Missile Defense

Patty-Jane Geller

Missile defense is a critical component of the U.S. national security architecture that enables U.S. military efforts and can protect critical infrastructure, from population and industrial centers to politically and historically important sites. It can strengthen U.S. diplomatic and deterrence efforts and provide both time and options to senior decision-makers during crises involving missiles that fly on ballistic and non-ballistic trajectories.

The Growing Missile Threat

Missiles remain a weapon of choice for adversaries who view them as cost-effective and symbols of power compared to other types of conventional weapons.[1] The number of states that possess missiles will continue to increase, as will the sophistication of these weapons, as modern technologies become cheaper and more widely available.

In 2022, North Korea intensified its missile testing efforts, conducting its first test of an intercontinental ballistic missile (ICBM) since 2017 in addition to tests of several shorter-range missiles and even a hypersonic missile capable of maneuvering during flight.[2] These tests allow Pyongyang to keep improving and adapting its missile program and by so doing add to an already formidable threat. North Korea also continues to advance its ability to overcome missile defenses, including those that protect the United States, with missiles that supposedly can carry multiple warheads and decoys.[3]

Iran continues to modernize and proliferate its regional missile systems. Its recent launches of solid-fuel rockets demonstrate that Iran has the ability to build and successfully launch sophisticated missiles, which implies in turn that it has or is developing the ability to advance to an ICBM capability.[4]

China and Russia, in addition to their vast ballistic missile inventories, are investing in new ground-launched, air-launched, and sea-launched cruise missiles that uniquely challenge the United States in different domains and are deploying new hypersonic glide vehicles.[5] China is rapidly building hundreds of new missiles, including modern ICBMs that can carry multiple warheads and theater-range missiles that can strike U.S. assets with precision.[6] Russia is developing entirely new capabilities, such as a nuclear-powered cruise missile, that are intended to avoid U.S. sensors and missile defenses. It has employed its Kinzhal hypersonic missile for the first time in Ukraine.[7] Russia's conventionally armed sea-launched and air-launched cruise missiles can strike strategic nodes within the U.S. homeland, even from Russian territory, and China is developing a long-range conventional strike capability of its own.[8]

The Strategic Role of Missile Defense

Missile defense plays a critical role both in deterring an attack and in mitigating the damage to U.S. forces, infrastructure, and population centers in the event deterrence fails. The ability to deter an attack depends on convincing the adversary that the attack will fail, that the cost of carrying out a successful attack is prohibitively high, or that the consequences will outweigh the perceived benefit of an attack. A U.S. missile defense system strengthens deterrence by offering a degree of protection to U.S. populations, military forces, and allies, making it harder for an adversary to threaten them with missiles. By raising the threshold for missile attack, missile defense can complicate an adversary's planning, remove the option for a "cheap shot" against the United States and its allies, and perhaps make the adversary think twice before launching an attack. By protecting key

U.S. assets, missile defense also mitigates an adversary's ability to intimidate or coerce the United States into making concessions.

Missile defense systems help to enable U.S. and allied conventional operations. During a regional conflict, adversaries could deny the United States the ability to conduct offensive operations by targeting U.S. and allied forward-deployed personnel or military assets. In addition, they might try to decouple the United States from defense of its allies by threatening to strike U.S. forces or the U.S. homeland if the United States intervenes in a regional conflict. Missile defenses can therefore strengthen the credibility of U.S. extended deterrence by making it easier for the U.S. military to introduce reinforcements that can move more freely through a region.

A missile defense system gives decision-makers more time to choose the most de-escalatory course of action. Without the ability to defend against an attack, U.S. authorities would be limited to an unappealing set of responses that could range from preemptive attacks to acceding to an enemy's demands or actions. By assuring some level of protection, robust missile defense systems would affect the dynamics of decision-making by removing the need to take immediate action. Missile defense can therefore be profoundly stabilizing.

Finally, missile defense minimizes damage if deterrence fails. A strong missile defense system would not only help to protect countless American lives; it would also help to keep U.S. forces available during a fight. During a campaign against China in the Indo-Pacific, for example, missile defenses deployed in the region could lower the loss rate for U.S. forces compared to the rate of replacement, thereby extending the war effort and giving U.S. forces more time to prevail.

The U.S. Missile Defense System

The U.S. missile defense system has three critical physical components:

- Sensors,
- Interceptors, and
- Command and control infrastructure that provides data from sensors to interceptors.

Of these, interceptors receive much of the public's attention because of their visible and kinetic nature. Components of missile defense systems can be classified based on the phase of flight during which intercept occurs, although some—for example, the command and control infrastructure or radars—can support intercepts in various phases of flight. Interceptors can shoot down an adversary ballistic missile in the boost, ascent, midcourse, or terminal phase of its flight. As cruise missiles and hypersonic glide vehicles continue to proliferate, the Missile Defense Agency (MDA) and the military services must therefore consider intercept in the boost, glide, or terminal phase of flight.

Another way to classify missile defense systems is by the range of an incoming missile (short-range, medium-range, intermediate-range, or intercontinental-range) that an interceptor is designed to shoot down. An interceptor's flight time determines both the time available to conduct an intercept and the optimal interceptor placement to improve intercept probability. With ICBMs, the United States has "30 minutes or less"[9] to detect the missile, track it, provide the information to the missile defense system, find the optimal firing solution, launch an interceptor, and shoot down the incoming missile, ideally with enough time to fire another interceptor if the first attempt fails. The time frame is shorter for intercepting short-range, medium-range, and intermediate-range ballistic missiles.

Finally, missile defense can be framed by the origin of interceptor launch. At present, U.S. interceptors are launched from the ground or from the sea. In the past, the United States explored possible ways to launch interceptors from the air or from space, but such efforts have been limited since the U.S. withdrawal from the Anti-Ballistic Missile Treaty in 2002.[10]

The current U.S. missile defense system is a result of investments made by successive U.S. Administrations. President Ronald Reagan envisioned the program—the Strategic Defense Initiative (SDI)—as a layered ballistic missile defense (BMD) system that would render nuclear missiles "impotent and obsolete."[11] These layers would have boost, ascent, midcourse, and terminal interceptors, including directed-energy interceptors, providing the United States with more than one opportunity to shoot down an incoming missile.

The United States stopped far short of this goal even though the SDI program generated tremendous technological advances and benefits.[12] Instead

MAP 18

U.S. Missile Defense Assets

GBI—Ground-based interceptors
GFC—Fire control center
GMD—Ground-based midcourse defense

IDT—In-Flight Interceptor Communications System (IFICS) Data Terminal

TPY-2—Transportable Radar Surveillance and Control Model 2
UEWR—Upgraded early warning radar

1. **Shemya, AK**
   - Cobra Dane radar
   - IDT
2. **Pearl Harbor, HI (base)**
   - Sea-based X-Band radar
3. **Clear, AK**
   - UEWR
4. **Ft. Greely, AK**
   - 40 GBIs
   - GMD
   - GFC
   - IDT
5. **Vandenberg AFB, CA**
   - 4 GBIs
   - 2 IDTs
6. **Beale AFB, CA**
   - UEWR
7. **Schriever AFB, CO**
   - GFC
8. **Ft. Drum, NY**
   - IDT
9. **Cape Cod, MA**
   - UEWR
10. **Thule, Greenland**
    - UEWR
11. **Fylingdales, UK**
    - UEWR
12. **Rota, Spain (base)**
    - Sea-based Aegis BMD SPY-1 radar
13. **Kurecik AFB, Turkey**
    - TPY-2 radar
14. **Israel**
    - TPY-2 radar
15. **CENTCOM-Middle East**
    - TPY-2 radar
16. **Shariki, Japan**
    - TPY-2 radar
17. **Kyogamisaki, Japan**
    - TPY-2 radar
18. **Outer space**
    - Defense support program satellites
    - Space-based infrared system satellites
    - Space-based kill assessment sensors

NOTE: Locations are approximate.

SOURCES:

- Fact Sheet, "Upgraded Early Warning Radars, AN/FPS-132," U.S. Department of Defense, Missile Defense Agency, approved for public release July 28, 2016, https://www.mda.mil/global/documents/pdf/uewr1.pdf (accessed August 17, 2022).
- William Cole, "'Golf Ball' Radar Leaves Pearl Harbor After $24M Upgrade," *Honolulu Star-Advertiser*, October 8, 2019, https://www.staradvertiser.com/2019/10/08/hawaii-news/golf-ball-radar-leaves-pearl-harbor-after-24m-upgrade/ (accessed August 17, 2022).
- Missile Defense Advocacy Alliance, "Ground-Based Midcourse Defense (GMD)," January 31, 2019, https://missiledefenseadvocacy.org/defense-systems/ground-based-midcourse-defense/ (accessed August 17, 2022).
- Thomas Karako, Ian Williams, and Wes Rumbaugh, *Missile Defense 2020: Next Steps for Defending the Homeland*, Center for Strategic and International Studies, Missile Defense Project, April 2017, https://csis-website-prod.s3.amazonaws.com/s3fs-public/publication/170406_Karako_MissileDefense2020_Web.pdf (accessed August 17, 2022).

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of a comprehensive layered system, the United States has no boost-phase ballistic missile defense systems and no defense against the advanced ballistic missile threats from China or Russia. The volatility and inconsistency of priority and funding for missile defense by successive Administrations and Congresses—Administrations and Congresses controlled by *both* major political parties—have yielded a system that is limited both numerically and technologically and incapable of defending against more sophisticated or more numerous long-range missile attacks.

The National Missile Defense Act of 1999 made it U.S. policy to protect the homeland only from a "limited ballistic missile attack."[13] The National Defense Authorization Act (NDAA) for Fiscal Year 2017 dropped the word "limited" even as it continued to focus on ballistic missiles.[14] Then the 2020 NDAA made it a matter of policy to rely on nuclear deterrence to defend against "near-peer intercontinental missile threats" and focus on improving missile defense against "rogue states."[15] In the future, as technological trends progress and modern technologies become cheaper and more widely available, North Korean or Iranian ballistic missiles may rival—in sophistication if not in numbers—those of Russia or China. Consequently, the United States must remain aware of how such threats are evolving and be prepared to alter its missile defense posture accordingly.

In January 2019, the Trump Administration published its congressionally mandated Missile Defense Review (MDR), a statement of policy intended to guide the Administration's missile defense programs. The 2019 MDR addresses the dangerous threat environment that has evolved since the previous MDR in 2010 and recognizes that future missile defense systems must defend against cruise and hypersonic missiles in addition to ballistic missiles.[16] The Biden Administration completed its MDR in 2022 but has not yet released the document to the public.

For fiscal year (FY) 2023, the Biden Administration has requested $9.6 billion for the MDA,[17] a decrease from the $10.3 billion finally agreed upon for FY 2022.[18]

Interceptors

Interceptors are one major component of the U.S. missile defense system. Different types of interceptors that respond to different missile threats have been emphasized over the years, and the composition of today's U.S. missile defense reflects these choices.

