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Costs of Implementing Recommendations of the 2019 Missile Defense Review

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At a Glance

In January 2019, the Department of Defense released the Missile Defense Review (MDR), which describes the Administration's plans and policies for defenses against ballistic and cruise missiles. In this report, the Congressional Budget Office analyzes the MDR and estimates the potential costs of implementing its recommendations.

- **Early Initiatives.** CBO estimates that, before the release of the MDR, the Administration increased the 10-year costs of missile defense plans by about $50 billion (or 40 percent) to fund high-priority initiatives that were undertaken while the review was in process. That total reflects a comparison between CBO's 10-year projections of the 2017 budget plan (the last plan before the MDR was commissioned) and the 2020 budget plan (the first plan after the MDR was released).
- **Threat-Based Expansions.** The MDR identifies two expansions of missile defense systems that might be pursued in the future if threat conditions warrant. CBO estimates that building 40 more interceptor silos in Alaska would cost about $5 billion (including interceptors). A new midcourse interceptor site in the eastern United States would cost at least $4 billion to build and about $80 million per year to operate.
- **Directed Studies.** The MDR also commissions numerous studies that could lead to expansions of existing systems or development of new systems. Where possible, CBO has estimated the cost of implementing such policies. Some of those expansions or new systems, if implemented, could cost tens or hundreds of billions of dollars.

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Notes

Unless this report indicates otherwise, all years referred to are federal fiscal years, which run from October 1 to September 30 and are designated by the calendar year in which they end.

Numbers in the text and tables may not add up to totals because of rounding.

In this report, “cost” refers to budget authority, the amount that would need to be appropriated to implement the Administration’s plans.

On the cover (clockwise from top left): The U.S.S. *Hopper* (DDG 70) launches an SM-3 Block IB missile defense interceptor in a developmental test off the west coast of Hawaii; personnel at the Missile Defense Integration and Operation Center on Schriever Air Force Base in Colorado Springs, Colorado, work at the test control facility during Flight Test Ground-Based Interceptor-06b; a THAAD interceptor is launched from the Reagan Test Site, Kwajalein Atoll, in the Republic of the Marshall Islands, during Flight Test THAAD-23; and the sea-based X-band radar under way in the waters around the Aleutian Island chain of Alaska (all photos courtesy of the Missile Defense Agency).

Costs of Implementing Recommendations of the 2019 Missile Defense Review

Summary

In January 2017, the Administration initiated a review of the United States' missile defense capabilities to recommend policies it could pursue and forces it could field. Two years later, in January 2019, the Administration released the Missile Defense Review (MDR), which focuses on defenses against both ballistic missiles (which are initially launched with a rocket booster and then continue to their target via nonpowered flight) and cruise missiles (which are powered throughout their flight with jet engines).[1] The John S. McCain National Defense Authorization Act for Fiscal Year 2019 (Public Law 115-232) required the Congressional Budget Office to estimate the 10-year costs of implementing recommendations in the MDR. Those estimates are the subject of this report.

Costs of Early Initiatives

Although the report was not released until January 2019, accounts in the press suggest that the MDR was largely completed in fall 2017.[2] In that case, high-priority changes suggested by analysis conducted for the MDR most likely guided a request for emergency appropriations in fiscal year 2018 and were also reflected in the fiscal year 2019 and fiscal year 2020 budget submissions, which were developed before the MDR's formal release.

To estimate the cost of those changes, CBO first estimated the 10-year costs of the missile defense plans laid out in the Department of Defense's (DoD's) 2017 budget submission (the last budget formulated before the Administration commissioned the MDR) and the 10-year costs of the missile defense plans laid out in the 2020 budget submission (the last budget submission developed before the MDR was released).[3] The difference between those two 10-year cost estimates, as described in this report, reflects the cost of the changes to missile defense programs that were informed by analysis conducted for the MDR and implemented before the MDR was released.

CBO estimates that the 10-year costs of DoD's missile defense plans (as described in the 2020 budget request) would be about $176 billion (in current dollars) from 2020 through 2029. Those estimated costs are about $50 billion (or 40 percent) higher than CBO's projection of the 10-year costs of the 2017 plan, which covered the 2017–2026 period (see Figure 1). That difference, amounting to about $5 billion per year, constitutes CBO's estimate of the cost of changes to missile defense forces and policies that were incorporated into the 2020 plans before the release of the MDR.

CBO's 10-year cost estimates include costs associated with research, development, procurement, sustainment, and operation of missile defenses. They do not include the costs of assets like early-warning radars or satellites that were historically part of the nuclear forces even though they are currently used for missile defense. CBO's estimates come with substantial uncertainty because of uncertainty in some missile defense plans and in the future quantity and capabilities of adversaries' missile fleets, which could affect those defense plans.

Costs of Recommendations in the Missile Defense Review

The MDR also describes other recommended changes that might be pursued but that were not included in recent budget submissions. Where possible, CBO estimated the costs of those recommendations (see Table 1). Those estimates represent new costs—that is, if the recommendations were implemented, DoD would incur

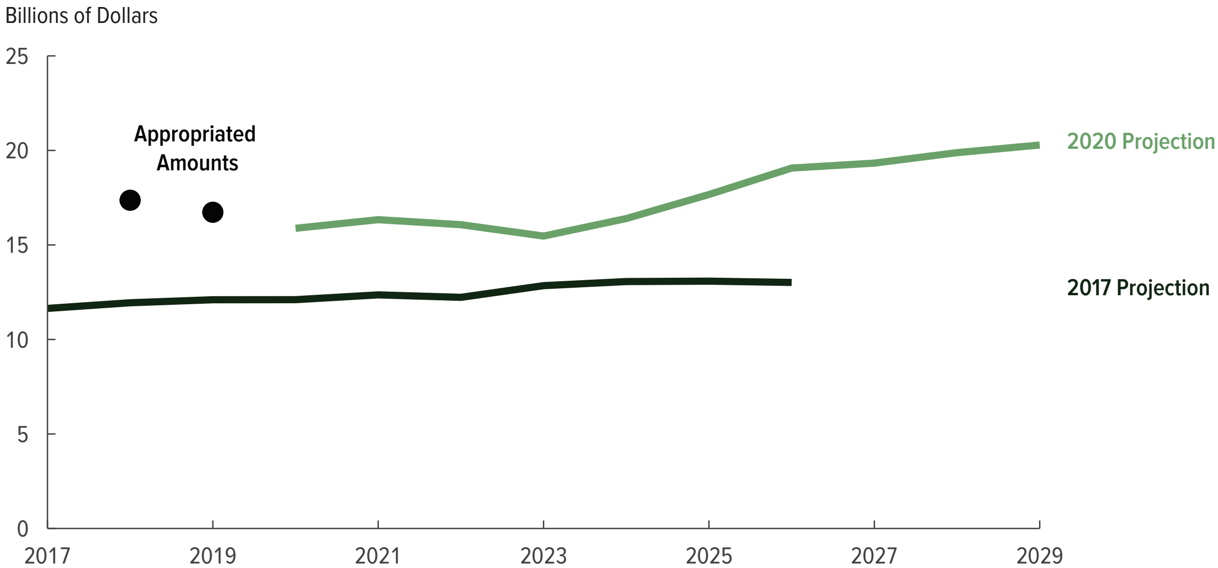
1. See Office of the Secretary of Defense, *Missile Defense Review* (2019), https://go.usa.gov/x7MQB (PDF, 27.3 MB).

2. See Jen Judson, "After Repeated Delays, Will the Pentagon's Missile Defense Review Be Out Soon?" *Defense News* (September 4, 2018), https://tinyurl.com/yylk9yq2.

3. Although the 2020 budget submission was released several weeks after the MDR, developing DoD's budget submission is a year-long process.

Figure 1.

CBO's 10-Year Projections of the Annual Costs of DoD's 2017 and 2020 Missile Defense Plans



Data source: Congressional Budget Office. See www.cbo.gov/publication/56949#data.

DoD = Department of Defense.

costs over and above CBO's 10-year projections of the cost of the 2020 plan. Because the current dollar costs would depend heavily on the year in which costs were incurred, and because the schedule is uncertain for all of those efforts, the estimates are in constant 2020 dollars.

The MDR identifies two expansions of current systems that could be pursued if threat conditions warranted:

- **Expand Ground-Based Midcourse Defense (GMD) at Fort Greely in Alaska to as many as 100 interceptors from the 60 currently planned.** CBO estimates that adding 40 silos and interceptors would cost a total of about $5 billion.[4]
- **Establish a new GMD site in the continental United States.** CBO estimates that it would cost about $4 billion to establish a new GMD site with 20 silos and interceptors and about $80 million per year to operate the site.

Additionally, the MDR directs DoD to study three potential expansions of current systems:

- **Increase the number of Terminal High Altitude Area Defense (THAAD) batteries.** The MDR directs DoD to determine whether the current number of THAAD batteries is sufficient. If more were required, each additional battery would cost about $800 million to procure and about $30 million per year to operate, in CBO's estimation.
- **Make all Aegis destroyers fully ballistic missile defense (BMD) capable.** Provided that current shipyard capacity was adequate to install necessary upgrades, all 94 Aegis ships available in 2029 could be BMD-capable without any additional cost beyond what is already included in CBO's projection, the agency estimates. However, new costs could be incurred if DoD purchased more missile defense interceptors than those currently planned to outfit those ships.
- **Develop a plan to make the Aegis Ashore test facility at the Pacific Missile Range Facility (PMRF) operational within 30 days of a directive to do so.** By CBO's estimate, no investment costs would be required to enable operations at the test facility.

4. Expansion of GMD, whether at Fort Greely or another site, would require the purchase of ground-based interceptors. CBO's estimates incorporate the assumption that the cost to purchase those interceptors, which are currently being redesigned, would be the same as that to purchase the current version.

Table 1.

