the detonation altitude could be reduced.



Scenario 5, "Guam," could have the purpose of demonstrating EMP effects on critical infrastructure of the U.S. and its Asian allies. The potential missile trajectory would transit over Japan and terminate in international waters about 35 kilometers to the north of Guam, consistent with August 10, 2017 threat by North Korea to "hit the waters 30 to 40 kilometers away from Guam."[53] Detonation at 150 kilometers altitude would produce both E1 and E3 effects, affecting electrical equipment on U.S. military bases and undersea telecom cables transiting the island. Alternative detonation at 40 kilometers altitude would produce only E1 effects and suppress effects on satellites. Such EMP detonations could be judged as acts of war, compelling Article 51 retaliation against North Korea.

Measurement of E1 and E3 Effects

Because of inadequate theoretical understanding of EMP at the time, the 1962 Starfish Prime test was inadequately instrumented, with recorded waveforms going "off-scale" (EMP signal strength was much higher than instrument settings). While the physics of nuclear EMP are now well-understood, there has been much active debate on the magnitude of EMP effects on critical infrastructure, especially with a paucity of data in the unclassified realm. Proactive instrumentation of EMP effects during North Korean atmospheric tests, as well as post mortems on infrastructure failures, have the potential to inform protective measures.

Recording Devices

The E1 pulse can be instrumented by commonly available digital recording oscilloscopes operating in the gigahertz range coupled to Baum electric and magnetic field sensors. If scientific instrumentation is unavailable, a simple whip antenna will suffice to get rough measurement of EMP field levels. Unfortunately, the internal circuitry of digital oscilloscopes may not survive exposure to the E1 pulse, so it is prudent to enclose the scopes in a Faraday cage and use internal battery power. A readily available but less capable alternative is a commercially produced recording device, EMP.Alert™ from Emprimus. This shielded device measures E1 fields and digitally records only peak values on internal data storage.

The E3 pulse can be directly observed by commercially available magnetometers, such as those used by the United States Geological Service. Because the internal circuitry of the magnetometer may not survive exposure to the E1 pulse, a Faraday cage enclosure will be prudent, with internal battery power.

The E3 pulse can also be derived by measuring induced voltages on long conductors. There is commercially available equipment to monitor Geomagnetically Induced Current (GIC) in the neutral leads of transformers, for example, ECLIPSE™ from Advanced Power Technologies.

At landing stations of undersea telecommunications cables, the power feed equipment (PFE) output lead would be another appropriate point to measure the E3-induced current. Care should be taken that existing instrumentation does not go "off-scale" as the induced voltage could be up to tens of volts/kilometer—or many thousands of volts integrated over the length of a long undersea cable.

Instrumentation Locations

Our three EMP test scenarios—South Pacific, Johnston Island, and Guam—illustrate the potential for instrumentation of EMP effects. Of course, a North Korean EMP test may be in other locations as well. We suggest the following Pacific Region locations as illustrative of a range of possible monitoring sites:

1. Guam
2. Hawaii

3. Johnston Island
4. Wake Island
5. Midway Island
6. Northern Mariana Islands
7. Rose Atoll
8. Attu Station in the Aleutian Islands
9. Adak Island in the Aleutians
10. Fort Greely, Alaska
11. French Polynesia
12. Pitcairn Island

A network of EMP instrumentation locations could be of similar value to the global array of seismographs that provide intelligence on North Korean underground nuclear tests.

Conclusions

There are no low-risk or impact-free trajectories, altitudes, and locations for North Korea to conduct atmospheric tests in the Pacific, including EMP tests, as our analysis shows:

- "North Pacific," the trajectory of past missile tests, sends a plutonium warhead over the Japanese island of Hokkaido. Aircraft near the detonation might be affected by blast.
- "Philippine Sea," the only trajectory that avoids sending a plutonium warhead over inhabited landmasses, follows a narrow corridor between South Korea to the east and the island of Taiwan to the west. Errors in missile guidance or fuze operation could be catastrophic for populations along the flight path.
- "South Pacific," a trajectory for an EMP test that terminates in a vast expanse of empty ocean, sends a plutonium warhead over Japan. Moreover, an error in missile guidance or fuzing could cause a detonation near Hawaii.
- EMP tests near Hawaii or Guam are likely to have significant impact on critical infrastructure and undersea communications cables. EMP tests near U.S. territory could be viewed as acts of war.
- Regardless of location, a high-altitude EMP test is likely to cause nuclear effects for large regions of the earth, debilitating satellite networks, international telecommunications, cloud data storage, and financial transactions—resulting in global economic impact and, possibly, worldwide catastrophe.

Policy Recommendations for the U.S. Government

We make the following policy recommendations for the U.S. Government:

1. A North Korean atmospheric test of a nuclear warhead in the Pacific would be a risky and provocative act. Through diplomatic channels and otherwise, the North Korean regime should be warned that there are no “low-risk” or “low-impact” test options.
2. It would be technically challenging for North Korea to conduct a test of wide-area EMP effects without impacting satellites and the extensive network of undersea telecommunication cables in the Pacific. Because submarine fiber optic cable networks are ubiquitous and provide approximately 98% of all international voice, data, video, and internet traffic,[54] the concurrent loss of a significant share of the world’s roughly 400 submarine fiber optic cables, which enable at least $10 trillion dollars of global transactions each day, would be likely to cause a global recession or severe depression harmful to every nation on the planet. American trading partners in the Pacific, including China, should be alerted that some North Korean test scenarios could interrupt undersea telecommunications necessary for financial transactions, international trade, logistical control of global supply chains, and China’s ability to reliably import the agricultural and energy commodities upon which its economy depends.
3. Because the Limited Test Ban Treaty of 1963 halted atmospheric tests and scientific observation of EMP events, any test of EMP effects by North Korea will be a rare opportunity to gather more data on these important phenomena and their impact on modern infrastructure. United States and allied deployment of instrumentation of E1 and E3 EMP effects in the Pacific region could have high strategic value. Any attempts by North Korea or other adversaries to establish EMP instrumentation in the Pacific region should be closely monitored.
4. Anticipating that no financial recovery will be available to reconstitute critical infrastructures that may be damaged by high-altitude North Korean EMP testing, the United States and its allies (and possibly quasi-allies such as China), should redouble their efforts to discourage North Korean atmospheric nuclear testing *before testing occurs*.
5. Because some North Korean atmospheric nuclear test scenarios may effectuate an act of war, constitute a material breach of the ENMOD Convention, and/or cause severe harm to other nations, the United States and its allies (and possibly quasi-allies) should be prepared to execute “anticipatory self-defense” measures as may be essential and time-urgent.

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