While the United States is working to improve its ability to strike down cruise missiles and hypersonic glide vehicles, the primary mission of its fully operational missile defense systems today is to intercept ballistic missiles. Missile defense interceptors are designed to intercept ballistic missiles in three different phases of flight.

- **The boost phase** extends from the time a missile is launched from its platform until its engines stop thrusting.

- **The midcourse phase** is the longest and thus offers a unique opportunity to intercept an incoming threat and, depending on other circumstances like the trajectory of the incoming threat and quality of U.S. tracking data, a second shot if the first intercept attempt fails.

- **The terminal phase** is less than one minute long, occurring as the missile plummets through the atmosphere toward the target, and offers a very limited opportunity to intercept a ballistic missile threat.

Boost-Phase Interceptors. The United States currently has no capability to shoot down missiles in their boost phase. Technologically, boost-phase intercept is the most challenging option because of the very short time during which a missile is boosting, the missile's extraordinary rate of acceleration during this brief window of time, and the need to have the interceptor close to the launch site.[19] This phase, however, is also the most beneficial time to strike. A boosting ballistic missile is at its slowest speed compared to other phases; it is therefore not yet able to maneuver evasively and has not yet deployed decoys that complicate the targeting and intercept problem.

In the past, the United States pursued several boost-phase programs, including the Airborne Laser, the Network Centric Air Defense Element, the Kinetic Energy Interceptor, and the Air Launched Hit-to-Kill missile. Each of these programs was eventually cancelled because of technical, operational, or cost challenges, and the United States has not progressed significantly on any boost-phase program since then.

Midcourse-Phase Interceptors. Intercepting missiles in their midcourse phase offers more time for intercept and presents fewer technological challenges than intercept in the boost phase presents, but it also allows the missile time to deploy decoys and countermeasures that can complicate interception by confusing sensors and radars. The United States deploys two systems that can shoot down incoming missiles in the midcourse phase of flight:

- The Ground-Based Midcourse Defense (GMD) system and
- The Aegis defense system.

The Ground-Based Midcourse Defense system is the only operational system capable of shooting down a long-range ballistic missile headed for the U.S. homeland. It consists of 40 Ground-Based Interceptors (GBIs) at Fort Greeley, Alaska, and four at Vandenberg Air Force Base, California. A GBI consists of a multi-staged rocket booster and an Exoatmospheric Kill Vehicle (EKV), which intercepts the incoming missile with hit-to-kill technology. In September 2021, the MDA "demonstrated the capability to select a 2-stage or 3-stage burn of a Ground Based Interceptor (GBI) booster, which enables an earlier release of the kill vehicle to greatly expand the engagement area and time to counter the inbound threat."[20]

To increase the probability of an intercept, the United States has to shoot multiple interceptors at each incoming ballistic missile. At present, because its inventory of interceptors is limited, the United States can shoot down only a handful of ballistic missiles that have relatively unsophisticated countermeasures.

In 2017, Congress approved a White House request to increase the number of GBIs from 44 to 64 to keep up with the advancing ballistic missile threat, particularly from North Korea.[21] The MDA intended to produce a Redesigned Kill Vehicle (RKV) to top 20 additional GBIs that would fill the new silos, but this program was canceled in 2019 because of technological difficulties.[22] The MDA instead initiated the Next Generation Interceptor (NGI) program to build an entirely new interceptor that would add both capacity and capability to the GMD system. NGIs will begin to fill the 20 empty silos around 2028 and could eventually replace some or all of the existing 44 GBIs. Unlike the GBIs, the NGI will feature multiple kill vehicles, enabling a single NGI to shoot at multiple objects ejected from one incoming missile.[23]

Contracts to develop the NGI were awarded to Lockheed Martin and a Northrop Grumman–Raytheon team in March 2021.[24] The FY 2023 budget request includes $1.766 billion for NGI to support these two competing designs through Critical Design Review in FY 2025.[25]

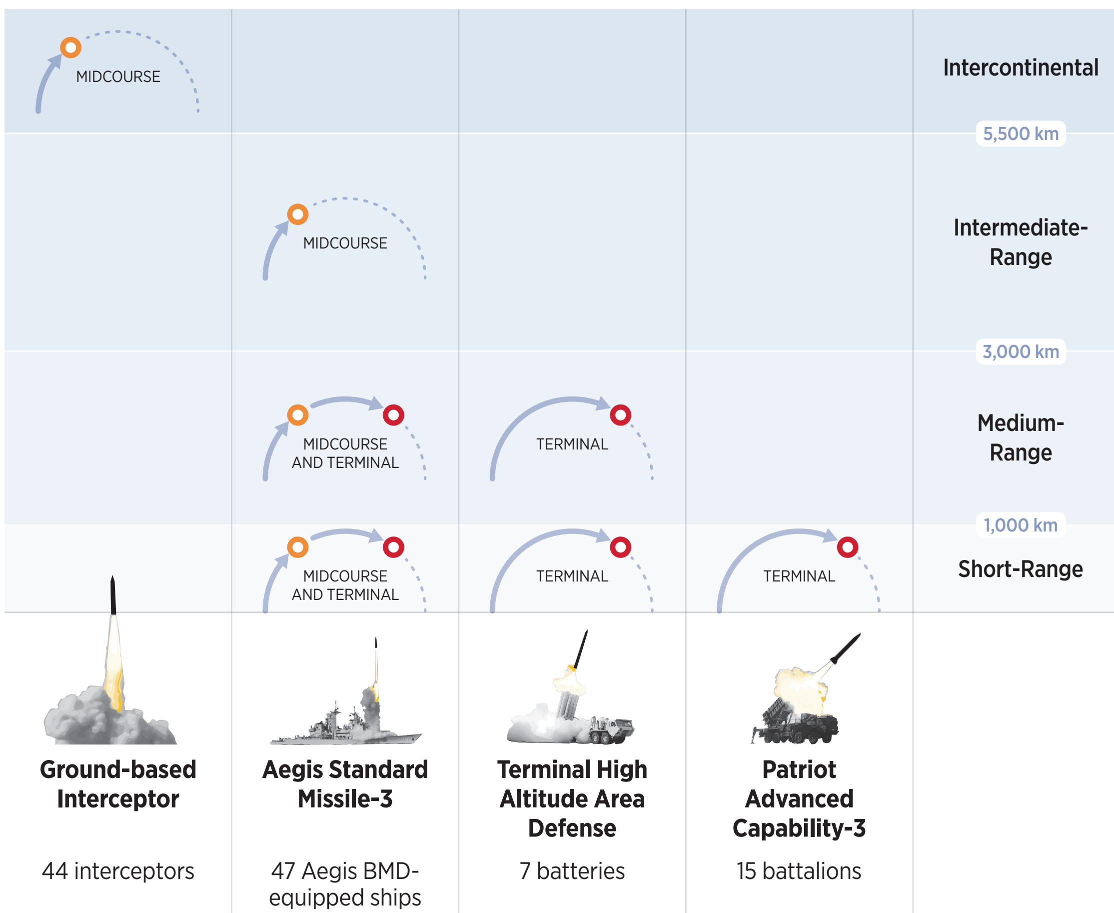
The Aegis defense system is a sea-based component of the U.S. missile defense system. It is designed to address the threat of short-range, medium-range (1,000–3,000 kilometers), and intermediate-range (3,000–5,500 kilometers) ballistic missiles. It utilizes different versions of the Standard Missile-3 (SM-3) and SM-6 depending on the threat and other considerations like ship location and quality of tracking data. The Aegis system also has capability against aerial threats and cruise missiles.[26] According to the FY 2023 budget submission, the number of BMD-capable Navy Aegis ships should increase to 50 by the end of FY 2023.[27] Japan also has several Aegis BMD-capable destroyers and cooperated with the United States to develop the latest SM-3 missile, the SM-3 Block IIA.[28]

The United States also deploys a land-based version of Aegis, called the Aegis Ashore system, in Romania, and another is nearing completion in Poland. Aegis Ashore sites relieve some of the stress on the naval fleet because BMD-capable cruisers and destroyers are multi-mission and are used for other purposes, such as wartime fleet operations and even anti-piracy operations. These Aegis Ashore sites help to protect U.S. allies and forces in Europe from the Iranian ballistic missile threat.

Aegis BMD will also play a significant role in the development of a missile defense system on the U.S. territory of Guam. Former Commander of U.S. Indo-Pacific Command (INDOPACOM) Admiral Philip Davidson has testified that "the most important action we can take to increase the joint force's lethality [in the region] is to introduce a 360-degree, persistent, air and missile defense capability on Guam (Guam Defense System (GDS))."[29] Current INDOPACOM Commander Admiral John Aquilino testified in March 2022 that "Guam's strategic importance is difficult to overstate" and emphasized "the importance of the island for sustaining the joint force as our main operating base and home to 130,000

FIGURE 5

U.S. Missile Defense: Interceptors



SOURCES: Center for Strategic and International Studies, Missile Defense Project, "Aegis Ballistic Missile Defense," *Missile Threat*, last updated August 4, 2021, https://missilethreat.csis.org/system/aegis/ (accessed August 17, 2022), and U.S. Department of Defense, Ofce of the Under Secretary of Defense (Comptroller)/Chief Financial Ofcer, *United States Department of Defense Fiscal Year 2023 Budget Request, Program Acquisition Cost by Weapon System*, April 2022, pp. 4–5, https://comptroller.defense.gov/Portals/45/Documents/defbudget/FY2023/FY2023_Weapons.pdf (accessed August 17, 2022).

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Americans."[30] The FY 2023 budget request includes a total of $892 million to continue development of an architecture for Guam defense and to begin procurement of needed components, including SM-3, SM-6, and Aegis fire control components.[31]

In November 2020, the U.S. Navy and the MDA shot down an intercontinental-range ballistic missile using the SM-3 interceptor class Block IIA against an ICBM target.[32] The test, FTM-44, was the first step in a plan to use SM-3 Block IIAs as an "underlay" to the GMD system to defend the homeland, with GBIs taking the first shot at an incoming target and SM-3 interceptors taking a second shot if the GBIs miss.[33] The MDA had initially planned to test the SM-3 IIA against a more complicated ICBM as the next step. However, the budget request for FY

2023 eliminates funds to pursue the SM-3 IIA as a homeland underlay.[34]

Terminal-Phase Interceptors. The United States currently deploys three terminal-phase missile defense systems:

- Terminal High Altitude Area Defense (THAAD);
- The Patriot missile defense system; and
- Aegis BMD.