Potential Costs If Directives in the Missile Defense Review Resulted in Deployed Systems

Category	Estimated Costs (2020 Dollars)
Threat-Based Expansions of Current Systems	
Expand GMD Further at Current Base	About $5 billion for 40 new silos at Fort Greely, Alaska, and interceptors to fill them
Build New GMD Site in Eastern United States	At least $4 billion to establish a new GMD site comprising 20 silos and interceptors and about $80 million per year to operate it
Expansions of Current Systems That Might Result From Directed Studies	
Increase the Number of THAAD Batteries	About $800 million to procure and about $30 million to operate each additional THAAD battery
Make All Aegis Destroyers Fully Missile Defense Capable	The Navy and the Missile Defense Agency are currently expanding the Aegis destroyer fleet through a combination of building new ships and upgrading older ships. In CBO's projections, no additional costs for upgrades beyond currently planned amounts would be necessary to install missile defense capability on all Aegis ships, provided that shipyard capacity was available. If additional interceptors or upgrades to ship systems like electrical power or radars were needed, additional costs would be incurred.
Make the Aegis Ashore Test Facility Operational	No investment costs would be required to make the test facility operational for short periods. If the facility was operational for extended periods, additional housing for personnel might be needed. In addition, the Pacific Missile Range Facility would not be able to host other training and test operations, so other venues for those activities would need to be identified or built, which could be expensive.
New Systems or Capabilities That Might Result From Directed Studies	
Add F-35 Aircraft Sensors to Missile Defense	CBO did not have enough information to estimate those costs.
Develop a Boost-Phase Interceptor to Be Fielded on the F-35	Using a concept from an existing study, CBO estimates that it would cost $15 billion to $20 billion to develop appropriate interceptors and produce 350 each of two variants. Operational costs would depend on the approach but could be as much as $10 billion to $20 billion per year to operate a standing defense against North Korea using F-35s, plus another $10 billion to $20 billion in one-time costs to procure dedicated F-35 aircraft for the mission, if needed.
Develop a Constellation of Space-Based Interceptors	Existing studies estimated the cost of such a constellation to be between $50 billion and $400 billion over 20 years, depending on the capabilities of the defense. Because launch and satellite production costs have come down, CBO estimates that those costs could be 20 percent to 40 percent lower.
Develop a Constellation of Satellites to Track Ballistic and Hypersonic Missiles	CBO did not have enough information to estimate those costs.
Develop Defenses Against Hypersonic Missiles	CBO did not have enough information to estimate those costs.

Data source: Congressional Budget Office. See www.cbo.gov/publication/56949#data.

GMD = Ground-Based Midcourse Defense; THAAD = Terminal High Altitude Area Defense.

However, costs could be incurred, perhaps substantial ones, to house personnel and relocate non-missile-defense test activities if the test site remained operational for an extended period.

The MDR also directs DoD to conduct several studies that could result in new systems or capabilities. For three of those studies—incorporating the F-35 sensors into missile defense, developing a new satellite constellation to track ballistic and hypersonic missile threats, and developing defenses against hypersonic missiles—there was not enough detail for CBO to fully estimate the costs of developing the systems. For the remaining two studies, CBO provides estimates based on previous technical analyses to illustrate the magnitude of potential costs of developing those systems:

- **Boost-phase missile defense interceptors to be fielded on F-35 fighter aircraft.** CBO reviewed several past studies of airborne interceptors (ABIs), which all concluded that the aircraft carrying ABIs would have to be close to or within the airspace of the country launching the ballistic missile for an interceptor to be able to reach the ballistic missile while its engines were still burning. Thus, a complete defense would not be possible in peacetime in most cases, particularly against large- or medium-sized countries. However, one study concluded that it might be possible to defend against launches from a relatively small adversary like North Korea during peacetime.[5] CBO estimates that it would cost $15 billion to $20 billion to establish a defensive capability by developing the study's two types of ABIs, produce 350 of each design, and integrate those weapons onto the F-35. That estimate does not include operation or training costs, which would depend on what those operations entailed.[6]

  Maintaining a standing peacetime defense with the F-35, which would require 30 to 60 aircraft aloft and on station at all times, would incur substantial operating costs. Altogether, CBO estimates, developing and fielding a standing ABI defense against North Korea using F-35 aircraft and the concept described in the referenced study would cost $25 billion to $40 billion, with an additional $10 billion to $20 billion a year to operate it. Costs would be lower if DoD did not have to purchase new F-35s for the mission, and operating costs could be substantially lower if it used a less sophisticated, lower-cost aircraft for the mission.

- **Space-based ballistic missile interceptors.** Previous studies of space-based interceptors have found that maintaining a robust global defense requires many interceptors to be in orbit.[7] For example, a 2011 study commissioned by the Missile Defense Agency (MDA) estimated that a constellation of 24 satellites would provide a limited defense and a constellation of 960 satellites would provide a more complete defense.[8] Other studies, including one by CBO in 2004 and one by the National Research Council in 2012, reached similar conclusions.[9]

  The 2004 CBO study and the 2012 National Research Council study, when considered together, indicated that fielding and operating constellations of space-based interceptors would cost roughly $50 billion to $400 billion over 20 years. However, space-related costs like launch and satellite production have decreased in recent years. In CBO's estimation, the 20-year costs would be 20 percent to 30 percent lower if there was a modest reduction in the costs of launch and satellite production relative to the values used in the initial studies, and they would be 30 percent to 40 percent lower if there was a larger reduction in those costs. With such larger cost reductions, the range of costs estimated in those earlier studies would fall to between about $40 billion and $250 billion.

Background

Historically, the United States has pursued missile defenses to thwart attacks from ballistic missiles and cruise missiles by intercepting them in flight. Ballistic missiles are initially launched with a rocket booster and then continue to their target via nonpowered flight, carving an arc through space like a fly ball in baseball. They are challenging to defend against primarily because of

5. See Dean A. Wilkening, "Airborne Boost-Phase Missile Defense," *Science and Global Security*, vol. 12 (2004), pp. 1–67, https://tinyurl.com/y69o8osd (PDF, 1.78 MB).

6. The approach for cost estimation is described in Congressional Budget Office, *Alternatives for Boost-Phase Missile Defense* (July 2004), www.cbo.gov/publication/15852.

7. To be effective, a space-based defense must have at least one satellite in the proper location at the right time to launch at least one interceptor at each threat missile. Because satellites are constantly moving while in orbit, the earth is spinning below the orbiting satellites, and adversaries can launch multiple missiles at times of their choosing, a complete defense requires many satellites. To reduce the number of satellites, designers can choose to limit the defense to certain latitudes or to limit the number of threat missiles that can be engaged.

8. See Patrick J. O'Reilly, Department of Defense Missile Defense Agency, letter to the Honorable Jon Kyl (June 22, 2011), https://tinyurl.com/y4kb37nc (PDF, 840 KB).

9. See Congressional Budget Office, *Alternatives for Boost-Phase Missile Defense* (July 2004), www.cbo.gov/publication/15852; and National Research Council, *Making Sense of Ballistic Missile Defense: An Assessment of Concepts and Systems for U.S. Boost-Phase Missile Defense in Comparison to Other Alternatives* (National Academies Press, 2012), https://doi.org/10.17226/13189.

their high altitude and high speed. Cruise missiles, which are powered by jet engines, are challenging to defend against because they can fly at low altitude to avoid detection and can maneuver in flight.

A Brief History of U.S. Missile Defenses

Development of defenses against both ballistic missiles and cruise missiles has been ongoing for many decades. Because those types of missiles present different challenges to defenses, the efforts have proceeded along different paths.

Ballistic Missile Defense. Ballistic missiles were first used to attack adversaries during World War II, when Germany deployed the V-2 missile; in response, some nations began to develop ballistic missile defenses. The first U.S. ballistic missile defense programs began just after the war ended, but those efforts took on a new urgency with the development of intercontinental ballistic missiles (ICBMs) in the late 1950s.[10] Several early defense concepts were rejected because of technical difficulty, high costs, and concerns over using nuclear warheads on interceptors near cities. In the late 1960s, the United States developed and eventually deployed the Safeguard system, which fielded BMD interceptors to protect U.S. ICBM silos, thereby improving their survival chances and enhancing deterrence based on assured retaliation. Safeguard used two types of interceptors—one short range (Sprint) and one longer range (Spartan). Both carried nuclear warheads designed to destroy incoming threat missiles at high altitudes.

However, both the Soviet Union and the United States became concerned that large-scale BMD deployments could accelerate the nuclear arms race; to protect against such acceleration, they negotiated the Anti-Ballistic Missile (ABM) Treaty (signed in 1972 and amended in 1974). The treaty limited deployments of homeland missile defenses to a single land-based site containing no more than 100 interceptors, placed constraints on BMD radars, and banned mobile BMD systems, but it permitted research on missile defense technology more generally.[11] Although the existing Safeguard deployments complied with the ABM treaty, they were closed after being fully operational for only about six months because of technical and operational limitations.

In the early 1980s, interest in homeland missile defense returned to the forefront with the creation of the Strategic Defense Initiative (SDI), whose goal was to develop a missile defense that would make nuclear weapons "impotent and obsolete."[12] That program led to research on numerous ballistic missile defense concepts, many of which were to be based in space. The overall SDI defense architecture, which combined several different types of systems to engage threat missiles, evolved substantially over the years, generally becoming more limited in scope with each change. Several of the technical concepts in SDI have been revisited periodically since that time.

One result of the evolution of SDI is that most of the current U.S. missile defense strategy focuses on the concept of "hit to kill," that is, destroying a target missile in flight by direct collision with an interceptor missile rather than with an explosive warhead or nuclear weapon. The concept's feasibility was successfully demonstrated by the Homing Overlay Experiment test in 1984, and subsequently, hit-to-kill interceptors have been employed in almost all U.S. homeland and regional BMD programs.

The United States withdrew from the ABM Treaty in 2002 to pursue a broader set of BMD programs banned by the treaty. Ground-based interceptors for homeland defense were eventually developed and deployed as the Ground-Based Midcourse Defense system in Alaska in 2004. Although the size of the GMD system itself was compliant with the ABM treaty, the geographical layout of the system and the sensors it relies on were not.

Cruise Missile Defense. Because cruise missiles are essentially unpiloted aircraft, cruise missile defense has generally been approached as an extension of defenses against aircraft. In the early days of the Cold War, the

10. Several more detailed but still brief histories of ballistic missile defense are available. See Missile Defense Agency, *Missile Defense: The First Seventy Years*, 13-MDA-7397 (2013), www.mda.mil/global/documents/pdf/first70.pdf (7.3 MB); and Thomas Karako, Ian Williams, and Wes Rumbaugh, *Missile Defense 2020*, (Center for Strategic and International Studies, April 2017), pp. 14–51, www.csis.org/analysis/missile-defense-2020.

11. For a more detailed description of the ABM treaty, see Arms Control Association, "The Anti-Ballistic Missile (ABM) Treaty at a Glance" (July 2017), www.armscontrol.org/factsheets/abmtreaty.

12. See Ronald Reagan, President of the United States, "Address to the Nation on Defense and National Security" (speech, March 23, 1983), www.reaganlibrary.gov/research/speeches/32383d.

