Missile Defense

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Missile defense is a critical part of the national security architecture that enables U.S. military efforts, deters attacks, and protects such critical infrastructure as population, industrial centers, and politically and historically important sites. It can strengthen U.S. diplomatic and deterrence efforts and give senior decision-makers the time and options they need to respond effectively 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 coercive tools and symbols of power.[1] Both the number of states that possess missiles and the sophistication of those missiles will continue to increase as modern technologies become cheaper and more widely available. North Korea, Iran, China, and Russia all possess missile arsenals that threaten U.S. interests, forces deployed abroad, and allies and partners.

As one example of the growing threat, General Glen VanHerck, Commander, U.S. Northern Command and North American Aerospace Defense Command, testified in March 2023 that North Korea had "tested at least 65 conventional theater and long-range nuclear capabilities over the last year."[2] These tests enable Pyongyang to improve and adapt its missile program, adding to an already formidable threat. North Korea has stated that it tested its "most powerful" missile to date in April 2023,[3] and two short-range missiles that it test fired appear to have landed within Japan's exclusive economic maritime zone.[4] Pyongyang will likely continue its aggressive development and testing as it seeks to make its missile forces more survivable before and after launch.[5]

In similar fashion, Iran continues to modernize and proliferate its regional missile systems. It says it recently successfully tested a missile with a range of 2,000 kilometers.[6] It also displayed its first hypersonic missile and has provided Russia with hundreds of loitering munitions for Russia's war in Ukraine.[7] Tehran's continued pursuit of "space launch vehicles (SLVs)—including its Simorgh—shortens the timeline to an ICBM if it decided to develop one because SLVs and ICBMs use similar technologies."[8]

According to Assistant Secretary of Defense for Space Policy John Plumb, China "has accelerated its efforts to develop, test, and field advanced missile systems of all classes and ranges, including ballistic, cruise, and hypersonic glide vehicles."[9] The U.S. Department of Defense (DOD) has noted that in 2021, China "launched approximately 135 ballistic missiles for testing and training, more than the rest of the world combined excluding ballistic missile employment in conflict zones."[10] China also launched 11 missiles into waters near Taiwan in August 2022.[11] Beijing 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, and "[t]he number of warheads on the PRC's land-based ICBMs capable of threatening the United States is expected to grow to roughly 200 in the next five years."[12] In 2021, China tested a fractional orbital bombardment system (FOBS) that deployed a hypersonic glide.[13]

Russia has launched thousands of air and missile platforms against Ukraine to "terrorize the Ukrainian people while degrading Ukraine's warfighting capability."[14] According to General VanHerck, Russia's invasion of Ukraine in 2022 "proved that [it] has the capability and capacity to inflict significant damage to infrastructure and other critical targets with its all-domain long-range strike capabilities." Capabilities that Russia "has showcased in Ukraine" include "air- and sea-launched cruise missiles capable of striking North America, cyber activities, and economic coercion." Russia also has "continued to conduct major military exercises and test developmental capabilities that will compound the threat to North America once fielded" and "is testing its special mission Belgorod nuclear submarine, a modern platform capable of carrying the nuclear-capable Poseidon torpedo, designed to hold the homeland at risk by striking coastal targets from thousands of miles away."[15]

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 the ability to convince an 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.

A U.S. missile defense system strengthens deterrence by offering a degree of protection to U.S. populations, military forces, and allies that makes it harder for an adversary to threaten them with missiles.[16] 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 an adversary think twice before launching an attack, especially a larger-scale attack that would certainly prompt a robust U.S. response. 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 on behalf of others 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 best course of action. Without the ability to defend against an impending 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 providing some level of protection, robust missile defense systems could affect the dynamics of decision-making by removing the need to take immediate action—an especially critical consideration in the event of an unauthorized or accidental missile launch by an adversary. Missile defense can therefore be profoundly stabilizing.