A THAAD battery can shoot down short-range and intermediate-range ballistic missiles inside and just outside of the atmosphere.[35] It consists of a launcher, interceptors, the Army Navy/Transportable Radar Surveillance and Control Model 2 (AN/TPY-2) radar, and fire control.[36] The system is transportable and rapidly deployable. THAAD batteries have been deployed to such countries as Japan, South Korea, Israel, and the United Arab Emirates (UAE), and the U.S. signed a deal in 2020 to deliver THAAD to Saudi Arabia.[37] THAAD was employed successfully to intercept missiles for the first time in the UAE in February 2022.[38]

Patriot is an air-defense and short-range ballistic missile defense system. A battery is comprised of a launcher, interceptors, AN/MPQ-53/65 radar, an engagement control station, and diesel-powered generator units. The Patriot family of missile defense interceptors has been upgraded over time, from the initial Patriot Advanced Capability-1 (PAC-1) deployed in Europe in 1988 to the PAC-3 configuration deployed around the world today. The most recent Patriot upgrade, the PAC-3 Missile Segment Enhancement, expands the lethal battlespace with an advanced solid rocket motor.[39] The system is transportable, and the United States currently deploys it in several theaters around the world.[40]

Assessment. Interceptor strength is difficult to assess because, while deploying more interceptors to increase capacity or defend more targets is always preferable, deploying more short-range to medium-range interceptors to unprotected locations or increasing interceptor capacity ad infinitum is simply not feasible. Congress provided funding in FY 2022 to procure additional SM-3 Block IIA, PAC-3, and THAAD interceptors.[41] The FY 2023 budget would continue this effort for PAC-3 interceptors and continue funding for the eighth THAAD battery, but it would reduce procurement for THAAD and SM-3 IIA interceptors.[42]

To increase the defended battlespace, the MDA is pursuing the Patriot Launch-on-Remote (THAAD) capability, which integrates the PAC-3 and THAAD systems by enabling a PAC-3 launch using a THAAD AN/TPY-2 radar. Launch-on-Remote is a significant capability that can increase the defended area by spreading out missiles.[43] After two failed tests for the capability in 2020, the MDA, in conjunction with the Army, conducted two successful tests early in 2022.[44] The Army plans to field this capability "across all Patriot battalions beginning in Fiscal Year 2023."[45]

Progress on building a Guam defense system has moved slowly compared to the urgency of the Chinese threat.[46] Even though this missile defense system first appeared on the INDOPACOM Unfunded Priorities List in 2019, the President requested and Congress first provided funding for the system only in FY 2022.[47] Even so, the $192 million that was appropriated fell far short of the $350 million requested by INDOPACOM for that year.[48] However, the FY 2023 budget request includes $892 million "for the Missile Defense Agency, the Army, and the Navy to develop and field missile defense capabilities" that would "augment the existing Terminal High Altitude Area Defense (THAAD) battery currently emplaced on the island…and bolster U.S. military posture in the Indo-Pacific region."[49]

The Commander of U.S. Northern Command (NORTHCOM), General Glen VanHerck, recently testified that "[w]hile current BMD capability and capacity is sufficient to defeat a limited ballistic missile attack from a rogue nation, North Korea's ongoing development of increasingly complex and capable strategic weapons requires the Next Generation Interceptor to be fielded on time or early."[50] The increasing capacity of North Korea's ballistic missiles to strike the U.S. homeland and North Korea's ability to deploy decoys cause concern that the rogue state may eventually be able to overwhelm the current GMD system.[51]

Following a delay in awarding the NGI contract, the program appears to be on track for an initial fielding in 2028 if not 2027.[52] NGI will add needed capacity and capability to the GMD system. In addition to accelerating the NGI program, the MDA and Congress continue to support a GMD service life extension program (SLEP) that is intended to maintain the existing fleet through this decade and beyond 2030. Given that NGI will not replace the existing GBI fleet—at least not initially—it is critical that the existing interceptors can remain in service. The GMD system was largely built in the early 2000s, and many parts—including the GBI kill vehicles, boosters, and ground systems—are subject to degradation from aging. The SLEP, for instance, will include the delivery of five new boosters to ensure that the number of interceptors does not decrease, and it is essential that this effort to avoid a decrease in capacity continues.[53] The MDA will also need to consider additional NGI purchases after the initial 20 to begin replacing existing GBIs in the 2030s.

In 2019, to strengthen homeland missile defense after the RKV was canceled and before NGI comes online, the Trump Administration proposed the development of an underlay using SM-3 Block IIA and THAAD interceptors. General VanHerck agreed to the value of an underlay in 2021, stating that "an underlayer would give us additional capacity and capability" to address threats to the homeland.[54] The MDA had progressed toward this underlay after its successful test of the SM-3 IIA against an ICBM target in 2020, but the Department of Defense (DOD) had not articulated a concept of operations for employing the SM-3 Block IIA and THAAD for homeland defense, including where in the United States those systems could be deployed or how many would be required, as requested by Congress. The budget request for FY 2023 eliminates all funding for the layered homeland defense program.

While the MDA is investing both in the GMD SLEP and the NGI program to ensure defense of the homeland, forgoing a homeland underlay will deprive the homeland of added capacity against an uncertain North Korean threat. The utility of exploring the use of SM-3 and THAAD interceptors for ICBMs can also extend beyond an underlay for the continental United States, as they can work for other missions or defended assets like Hawaii, Alaska, and Guam as well. Using SM-3 and THAAD interceptors to defend against ICBMs could still be advantageous for the United States, but it would require a commitment to move quickly that neither the DOD nor Congress has demonstrated.

Currently, the only interceptor the United States has available to intercept hypersonic missiles is the SM-6.[55] To strengthen U.S. capability against maneuverable hypersonic missiles, the MDA is in the early stages of developing the Glide Phase Interceptor (GPI), which is designed to intercept regional hypersonic missiles in their glide phase of flight. In 2021, the MDA awarded Other Transaction Authority (OTA) agreements to Lockheed Martin, Northrop Grumman, and Raytheon to develop design concepts for the GPI.[56] For FY 2022, Congress added $39.9 million to the MDA's requested amount of $247.9 million for hypersonic defense,[57] and the FY 2023 budget request includes $225.5 million for the program.[58]

The Army's Indirect Fire Protection Capability Increment 2 (IFPC 2) program has been moving very slowly but has seen recent improvement. The IFPC 2 would defend against short-range rockets, artillery, and mortars as well as cruise missiles, against which the United States, as noted, lacks a sufficient defensive capability.[59] As a system, IFPC would fill the gap between short-range tactical air defense and ballistic missile defense like PAC-3 and THAAD.

In response to a congressional requirement that it field an interim cruise missile defense capability in response to the increasing cruise missile threat, the Army purchased two Iron Dome batteries manufactured by the Israeli company Rafael.[60] Despite prior concerns about integrating Iron Dome as part of an enduring IFPC solution, the Army is preparing the Iron Dome systems for operational deployment and integration into its future missile defense command and control system.[61] In 2021, the Army deployed Iron Dome to Guam and conducted a successful simulation to test the system.[62] However, no evidence indicates that Iron Dome will be integrated into the Guam defense system that is under development. In September 2021, the Army awarded a contract to Dynetics to develop its own enduring IFPC 2 system, which is scheduled to reach combat capability in FY 2023.[63]

Overall, the United States has multiple capable interceptors, but there is much room for improvement. The most important step for the near future will be on-time or early delivery of the NGI to ensure protection of the homeland from North Korea and to mitigate the growing threat from China.

Sensors

The sensor component of the U.S. missile defense system is distributed across the land, sea, and space domains and provides the United States and its allies with the earliest possible warning of a launch of enemy missiles in addition to missile tracking and discrimination. These sensors can detect a missile launch, track a missile in flight, and even classify the type of projectile, its speed, and the target against which the missile has been directed. They relay this information to the command and control stations that operate interceptor systems like Aegis (primarily a sea-based system) or THAAD (a land-based system).

Land-Based. On land, the major sensor installations are the upgraded early warning radars (UEWRs), which are concentrated along the North Atlantic and Pacific corridors that present the most direct flight path for a missile aimed at the United States. They include the phased array early warning radars based in California, the United Kingdom, and Greenland that scan objects up to 3,000 miles away.[64] Two additional sites—one in Cape Cod, Massachusetts, and the other in Clear, Alaska—have been modernized for use in the layered ballistic missile defense system after facing delays.[65] These sensors focus on threats that can be detected in the missile's boost or launch phase when the release of exhaust gases creates a heat trail that is relatively easy for sensors to detect. A shorter-range (2,000-mile) radar called the Cobra Dane is based in Shemya, Alaska.[66]

The United States also deploys mobile land-based sensors called AN/TPY-2s. These sensors can be forward deployed for early threat detection or kept in terminal mode to provide tracking and fire control support for the THAAD interceptors.[67] Of the United States' 12 AN/TPY-2 systems, five are forward deployed with U.S. allies.[68] The United States plans to field a 13th AN/TPY-2 radar in FY 2025 for service with the eighth THAAD battery.[69] In cooperation with the Republic of Korea, the United States deploys a THAAD missile system accompanied by an AN/TPY-2 on the Korean Peninsula.

To fill a gap in missile discrimination capability for tracking North Korean missiles over the Pacific, the MDA is developing the Long Range Discrimination Radar (LRDR) in Northern Alaska to improve coverage in the northern Pacific. The LRDR utilizes the SPY-7 radar, which the MDA will also purchase for the Guam defense system.[70] The DOD had also identified the need to develop the Homeland Defense Radar–Hawaii (HDR–H) to fill a tracking and discrimination gap over Hawaii. The Trump Administration's FY 2021 budget request omitted funding for HDR–H because of budget constraints, as did the Biden Administration's request for FY 2022. In both years, Congress provided the funding needed to proceed with the radar, and in FY 2022, it mandated that future budget requests must include adequate funding to build and operate the HDR–H by 2028.[71] However, the FY 2023 budget request again excludes funding for the HDR–H.[72]

Sea-Based. There are two types of sea-based sensors. The first is the Sea-Based X-band (SBX) radar, which is mounted on an oil-drilling platform and can be relocated to different parts of the globe as threats evolve.[73] SBX is employed primarily in the Pacific. The second radar is the SPY-1 radar system, which is mounted on U.S. Navy vessels equipped with the Aegis Combat System and therefore is able to provide data that can be utilized for ballistic missile missions. The Navy is replacing all SPY-1 radars with the SPY-6 radar, which will have a greater detection range and other advanced capabilities.[74]

Space-Based. Finally, U.S. missile defense sensors operate in space. From the ultimate high ground, space-based sensors have the potential to detect and track missile launches from almost any location from boost to terminal phase, unlike ground-based radars that are limited in their tracking range.[75] The MDA, the U.S. Space Force, and the Space Development Agency (SDA) all control aspects of the space missile defense sensor system.

The oldest system that contributes to the missile defense mission is the Defense Support Program (DSP), a constellation of satellites that use infrared sensors to identify heat from booster and missile plumes to detect an initial launch. The DSP satellite system has gradually been replaced by the Space-Based Infrared Radar System (SBIRS) to improve the delivery of missile defense and battlefield intelligence.[76] For instance, SBIRS can scan a wide swath of territory while simultaneously tracking a specific target, making it a useful means for observing tactical, or short-range, ballistic missiles.[77]

The Space Force launched the sixth and final SBIRS satellite in August 2022.[78] The Air Force originally planned to launch eight SBIRS satellites, but because of congressional funding delays, it decided to end production of SBIRS early and move on to development of its replacement, the Next-Generation Overhead Persistent Infrared (Next-Gen OPIR) satellite, in 2017.[79] The seventh and eighth SBIRS satellites will be switched to Next-Gen OPIR satellites, the first of which is to be delivered "no later than FY 2025."[80] The Next-Gen OPIR satellites are designed to be more survivable against cyber and electronic attacks.