United States fielded extensive defenses of the homeland against Soviet aircraft. However, with the advent of ICBMs in the late 1950s—which at the time were considered to be very difficult, if not impossible, to defend against—interest in and funding for robust continental air defense waned. The result was a reduced homeland air defense system that included early warning radars in Canada (the Distant Early Warning line, or DEW line, later upgraded to the North Warning System, and the Pine Tree line in central Canada), Federal Aviation Administration radars in and around the United States (primarily used for civilian air traffic control), and a reduced intercept capability based largely on Airborne Warning and Control System (AWACS) aircraft and fighter aircraft at bases in Canada and the United States.

After the attacks of September 11, 2001, that defense was augmented with a quick-response air defense capability, which largely focused on protecting Washington, D.C. In the past decade, however, the development of longer-range and more advanced cruise missiles carrying either nuclear or conventional weapons by potential adversaries has led to renewed interest in expanding homeland air defense to enhance its effectiveness against cruise missiles.

Types of Current Missile Defense Systems

Current systems for defending against missiles have components that perform three primary functions:

- **Sensors.** The defense system must first detect that a threat missile has been launched and its track determined using a variety of sensors.
- **Command and Control Systems.** Operators must assess the threat missile's current track to predict its future track and likely target (which, given uncertainties in sensing, is generally an array of potential tracks rather than a single trajectory) and determine the appropriate defensive response, which is accomplished with command and control systems.
- **Platforms and Interceptors.** The chosen defensive system must engage the missile, which (for current systems) is accomplished with an interceptor missile operating either as a stand-alone system or carried on a multipurpose platform (such as a ship or an airplane).

The United States currently fields numerous systems that perform those missile defense functions, and plans call for fielding more systems in the future. Those systems can be categorized in several different ways: by type of threat missile and the portion of the threat trajectory in which intercept occurs, by range of threat ballistic missile and area defended, and by the function the system performs in the defense sequence.

By type of threat missile and the portion of the threat trajectory in which intercept occurs. Currently the United States fields defenses against ballistic missiles and cruise missiles.[13] Defense against ballistic missiles is generally categorized according to the portion of the trajectory in which the intercept occurs (boost phase, midcourse phase, or terminal phase). The necessary capabilities of the interceptors and sensors vary for each of those phases, and each presents unique challenges.

Boost phase refers to the initial portion of the trajectory, which occurs while the rocket booster is still burning. That phase generally lasts for only a few minutes, during which time the missile passes through and (except for short-range missiles) out of the atmosphere. Intercepting a missile outside the atmosphere (an exoatmospheric intercept) requires a different interceptor design than intercepting one inside the atmosphere (an endoatmospheric intercept), particularly in terms of the sensors used to home on the target and the method they use to adjust the interceptor's trajectory as it nears the point of intercept.

The midcourse phase begins after the rocket booster completes firing and ends when the warhead reenters the atmosphere. Except for short-range missiles, most warheads separate from the rocket booster and present a smaller target for the remainder of the trajectory. During this phase the threat missile may also deploy decoy warheads or other countermeasures to confuse defenses. The midcourse phase can last from a few minutes for short-range missiles to 20 minutes or more for long-range missiles.

The terminal phase occurs after the warhead reenters the atmosphere and nears the target. It is moving very rapidly during that phase, which lasts for only a few minutes. Generally, terminal-phase defenses are only capable of defending a small area and are often referred to as point defenses, whereas boost-phase or midcourse defenses can defend much larger areas. The United States

13. For a brief introduction to ballistic missiles, see Congressional Budget Office, *Options for Deploying Missile Defenses in Europe* (February 2009), Appendix A, www.cbo.gov/publication/41165.

currently fields several systems that perform midcourse and terminal defense, but it does not currently field any boost-phase ballistic missile defenses (although the MDR directs DoD to perform studies of two potential boost-phase defense systems).

Systems that provide cruise missile defense generally also provide defense against aircraft, although cruise missiles often present a greater challenge than aircraft because, with their small size and their ability to fly at low altitudes to avoid tracking sensors, they may be harder to detect. Some systems can defend against aircraft, cruise missiles, and short-range ballistic missiles.

By range of threat ballistic missile and area defended. Ballistic missiles are often characterized by their range—that is, the distance over which they can fly to strike targets:

- Short-range ballistic missiles (SRBMs) have ranges from 500 kilometers (km) to 1,000 km; [14]
- Medium-range ballistic missiles (MRBMs) have ranges from 1,000 km to 3,000 km;
- Intermediate-range ballistic missiles (IRBMs) have ranges from 3,000 km to 5,500 km; and
- Intercontinental ballistic missiles (ICBMs) have ranges over 5,500 km.

Generally, the longer the range of the threat missile, the more capable an interceptor needs to be in terms of speed (and thus range) and ability to adjust its own trajectory to correct for uncertainties in the predicted position of the threat missile. Interceptors that are effective over a greater range can defend a larger area. In this report, CBO refers to systems that can defend against ICBMs as homeland defenses (that is, they would be capable of defending at least a portion of the U.S. homeland against ICBMs launched from a likely adversary's territory), while systems that defend against threats of IRBM-range or shorter are referred to as regional defenses. The United States currently fields both homeland and regional ballistic missile defenses; some systems fall in both categories.

By the function the system performs in the defense sequence. A system can be categorized by which of the three primary missile defense functions performed by its components (which are sensors, command and control systems, and interceptors, including the platforms that carry them). In some cases, individual missile defense acquisition programs cover more than one of those functions; for example, the current Patriot system includes a radar, interceptors and their launchers, and internal command and control systems that connect those systems.

14. One kilometer (km) equals about 0.62 miles. For example, 500 km corresponds to about 300 miles.

The 2019 Missile Defense Review and CBO's Approach to Analyzing It

In January 2017, shortly after taking office, President Trump issued a memorandum on rebuilding the U.S. Armed Forces. It outlined several initiatives, one of which directed DoD to conduct a ballistic Missile Defense Review "to identify ways of strengthening missile-defense capabilities, rebalancing homeland and theater defense priorities, and highlighting priority funding areas."[15] The John S. McCain National Defense Authorization Act for Fiscal Year 2019 required the Congressional Budget Office to estimate the 10-year costs of implementing recommendations in the MDR. This report fulfills that requirement.

The Missile Defense Review

The Department of Defense released the Missile Defense Review in January 2019.[16] The final report reflects a broadening of focus (relative to the initial charge) to include defenses against cruise missiles and a new category of threat missiles referred to as hypersonic weapons (see Box 1).

The MDR draws several conclusions about current conditions and missile threats:

- The threat from ballistic and cruise missiles has increased in recent years, as both the number and the technical sophistication of missiles fielded by potential adversaries have grown.
- New advanced threats including hypersonic weapons and maneuvering warheads are being developed by potential adversaries.
- Missile threats span geographic regions, and defense requires effective coordination among regional and global commanders.

15. See Donald J. Trump, President of the United States, "Presidential Memorandum on Rebuilding the U.S. Armed Forces" (January 27, 2017), https://go.usa.gov/xGkv2.

16. See Office of the Secretary of Defense, *Missile Defense Review* (2019), https://go.usa.gov/x7MQB (PDF, 27.3 MB).

Box 1.

Hypersonic Weapons

The Missile Defense Review (MDR) identifies hypersonic weapons as a new threat to be addressed by both U.S. homeland and regional missile defenses. Hypersonic weapons travel at very high speeds—most sources define weapons as hypersonic if they travel faster than five times the speed of sound (Mach 5), which is equivalent to about 3,800 miles per hour or 1 mile per second. On the basis of speed alone, ballistic missiles (except those with short ranges) meet the definition of hypersonic weapons—intercontinental ballistic missiles, for example, reach speeds as much as 17,000 miles per hour. But, unlike ballistic missiles, the hypersonic weapons currently under development have trajectories that lie mostly in the stratosphere, above approximately 25 kilometers to 30 kilometers (80,000 feet to 100,000 feet) in altitude—higher than where most existing air defense and terminal-phase ballistic missile defense (BMD) systems operate and lower than where midcourse BMD systems operate. As aerodynamic vehicles, hypersonic weapons also would have the ability to maneuver in flight, which makes it more difficult both to intercept them and to predict which targets they are attacking.

The United States has pursued research on hypersonic weapons with some test successes since the late 1940s, but to date none of those programs has led to the fielding of an operational weapon.[1] Several U.S. development programs are now in progress. In recent years, other countries, notably Russia and China, have also begun to develop hypersonic weapons. Russia has stated that it is developing hypersonic weapons to overcome U.S. missile defenses in response to the United States' 2001 decision to withdraw from the 1972 Anti-Ballistic Missile Treaty, which limited missile defenses for both the United States and Russia.[2] China's hypersonic program has grown substantially in the past decade: The Chinese have conducted numerous flight tests, made improvements in their ground test infrastructure (for example, hypersonic wind tunnels), and trained a large cadre of aerospace engineers to support those efforts.[3]

The two most common types of hypersonic weapons currently under development are hypersonic glide vehicles (HGVs) and hypersonic cruise missiles (HCMs). HGVs are typically launched with a rocket booster, like the payload of a ballistic missile; however, unlike ballistic missiles, at some point after the booster has completed firing, they are directed back into the upper atmosphere where they glide using aerodynamic lift (like an airplane wing) toward their target. They are also able to change their flight path by turning while they are coasting. However, both coasting and maneuvering phases are subject to friction, so HGVs slow down as they fly; the more sharply they turn, the more they slow down.

HCMs have also been researched for decades. However, they are particularly technically challenging due to the need for a supersonic combustion ramjet (scramjet) engine, so most of the current hypersonic weapons development programs are based on the HGV concept. Conventional jet engines cannot operate at hypersonic speeds and traditional ramjet engines operate only up to around Mach 3 or 4. Operating a scramjet has been described as "fiendishly tricky," like "keeping a match lit in a hurricane."[4]

1. See Mark J. Lewis, "Hypersonic Weapons Come of Age," *Air Force Magazine*, vol. 99, no. 3 (March 2016), p. 47, www.airforcemag.com/issue/2016-03.

2. See Ivan Oelrich, "Cool Your Jets: Some Perspective on the Hyping of Hypersonic Weapons," *Bulletin of the Atomic Scientists*, vol. 76, no. 1 (2020), p. 37, https://doi.org/10.1080/00963402.2019.1701283.

3. See Guy Norris, "Hyper Threat," *Aviation Week and Space Technology*, vol. 179, no. 4 (February 20–March 5, 2017), pp. 20–23, https://tinyurl.com/y4oyhm5f (PDF, 9.18 MB); John A. Tirpak, "The Great Hypersonic Race," *Air Force Magazine*, vol. 101, no. 8 (August 2018), www.airforcemag.com/issue/2018-08; and David Lague, "China Leads U.S. on Potent Super-fast Missiles," *Reuters*, Special Report (April 25, 2019), https://tinyurl.com/yyk33wcu.