Finally, in both nuclear and conventional missile attack scenarios, 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.[17]

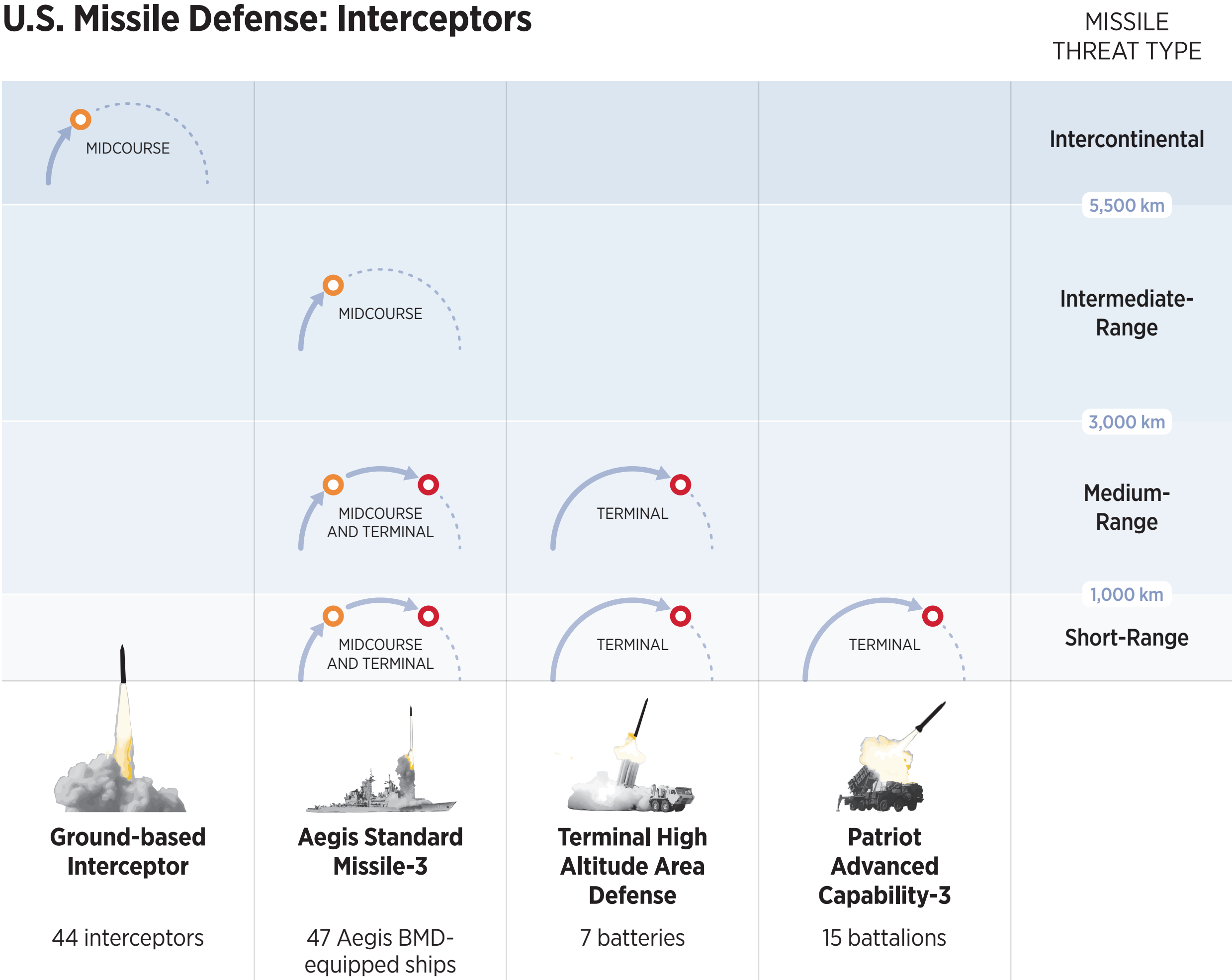
Since the end of the Cold War, Congress has supported the development of a regional missile defense system, but it has not supported the development of a comprehensive layered system to protect the homeland. The reason: a lingering Cold War–era view that U.S. missile defenses would be "destabilizing" vis-à-vis the Soviet Union. Skeptics argued that the Soviets would be incentivized to strike first before defenses could be deployed or more likely to strike first in a crisis for fear that a U.S. missile defense system would undermine their retaliatory capability after a U.S. first strike. The notion of long-range missile defenses as destabilizing was codified in the 1972 Anti-Ballistic Missile (ABM) Treaty, from which the United States withdrew in 2002 citing the need to develop such defenses against North Korea's and Iran's evolving missile capabilities.