The MDA also has developed and deployed Space-based Kill Assessment (SKA) sensors on commercial satellites.[81] SKA uses a network of infrared sensors to provide a hit and kill assessment of homeland defense intercepts. After several years of successful testing of SKA sensors in orbit, the FY 2023 budget supports integrating SKA into the homeland defense system.[82]

The United States is developing a system of satellites capable of providing global detection, tracking, and discrimination of any missile launch. Dating back as far as President Reagan's Strategic Defense Initiative, successive Administrations have called for a proliferated layer of sensing satellites in space to track the flight of any type of missile—not just ballistic—from birth to death. A layer of space-based sensors can be particularly useful in tracking hypersonic vehicles, which fly at lower altitudes than ballistic missiles and can maneuver during flight. The DSP and SBIRS systems were designed for ballistic missiles and can lose track of missiles flying at lower altitudes. Since many new threats are not flying on ballistic trajectories, Congress has been paying close attention to development of this space sensor layer.

Beginning in 2009, the MDA operated two Space Tracking and Surveillance System-Demonstrators (STSS-D) satellites in an effort to demonstrate this capability to track ballistic missiles that exit and reenter the Earth's atmosphere during the midcourse phase.[83] Data obtained by those demonstration satellites were used to provide risk reduction to support future space trackers. Both satellites were decommissioned in March 2022.[84] Today, the SDA, in conjunction with the MDA, is developing a space Tracking Layer of satellites proliferated in Low-Earth Orbit (LEO) as part of the SDA's National Defense Space Architecture. According to the SDA:

> Once fully operational, the SDA Tracking Layer will consist of a proliferated heterogeneous constellation of Wide Field of View (WFOV) space vehicles (SVs) that provide persistent global coverage and custody capability combined with the Missile Defense Agency (MDA) Hypersonic and Ballistic Tracking Space Sensor (HBTSS) Medium Field of View (MFOV) SVs that provide precision global access capability.[85]

Once deployed, the Tracking Layer will be able to detect, track, and discriminate among any types of missile launch throughout the entirety of the missile's flights, including both hypersonic glide vehicles and dimmer ballistic missile targets. The SDA is also exploring the ability of space sensors to provide fire control information directly to weapon platforms like THAAD or Aegis (as opposed to the data going through a ground station).

In FY 2022, Congress provided $256 million to the MDA for the HBTSS. In 2021, the MDA awarded contracts to Northrop Grumman and L3Harris to develop HBTSS prototypes, which are on track to launch in FY 2023. The budget request for FY 2023 includes $89.2 million for this effort.[86] Congress also added $550 million in FY 2022 for the SDA's tracking layer. The first eight satellites as part of Tranche 0 are projected to launch in 2023.[87] The SDA is also working to award a contract for Tranche 1 satellites to launch in 2025.[88]

Assessment. Senior defense leaders have stated repeatedly that deploying sensor satellites to space to track missiles from the high ground throughout their entire flight is the best way to advance sensor capability. According to Admiral Charles Richard, Commander of U.S. Strategic Command (STRATCOM):

> Future space-based sensors may be able to provide birth-to-death detection, tracking, and discrimination of hypersonic glide vehicle, cruise missile, and ballistic missile threats globally. These abilities cannot be fully achieved with the current or future terrestrial-based radar architecture due to the constraints of geography and characteristics of future missile threats.[89]

Initially, the space-based sensor program was plagued by insufficient funding requests and bureaucratic infighting over whether the SDA or the MDA would develop the HBTSS.[90] Since then, clear roles for the SDA and MDA have been defined, contracts for the HBTSS have been awarded, and the SDA's Tracking Layer has progressed steadily. A strong assessment of missile defense sensing capabilities will depend on progress made on the space-based sensor effort, especially in view of commanders' urgent need for improved missile tracking as well as the technological challenges associated with developing a sensor that can perform in LEO.[91]

Development of land-based sensors to fill the missile discrimination capability gap over the Pacific has progressed slowly. Development of the LRDR has been delayed by at least a year.[92] The HDR-H project continues to face an uncertain future: Congress provides appropriations for the program, but the DOD does not include it in its budget request despite explicit congressional direction to do so. This way of funding a program that was originally proposed to fill a discrimination gap over Hawaii is problematic, as the DOD and Congress have never resolved their differences over the need for this capability.

Improved sensor capabilities are also critical to addressing the cruise missile threat to the homeland. As noted previously, the United States has no dedicated missile defense system to counter this threat. Due to their low-trajectories, cruise missiles are more difficult to detect and track than are ballistic missiles. Russia's ability to strike key strategic nodes in the U.S. homeland from its own territory is of particular concern. To address the cruise missile threat, General VanHerck has emphasized improving domain awareness, because early identification of a threat allows for options like left-of-launch operations or diplomacy to avoid having to shoot down cruise missiles inside the U.S.[93]

The MDA included $11 million in the FY 2023 budget request (down from $14 million in FY 2022) to develop an architecture for cruise missile defense of the homeland. In 2021, General VanHerck requested funding for a new elevated sensor to help detect cruise missiles aimed at Washington, D.C.[94] The NORTHCOM unfunded priorities lists for both FY 2022 and FY 2023 include additional funding for a cruise missile defense homeland kill chain demonstration.[95] Developing a capability to detect, track, and eventually intercept a conventional cruise missile attack will be critical to denying adversaries the ability to hold the homeland at risk below the nuclear threshold.

The Next-Gen OPIR program appears to remain on schedule after early delays, and the FY 2023 budget request continues to fund the program. It also includes funding for several LEO and Medium Earth Orbit satellites to enhance missile warning capabilities.[96] The Army is also progressing quickly on development of the Lower-Tier Air and Missile Defense System radars that will provide 360-degree threat coverage for PAC-3 and other regional missile defense batteries; the current Patriot radar can scan only one-third of the sky at a time.[97]

The space-sensor project is now on track compared to previous years. It is important that land-based radar coverage moves forward to stabilize the future sensor architecture.

Command and Control

Command and control of the U.S. ballistic missile defense system requires bringing together data from U.S. sensors and radars and relaying those data to interceptor operators so that they can destroy incoming missiles directed against the U.S. and its allies. The operational hub of missile defense command and control is the Joint Functional Component Command for Integrated Missile Defense (JFCC IMD), a component of STRATCOM housed at Schriever Air Force Base, Colorado. JFCC IMD brings together Army, Navy, Marine Corps, Space, and Air Force personnel and is co-located with the MDA's Missile Defense Integration and Operation Center (MDIOC). This concentration of leadership from across the various agencies helps to streamline decision-making for those who command and operate the U.S. missile defense system.[98]

Command and control of the GMD system to defend the homeland utilizes the Ground-based Midcourse Defense Fire Control (GFC) system, which consists of a suite of hardware, software, and personnel located in Fort Greely, Alaska, and Vandenberg Air Force Base, California.[99] The system involves collecting data on missile movement from sensors and radars to inform the launch of GBIs.

Once a missile is launched, data from the U.S. global network of sensors and radars travel through secure satellite communications and ground-based redundant communications lines to the Command Launch Equipment (CLE) software that can task GBIs to fire at the incoming missile. Then, once the NORTHCOM Commander—who becomes the supported commander during GMD execution—in consultation with the President has determined the most effective response to a missile threat, the CLE fire response option is relayed to the appropriate GBIs in the field.[100] When the selected missiles have been fired, they maintain contact with In-Flight Interceptor Communications System (IFICS) Data Terminals (IDTs) to receive updated flight information that helps to guide them to their target.[101]

To prepare for and execute GMD operations, the NORTHCOM Commander can also utilize situational awareness data from the Command and Control, Battle Management and Communication (C2BMC) system. Through its software and network systems, C2BMC helps to process and integrate sensor information to provide a more complete picture of the battlespace.[102] The GMD Fire Control system acts as the primary decision aid for GMD execution, and the C2BMC system provides integrated battlefield awareness information before and during GMD operations.[103] It also provides information to other missile defense systems like THAAD and Patriot. Dozens of C2BMC workstations are distributed throughout the world at U.S. military bases.

C2BMC has undergone multiple technical upgrades (called spirals) since 2004 to bring more missile defense elements into the network. In 2019, the MDA completed an upgrade that will help to expand Aegis missile defense coverage by enabling Aegis Weapons Systems to engage on remote.

Regional missile defense systems like THAAD, PAC-3, and Aegis are equipped with their own individual fire control systems to control the launch of their interceptors. The C2BMC system can also provide tracking information to individual missile defense batteries from other regional sensors. Aegis BMD systems have onboard control governed by the Aegis Combat System, and they can provide their sensor data to the GMD system through C2BMC.[104]

C2BMC connects sensors and shooters around the world to a global network, but there is no comparable system to link sensors and shooters in a single region. The Army is developing the Integrated Air and Missile Defense (IAMD) Battle Command System (IBCS) to provide this capability. Once fielded, IBCS would connect all sensors and shooters in a region to a single fire control network.[105] Like IFPC, IBCS would also link defenses against smaller threats with ballistic missile defense.

Assessment. A strong global command and control system is critical to missile defense because linking information from sensors can increase domain awareness and the time available to engage a target, thereby improving the probability of intercept. In addition, according to General VanHerck, "[g]lobal all-domain awareness will generate a significant deterrent effect by making it clear that we can see potential aggressors wherever they are, which inherently casts doubt on their ability to achieve their objectives."[106] This concept is especially important in dealing with cruise missile threats to the homeland, against which the U.S. has no comprehensive interceptor capability.

Continuing to upgrade the C2BMC will remain critical to increasing the integration of missile defense elements across the world and therefore improving chances of intercept. For instance, it was revealed in 2021 that the MDA provided U.S. Indo-Pacific Command with a hypersonic missile defense capability, largely as a result of C2BMC improvements that allow sensors to see the threat sooner.[107] The MDA is nearing completion of another upgrade to incorporate the LRDR into C2BMC after a delay.[108] It also has linked C2BMC to the Army's IBCS, and the next round of upgrades will further integrate those systems as well as enhance the threat data provided to the GMD system.[109]

The United States will need a more advanced command and control capability as global missile threats shift to include cruise and hypersonic missiles in addition to ballistic missiles. The DOD is currently developing a Joint All Domain C2 (JADC2) system to integrate non-compatible sensors across all domains into a single network so that it can respond to the complex threat more efficiently. Missile defense command and control will strengthen as the services begin to field JADC2 capabilities.