4. See Ivan Oelrich, "Cool Your Jets: Some Perspective on the Hyping of Hypersonic Weapons," *Bulletin of the Atomic Scientists*, vol. 76, no. 1 (2020), p. 43, https://doi.org/10.1080/00963402.2019.1701283.

- Active missile defenses need to be integrated with passive defenses (such as hardening of potential targets against the effects of attack) and offensive strike capabilities to destroy threat missiles before they are launched.

In addition, the MDR addresses the future missile defense posture in several ways. In particular, it identifies several expansions of currently deployed forces that could be pursued if conditions warranted, and it recommends that various DoD organizations study particular missile defense systems and concepts that could lead to changes in the management or composition of missile defense forces. Those recommendations include:

- Developing plans for coordination between commanders and designating responsible parties for improvements in coordination and communication;
- Performing assessments of or developing plans for potential expansions in size, capability, or utilization of various components of current forces; and
- Studying the development and fielding of new missile defense systems such as space-based interceptors or air-launched interceptors.

CBO's Approach to Analyzing the Missile Defense Review

Two factors complicate the estimates that CBO was mandated to produce. First, two years passed between the commissioning of the MDR and its publication, during which time there were notable changes to missile defense plans. Second, the MDR does not make any explicit recommendations to deploy or develop specific systems. Instead, the MDR draws several conclusions, notes several expansions of forces that might be undertaken in certain circumstances, and requires a number of studies that could lead to changes in missile defense forces. Any changes that are implemented could add to the costs of missile defenses.

To account for those complications, CBO estimated the budgetary impact of the Administration's missile defense policies and force structure plans in two parts. First, the agency estimated the impact of changes in policy and structure that were implemented while the MDR was in process (that is, changes that occurred after the Administration entered office but before the MDR report was published). CBO interpreted the difference between its estimate of the costs of plans for missile defenses contained in the 2017 budget submission and its estimate of the costs of plans for missile defenses in the 2020 budget submission (which was completed in 2019) as being informed by the analysis done for the MDR and implemented before the MDR was published. The January 2017 memorandum that called for a Missile Defense Review did not specify a due date for the review, but subsequent statements by the Administration indicated that a one-year timeline was expected, and press reports suggested that the MDR was largely completed in fall 2017.[17] Consequently, analysis for the MDR was probably the basis for a fiscal year 2018 emergency budget amendment that included $4 billion "to support urgent missile defeat and defense enhancements," as well as informing the 2019 and 2020 budget submissions.[18]

Second, CBO estimated (where possible) the cost of the MDR's additional suggestions (both those that might be taken if circumstances warranted and those that might result from future analyses). To estimate those additional costs, CBO used different approaches for each category of potential changes. For cases in which the MDR suggests future expansions in the size, capability, or utilization of currently planned forces that could be made if conditions warranted, CBO made estimates based on historical costs (where possible). For cases in which the MDR commissioned analyses that may or may not lead to development of new missile defense systems in the future, CBO estimated a range of potential costs if such development programs were pursued based on past analyses of similar systems performed by CBO or other analytical organizations.

However, CBO did not estimate the costs for several categories of potential improvements. Those changes include improved coordination between regional and global commanders to facilitate missile defenses over the full extent of threat missile trajectories and coordination between missile defense commanders and offensive strike commanders to reduce the number of threat missiles that defenses would need to engage, as well as other administrative and procedural improvements. Although some costs might be incurred to upgrade communications or other systems or procedures to enable the desired improvements, there was not enough detail in the MDR about the form those improvements might take for CBO to estimate the costs. In addition, CBO did not estimate whether any additional long-range conventional

17. See Department of Defense, "Pentagon Announces Start of Ballistic Missile Defense Review" (May 5, 2017), https://go.usa.gov/xGKpE; and Jen Judson, "After Repeated Delays, Will the Pentagon's Missile Defense Review Be Out Soon?" *Defense News* (September 4, 2018), https://tinyurl.com/yxkojq4j.

18. CBO did not use the fiscal year 2018 budget request, which was submitted shortly after the MDR was commissioned, to provide a pre-MDR comparison because it contains only a single year of budget values rather than the more typical five-year budget plans. For the emergency budget amendment, see Donald J. Trump, President of the United States, letter to the Honorable Paul D. Ryan, Speaker, House of Representatives (November 6, 2017), https://go.usa.gov/xGKd8 (PDF, 280 KB).

strike forces would be required to serve the mission as described in the MDR as such analysis is beyond the scope of this report.

Current and Future Missile Defense Forces and Programs Encompassed by the 2020 Budget Submission

For this study, CBO divided missile defenses into three broad categories by range or type of threat missile and area defended: homeland ballistic missile defenses, regional ballistic missile defenses, and cruise missile defenses. Within those categories, systems are further differentiated by the function performed by their components: platforms and interceptors, sensors, and command and control.

Homeland Ballistic Missile Defense

The primary system for defending the United States against long-range ballistic missiles is the Ground-Based Midcourse Defense system. However, the Aegis Ballistic Missile Defense (Aegis BMD) system, which is primarily a regional defense system, may also be able to defend a portion of the U.S. homeland against long-range missiles in some situations.

Platforms and Interceptors. The GMD system uses ground-based interceptors (GBIs), which are long-range interceptors that are launched from underground silos. Each GBI comprises a rocket booster and a kill vehicle that separates from the booster. The system uses ground-based radar and onboard infrared sensors to discriminate the threat warhead from any decoys and to track it, and the kill vehicle adjusts its own trajectory to destroy the target with the force of impact.

The GMD system currently fields 44 interceptors (40 are located in Alaska, and 4 are in California). Construction of a new missile field in Alaska, which began in 2018 and is nearing completion, will add another 20 missiles. However, there is a great deal of uncertainty surrounding GMD hardware because the GMD system is just beginning a major redesign effort. The 2020 budget (submitted in March 2019) included continued funding for an ongoing program to design an improved kill vehicle to replace the existing version, but DoD canceled that program in August 2019, citing technical design flaws, and called for a complete redesign of both the kill vehicle and the GBI booster.[19] The redesigned interceptor, referred to as the Next-Generation Interceptor, is not expected to be available until the late 2020s.

The Aegis BMD system, which is primarily a regional defense system and is described in more detail in the next section, may have a limited capability for homeland defense. The Aegis BMD system uses several different interceptors; one of those, the Standard Missile 3 Block IIA (SM-3 Block IIA), is in development and may be fast and nimble enough to intercept ICBMs in some situations, although that mission was not a goal in its design. An intercept test of the SM-3 Block IIA against an ICBM was scheduled for mid-2020, but it was delayed until November 2020 because of the 2020–2021 coronavirus pandemic. According to DoD, preliminary data indicate that the test was successful.[20]

Sensors. Numerous sensors, primarily radars, support homeland ballistic missile defense. Some of those sensors were fielded expressly for the missile defense mission, but others were fielded before the current generation of missile defenses was implemented in order to provide warning of attack to strategic nuclear forces.

The Sea-Based X-band (SBX) Radar was built specifically for missile defense.[21] The SBX is a long-range tracking radar mounted on a floating oil-drilling platform, which allows it to move near areas of potential conflict in order to be in position to track missile threats. It has been operating in the Pacific Ocean for more than 10 years, and plans call for it to be at sea about 90 percent of the time over the next five years.

The Missile Defense Agency also has several radar sensors in various stages of development for future implementation. The Long-Range Discrimination Radar, designed to help operators distinguish actual threat warheads from decoys, is under construction in Alaska and is slated to begin initial operational testing soon and to be fully

19. See Rich Abott, "Hill: NGI Has Flexibility in Development Cycle, Replaces Whole Interceptor," *Defense Daily* (March 10, 2020), https://tinyurl.com/y56pjmgj.

20. Department of Defense, "U.S. Successfully Conducts SM-3 Block IIA Intercept Test Against an Intercontinental Ballistic Missile Target" (November 17, 2020), https://go.usa.gov/x7tZk.

21. Radars are often classified by band, which refers to the wavelength of the electromagnetic waves they use to detect targets. Generally, the wavelength is related to the minimum distance between objects at which the radar can distinguish them from each other. X-band radars use wavelengths of a few centimeters and can distinguish between objects that are separated by as little as several centimeters (a few inches).

operational in 2023.[22] The Homeland Defense Radar–Hawaii is currently in the planning stages. Potential locations have been identified on Oahu, and plans in the 2020 budget called for initial operations to begin in 2023. A third radar, the Pacific Discriminating Radar, entered the planning stages in 2018. The 2020 budget called for initial operations in 2026; the location for that radar has not yet been publicly identified.[23]

MDA is also testing satellite sensors for missile defense. The Space Tracking Satellite System program was designed to track threat missiles during the boost phase and, after separation, to track the warhead through the midcourse phase to help distinguish warheads from decoys. The full system has not been fielded, but two demonstration satellites were launched in 2009 and are still operating to test the system and to support tests of other missile defense systems. In addition, MDA recently fielded the Space-Based Kill Assessment system, which is a constellation of sensors hosted on commercial satellites. It measures the energy in the collision between an interceptor and the threat missile to determine whether the intercept was successful.

Current U.S. missile defenses also use information from sensors that historically have been part of the nuclear early-warning system, including long-range radars and infrared satellites. Over roughly the last decade, MDA has been upgrading the early-warning radars—located in the United Kingdom, Greenland, Alaska, Massachusetts, and California—to improve their performance for the missile defense mission. Those upgrades are largely complete. Infrared satellites have been used since the Cold War to provide warning by detecting the hot exhaust plume from rocket engines; they can also provide missile defense operators with what would usually be the first indication that a threat missile has been launched, along with a rough indication of the direction it is heading. The most recent generation of those satellites is the Space-Based Infrared System (SBIRS).

Shorter-range sensors can also contribute to homeland defense if they are in an advantageous location. The radars from the THAAD system (which are described more fully below) can also operate in a stand-alone mode to support other defense systems. The United States has fielded several of those radars in select locations in East Asia and the Middle East to enable early tracking of potential threat launches in those regions, some of which could threaten the U.S. homeland. In addition, radars from the Aegis system could detect threats to the homeland if they happen to be in an advantageous location. Those radars are deployed on Aegis-capable ships, as well as Aegis Ashore locations in Romania and Poland. (The Aegis Ashore system in Poland is still under construction.)

Command and Control. Homeland ballistic missile defenses are integrated through a system called Command, Control, Battle Management, and Communications (C2BMC). Developed by MDA, C2BMC collects and synchronizes data from all the sensors and defensive systems and synthesizes them into a single picture that provides the current and projected status of threat missiles and the operational status of defensive systems. Commanders around the world use the system to coordinate planning for and execution of missile defense engagements. The system can support flight tests and real-world operations concurrently.