The U.S. Missile Defense System

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

FIGURE 7

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 September 14, 2023), and 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, Program Acquisition Cost by Weapon System*, April 2022, pp. 4–5, https://comptroller.defense.gov/Portals/45/Documents/defbudget/FY2023/FY2023_Weapons.pdf (accessed September 14, 2023).

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- 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 intercepts in all four phases 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). An interceptor's flight time determines both the time available to conduct an intercept and the optimal interceptor placement to improve intercept probability. With an intercontinental ballistic missile (ICBM), the United States has "30 minutes or less"[18] 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—a tactic known as "shoot-look-shoot." The time needed to intercept short-range, medium-range, and intermediate-range ballistic missiles is shorter.

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 intercept ballistic missiles from the air or in space,[19] but such efforts have been limited since the U.S. withdrawal from the ABM Treaty in 2002.

The current U.S. missile defense system is a result of investments made by successive U.S. Administrations with the support of Congress. President Ronald Reagan envisioned a defensive shield—the Strategic Defense Initiative (SDI)—as a layered ballistic missile defense (BMD) system that ultimately would render nuclear missiles "impotent and obsolete."[20] 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.[21] Instead of a comprehensive layered system, the United States has no boost-phase BMD systems and extremely limited midcourse defense against the advanced ballistic missile threats from China and Russia. The volatility and inconsistency of priority and funding for missile defense by successive Administrations and Congresses—controlled by *both* major political parties—have yielded a system that is limited both numerically and technologically and is extremely limited in 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."[22] The National Defense Authorization Act (NDAA) for Fiscal Year 2017 dropped the word "limited" even as it continued to focus on ballistic missiles.[23] 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."[24] In the future, as technological trends progress and modern technologies become cheaper and more widely available, North Korean or Iranian ballistic missiles and countermeasures 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 addressed the dangerous threat environment that had evolved since the previous MDR in 2010 and recognized that future missile defense systems will have to defend against cruise and hypersonic missiles in addition to ballistic missiles.[25]

The Biden Administration's 2022 Missile Defense Review recognizes that the "evolution of offensive air and missile threats has accelerated greatly since the United States began developing its first ballistic missile defense systems over fifty years ago" and that "[t]his trend represents a growing national security challenge expected to multiply in scope and complexity over the coming decade."[26] However, it does not include any major new initiatives or any reference to the Trump Administration's nascent proposal for building a "layered" missile defense for the U.S. homeland.

For fiscal year (FY) 2024, the Biden Administration has requested $10.9 billion for the MDA,[27] $1 billion more than the $9.6 billion it requested in FY 2023.[28]

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, its fully operational missile defense systems are best suited to the interception of ballistic missiles. Missile defense interceptors can potentially 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 an optimal 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, enables more shots if the first intercept attempt fails.

- **The terminal phase,** typically less than one minute long, occurs 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.[29] This is also, however, 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 countermeasures or multiple warheads 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. Eventually, each of these programs was cancelled because of technical, operational, or cost challenges, and other boost-phase programs have not progressed significantly.