In addition, NORTHCOM and the North American Aerospace Defense Command have conducted a series of Global Information Dominance Experiments (GIDE) that "provid[e] combatant commanders, intelligence and operations directors, and other participants at multiple sites with a shared, customizable, and near real-time data set" by collecting and integrating information from multiple sensors needed for decision-making and sending that information to commanders quickly.[110] Sensor information can tend to exist in stovepipes, and if it is not integrated, the result can be failure to detect a threat.[111] GIDE also uses artificial intelligence and machine learning cues to ensure that the commander receives a full data picture.[112]

IBCS will also provide an important improvement in regional missile defenses. The system will link all missile defense sensors and interceptors to one fire control center, as opposed to today's more stovepiped approach in which each unit operates its co-located sensor and launcher independently. By permitting air and missile defenses to function as a joint kill web rather than as a linear kill chain, IBCS will be able to determine the best shooter to take down an incoming missile, in turn increasing the defended battlespace.

After an initial multi-year delay due to technical issues, the Army has awarded a production contract for IBCS to Northrop Grumman, and the program is now on its new schedule for full production by the end of 2022.[113] Advancements underway in missile defense command and control will become increasingly necessary to enable defense against the growing missile threat.

Conclusion

By successive choices of post–Cold War Administrations and Congresses, the United States does not have in place a comprehensive set of missile defense systems that would be capable of defending the homeland and allies from robust ballistic missile threats. U.S. efforts have focused on a limited architecture that protects the homeland and on deploying and advancing regional missile defense systems.

Although the United States has in place multiple types of capable interceptors, a vast sensor network, and a command and control system, many elements of the missile defense system need to be improved to defend against today's threat more efficiently. At the same time, the development of missile threats, both qualitative and quantitative, is outpacing the speed of missile defense research, development, and deployment to address those threats. Senior leaders continue to stress the importance of U.S. missile defense, but if the nation is to realize the strategic benefits that missile defense provides, Congress must ensure that the funding of critical programs like NGI, space sensors, and JADC2 is commensurate with that importance.

Endnotes

1. U.S. Air Force, National Air and Space Intelligence Center (NASIC), and Defense Intelligence Ballistic Missile Analysis Committee, *2020 Ballistic and Cruise Missile Threat*, July 2020, p. 2, https://media.defense.gov/2021/Jan/11/2002563190/-1/-1/1/2020%20BALLISTIC%20AND%20CRUISE%20MISSILE%20THREAT_FINAL_2OCT_REDUCEDFILE.PDF (accessed June 10, 2022).
2. BBC News, "North Korea Tests Banned Intercontinental Missile," March 24, 2022, https://www.bbc.com/news/world-asia-60858999#:~:text=North%20Korea%20has%20tested%20a,flying%20for%20over%20an%20hour (accessed June 10, 2022); Yoonjung Seo, Junko Ogura, and Jessie Yeung, "North Korea Launches 9th Missile Test of the Year," CNN, updated March 5, 2022, https://www.cnn.com/2022/03/04/asia/north-korea-missile-test-intl-hnk/index.html (accessed June 10, 2022); Ralph Savelsberg and Tomohiko Kawaguchi, "North Korea's Hypersonic Missile Claims Are Credible, Exclusive Analysis Shows," *Breaking Defense*, February 16, 2022, https://breakingdefense.com/2022/02/north-koreas-hypersonic-missile-claims-are-credible-exclusive-analysis-shows/ (accessed June 10, 2022); and Soo-Hyang Choi and Josh Smith, "Kim Jong Un Observes Missile Test to Boost Nuclear Capabilities," Reuters, April 17, 2022, https://www.reuters.com/world/asia-pacific/nkorean-leader-observes-new-weapons-test-enhance-nuclear-capabilities-kcna-2022-04-16/ (accessed June 10, 2022).
3. Mary Beth D. Nikitin, "North Korea's Nuclear Weapons and Missile Programs," Congressional Research Service *In Focus* No. 10472, updated April 8, 2022, https://fas.org/sgp/crs/nuke/IF10472.pdf (accessed June 10, 2022).
4. Associated Press, "Report: Iran Launched Solid-Fuel Satellite Rocket into Space," ABC News, January 13, 2022, https://abcnews.go.com/International/wireStory/report-iran-launched-solid-fuel-satellite-rocket-space-82245006 (accessed June 10, 2022).
5. General Glen D. VanHerck, United States Air Force, Commander, United States Northern Command and North American Aerospace Defense Command, statement before the Committee on Armed Services, U.S. Senate, March 24, 2022, pp. 5–6 and 7–8, https://www.armed-services.senate.gov/imo/media/doc/USNORTHCOM%20and%20NORAD%202022%20Posture%20Statement%20FINAL%20(SASC).pdf (accessed June 10, 2022).
6. U.S. Department of Defense, Office of the Secretary of Defense, *Annual Report to Congress: Military and Security Developments Involving the People's Republic of China 2021*, p. 60, https://media.defense.gov/2021/Nov/03/2002885874/-1/-1/0/2021-CMPR-FINAL.PDF (accessed June 10, 2022).
7. U.S. Air Force, National Air and Space Intelligence Center (NASIC), and Defense Intelligence Ballistic Missile Analysis Committee, *2020 Ballistic and Cruise Missile Threat,* p. 36, and Paul Kirby, "Russia Claims First Use of Hypersonic Kinzhal Missile in Ukraine," BBC News, March 19, 2022, https://www.bbc.com/news/world-europe-60806151 (accessed June 10, 2022).
8. VanHerck, statement before Senate Armed Services Committee, March 24, 2022, pp. 6 and 8.
9. Matthew Kroenig, "The Case for the US ICBM Force," *Strategic Studies Quarterly*, Vol. 12, No. 3 (Fall 2018), p. 59, https://www.airuniversity.af.edu/Portals/10/SSQ/documents/Volume-12_Issue-3/Kroenig.pdf (accessed June 10, 2022).
10. The platform carrying air-launched ballistic missile interceptors has to be close to the launch area, aloft, properly oriented, and generally within the range of enemies' anti-access/area-denial systems because of payload limits on airborne platforms themselves. These requirements make airborne intercepts particularly challenging.
11. Ronald Reagan, "Address to the Nation on National Security," March 23, 1983, https://millercenter.org/the-presidency/presidential-speeches/march-23-1983-address-nation-national-security (accessed June 10, 2022).
12. For example, SDI Organization investment helped to make certain electronic and optical components cheaper and more effective and helped to reduce the cost per pixel on a display screen by a factor of 20. Additional advances were made in areas of sensor technology, communications, and computers. For more information, see James A. Abrahamson and Henry F. Cooper, *What Did We Get for Our $30-Billion Investment in SDI/BMD?* National Institute for Public Policy, September 1993, pp. 9–11, http://highfrontier.org/wp-content/uploads/2016/08/What-for-30B_.pdf (accessed June 10, 2022).
13. Sec. 2, "National Missile Defense Policy," in H.R. 4, National Missile Defense Act of 1999, Public Law 106-38, 106th Cong., July 22, 1999, https://www.congress.gov/106/plaws/publ38/PLAW-106publ38.pdf (accessed June 10, 2022).
14. Sec. 1681, "National Missile Defense Policy," in S. 2943, National Defense Authorization Act for Fiscal Year 2017, Public Law 114–328, 114th Cong., December 23, 2016, https://www.congress.gov/114/plaws/publ328/PLAW-114publ328.pdf (accessed June 10, 2022). The understanding of the word "limited" changed over time, from scaling a missile defense system to shoot down about 200 reentry vehicles right after the end of the Cold War (because that is how many a rogue Soviet commander was believed to be able to launch from a submarine) to scaling it to shoot down only a handful of relatively less sophisticated North Korean or Iranian ballistic missiles. For more information, see Independent Working Group on Missile Defense, the Space Relationship, and the Twenty-First Century, *2009 Report*, Institute for Foreign Policy Research and Analysis, 2009, p. 17, http://www.space-library.com/0902IFPA_IWG2009.pdf (accessed June 10, 2022).
15. Sec. 1681, "National Missile Defense Policy," in S. 1790, National Defense Authorization Act for Fiscal Year 2020, Public Law 116-92, 116th Cong., December 20, 2018, https://www.congress.gov/bill/116th-congress/senate-bill/1790?q=%7B%22search%22%3A%5B%22s+1790%22%5D%7D&s=1&r=1 (accessed June 11, 2022).
16. U.S. Department of Defense, Office of the Secretary of Defense, *2019 Missile Defense Review*, passim, https://media.defense.gov/2019/Jan/17/2002080666/-1/-1/1/2019-MISSILE-DEFENSE-REVIEW.PDF (accessed June 11, 2022). See also U.S. Air Force, National Air and Space Intelligence Center (NASIC), and Defense Intelligence Ballistic Missile Analysis Committee, *2020 Ballistic and Cruise Missile Threat*.