Regional Ballistic Missile Defense

The United States fields several systems to perform regional ballistic missile defense, with the mission to protect U.S. forces and bases abroad, friends, and allies against ballistic missile attack. Current regional defense systems include Aegis BMD, THAAD, and Patriot; each of those are complete integrated systems, comprising interceptors, sensors, and an internal command and control capability. Their capabilities can be enhanced if they can get data from early-warning satellites or other sensors in the region to let them know that an attack is under way.

Platforms and Interceptors. The Aegis BMD system was designed to be deployed on Navy ships (specifically, the DDG-51 Arleigh Burke class destroyers and CG-47 Ticonderoga class cruisers) by upgrading the existing Aegis air defense system to add ballistic missile defense capability. At the time of the MDR's release, there were 38 ships with Aegis BMD capability, and both new ships and upgrades to existing ships will increase that number in the coming years. A land-based version of Aegis BMD has also been developed; currently, the United States has one operational Aegis Ashore location in Romania and a second site under construction in Poland. Navy personnel operate both the sea-based

22. Those dates are delayed from previous plans because construction activities were halted because of the pandemic.

23. The fiscal year 2021 budget submission called for the postponement of both the Hawaii and Pacific radars.

and land-based versions. Aegis BMD has the ability to perform midcourse intercepts using three versions of the Standard Missile 3 (the SM-3 Block IA, the SM-3 Block IB, and the more capable SM-3 Block IIA) against missiles of up to intermediate range. (The SM-3 Block IIA may be able to intercept ICBMs in some situations.) Aegis BMD is also capable of terminal-phase intercepts using the SM-2 Block IV and SM-6 interceptors.

THAAD interceptors are capable of intercepting short-range, medium-range, and intermediate-range ballistic missiles in the late midcourse and terminal phases and have the unique capability to perform intercepts both inside and outside the atmosphere. They are transportable and can be deployed on short notice; currently, DoD has seven THAAD batteries, with two of those deployed overseas (one in Guam and one in South Korea). The system is operated by Army personnel.

The Patriot Advanced Capability-3 system (PAC-3) is designed to intercept short-range and medium-range ballistic missiles, and it may have the capability to intercept IRBMs in the terminal phase. However, as the speed (and thus range) of the threat missile increases, the area the system can defend decreases. The PAC-3 is the result of a series of upgrades to the original Patriot system, which was fielded in the early 1980s with only air defense capability. The United States currently has 60 Patriot batteries, of which about half are deployed at sites in East Asia, Europe and the Middle East. The system is operated by Army personnel and can be deployed on short notice.

Sensors. Each regional defense system described above includes a radar for tracking threat missiles. The Aegis BMD radar for both ship and ashore configurations is referred to as the SPY-1D. The next generation of the DDG-51 class ships, referred to as Flight III, will be equipped with a new, more capable radar called the Air and Missile Defense Radar or SPY-6, which is expected to be easier to maintain and to have substantially longer range than the SPY-1D. The radar for the THAAD system is referred to as the AN/TPY-2. That radar can also be operated in a stand-alone mode and deployed to monitor potential missile threat areas, where it is known as the Forward Based X-Band Transportable radar. The PAC-3 radar has been upgraded several times, and a contract to build a new and more capable replacement, referred to as the Lower Tier Air and Missile Defense Sensor, was awarded in October 2019.

Command and Control. All regional missile defense systems are compatible with MDA's C2BMC system, but the services that operate the systems also have their own command and control systems to link the various parts of their missile defense architecture. The Navy uses the Cooperative Engagement Capability (CEC) and the Army is developing the Army Integrated Air and Missile Defense system (AIAMD). Those systems have (at least) two common features designed to achieve the most efficient defense: first, they provide as much information as possible to operators so that the best choice of defensive approach is selected, and second, they share data between interceptor systems and sensors (including between sensors from other systems). The second feature—sometimes referred to as any sensor, any shooter—allows an interceptor to launch toward a target that its own sensor may not yet have observed (launch on remote) or to receive final track updates from other sensors that allow the system to fine-tune its own trajectory in order to enhance the probability of a successful intercept (engage on remote).

Cruise Missile Defense

The United States fields a variety of systems to defend against cruise missiles. Currently, homeland cruise missile defense is based primarily on air-to-air missiles (AAMs) launched from aircraft that are supplemented with short-range surface-to-air missiles (SAMs), and it focuses on the Washington, D.C., area. Cruise missile defense of deployed forces and allies is composed of systems that perform both air and ballistic missile defense (which were described in the previous section), AWACS aircraft, AAMs launched from aircraft, and short-range SAMs designed to intercept airborne targets.

Platforms and Interceptors. The current vision for homeland cruise missile defense is centered on fighter aircraft, primarily the F-16, carrying AAMs. The current generation of those AAMs consists of the Advanced Medium-Range Air-to-Air Missile (AMRAAM) and the Sidewinder. A more capable replacement for the AMRAAM, the Joint Advanced Tactical Missile, is under development. Fighter-based defense is supplemented with ground-launched interceptors to provide point defense of particularly valuable targets. As of 2020, that type of layered defense is only fully implemented in the Washington, D.C. area, but DoD plans to extend similar defenses to additional U.S. locations in the coming years.

Cruise missile defense of deployed forces and other regional targets outside of the homeland are largely provided by systems that offer both air and ballistic missile defense. In particular, ground targets are defended by the Patriot system, and sea-based defense is provided by the Aegis air defense system. Plans call for ground-based air defenses to be upgraded through the Indirect Fires Protection Capability (IFPC) program. On the sea-based front, in addition to the SM-2 Block IV and SM-6 interceptors, the Aegis system provides shorter-range cruise missile defense using the Evolved Sea Sparrow Missile. Moreover, homeland cruise missile defense systems can also be used for regional defense.

Sensors. The Aegis, Patriot, fighter aircraft, and IFPC systems all include integrated radars. Those radars are currently slated to be upgraded in the coming years. In particular, selected F-16 aircraft are receiving upgraded active electronically steered array radars as part of the plan to improve homeland air and cruise missile defense. On the ground, Sentinel radar supports short-range ground-based interceptor systems for both homeland and regional cruise missile defense.

Cruise missiles fly at low altitudes that can make them difficult for ground-based sensors to detect. Because of the curvature of the earth, low-flying targets remain below the horizon until they are close to the sensor. However, sensors that operate at higher altitudes can detect low-flying cruise missiles from greater range. The United States operates several different types of sensor-carrying aircraft to detect airborne threats, including cruise missiles.

Command and Control. Cruise missile defense systems use integrated air and missile defense command and control systems, including the Navy's CEC, the Army's AIAMD, and the Air Force's AWACS aircraft.

Costs of Missile Defense in the 2020 and 2017 Budget Submissions

CBO estimated the 10-year costs of missile defense plans in the Administration's fiscal year 2020 budget submission by reviewing the budget line-by-line to identify missile defense programs, analyzing the plans described for those programs over the five years included in the budget request, and then projecting those plans over the remaining five years of the 10-year period of 2020 to 2029. That cost estimate serves two purposes. First, it provides context for the potential additional cost of recommendations in the MDR (which are described later in this report). Second, when compared with CBO's estimate of the costs of missile defenses before the commissioning of the MDR as captured in the 2017 budget submission, it allows CBO to estimate the costs of changes in missile defenses implemented while the MDR was being prepared.

Total Costs of Plans in the 2020 Budget Submission

Over a 10-year period from 2020 through 2029, the costs of DoD's missile defense plans described in the fiscal year 2020 budget submission would be about $176 billion, CBO estimates. That amount includes the costs for research, development, procurement, sustainment, and operation of missile defenses. For the most part, it does not include the costs associated with assets that were historically part of the nuclear forces, such as early-warning radars and the SBIRS constellation. However, it does include costs associated with upgrading those systems to improve their missile defense capability as well as costs associated with integrating those systems into the missile defense command and control architecture.

Of the $176 billion total, about 55 percent is for MDA and 30 percent is for the Army; the remainder is split among the other services and defense agencies (see Table 2). About 35 percent of the total is for systems that are primarily for homeland ballistic missile defense (including long-range radars and C2BMC, which can also contribute to regional defense in certain circumstances), about 40 percent is for systems that are primarily for regional ballistic missile defense, and the remaining 25 percent is for cruise missile defense (see Table 3).

CBO's estimates come with substantial uncertainty. One of the primary sources of uncertainty is that the final configuration for many programs is not yet well defined. MDA has historically concentrated on improving capability through continuous upgrades to systems rather than building up systems to a predefined final configuration in either capability or quantity. Furthermore, missile defense efforts have changed greatly over the last several years. Both the quantity and the capability of missile threats have grown rapidly, particularly among potential near-peer adversaries; as a result, some U.S. missile defense programs have changed substantially. For example, MDA recently started a major redesign effort for the GMD system. Missile defense organizations have also been in flux; MDA leadership changed substantially in 2019.

Table 2.

CBO's Projections of the 10-Year Costs of DoD's 2020 Missile Defense Plans, by Agency

Billions of Dollars

	10-Year Total Costs (2020 to 2029)
MDA	95
Army	50
Other Branches and Agencies	31
Total	**176**

Data source: Congressional Budget Office. See www.cbo.gov/publication/56949#data.

DoD = Department of Defense; MDA = Missile Defense Agency.

Potential for cost growth in development programs is not included in CBO's estimate. Although missile defense programs have sometimes experienced substantial cost growth over the years, historically the MDA budget (which makes up the majority of missile defense spending) has generally been managed on a year-to-year basis within a designated budget topline for the agency, such that growth in some programs is offset by reductions in other programs.

Comparing the Costs of Missile Defense in the 2020 and 2017 Budget Submissions

CBO's projection of the 10-year costs of the 2020 plan, covering the 2020–2029 period, is about $50 billion (or 40 percent) higher than its projection of the 10-year costs of the 2017 plan, covering the 2017–2026 period (see Figure 1 on page 2). That difference does not include funding for 2018 and 2019 that the Congress provided in excess of the amounts anticipated in the 2017 plan for those years, including the emergency appropriations that the Congress provided in 2018.

In November 2017, the Administration submitted a 2018 emergency budget amendment that included $4 billion "to support urgent missile defeat and defense enhancements."[24] Those funds, which were approved by the Congress in December 2017, were intended to pay for the construction of new GMD interceptor silos in Alaska, the procurement of new interceptors for several missile defense systems, and the procurement of other missile defense system and sensor upgrades. CBO interprets those projects as being in response to the MDR (even though they preceded the report's release). The implementation of the Administration's early initiatives in missile defense, which began with the 2018 emergency appropriation, led to an increase in requested missile defense budgets and appropriated funding in 2019 and 2020. The actual appropriated amounts for 2018 (including the emergency appropriation) and 2019 average about $5 billion per year more than CBO's estimate for those years in the 2017 plan, about the same as the average annual difference between the 10-year costs of the 2020 and 2017 plans (see Figure 1 on page 2).