Midcourse-Phase Interceptors. Intercepting missiles in their midcourse phase offers more time for intercept attempts and presents relatively fewer technological challenges than intercepts in the boost phase present, but it also allows the missile time to deploy decoys and countermeasures that can complicate interception by overwhelming 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 GMD system is the only operational system that is designed to shoot 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) that intercepts the incoming missile with hit-to-kill technology. In FY 2023, the MDA "increased US Northern Command Ground Based Interceptor capacity in the most advanced configuration with Capability Enhanced-II Block 1 Exo-atmospheric Kill Vehicles integrated on new Configuration 2 boost vehicles."[30]

To increase the probability of an intercept, the United States can launch multiple interceptors at each incoming ballistic missile. At present, because the inventory of interceptors is limited, the United States can intercept 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.[31] 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.[32] 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. The MDA plans to field NGIs "no later than the end of 2028,"[33] and they could eventually replace some or all of the existing 44 GBIs. Unlike the GBIs, the NGIs will feature multiple kill vehicles, giving a single NGI multiple opportunities to intercept an incoming threat.[34]

Contracts to develop the NGI were awarded to Lockheed Martin and a Northrop Grumman–Raytheon team in March 2021.[35] The FY 2024 presidential budget request includes $2.1 billion for NGI to support these two competing contracts.[36]

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 (aircraft and unmanned aerial systems) and cruise missiles.[37] According to the FY 2024 MDA budget submission, "[b]y the end of FY 2024, there will be 53 total BMD capable ships requiring maintenance support."[38] Japan has several Aegis BMD-capable destroyers and cooperated with the United States to develop the latest SM-3 missile, the SM-3 Block IIA.[39]

The United States also deploys a land-based version of Aegis, the Aegis Ashore system, in Romania and another in Poland. The site in Poland experienced repeated delays in achieving initial operational capability but "is expected to be delivered" in FY 2023.[40] Aegis Ashore sites relieve some of the requirements 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, one of the MDA's priorities in the FY 2024 budget request. 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))**."[41] 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 Americans."[42]

The FY 2024 budget request includes a total of $1.5 billion 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.[43]

In November 2020, the U.S. Navy and the MDA shot down an ICBM-type target using the SM-3 Block IIA.[44] 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 shots at an incoming target and SM-3 interceptors taking shots if the GBIs miss.[45] The MDA had planned to test the SM-3 IIA against a more sophisticated ICBM countermeasure set as the next step, but the budget request for FY 2023 eliminated funds to pursue the SM-3 IIA as a homeland underlay.[46] According to the Government Accountability Office, the MDA "did not complete its fiscal year 2022 flight, ground, and cyber baseline test program" and did not meet its annual goals for fielding the systems, leaving the warfighter with "less fielded capability than planned."[47]

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 "intercept and destroy ballistic missiles inside or outside the atmosphere during their final, or terminal, phase of flight"[48] and consists of a launcher, interceptors, the Army Navy/Transportable Radar Surveillance and Control Model 2 (AN/TPY-2) radar, and fire control.[49] 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.[50] In February 2022, THAAD was "employed successfully by the UAE in the first two combat employments of that system."[51]

Patriot is an air-defense and short-range ballistic missile defense system. A battery includes 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 a two-pulse solid rocket motor."[52] The system is transportable and "is currently deployed in multiple theaters around the world with daily operational activities."[53] Particularly notable is the system's combat performance in Ukraine, where it has intercepted Russian Kinzhal hypersonic missiles among others.[54]

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 interceptor to utilize targeting data from a THAAD AN/TPY-2 radar. Launch-on-Remote is a significant capability that can increase the defended area by spreading out missiles.[55] After two failed tests in 2020, the MDA, in conjunction with the Army, conducted two successful tests early in 2022.[56] The MDA, in coordination with the Army, "will begin global fielding this fiscal year."[57]

Progress on building a Guam defense system has moved slowly despite the urgency of the Chinese threat.[58] 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.[59] The $192 million that was appropriated fell far short of the $350 million requested by INDOPACOM for that year,[60] but the FY 2024 budget request includes $1.5 billion to strengthen the island's missile defense.[61]