17. U.S. Department of Defense, Office of the Under Secretary of Defense (Comptroller)/Chief Financial Officer, *United States Department of Defense Fiscal Year 2023 Budget Request: Defense Budget Overview*, April 2022, p. 2-14, https://comptroller.defense.gov/Portals/45/Documents/defbudget/FY2023/FY2023_Budget_Request_Overview_Book.pdf (accessed June 11, 2022).
18. Explanatory Statement, "Division C—Department of Defense Appropriations Act, 2022," in *Consolidated Appropriations Act, 2022*, Committee Print of the Committee on Appropriations, U.S. House of Representatives, on H.R. 2471/Public Law 117-103 [Legislative Text and Explanatory Statement], Book 1 of 2, Divisions A–F, 117th Cong., 2nd Sess., April 2022, p. 449, https://www.govinfo.gov/content/pkg/CPRT-117HPRT47047/pdf/CPRT-117HPRT47047.pdf (accessed June 12, 2022). See also "Explanatory Statement Submitted by Ms. DeLauro, Chair of the House Committee on Appropriations, Regarding the House Amendment to the Senate Amendment to H.R. 2471, Consolidated Appropriations Act, 2022," *Congressional Record*, Vol. 168, No. 42—Book III, 117th Cong., 2nd Sess., March 9, 2022, p. H1868, https://www.congress.gov/117/crec/2022/03/09/168/42/CREC-2022-03-09-house-bk3.pdf (accessed June 12, 2022).
19. National Research Council, Division on Engineering and Physical Sciences, Committee on an Assessment of Concepts and Systems for U.S. Boost-Phase Missile Defense in Comparison to Other Alternatives, *Making Sense of Ballistic Missile Defense: An Assessment of Concepts and Systems for U.S. Boost-Phase Missile Defense in Comparison to Other Alternatives* (Washington: National Academies Press, 2012), pp. 8–9, https://nap.nationalacademies.org/read/13189/chapter/2#8 (accessed June 12, 2022).
20. Vice Admiral Jon A. Hill, USN, Director, Missile Defense Agency, statement before the Subcommittee on Strategic Forces, Committee on Armed Services, U.S. House of Representatives, May 11, 2022, p. 6, https://armedservices.house.gov/_cache/files/4/f/4ff340b3-e1a6-436c-99b8-18db4cea4089/2BFBA2F9187724987A3A950972410120.20220511-str-witness-statement-hill.pdf (accessed May 18, 2022).
21. Jen Judson, "Countering North Korea: Congress Authorizes Major Buildup in Homeland Missile Defense," *Defense News*, November 17, 2017, https://www.defensenews.com/congress/2017/11/17/countering-north-korea-hill-authorizes-major-buildup-in-homeland-missile-defense/ (accessed June 12, 2022).
22. In June 2021, MDA Director Vice Admiral Jon Hill testified that "[w]e have all 20 silos installed [at Missile Field 4 in Fort Greely, Alaska] and now we are doing integration." See statement of Vice Admiral Jon Hill, Director, Missile Defense Agency, in stenographic transcript of *Hearing to Receive Testimony on Missile Defense Strategies, Policies, and Programs in Review of the Defense Authorization Request for Fiscal Year 2022 and the Future Years Defense Program*, Subcommittee on Strategic Forces, Committee on Armed Services, U.S. Senate, June 9, 2021, p. 55, https://www.armed-services.senate.gov/imo/media/doc/21-48_06-09-2021.pdf (accessed June 19, 2022).
23. Patty-Jane Geller, "It's Time to Get Homeland Missile Defense Right," *Defense News*, January 4, 2021, https://www.defensenews.com/opinion/commentary/2021/01/04/its-time-to-get-homeland-missile-defense-right/ (accessed June 12, 2022).
24. Press release, "Contracts Awarded for Next Generation Interceptor Program," U.S. Department of Defense, March 23, 2021, https://www.defense.gov/Newsroom/Releases/Release/Article/2547665/contracts-awarded-for-next-generation-interceptor-program/ (accessed June 12, 2022).
25. Exhibit R-2, "RDT&E Budget Item Justification: PB 2023 Missile Defense Agency, Appropriation/Budget Activity 0400: Research, Development, Test & Evaluation, Defense-Wide / BA 4: Advanced Component Development & Prototypes (ACD&P), R-1 Program Element (Number/Name) PE 0604874C / Improved Homeland Defense Interceptors," in U.S. Department of Defense, *Department of Defense Fiscal Year (FY) 2023 Budget Estimates, Missile Defense Agency, Defense-Wide Justification Book Volume 2a of 5: Research, Development, Test & Evaluation, Defense-Wide*, April 2022, p. 683, https://comptroller.defense.gov/Portals/45/Documents/defbudget/fy2023/budget_justification/pdfs/03_RDT_and_E/RDTE_Vol2_MDA_RDTE_PB23_Justification_Book.pdf (accessed June 12, 2022), and Exhibit R-2A, "RDT&E Project Justification: PB 2023 Missile Defense Agency, Appropriation/Budget Activity 0400 / 4, R-1 Program Element (Number/Name) PE 0604874C / Improved Homeland Defense Interceptors, Project (Number/Name) MD80 / Next Generation Interceptor Development (NGI)," in ibid., p. 690.
26. Center for Strategic and International Studies, Missile Defense Project, "Aegis Ballistic Missile Defense," *Missile Threat*, last updated August 4, 2021, https://missilethreat.csis.org/system/aegis/ (accessed June 13, 2022).
27. Op-5 Exhibit, "Missile Defense Agency, Operation and Maintenance Defense-Wide, Fiscal Year (FY) 2023 President's Budget, IV. Performance Criteria and Evaluation Summary," in U.S. Department of Defense, *Department of Defense Fiscal Year (FY) 2023 Budget Estimates, Missile Defense Agency, Defense-Wide Justification Book Volume 2b of 2: Procurement, Defense-Wide (Includes O&M and MILCON)*, April 2022, p. lvii, https://comptroller.defense.gov/Portals/45/Documents/defbudget/fy2023/budget_justification/pdfs/02_Procurement/PROC_MDA_VOL2B_PB_2023.pdf (accessed June 12, 2022).
28. U.S. Department of Defense, Missile Defense Agency, "Elements: Sea-Based Weapons Systems," last updated July 21, 2021, https://www.mda.mil/system/aegis_bmd.html (accessed June 12, 2022).
29. Admiral Philip S. Davidson, U.S. Navy, Commander, U.S. Indo-Pacific Command, statement "On U.S. Indo-Pacific Command Posture" before the Committee on Armed Services, U.S. Senate, March 9, 2021, p. 5, https://www.armed-services.senate.gov/imo/media/doc/Davidson_03-09-21.pdf (accessed June 12, 2022).
30. Admiral John C. Aquilino, U.S. Navy, Commander, U.S. Indo-Pacific Command, statement "On U.S. Indo-Pacific Command Posture" before the Committee on Armed Services, U.S. House of Representatives, March 9, 2022, p. 13, https://www.congress.gov/117/meeting/house/114487/witnesses/HHRG-117-AS00-Wstate-AquilinoJ-20220309.pdf (accessed June 12, 2022).
31. Vice Admiral Jon A. Hill, Director, Missile Defense Agency, in transcript, "Missile Defense Agency Officials Hold a News Briefing on President Biden's Fiscal 2023 Missile Defense Budget," U.S. Department of Defense, March 28, 2022, https://www.defense.gov/News/Transcripts/Transcript/Article/2981858/missile-defense-agency-officials-hold-a-news-briefing-on-president-bidens-fisca/ (accessed June 12, 2022).

32. News release, "U.S. Successfully Conducts SM-3 Block IIA Intercept Test Against an Intercontinental Ballistic Missile Target," U.S. Department of Defense, Missile Defense Agency, November 16, 2020, https://www.mda.mil/news/20news0003.html (accessed June 12, 2022).

33. A homeland defense "underlay" would enable a "Shoot-Look-Shoot" or "Shoot-Assess-Shoot" doctrine, which entails shooting a first layer of interceptors at a target, performing a kill assessment, and then shooting the next layer of interceptors at the target, continuing through all available layers. This doctrine decreases the number of interceptors required to fire at a target that overcompensate for lack of a backup. See U.S. Department of Defense, Missile Defense Agency, *Fiscal Year (FY) 2021 Budget Estimates Overview*, p. 9, https://www.mda.mil/global/documents/pdf/budgetfy21.pdf (accessed June 12, 2022).

34. Exhibit R-2A, "RDT&E Project Justification: PB 2023 Missile Defense Agency, Appropriation/Budget Activity 0400 / 4, R-1 Program Element (Number/Name) PE 0603892C / AEGIS BMD, Project (Number/Name) MD09 / Aegis BMD," in U.S. Department of Defense, *Department of Defense Fiscal Year (FY) 2023 Budget Estimates, Missile Defense Agency, Defense-Wide Justification Book Volume 2a of 5: Research, Development, Test & Evaluation, Defense-Wide*, p. 283.

35. Fact Sheet, "Terminal High Altitude Area Defense," U.S. Department of Defense, Missile Defense Agency, approved for public release September 30, 2020, https://www.mda.mil/global/documents/pdf/thaad.pdf (accessed June 13, 2022).

36. One THAAD battery "nominally consists of 6 truck-mounted launchers, 48 interceptors (8 per launcher), 1 Army/Navy Transportable Radar Surveillance and Control Mode 2 (AN/TPY-2) radar, a Tactical Fire Control/Communications component, and the Heavy Expanded Mobility Tactical Trucks (HEMTTs)." U.S. Department of Defense, Office of the Undersecretary of Defense (Comptroller)/Chief Financial Officer, *United States Department of Defense Fiscal Year 2023 Budget Request, Program Acquisition Cost by Weapon System*, April 2022, p. 4-3, https://comptroller.defense.gov/Portals/45/Documents/defbudget/FY2023/FY2023_Weapons.pdf (accessed June 13, 2022).

37. Jason Sherman, "MDA Awards Lockheed Nearly $1B THAAD Contract for Army, Saudi Arabia," *Inside Defense*, March 26, 2020, https://insidedefense.com/daily-news/mda-awards-lockheed-nearly-1b-thaad-contract-army-saudi-arabia (accessed June 12, 2022).

38. Jeremy Binnie, "CENTCOM Commander Confirms UAE Successfully Used THAAD," Janes, February 9, 2022, https://www.janes.com/defence-news/news-detail/centcom-commander-confirms-uae-successfully-used-thaad (accessed June 13, 2022).

39. Lockheed Martin, "PAC-3: Defending Against Emerging Advanced Threats Around the World," https://www.lockheedmartin.com/en-us/products/pac3-mse.html (accessed June 13, 2022).

40. Fact Sheet, "Patriot Advanced Capability-3," U.S. Department of Defense, Missile Defense Agency, approved for public release September 30, 2020, https://www.mda.mil/global/documents/pdf/pac3.pdf (accessed June 13, 2022).

41. Explanatory Statement, "Division C—Department of Defense Appropriations Act, 2022," in *Consolidated Appropriations Act, 2022*, Committee Print on H.R. 2471, pp. 545, 547, 624, 625, and 627.

42. U.S. Department of Defense, Office of the Undersecretary of Defense (Comptroller)/Chief Financial Officer, *United States Department of Defense Fiscal Year 2023 Budget Request, Program Acquisition Cost by Weapon System*, pp. 4-3, 4-4, and 4-6. The budget request increases PAC-3 Missile Segment Enhancement procurement from 180 to 252, reduces THAAD interceptor procurement from 39 to three, and reduces SM-3 Block IIA procurement from 16 to 10.

43. Jen Judson, "In First, MDA Remotely Launches a Missile," *Defense News*, August 20, 2019, https://www.defensenews.com/land/2019/08/30/first-remotely-launched-terminal-missile-defense-test-deemed-a-success/ (accessed June 12, 2022).

44. Table 4, "Fiscal Year (FY) 2020 Flight Tests," in U.S. Government Accountability Office, *Missile Defense: Fiscal Year 2020 Delivery and Testing Progressed, but Annual Goals Unmet*, GAO-21-314, April 2021, p. 12, https://www.gao.gov/assets/gao-21-314.pdf (accessed June 13, 2022); Jen Judson, "Missile Defense Agency Fires Patriot Missile from THAAD System," *Defense News*, March 10, 2022, https://www.defensenews.com/pentagon/2022/03/10/missile-defense-agency-fires-patriot-missile-from-thaad-system/ (accessed June 13, 2022); and news release, "Missile Defense Agency and U.S. Army Test Integration of THAAD and Patriot Missile Defense Systems," U.S. Department of Defense, Missile Defense Agency, March 29, 2022, https://www.mda.mil/news/22news0004.html (accessed June 13, 2022).

45. Lieutenant General Daniel L. Karbler, USA, Commanding General, U.S. Army Space and Missile Defense Command, and Commander, Joint Functional Component Command for Integrated Missile Defense, statement on "Fiscal Year 2023 Authorization Request for Missile Defense" before the Subcommittee on Strategic Forces, Committee on Armed Services, U.S. Senate, May 11, 2022, p. 12, https://armedservices.house.gov/_cache/files/d/e/dee1d7ca-23c0-4dd0-9207-a8803c9e8857/094C7DAE7B31E2A86783A4B6258EF2F1.20220511-str-witness-statement-karbler-.pdf (accessed June 13, 2022).

46. Former INDOPACOM Commander Admiral Phil Davidson has identified "the next six years" as a likely window for a Chinese invasion of Taiwan. Mallory Shelbourne, "Davidson: China Could Try to Take Control of Taiwan in 'Next Six Years'," U.S. Naval Institute News, March 9, 2021, https://news.usni.org/2021/03/09/davidson-china-could-try-to-take-control-of-taiwan-in-next-six-years (accessed June 13, 2022).