All categories of missile defense have higher estimated costs in the 2020 plan than they had in the 2017 plan. The cost of cruise missile defense increased by the highest percentage: The estimated costs of the 2020 plan are more than double those of the 2017 plan (see Table 4). Similarly, the estimated 10-year costs of the 2020 plan for the Army missile defense programs are more than double those costs in the 2017 plan. MDA costs and missile defense costs for the rest of DoD also increased, but the percentage growth in those categories was smaller than that for the Army.

Only about $5 billion of the $50 billion increase in total missile defense costs is the result of major new programs that have been instituted since 2017—a new GMD missile field at Fort Greely and new radars in Hawaii and another unspecified location in the Pacific region.[25] Most of the rest is spread among numerous ongoing programs throughout the United States' missile defense portfolio. Finally, because the 10-year estimation period for the 2020 plan (2020 to 2029) begins and ends three years later that the estimation period for the 2017 plan (2017 to 2026), $8 billion (or about 15 percent) of the increase can be attributed to the effects of inflation if no other programmatic changes had occurred.

Costs of Recommendations in the Missile Defense Review

In addition to changes the Administration made to missile defense plans before its release, the MDR calls for DoD to undertake several studies or make decisions regarding potential additions or other changes to missile

24. See Donald J. Trump, President of the United States, letter to the Honorable Paul D. Ryan, Speaker, House of Representatives (November 6, 2017), https://go.usa.gov/xGKd8 (PDF, 280 KB).

25. The fiscal year 2021 budget submission called for postponement of the Hawaii and Pacific radars.

Table 3.

CBO's Projections of the 10-Year Costs of DoD's 2020 Missile Defense Plans, by Type of Defense

Billions of Dollars

	10-Year Total Costs (2020 to 2029)
Primarily Homeland Ballistic Missile Defense	61
Primarily Regional Ballistic Missile Defense	69
Primarily Cruise Missile Defense	46
Total	**176**

Data source: Congressional Budget Office. See www.cbo.gov/publication/56949#data.

DoD = Department of Defense.

defenses that could be made in the future. Those additions fall into three categories:

- Expansions of current systems that might be made if the emerging threat environment warranted;
- Expansions of current missile defense systems that might result from studies that DoD is directed to conduct; and
- Development of new missile defense systems or capabilities that might result from studies that DoD is directed to conduct.

None of those studies are likely to result in reductions to missile defense forces. To CBO's knowledge, none of the results of those studies have been released to the public.

Five of the actions identified in the MDR concern improvements in organization, coordination, or policies, and in those cases, there was not enough information for CBO to estimate the potential costs. Of the remaining actions, directed studies could lead to three instances of expansion of current systems and five instances of development of new systems. For each of those cases, where it was possible to do so, CBO formulated an estimate of possible costs based on historical costs or a range of potential costs based on prior estimates for similar systems published by CBO or other groups.

The estimates in this section represent new costs—that is, they would be incurred over and above the 10-year projected costs described in the previous section if they were adopted. The estimates in this section are in 2020 dollars because the schedule is uncertain for all of those efforts.

Expansions That Might be Undertaken Depending on Threat Conditions

The MDR identifies two possible expansions of current systems that could be made if threat conditions warrant: expansion of GMD at Fort Greely by increasing the number of GBIs fielded there to as many as 100; and establishment of a new GMD site in the continental United States. CBO estimated the potential cost of those expansions, based on historical costs (either actual or estimated).

Expand GMD at Fort Greely. The missile defense base at Fort Greely, Alaska, currently fields 40 GBIs, and construction of 20 additional interceptor silos is nearing completion. The MDR indicates that Fort Greely could field up to 40 more interceptors, bringing the total number to 100. (There are 4 additional GMD silos at Vandenberg Air Force Base in California, so the total U.S. force would be 104.)

Expanding the number of GBIs would involve two steps: constructing the silos to hold the interceptors and then installing the interceptors. Because the current expansion is ongoing, if MDA were to construct an additional 40 silos, as suggested in the MDR, that work would probably begin no earlier than 2022 and would most likely start later.

Procurement of the new interceptors needed to fill the 20 silos currently under construction was delayed in the President's 2020 budget request because of technical problems with the kill vehicle. After a subsequent program review, DoD decided to cancel the kill vehicle improvement program and to undertake a complete redesign of both the kill vehicle and the GBI booster. In light of those changes to the program, procurement of new interceptors is expected to be delayed until the late 2020s. Until then, there are few (if any) extra interceptors to install in any newly constructed silos.

CBO estimates that adding 40 silos and interceptors would cost about $5 billion (in 2020 dollars), of which about half would go to construct the silos and about half to purchase interceptors. CBO's estimate is based on the actual and future planned costs for the current expansion at Fort Greely from 40 to 60 interceptors. The estimate

Table 4.

Comparison of CBO's 10-Year Projections of the Costs of Missile Defense Programs in the 2017 and 2020 Budget Submissions, by Category

Billions of Dollars

	Primarily Homeland Ballistic Missile Defense	Primarily Regional Ballistic Missile Defense	Primarily Cruise Missile Defense	Total
	10-Year Total Costs			
2017 Budget Submission	45	57	22	124
	Differences in 10-Year Total Costs			
Increases in Costs Between 2017 and 2020 Budget Submissions	16 (36%)	12 (21%)	23 (103%)	52 (42%)
	10-Year Total Costs			
2020 Budget Submission	61	69	46	176

Data source: Congressional Budget Office. See www.cbo.gov/publication/56949#data.

incorporates the assumption that the production unit cost for interceptors—currently about $65 million each—would remain the same after the kill vehicle and GBI booster are redesigned. However, it is possible that the redesigned interceptor would be more expensive to produce, particularly if it is more capable than the current version.

CBO's estimate does not include the potentially substantial cost of redesigning and testing the new generation of interceptors, which would be done regardless of whether the MDA undertook the additional expansion of GMD capacity. The estimate also does not include any additional testing that might be required or incremental operation costs that might be incurred because of the increase in the number of interceptors.

Add a New GMD Site in the United States. The MDR also suggests that homeland defense could be strengthened by building a new GBI site in the continental United States. The establishment of another GMD installation in the United States—in particular, one closer to the East Coast to improve defense against a potential missile threat from Iran—is not a new idea.[26]

The National Defense Authorization Act for Fiscal Year 2013 required DoD to identify three potential locations for a new homeland missile defense site, and in 2019, a DoD official indicated that Fort Drum in New York would be the preferred site.[27]

CBO estimates that it would cost about $4 billion (in 2020 dollars) to establish a new GMD site, including the construction of 20 silos and the purchase of 20 interceptors to fill those silos, and about $80 million per year to operate the site. That estimate draws on a previous CBO estimate of GMD expansion in the United States completed as part of the overall cost estimate for the 2013 National Defense Authorization Act.[28] The current estimate does not include costs already incurred for the site selection process. Additionally, because Fort Drum is an active Army base, the estimate does not include the cost of purchasing land for the base or for constructing infrastructure required to support military operations there. The estimate incorporates the assumption that the unit production cost for interceptors—currently about $65 million each—would remain the same after the system is redesigned. However, production costs for

26. Adding an East Coast site was one of the recommendations made in the 2012 National Research Council study. See National Research Council, *Making Sense of Ballistic Missile Defense: An Assessment of Concepts and Systems for U.S. Boost-Phase Missile Defense in Comparison to Other Alternatives* (National Academies Press, 2012), https://doi.org/10.17226/13189.

27. See Abraham Kenmore, "Fort Drum Named Preferred Location for Any Future East Coast Missile Defense Site," *The Post-Star* (June 27, 2019), https://tinyurl.com/yyv84ch7.

28. See Congressional Budget Office, cost estimate for H.R. 4310, the National Defense Authorization Act for Fiscal Year 2013 (May 15, 2012), www.cbo.gov/publication/43252.

redesigned interceptors might be higher than the current version, and some categories of costs (discussed above) are not included in CBO's estimate.

Possible Expansions of Current Systems

The MDR directed DoD to conduct studies that may result in three possible expansions of current systems: increasing the number of THAAD batteries; installing Aegis ballistic missile defenses on all the ships in the Navy's destroyer fleet; and converting the Aegis Ashore test site on Kauai to an operational system.

Increase the Number of THAAD Batteries. Currently, the Army fields seven THAAD batteries. According to DoD officials, the existing batteries are in high demand and, because of current missile threats, several batteries have been deployed abroad for extended periods. Therefore, the MDR suggests that additional THAAD batteries may be needed in the future and calls for a study to assess the number of batteries necessary to support worldwide deployments.

If DoD concluded that additional THAAD batteries were required, in CBO's estimatation, each additional battery would cost about $800 million (in 2020 dollars) to procure and about $30 million per year to operate. CBO based its estimates on actual costs for the most recently purchased battery.

Make All Aegis Destroyers Fully Missile-Defense Capable. The MDR also directs DoD to develop a plan to upgrade all Aegis destroyers to be "fully missile defense capable" within 10 years.[29] When the MDR was released, there were 38 BMD-capable Aegis ships in the Navy fleet, and existing plans called for 60 ships to be BMD-capable by 2023 (out of a total of 76 Aegis ships expected to be in the fleet at that time). To reach that 60-ship goal, the Navy and MDA are expanding the BMD-capable fleet through a combination of new ship construction (all new Aegis ships will be BMD-capable) and upgrades to existing ships.

The MDR does not define what is meant by fully missile defense capable. The Aegis destroyer fleet consists of several "flights" of ships with varying levels of capability, and even within a flight, the capabilities of individual ships can vary because of postconstruction upgrades.[30] Some older ships may need other types of improvements before they can upgrade their BMD systems to the desired level of capability, which would incur new costs. CBO has not estimated those costs. For this report, CBO assumed that the MDR requirement is for ships to receive the most recent version of the BMD system consistent with the ship's current configuration.

Assuming that shipyard capacity was sufficient, all 94 Aegis ships that will be in the fleet by 2029 could be made fully BMD-capable without any additional costs beyond those already included in CBO's projection of currently planned missile defense costs, the agency estimates. Because all new ships will be built BMD-capable, making the full fleet capable depends on the rate at which existing ships can be upgraded. In CBO's projection of the plan for upgrading Aegis ships that currently have no BMD capability (as opposed to changing from an older BMD system to a newer version), BMD systems could be purchased for all of those ships within the 10-year window if current rates of procurement of those upgrades were maintained. Completing installation of those systems within the 10-year period would require coordination of the schedules of those ships and the available shipyards; assessing the feasibility of that coordination is beyond the scope of this report.