General VanHerck recently testified that he remains "confident in our current capability to defend the homeland against a limited DPRK [Democratic People's Republic of Korea] ballistic missile threat" but is "concerned about future capacity and capability to respond to advancing DPRK ballistic missile threats, making it crucial to field the Next Generation Interceptor (NGI) as funded in the FY23 Consolidated Appropriations Act (P.L. 117-328)."[62]

The first NGI flight tests are scheduled for "the 2027 timeframe."[63] NGI will add needed capacity and capability to the GMD system, which some see as in danger of being overwhelmed by the increasing capacity of North Korea's ballistic missiles to strike the U.S. homeland and by North Korea's ability to deploy countermeasures.[64]

The MDA and Congress also 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 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 MDA will 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 that "an underlayer would give us additional capacity and capability" to address threats to the homeland.[65] The MDA had progressed toward this underlay after its successful test of the SM-3 IIA against an ICBM-type target in 2020, but the 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. In addition, no funding for the layered homeland defense program was included in the budget request for FY 2023, and none is included in the budget request for FY 2024.

However, even though the MDA is investing 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 worsening missile threats. The utility of exploring the use of SM-3 and THAAD interceptors to shoot down ICBMs can also extend beyond an underlay for the continental United States, as they can work for other missions or defend assets like Hawaii, Alaska, and Guam.

Currently, the only interceptor the United States has available to intercept hypersonic missiles is the SM-6.[66] 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, and plans to conduct a simulated engagement against a hypersonic glide vehicle in FY 2024.[67] The FY 2024 budget request includes $209 million for hypersonic defense.[68]

The Army's Indirect Fire Protection Capability Increment 2 (IFPC 2) program has been moving very slowly, and a key assessment of the system has recently been delayed by a year.[69] 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.[70] 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.[71] 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.[72] In 2021, the Army deployed Iron Dome to Guam and conducted a successful simulation to test the system,[73] but there is as yet no evidence to indicate 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.[74] The Army set the initial date of March 2024 to receive 16 launcher prototypes and 60 "fieldable" interceptors.[75]

Overall, the United States has multiple capable interceptors, but there is much room for improvement, including strengthening missile defense capabilities against more robust missile threats from Russia and China, both qualitatively and quantitatively. 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. The United States also ought to invest in research and development of space-based missile defense if it is ever to have a truly comprehensive protection from larger-scale missile attacks.

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 an early warning of a launch of enemy ballistic missiles in addition to missile tracking and discrimination.[76] These sensors can detect a ballistic 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 UEWRs based in Alaska, California, Massachusetts, the United Kingdom, and Greenland that scan objects up to 3,000 miles away.[77] They support homeland missile defense by providing early warning and improving the quality of midcourse tracking data.[78]

The United States also deploys mobile AN/TPY-2 land-based sensors. Of the 12 AN/TPY-2 systems that have been produced so far, five "are operating in forward-based mode worldwide in support of the U.S. and its allies" and seven "are operating in terminal mode as part of THAAD weapon systems in support of Army and regional defense Missions."[79] According to Admiral Hill, "Radar 13, planned for delivery in March 2025, will be part of THAAD Battery 8 and be a fully modernized configuration that includes significant obsolescence redesigns leveraged from our ongoing Foreign Military Sales (FMS) cases."[80] 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.[81] The DOD has also identified the need to develop the Homeland Defense Radar–Hawaii (HDR–H) to fill a tracking and discrimination gap over Hawaii. The FY 2024 budget request includes $103.5 million for the radar, which will support the completion of acceptance testing and enable an operational flight test in FY 2023.[82]

Sea-Based. There are two types of sea-based sensors. The first is the Sea-Based X-band (SBX) radar, which is "mounted on a mobile, ocean-going, semi-submersible platform that provides the missile defense system with an extremely powerful and capable radar that can be positioned to cover any region of the globe."[83] SBX is employed primarily in the Pacific. The second is the SPY-1 radar system, which is mounted on U.S. Navy vessels equipped with the Aegis Combat System and is therefore able to provide data that can be utilized for ballistic missile missions. The Navy is installing the radar on 29 new ships and replacing all SPY-1 radars with the SPY-6 radar, which will have a greater detection range and other advanced capabilities.[84]