47. Sam LaGrone, "Pacific Commander Davidson Asks Congress to Fund 'Regain the Advantage' Plan Aimed at China," U.S. Naval Institute News, April 18, 2019, https://news.usni.org/2019/04/18/pacific-commander-davidson-asks-congress-to-fund-regain-the-advantage-plan-aimed-at-china (accessed June 13, 2022). The President's budget request included only $118.3 million for Guam defense in FY 2022: "$78.3 million to assess systems to support Defense of Guam" and "$40 million procurement for long lead items in FY 2022." See U.S. Department of Defense, Missile Defense Agency, *Fiscal Year (FY) 2022 Budget Estimates Overview*, approved for public release May 20, 2021, pp. 10–11, https://www.mda.mil/global/documents/pdf/Budget%20Overview%20FY22%20Booklet%20-%20FINAL.pdf (accessed June 13, 2022).

48. Jason Sherman, "Guam Defense System Wins FY-22 Boost to Accelerate Development, Procurement," *Inside Defense*, March 9, 2022, https://insidedefense.com/daily-news/guam-defense-system-wins-fy-22-boost-accelerate-development-procurement (accessed June 12, 2022), and Matthew Beinart, "INDOPACOM Chief Expects FY '22 Budget Request to Include Key Investments for Pacific Deterrence Initiative," *Defense Daily*, March 4, 2021, https://www.defensedaily.com/indopacom-chief-expects-fy-22-budget-request-include-key-investments-pacific-deterrence-initiative/budget/ (accessed June 13, 2022).
49. Dr. John Plumb, Assistant Secretary of Defense for Defense Policy, statement on "Missile Defense Strategy, Policies, and Programs" before the Subcommittee on Strategic Forces, Committee on Armed Services, U.S. Senate, May 18, 2022, pp. 6–7, https://www.armed-services.senate.gov/imo/media/doc/ASD%20Plumb%20SASC%20SF%20Missile%20Defense%20Written%20Statement%20-%20May,18%202022_FINAL.pdf (accessed June 19, 2022). See also U.S. Department of Defense, Office of the Under Secretary of Defense (Comptroller)/Chief Financial Officer, *United States Department of Defense Fiscal Year 2023 Budget Request: Defense Budget Overview*, March 2022, p. 10, https://comptroller.defense.gov/Portals/45/Documents/defbudget/FY2023/FY2023_Budget_Request.pd (accessed June 19, 2022). The reader may notice that note 17, *supra*, refers to a document bearing the same title but a publication date of April 2022 rather than March 2022. Although their titles are the same, the March 2022 document is a PowerPoint presentation that, unlike the April 2022 document, includes $892 for the defense of Guam.
50. VanHerck, statement before Senate Armed Services Committee, March 24, 2022, p. 16.
51. Testimony of General Glen VanHerck, Commander, United States Northern Command, in stenographic transcript of *Hearing to Receive Testimony on the Posture of United States Northern Command and United States Southern Command*, Committee on Armed Services, U.S. Senate, March 24, 2022, p. 39, https://www.armed-services.senate.gov/imo/media/doc/22-17_03-24-20221.pdf (accessed June 12, 2022).
52. See U.S. Department of Defense, *Department of Defense Fiscal Year (FY) 2023 Budget Estimates, Missile Defense Agency, Defense-Wide Justification Book Volume 2a of 5: Research, Development, Test & Evaluation, Defense-Wide*, p. xli. Additionally, the MDA is offering the NGI contractors cash fees for delivering the program before 2028. See Jason Sherman, "MDA Dangles Cash Incentives to Accelerate NGI Fielding," *Inside Defense*, April 29, 2021, https://insidedefense.com/daily-news/mda-dangles-cash-incentives-accelerate-ngi-fielding (accessed June 12, 2022).
53. U.S. Department of Defense, *Department of Defense Fiscal Year (FY) 2023 Budget Estimates, Missile Defense Agency, Defense-Wide Justification Book Volume 2a of 5: Research, Development, Test & Evaluation, Defense-Wide*, pp. xli–xlii.
54. Testimony of General Glen D. VanHerck, USAF, Commander, U.S. Northern Command and North American Aerospace Defense Command, in hearing, *National Security Challenges and U.S. Military Activity in North and South America*, Committee on Armed Services, U.S. House of Representatives, 117th Cong., 1st Sess., April 14, 2021, p. 56, https://www.congress.gov/117/chrg/CHRG-117hhrg44983/CHRG-117hhrg44983.pdf (accessed June 10, 2022).
55. Hill, statement before House Subcommittee on Strategic Forces, May 11, 2022, p. 10.
56. News release, "Missile Defense Agency Awards Contracts for Glide Phase Interceptor Design," U.S. Department of Defense, Missile Defense Agency, November 19, 2021, https://www.mda.mil/news/21news0016.html (accessed June 13, 2022).
57. Explanatory Statement, "Division C—Department of Defense Appropriations Act, 2022," in *Consolidated Appropriations Act, 2022*, Committee Print on H.R. 2471, p. 709.
58. U.S. Department of Defense, *Department of Defense Fiscal Year (FY) 2023 Budget Estimates, Missile Defense Agency, Defense-Wide Justification Book Volume 2a of 5: Research, Development, Test & Evaluation, Defense-Wide*, p. xlvii.
59. Sydney J. Freedberg Jr., "Army Reboots Cruise Missile Defense: IFPC & Iron Dome," *Breaking Defense*, March 11, 2019, https://breakingdefense.com/2019/03/army-reboots-cruise-missile-defense-ifpc-iron-dome/ (accessed June 12, 2022).
60. Jen Judson, "Iron Dome Plans Being Finalized as US Army Begins Training on Systems," *Defense News*, February 15, 2021, https://www.defensenews.com/land/2021/02/15/iron-dome-plans-being-finalized-as-us-army-begins-training-on-systems/ (accessed June 12, 2022).
61. Jason Sherman, "Iron Dome Shortcomings Prompt Army to Overhaul IFPC 2 Inc. 2 with New 'Shoot off' Competition," *Inside Defense*, March 5, 2020, https://insidedefense.com/daily-news/iron-dome-shortcomings-prompt-army-overhaul-ifpc-2-inc-2-new-shoot-competition (accessed June 12, 2022).
62. 6Park.News/Hawaii, "Army Says Iron Dome System Test Validates Layered Air Defense for Guam," November 23, 2021, https://6park.news/hawaii/army-says-iron-dome-system-test-validates-layered-air-defense-for-guam.html (accessed June 13, 2022).
63. U.S. Army Public Affairs, "Army Announces Contract Award for Indirect Fire Protection Capability Increment 2," September 24, 2021, https://www.army.mil/article/250595/army_announces_contract_award_for_indirect_fire_protection_capability_increment_2#:~:text=The%20IFPC%20Inc%202%20is,mortars%20and%20other%20aerial%20threats (accessed June 12, 2022).
64. Center for Strategic and International Studies Missile Defense Project, "Upgraded Early Warning Radar (UEWR)," *Missile Threat*, last updated June 24, 2021, https://missilethreat.csis.org/defsys/uewr/ (accessed June 12, 2022).
65. News release, "Raytheon Missiles & Defense Upgrades Two US Space Force Early Warning Radars," *Raytheon Missiles & Defense*, September 20, 2021, https://www.raytheonmissilesanddefense.com/news/2021/09/20/rmd-upgrades-two-us-space-force (accessed June 12, 2022).
66. Fact Sheet, "Cobra Dane," U.S. Department of Defense, Missile Defense Agency, approved for public release September 30, 2020, https://www.mda.mil/global/documents/pdf/cobradane.pdf (accessed June 13, 2022).

67. Fact Sheet, "Army Navy/Transportable Radar Surveillance (AN/TPY-2)," approved for public release May 24, 2022, https://www.mda.mil/global/documents/pdf/an_tpy2.pdf (accessed June 13, 2022).

68. Center for Strategic and International Studies, Missile Defense Project, "AN/TPY-2 Radar," *Missile Threat*, last updated June 30, 2021, https://missilethreat.csis.org/defsys/tpy-2/ (accessed June 13, 2022).

69. Hill, statement before House Subcommittee on Strategic Forces, May 11, 2022, p. 5.

70. Jason Sherman, "DOD Picks SPY-7 for Land-Based Aegis, Giving Lockheed First U.S. Customer for New Radar," *Inside Defense*, May 6, 2022, https://insidedefense.com/daily-news/dod-picks-spy-7-land-based-aegis-giving-lockheed-first-us-customer-new-radar (accessed June 12, 2022).

71. Sec. 1666, "Missile Defense Radar in Hawaii," in S. 1605, National Defense Authorization Act for Fiscal Year 2022, Public Law 117-81, 117th Cong., December 27, 2021, Sec. 1666, https://www.congress.gov/117/plaws/publ81/PLAW-117publ81.pdf (accessed June 13, 2022).

72. Jen Judson, "Missile Defense Agency Seeks $9.6 Billion in FY23 Budget," *Defense News*, March 29, 2022, https://www.defensenews.com/congress/budget/2022/03/29/missile-defense-agency-seeks-96-billion-in-fy23-budget/ (accessed June 12, 2022).

73. Fact Sheet, "Sea-Based X-Band Radar," U.S. Department of Defense, Missile Defense Agency, approved for public release September 30, 2020, https://www.mda.mil/global/documents/pdf/sbx.pdf (accessed June 13, 2022).

74. Inder Singh Bisht, "US Navy to Upgrade All Surface Ships with SPY-6 Radar in $3B Program," *The Defense Post*, April 7, 2022, https://www.thedefensepost.com/2022/04/07/us-navy-spy-6-radars/ (accessed June 13, 2022).

75. See U.S. Department of Defense, Office of the Secretary of Defense, *2019 Missile Defense Review*, p. 36, and Thomas Karako, "Opinion: Trump's Blind Spot," *Politico*, September 6, 2019, https://www.politico.com/story/2019/09/06/opinion-missile-defense-blind-1480426 (accessed June 13, 2022).

76. Fact Sheet, "Space Based Infrared System," U.S. Air Force, Air Force Space Command, March 22, 2017, http://www.afspc.af.mil/About-Us/Fact-Sheets/Display/Article/1012596/space-based-infrared-system/ (accessed June 13, 2022).

77. Center for Strategic and International Studies, Missile Defense Project, "Space-Based Infrared System (SBIRS)," *Missile Threat*, last updated July 26, 2021, https://missilethreat.csis.org/defsys/sbirs/ (accessed June 13, 2022).

78. Sandra Erwin, "ULA Launches the Last SBIRS U.S. Space Force Missile Warning Satellite," *SpaceNews*, August 4, 2022, https://spacenews.com/ula-launches-the-last-sbirs-u-s-space-force-missile-warning-satellite/ (accessed August 17, 2022).

79. Sandra Erwin, "Production of New Missile Warning Satellites Likely Delayed by Budget Impasse," *SpaceNews*, October 20, 2017, http://spacenews.com/production-of-new-missile-warning-satellites-likely-delayed-by-budget-impasse/ (accessed June 13, 2022).