However, additional costs may be incurred to fully execute the BMD mission on those ships. In particular, additional missile defense interceptors beyond those currently planned may be needed to outfit all deployed Aegis BMD ships. Because the number and type of interceptors carried on deployed ships are classified, an analysis of future interceptor needs is beyond the scope of this report. However, if new interceptors were needed, additional SM-3 Block IB interceptors would cost roughly $10 million each (in 2020 dollars) and the more capable SM-3 Block IIA would cost roughly $30 million each, CBO estimates.

Develop a Plan to Make the Aegis Ashore Test Facility Operational. The MDR requires DoD to develop a plan that would enable the Aegis Ashore test site in Kauai to be made operational within 30 days of receiving a directive to do so. The Aegis Ashore test facility, located at the Navy's Pacific Missile Range Facility in Hawaii, is

29. See Office of the Secretary of Defense, *Missile Defense Review* (2019), p. 54, https://go.usa.gov/x7MQB (PDF, 27.3 MB).

30. As ships of a given class are being constructed, major improvements are made periodically to the ship design. Ships with the same basic design are sometimes designated as a flight.

currently capable of conducting missile defense operations with no upgrades to the equipment. According to test facility personnel, the largest impact of making the facility operational would be the inability to conduct the many non-missile-defense test and certification activities at PMRF because of safety regulations in place when Aegis Ashore is active. PMRF is a unique facility and hosts many training and certification activities for the fleet, the bulk of which are not related to missile defense. The Navy also uses the Aegis Ashore test facility at PMRF to train the crews operating Aegis Ashore facilities in Romania and Poland, and access for that training would probably be lost if the test facility were operational.

No investment costs would be required to make the Aegis Ashore test facility operational, CBO estimates. However, stationing enough active duty personnel at PMRF to maintain operations for an extended period would be challenging given its small size and would incur some costs, the extent of which would depend on the duration of the operational status. If the test facility were made operational permanently, there would probably be additional costs, possibly substantial, because the Navy might need to upgrade the facility or some of the equipment and would have to move many of its non-missile-defense test activities now conducted at PMRF to a new location. CBO did not estimate those costs.

New Systems or Capabilities to Be Studied

Five potential new systems or capabilities could result from studies directed by the MDR. Specifically, those studies could lead to incorporation of the F-35 sensors into the missile defense architecture; incorporation of the F-35 fighter into missile defense through the development of a new air-launched boost-phase interceptor; development of space-based ballistic missile interceptors; development of a new satellite constellation for tracking ballistic and hypersonic missiles; and development of defenses against hypersonic threats.

For each of those concepts, DoD could pursue a wide range of approaches. For three of them, there was not enough information for CBO to estimate the costs, and a full analysis of the range of alternative approaches is beyond the scope of this report. For the remaining two concepts—developing a new air-launched boost-phase interceptor to be fielded on the F-35 and developing space-based interceptors—CBO could estimate the costs of illustrative examples because they are not new ideas and several studies have been published that explore alternative approaches that could be pursued. Those illustrative examples may or may not correspond to the approach that DoD eventually chooses to pursue if the capability is determined necessary.

Incorporate the F-35 Sensors Into Missile Defense. The MDR requires DoD to determine how best to integrate the United States' newest aircraft, the F-35 fighter, into both regional and homeland defense systems. One of the primary features of the F-35 is an advanced suite of sensors that have the ability to share data with other systems in the air, on the ground, or at sea; according to press reports, F-35 aircraft have provided sensor data during missile defense tests.[31] The costs of providing sensor data to the missile defense architecture at a meaningful level would depend on whether the F-35 would be fully dedicated to the missile defense mission or would contribute sensor data as a secondary mission when circumstances allow.

If the F-35 was fully dedicated to the missile defense mission and was required to maintain station at a particular location to guard against a missile launch, CBO estimates it would take at least 3 aircraft (and probably more) to keep a single F-35 continuously on station—that is, operating at its assigned location—and would have a total operating cost of at least $1 million per day. Incorporating the aircraft into C2BMC and training for the mission would also be necessary, but CBO did not have enough information to estimate the costs of those undertakings.

Develop a New Boost-Phase Interceptor to Be Fielded on the F-35. The MDR also suggests that the F-35 could be integrated into the missile defense architecture by equipping it with a new boost-phase interceptor.

The idea of a boost-phase missile defense interceptor on an aircraft is not new. In the 2000s, MDA researched two versions of airborne interceptors, but after initial development and (reportedly successful) testing, the programs were discontinued.[32] Several analytical studies

31. See Patrick Tucker, "Newly Revealed Experiment Shows How F-35 Could Help Intercept ICBMs," *Defense One* (December 6, 2017), https://tinyurl.com/y5gfaapv.

32. For details on the programs, see Missile Defense Advocacy Alliance, "Network Centric Airborne Defense Element (NCADE)" (accessed November 22, 2020), https://tinyurl.com/y5atc9tq; and Stephen Trimble, "Lockheed Proposes Funding Plan for Air-Launched Patriot Missile," *FlightGlobal* (April 7, 2009), https://tinyurl.com/yxn372uf.

in the past 15 years have examined the potential capability and costs of ABIs. CBO reviewed three of them: All three concluded that, in general, the aircraft carrying the ABIs would need to be near the launch site for an interceptor to be able to reach the threat missile while the threat missile's engines were still firing, which means that the aircraft carrying interceptors would have to be close to or within the airspace of the country launching the ballistic missile.[33] Even in that case, ABI launch platforms located out of range of an adversary's air defenses could successfully defend against threat missiles only if the threats were launched toward those platforms. The studies agreed that, with that limitation, a complete defense would not be possible in peacetime (when aircraft would need to patrol outside the adversary's border) for potential adversaries with a large- (Russia or China) or medium-sized (Iran) geographic area.

However, one study concluded that if sufficiently capable interceptors could be developed, it might be possible to defend against launches from a relatively small adversary, such as North Korea, during peacetime.[34] CBO used the technical analysis in that report to estimate a range of costs for such a system. The concept that DoD would use if it chose to pursue ABIs for the F-35 is unknown, but CBO's estimate is an illustrative example of the costs that might be incurred if DoD chose to do so. According to that study, because North Korea fields ballistic missiles with a variety of ranges, aircraft would need to be capable of intercepting missiles both inside and outside the atmosphere. CBO used the technical descriptions of those interceptors and its cost estimation approach from a previous study to estimate that it would cost $15 billion to $20 billion for DoD to develop both the exoatmospheric and endoatmospheric interceptors as described in the study, produce 350 of each design, and integrate those weapons onto the F-35.[35] That amount does not include any operation or training costs.

Developing and deploying airborne interceptors could provide the potential for boost-phase defense and would make it possible to place aircraft on alert awaiting warning that a launch may be imminent. However, those measures alone would not constitute a persistent defense against an adversary, particularly in the case of a salvo launch (that is, multiple missiles launched simultaneously or over a short period of time).

The study posits that to provide a standing defense against a salvo of 10 to 20 MRBM or ICBM missiles from North Korea, it would be necessary to maintain three sets of aircraft patrols continuously on station just outside the North Korean border. The aircraft on those patrols would need to carry a total of 120 to 240 interceptors (depending on whether 10 or 20 threat missiles were expected) to be able to counter the salvo of threat missiles because they would need to be able to fire multiple interceptors at each threat missile to improve the chances of intercept.[36] The number of aircraft required to be on station would depend on the number of interceptors the aircraft could carry; fighters would be able to carry four interceptors per aircraft. Thus, to maintain the standing defense described in the study using F-35 aircraft, 30 to 60 aircraft would need to be on station at all times, depending on the number of threat missiles expected. CBO estimates it would cost about $10 billion to $20 billion per year to operate those aircraft.[37]

It might also be necessary to procure additional aircraft; if it took about four aircraft in rotation to maintain one on station at all times, such a defense would require 120 to 240 aircraft dedicated to the mission. The current unit cost of an F-35 is about $90 million. Hence, procuring

33. Those studies include National Research Council, *Making Sense of Ballistic Missile Defense: An Assessment of Concepts and Systems for U.S. Boost-Phase Missile Defense in Comparison to Other Alternatives* (National Academies Press, 2012), https://doi.org/10.17226/13189; David K. Barton and others, "Report of the American Physical Society Study Group on Boost-Phase Intercept Systems for National Missile Defense: Scientific and Technical Issues," *Reviews of Modern Physics*, vol. 76 (October 2004), p. S1, https://doi.org/10.1103/RevModPhys.76.S1; and Dean A. Wilkening, "Airborne Boost-Phase Missile Defense," *Science and Global Security*, vol. 12 (2004), pp. 1–67, https://tinyurl.com/y69o8osd (PDF, 1.78 MB).

34. See Dean A. Wilkening, "Airborne Boost-Phase Missile Defense," *Science and Global Security*, vol. 12 (2004), pp. 1–67, https://tinyurl.com/y69o8osd (PDF, 1.78 MB).

35. The approach for cost estimation is described in Congressional Budget Office, *Alternatives for Boost-Phase Missile Defense* (July 2004), www.cbo.gov/publication/15852.

36. That calculation incorporates several assumptions: Aircraft would carry both endoatmospheric and exoatmospheric interceptors; two interceptors would be fired at each threat missile to increase the probability of successful intercept; and aircraft in each of the three patrol areas would need to be able to counter the full salvo on their own.

37. Those estimates are calculated using the current costs to operate F-35 aircraft. If operation costs were lower in the future as more aircraft entered the fleet, then the actual costs to operate a standing boost-phase defense would be lower.

the full complement of aircraft dedicated to the mission would cost an additional $10 billion to $20 billion.

All told, in CBO's estimatation (which is based on the the concept described in the referenced study), developing and fielding a standing ABI defense against a North Korean missile attack using F-35 aircraft would cost $25 billion to $40 billion (in 2020 dollars) to develop and procure the interceptors and to procure sufficient F-35 aircraft to be dedicated to the mission and an additional $10 billion to $20 billion a year to operate it.

However, it is not clear that an F-35 aircraft, with its sophisticated sensor suite and a stealth design that reduces the likelihood of its being detected, would be required for a persistent peacetime defense mission. Using less-expensive aircraft that can carry more interceptors could substantially reduce both investment and operating costs by reducing the operating cost per flight hour and the number of aircraft required (if aircraft with the ability to carry more interceptors were used).