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 phase to terminal phase, unlike ground-based radars that are limited in their tracking range.[85] 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. In 2020, the Department of Defense awarded a $222.5 million contract to keep the program going through 2030.[86] 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.[87] Because SBIRS can scan a wide swath of territory while simultaneously tracking a specific target, for example, it is useful in observing tactical, or short-range, ballistic missiles.[88]

The Space Force launched the sixth and final SBIRS satellite in August 2022.[89] 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.[90] The sixth SBIRS satellite was formally transferred from Space Systems Command to Space Operations Command on March 24, 2023.[91] The first of the Next-Gen OPIR satellites, which are designed to be more survivable against cyber and electronic attacks, is scheduled to launch in 2025.[92]

The MDA also has developed and deployed Spacebased Kill Assessment (SKA) sensors on commercial satellites.[93] 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 2024 budget supports "on-orbit operations by experimenting and participating in missile defense system ground and flight tests and providing situational awareness hit assessment to USNORTHCOM during declared periods of heightened activity."[94]

The United States is developing a system of satellites capable of providing global detection, tracking, and discrimination of any missile launch. Dating from as far back 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 (hypervelocity vehicles, for example), Congress has been paying close attention to development of a space sensor layer that is capable of tracking the evolving threat.

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. Data obtained by those demonstration satellites were used to provide risk reduction to support future space trackers. According to the MDA, "Space Vehicle[s] Vehicle 1 and 2 were retired on orbit on February 9, 2022 and March 8, 2022 respectively."[95]

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 Proliferated Warfighter Space Architecture, formerly known as the 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.[96]

Once deployed, the Tracking Layer will be able to detect, track, and discriminate among different types of missile launches throughout the entirety of the missiles' 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). The first 10 satellites were launched in April 2023.[97]

The MDA has requested $109.5 million for Missile Defense Space Programs in FY 2024 with a large portion of the funding dedicated to the HBTSS.[98] In 2021, the MDA awarded contracts to Northrop Grumman and L3Harris to develop HBTSS prototypes, which are scheduled to launch in the fourth quarter of FY 2023.[99]

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. For example, MDA Director Vice Admiral Jon Hill has stated that "[s]pace-based sensors are critical to integrated sensor-to-shooter capabilities used to defeat ballistic and hypersonic missile threats."[100] According to Admiral Charles Richard, then-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.[101]

The space-based sensor program has been plagued by insufficient funding requests and bureaucratic infighting over whether the SDA or the MDA would develop the HBTSS,[102] and despite some progress in resolving the conflict, congressional concern has reemerged.[103] A strong assessment of missile defense sensing capabilities depends on progress made on the space-based sensor effort, especially in view of warfighting commanders' urgent need for improved missile tracking as well as the technological challenges associated with developing a sensor that can perform in LEO.[104]

Development of land-based sensors to fill the missile discrimination capability gap over the Pacific has progressed slowly. Development of the LRDR completed initial fielding, but the program incurred delays that were "caused by the COVID-19 pandemic and other factors."[105]

Additionally, improved sensor capabilities are 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. Because of their low altitude in flight and uncertain trajectories, cruise missiles are more difficult to detect and track than ballistic missiles are. Russia's ability to strike key strategic nodes in the U.S. homeland from its own territory is of particular concern. To address this threat, General VanHerck has emphasized improving domain awareness, because early identification of a threat allows for options like left-of-launch operations (destroying a missile before it is launched or preventing its launch by neutralizing launch enablers) or alerting forces to take precautionary actions.[106]