80. Exhibit R-2, "RDT&E Budget Item Justification: PB 2022 Air Force, Appropriation/Budget Activity 3620F: Research, Development, Test & Evaluation, Space Force / BA 5: System Development & Demonstration (SDD), R-1 Program Element (Number/Name) PE 1206442SF / Next Generation OPIR," in U.S. Department of the Air Force, *Department of Defense Fiscal Year (FY) 2022 Budget Estimates, Air Force, Justification Book Volume 1 of 1: Research, Development, Test & Evaluation, Space Force*, May 2021, p. 220, https://www.saffm.hq.af.mil/Portals/84/documents/FY22/RDTE_/FY22%20DAF%20J-Book%20-%203620%20-%20SF%20RDT%20and%20E.pdf (accessed June 13, 2022).

81. Fact Sheet, "Spacebased Kill Assessment," U.S. Department of Defense, Missile Defense Agency, approved for public release September 30, 2020, https://www.mda.mil/global/documents/pdf/ska.pdf (accessed June 13, 2022).

82. U.S. Department of Defense, *Department of Defense Fiscal Year (FY) 2023 Budget Estimates, Missile Defense Agency, Defense-Wide Justification Book Volume 2a of 5: Research, Development, Test & Evaluation, Defense-Wide*, p. xl.

83. Fact Sheet, "Space Tracking and Surveillance System," U.S. Department of Defense, Missile Defense Agency, approved for public release September 30, 2020, https://www.mda.mil/global/documents/pdf/stss.pdf (accessed June 13, 2022).

84. Sandra Erwin, "DoD Decommissions Two Missile-Tracking Satellites After 12 Years in Orbit," *SpaceNews*, March 14, 2022, https://spacenews.com/dod-decommissions-two-missile-tracking-satellites-after-12-years-in-orbit/ (accessed June 13, 2022).

85. News release, "SDA Awards Contracts for the First Generation of the Tracking Layer," Space Development Agency, https://www.sda.mil/sda-awards-contracts-for-the-first-generation-of-the-tracking-layer/ (accessed June 13, 2022), and C. Todd Lopez, "Agency Awards Contracts for Tracking Layer of National Defense Space Architecture," U.S. Department of Defense, October 5, 2020, https://www.defense.gov/News/News-Stories/Article/Article/2372647/agency-awards-contracts-for-tracking-layer-of-national-defense-space-architectu/ (accessed June 13, 2022).

86. Exhibit R-2A, "RDT&E Project Justification: PB 2023 Missile Defense Agency, Appropriation/Budget Activity 0400 / 4, R-1 Program Element (Number/Name) PE 1206895C / Ballistic Missile Defense System Space Programs, Project (Number/Name) MD42 / Hypersonic & Ballistic Tracking Space Sensor (HBTSS) Prototyping," in U.S. Department of Defense, *Department of Defense Fiscal Year (FY) 2023 Budget Estimates, Missile Defense Agency, Defense-Wide Justification Book Volume 2a of 5: Research, Development, Test & Evaluation, Defense-Wide*, pp. 853–854.

87. SpaceX is building four, and L3Harris is building four.

88. Sandra Erwin, "Space Development Agency to Accelerate Deployment of Missile-Tracking Satellites," *SpaceNews*, April 10, 2022, https://spacenews.com/space-development-agency-to-accelerate-deployment-of-missile-tracking-satellites/ (accessed June 13, 2022).

89. Charles A. Richard, Commander, United States Strategic Command, statement before the Subcommittee on Strategic Forces, Committee on Armed Services, U.S. House of Representatives, February 27, 2020, p. 19, https://docs.house.gov/meetings/AS/AS29/20200227/110583/HHRG-116-AS29-Wstate-RichardC-20200227.pdf (accessed June 12, 2022).

90. Wes Rumbaugh, "Bad Idea: Ignoring Congressional Oversight on Space Sensor Development," Center for Strategic and International Studies, Defense 360, *Bad Ideas on National Security Series*, December 4, 2020, https://defense360.csis.org/bad-idea-ignoring-congressional-oversight-on-space-sensor-development/ (accessed June 13, 2022).
91. To detect hypersonic missiles maneuvering in the upper atmosphere close to LEO (a goal of HBTSS), space sensors may need to view them at a bit of an angle rather than by looking straight down. This side view makes hypersonic missiles appear dimmer, requiring more sensitive sensors.
92. Judson, "Missile Defense Agency Seeks $9.6 Billion in FY23 Budget."
93. VanHerck, statement before Senate Armed Services Committee, March 24, 2022, p. 13.
94. Jason Sherman, "VanHerck: Unfunded Elevated Radar 'Crucial' to Protecting U.S. Leadership in DC from Cruise Missile Strike," *Inside Defense*, August 20, 2021, https://insidedefense.com/daily-news/vanherck-unfunded-elevated-radar-%E2%80%98crucial%E2%80%99-protecting-us-leadership-dc-cruise-missile (accessed June 12, 2022).
95. Jen Judson, "US NORTHCOM Again Asks for Homeland Cruise Missile Defense in Wish List," *Defense News*, April 5, 2022, https://www.defensenews.com/pentagon/2022/04/05/us-northcom-again-asks-for-homeland-cruise-missile-defense-funding-in-wish-list/ (accessed June 12, 2022).
96. U.S. Department of Defense, Office of the Undersecretary of Defense (Comptroller)/Chief Financial Officer, *United States Department of Defense Fiscal Year 2023 Budget Request, Program Acquisition Cost by Weapon System*, p. 7-4.
97. Sydney J. Freedberg Jr., "Raytheon Readies LTAMDS Radar for Tests," *Breaking Defense*, March 16, 2021, https://breakingdefense.com/2021/03/raytheon-readies-ltamds-radar-for-tests/ (accessed June 12, 2022), and Ashley Roque, "US Army Plans for LTAMDS Buy, Foreign Military Sales," Janes, March 18, 2022, https://www.janes.com/defence-news/news-detail/us-army-plans-for-ltamds-buy-foreign-military-sales#:~:text=The%20US%20Army%20is%20poised,notice%20posted%20on%2016%20March.&text=foreign%2Dmilitary%2Dsales-,The%20US%20Army%20is%20poised%20to%20award%20Raytheon%20a%20contract,and%20Missile%20Defense%20Sen (accessed June 12, 2022).
98. Fact sheet, "Joint Functional Component Command for Integrated Missile Defense (JFCC IMD)," U.S. Strategic Command, current as of December 2020, https://www.stratcom.mil/Portals/8/Documents/JFCC%20IMD%20Fact%20Sheet_Dec%202020.pdf (accessed June 12, 2022).
99. Headquarters, Department of the Army, Army Techniques Publication No. 3-27.3, *Ground-based Midcourse Defense Operations*, October 2019, p. 2-1, https://fas.org/irp/doddir/army/atp3-27-3.pdf (accessed June 13, 2022), and U.S. Department of Defense, Missile Defense Agency, "Elements: Ground-based Midcourse Defense (GMD)," last updated July 21, 2021, https://www.mda.mil/system/gmd.html (accessed June 13, 2022).
100. Army Techniques Publication No. 3-27.3, *Ground-based Midcourse Defense Operations*, pp. 1-5 and 1-6.
101. Thomas Karako, Ian Williams, and Wes Rumbaugh, *Missile Defense 2020: Next Steps for Defending the Homeland*, Center for Strategic and International Studies, Missile Defense Project, April 2017, pp. 101–103, https://csis-website-prod.s3.amazonaws.com/s3fs-public/publication/170406_Karako_MissileDefense2020_Web.pdf (accessed June 13, 2022).
102. Fact Sheet, "Command and Control, Battle Management, and Communications," U.S. Department of Defense, Missile Defense Agency, approved for public release September 30, 2020, https://www.mda.mil/global/documents/pdf/c2bmc.pdf (accessed June 13, 2022).
103. Army Techniques Publication No. 3-27.3, *Ground-based Midcourse Defense Operations*, pp. 3-2 and 5-3.
104. Center for Strategic and International Studies, Missile Defense Project, "Aegis Ballistic Missile Defense."
105. Center for Strategic and International Studies, Missile Defense Project, "Integrated Air and Missile Defense Battle Command System (IBCS)," *Missile Threat*, last updated June 7, 2021, https://missilethreat.csis.org/defsys/ibcs/ (accessed June 13, 2022).
106. VanHerck, statement before Senate Armed Services Committee, March 24, 2022, p. 13.
107. Jason Sherman, "MDA Outfits INDOPACOM with Defense Against Hypersonic Weapons in Pacific," *Inside Defense*, May 4, 2021, https://insidedefense.com/daily-news/mda-outfits-indopacom-defense-against-hypersonic-weapons-pacific (accessed June 12, 2022).
108. Appendix II, "Program Overview: "Command, Control, Battle Management, and Communications (C2BMC)," in U.S. Government Accountability Office, *Missile Defense: Fiscal Year 2020 Delivery and Testing Progressed, but Annual Goals Unmet*, p. 25, and Dee Martinez, Comptroller, Missile Defense Agency, in transcript, "Missile Defense Agency Officials Hold a News Briefing on President Biden's Fiscal 2023 Missile Defense Budget."
109. Jen Judson, "Lockheed: New Missile Defense System Upgrades Will Produce More Comprehensive Battlefield Picture," *Defense News*, August 24, 2021, https://www.defensenews.com/digital-show-dailies/smd/2021/08/24/lockheed-new-missile-defense-system-upgrades-will-produce-more-comprehensive-battlefield-picture/ (accessed June 12, 2022).
110. VanHerck, statement before Senate Armed Services Committee, March 24, 2022, p. 14.
111. In 2015, for example, individual sensors failed to detect a gyrocopter that landed in the National Capital Region, but when NORAD went back and used the Pathfinder to analyze the information, it found the gyrocopter. See testimony of General Glen D. VanHerck, USAF, Commander, United States Northern Command and North American Aerospace Defense Command, in stenographic transcript of hearing *To Receive Testimony on United States Southern Command and United States Northern Command in Review of the Defense Authorization Request for Fiscal Year 2022 and the Future Years Defense Program*, Committee om Armed Services, U.S. Senate, March 16, 2021, p. 42, https://www.armed-services.senate.gov/imo/media/doc/21-12_03-16-2021.pdf (accessed June 12, 2022).

112. Air Force News Service, "NORAD, USNORTHCOM Lead 3rd Global Information Dominance Experiment," North American Aerospace Defense Command and U.S. Northern Command Public Affairs, July 22, 2021, https://www.af.mil/News/Article-Display/Article/2703548/norad-usnorthcom-lead-3rd-global-information-dominance-experiment/ (accessed June 12, 2022).

113. Jen Judson, "US Army's Delayed Battle Command System Begins Operational Testing," *Defense News*, February 9, 2022, https://www.defensenews.com/land/2022/02/09/us-armys-delayed-battle-command-system-begins-operational-testing/ (accessed June 12, 2022).