The Department of Defense is requesting $428.7 million in the FY 2024 defense budget "for the continued fielding of four new over-the-horizon radars."[107] These radars will provide long-range sensor coverage of likely air and cruise missile threats to North America, as well as a capability against hypersonic threats, and maritime surface vessels. NORTHCOM's unfunded priorities list for FY 2024 includes $212 million for nine long-range radars "to fill surveillance gaps caused by existing radar failures."[108] (This refers to Chinese balloon intrusions early in 2023 that initially went undetected.[109]) Additionally, 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 Space Force removed one of three planned geosynchronous orbit satellites, a part of the Next-Gen OPIR program, from its FY 2024 budget request.[110] The Army is also progressing on development of the Lower-Tier Air and Missile Defense System (LTAMDS) 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.[111] The LTAMDS program has experienced "cascading delays," and the current plan is to move it to the major capability acquisition phase in FY 2024.[112]

Command and Control

Command and control of the U.S. ballistic missile defense system requires bringing together data from sensors and radars and relaying those data to interceptors 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.[113]

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 specially trained personnel integrating GMD and supporting elements to manage all phases of engagement."[114] According to the MDA, "GMD employs integrated communications networks, fire control systems, globally deployed sensors and Ground-Based Interceptors that are capable of detecting, tracking and destroying ballistic missile threats," and as of June 2023, 44 GBIs were "currently emplaced" at Fort Greeley in Alaska and Vandenberg Air Force Base in California.[115]

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.[116] 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.[117]

To prepare for and execute GMD operations, the NORTHCOM Commander can also utilize situational awareness data from the Command and Control, Battle Management, and Communications (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.[118] 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.[119] 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 by remote sensing.

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 can provide their sensor data to the GMD system through C2BMC.[120]

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.[121] Like IFPC, IBCS would also link defenses against smaller threats with ballistic missile defense.

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. According to General VanHerck, "domain awareness" remains one of the challenges that makes homeland defense "a potential limiting factor to ensuring rapid and effective implementation and execution of global contingency plans."[122] Domain awareness is especially important in dealing with cruise missile threats to the homeland—threats against which the U.S. has no comprehensive interceptor capability.

Continuing to upgrade the C2BMC system 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.[123] The MDA is expecting the LRDR's operational acceptance in the fourth quarter of FY 2024 after a delay.[124] It also has linked C2BMC to the Army's IBCS, and it was expected that the round of upgrades announced in August 2021 would further integrate those systems and enhance the threat data provided to the GMD system.[125]

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) concept to integrate non-compatible sensors across all domains into a single network so that it can respond to a complex threat more efficiently.[126] 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 (NORAD) have conducted a series of Global Information Dominance Experiments (GIDE) that GIDE V Mission Commander Colonel Matthew Strohmeyer describes as "an opportunity to stress-test our current systems and processes, introduce new technologies and approaches, and learn in an experimentation environment that replicates real-world operations."[127] Sensor information can tend to exist in stovepipes, and if it is not integrated, the result can be failure to detect a threat.[128] GIDE also uses artificial intelligence and machine learning cues to ensure that the commander receives a full data picture.[129]

IBCS will 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.

The IBCS program has been approved for Full Rate Production in April 2023.[130] Advancements underway in missile defense command and control will become increasingly necessary to enable defense against the growing missile threat.

Conclusion

By choice of successive presidential 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 from Russia and China. U.S. efforts have focused on a limited architecture that protects the homeland from quantitatively small and qualitatively relatively less advanced threats and on deploying and advancing regional missile defense systems. The United States has not invested in space-based missile defense in any serious manner.

The United States has in place multiple types of capable interceptors, a vast sensor network, and a command and control system, but many elements of the missile defense system need to be improved to defend against today's threat more efficiently, and the system would have to be rethought from the ground up should a decision be made to provide a comprehensive layered and robust defense of the homeland against Russian and Chinese missile threats. 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 and the Administration must ensure that the funding of critical programs like NGI, space sensors, and JADC2 is commensurate with their importance and that the nation is investing in future research and development, including missile defense in space.

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