Develop Space-Based Ballistic Missile Interceptors. The MDR highlights the importance of space in the United States' future missile defense posture. From their high altitude, space-based systems can view large areas, which gives them the potential to observe and engage threat missiles over their full trajectories without being constrained by national boundaries. As part of an effort to exploit the advantages of space-based defenses, the MDR requires DoD to perform a study on "development and fielding of a space-based missile intercept layer capable of boost-phase defense."[38]

The United States has long considered placing interceptors in space for missile defense. Space-based interceptors were a critical component of the conceptual architectures of the 1980s-era Strategic Defense Initiative, and the idea has been revisited several times since then. However, because major improvements have been made in technologies applicable to basing interceptors in space, the MDR directs DoD to perform new analyses of "the technological and operational potential of space-basing in the evolving security environment."[39]

Several studies in the past 10 years have looked at the feasibility of space-based interceptors (SBIs) for boost-phase defense. The rocket engines for threat missiles burn for only a few minutes, so boost-phase interceptors need to be close to the launch site to be able to reach the threat missile in time. Moreover, adversaries can launch multiple missiles at times of their choosing. Because satellites in low-earth orbit (LEO) cannot maintain a fixed position relative to the earth—they are always moving along their orbits and those orbits move relative to the surface of the earth—those studies have found that many satellites are required to be in orbit to maintain global defense.

To reduce the number of satellites, defense designers might choose to limit the latitudes from which threat missile launches could be engaged or to limit the number of threat missiles that can be engaged. For example, a 2011 study commissioned by MDA estimated that a constellation of 24 satellites would provide only limited defense and would cost $26 billion over 20 years, whereas a constellation providing more complete defense would contain 960 satellites and would cost $282 billion over 20 years.[40] Other studies, including one by CBO, have reached similar conclusions, with costs ranging from $35 billion to $300 billion over 20 years for varying levels of defensive capability.[41]

However, as the MDR points out, space technology has changed significantly over the past decade. Commercial interest and investment in space have expanded greatly, leading to lower launch and satellite production costs and advances in the capability of smaller satellites to perform a range of missions effectively. A recent intergovernmental report on trends in the economics of space reported that growth in the number of small satellites launched was substantial, increasing from 23 in 2012 to

38. See Office of the Secretary of Defense, *Missile Defense Review* (2019), p. 84, https://go.usa.gov/x7MQB (PDF, 27.3 MB).

39. See Office of the Secretary of Defense, *Missile Defense Review* (2019), p. 37, https://go.usa.gov/x7MQB (PDF, 27.3 MB).

40. See Patrick J. O'Reilly, Department of Defense Missile Defense Agency, letter to the Honorable Jon Kyl (June 22, 2011), https://tinyurl.com/y4kb37nc (PDF, 840 KB).

41. See Congressional Budget Office, *Alternatives for Boost-Phase Missile Defense* (July 2004), www.cbo.gov/publication/15852; National Research Council, *Making Sense of Ballistic Missile Defense: An Assessment of Concepts and Systems for U.S. Boost-Phase Missile Defense in Comparison to Other Alternatives* (National Academies Press, 2012), https://doi.org/10.17226/13189; and David K. Barton and others, "Report of the American Physical Society Study Group on Boost-Phase Intercept Systems for National Missile Defense: Scientific and Technical Issues," *Reviews of Modern Physics*, vol. 76 (October 2004), p. S1, https://doi.org/10.1103/RevModPhys.76.S1.

a total of over 725 during the 2012–2017 period, with average annual growth of 66 percent.[42] Growth is likely to continue, with several commercial satellite companies planning to field large constellations of 1,000 or more small satellites, which would reduce the cost to develop and produce spacecraft and their components. Further, the same study concluded that the cost to lift one pound of payload to low-earth orbit had decreased to an estimated $1,200 per pound in 2018. (The cost in the early 2000s was $8,000 to $10,000.)[43] It is uncertain whether that trend in reduced launch costs will continue if large constellations are fielded and demand for launch services increases or if competition is leading to below-cost prices that cannot be sustained and that will rise in the future as the number of providers falls.[44]

CBO analyzed the results of two selected studies—one by CBO and one by the National Research Council (NRC)—to gauge the effect that reductions in space-related costs might have on the affordability of space-based interceptors.[45] Those studies considered constellations ranging from just over 350 moderately capable interceptors to as many as 1,000 more-capable interceptors to provide defense against launches from sites limited to bands between 25 degrees latitude and 45 degrees latitudes (both north and south). (The CBO study analyzed a smaller constellation of moderately capable interceptors, and the NRC study analyzed a larger constellation of more capable ones.) Performance of the two constellations against different types of ICBMs varied substantially (see Table 5). Both constellations were in position to defend against liquid-fueled ICBMs all the time, but the smaller constellation with moderately capable interceptors provided no defense against solid-fueled ICBMs; the more capable interceptors were in position to provide defense against solid-fueled ICBMs about 70 percent of the time.[46] Both of the constellations considered provided only limited defense against multiple ICBMs if launches were closely spaced in time.

The difference in estimated costs between the constellations modeled in those two studies reflects the difference in capability. The smaller constellation of moderately capable interceptors would cost about $50 billion to $75 billion over 20 years, comprising two parts: $30 billion to $40 billion to develop, produce, and field the initial set of satellites, followed by $2 billion to $3 billion per year to operate and sustain the constellation for 10 years (see Table 6). Most of the ongoing annual costs would cover the production and launching of replacement satellites when the satellites in orbit reached the end of their operational lifetime, assumed to be seven years. The constellation with more satellites carrying more capable interceptors would cost about $240 billion to $400 billion over 20 years: $130 billion to $210 billion for initial development and fielding and $11 billion to $19 billion per year on average to operate and sustain the constellation for 10 years. In both studies, estimates were based on launch costs of about $7,000 per pound (in 2020 dollars).

CBO examined the sensitivity of those cost estimates to lower kill vehicle and launch costs by adjusting the original estimates for two different scenarios:

- *A scenario with moderate cost reductions,* in which kill vehicle costs are 25 percent lower than the original study values and launch costs are $2,500 per pound, and
- *A scenario with larger cost reductions,* in which kill vehicle costs are 50 percent lower than the original study values and launch costs are $1,200 per pound.

Under the moderate cost-reduction scenario, the estimated 20-year costs to field SBI constellations would be reduced by 20 percent to 30 percent; under the larger cost-reduction scenario, estimated costs would be 30 percent to 40 percent lower than the original estimates (see Table 6). However, given the large number of interceptors that would need to be in orbit, the total costs of the SBI constellations described in those studies would still range from about $40 billion to more than $250 billion

42. National Aeronautics and Space Administration, International Space Station Program Science Forum, *International Space Station: Benefits for Humanity,* 3rd ed., NP-2018-06-013-JSC (2019), p. 18, https://go.usa.gov/x7tZv.

43. Ibid., p. 60.

44. See Jeff Foust, "Smallsat Launch Services Feel Pricing Pressure," *SpaceNews* (September 12, 2019), https://tinyurl.com/y5zr3gb8.

45. See Congressional Budget Office, *Alternatives for Boost-Phase Missile Defense* (July 2004), Option 4, www.cbo.gov/publication/15852; and National Research Council, *Making Sense of Ballistic Missile Defense: An Assessment of Concepts and Systems for U.S. Boost-Phase Missile Defense in Comparison to Other Alternatives* (National Academies Press, 2012), SBI options, Case 1, https://doi.org/10.17226/13189.

46. Solid-fueled ICBMs are more challenging for boost-phase defenses because their engines burn for a much shorter time that those of liquid-fueled ICBMs.

Table 5.

Description of Modeled Space-Based Interceptor Constellations and the Defense They Would Provide

	CBO's 2004 Study	NRC's 2012 Study
System Description	368 satellites with 1 interceptor each with maximum velocity of 4 kilometers per second	1,000 satellites with 1 interceptor each with maximum velocity of 5 kilometers per second
Geographical Region Defended Against	Launches from between 25 degrees and 45 degrees latitude (both north and south)	Launches from between 25 degrees and 45 degrees latitude (both north and south)
Defense Provided to U.S. Homeland	Defense against single liquid-fueled ICBMs 100 percent of the time	Defense against single liquid-fueled ICBMs 100 percent of the time
	Minimal defense against solid-fueled ICBMs	Defense against solid-fueled ICBMs about 70 percent of the time
	Minimal defense against salvo launches[a]	Minimal defense against salvo launches[a]

Data sources: Congressional Budget Office, using research from Congressional Budget Office, *Alternatives for Boost-Phase Missile Defense* Option 4 (July 2004), www.cbo.gov/publication/15852; and National Research Council, *Making Sense of Ballistic Missile Defense: An Assessment of Concepts and Systems for U.S. Boost-Phase Missile Defense in Comparison to Other Alternatives,* SBI Options, Case 1 (National Academies Press, 2012), https://doi.org/10.17226/13189. See www.cbo.gov/publication/56949#data.

ICBM = intercontinental ballistic missile; NRC = National Research Council.

a. Salvo launches are two or more missile launches that occur simultaneously or spaced very closely in time.

over a 20-year period. Refreshing the constellation as satellites reach the end of their operational lifetimes would incur a significant recurring cost that could extend beyond 20 years if the constellations continued to operate. It is also likely that additional sensors would need to be in place to enable the use of SBIs, which would necessitate additional costs as described below.

Develop a Constellation of Satellites to Track Ballistic and Hypersonic Missiles. Another way in which space assets could contribute to missile defense is through the deployment of a constellation of satellite-based sensors to track threat missiles. Initial detection and tracking of missiles during the boost phase with infrared sensors on satellites has been accomplished for decades by the Defense Support Program and its replacement, the SBIRS system. To guard against more capable threat missiles in the future, the MDR directs DoD to perform a study on how "to accelerate efforts to enhance missile defense space and discrimination sensors, to include addressing advanced missile threats."[47]

The Defense Support Program and the SBIRS system operate high above the earth in geosynchronous (36,000 km, or about 22,000 miles, above the earth) and highly elliptical orbits (10,000 km, or about 6,000 miles) or more above the earth during most of their time in orbit). A series of programs have been proposed in which satellites using infrared sensors in LEO (ranging from a few hundred kilometers to about 1,000 km above the earth) would provide tracking and discrimination of threat missiles in the midcourse phase; none of those programs have been deployed. However, MDA currently operates a pair of demonstration tracking satellites called the Space Tracking and Surveillance System (STSS). Those satellites were intended to lead to the development of a constellation of at least 9 satellites, although a recent study concluded that a constellation of at least 24 satellites would be required to perform missile defense tracking in LEO.[48]

However, rather than pursuing a constellation comprising a new generation of STSS satellites, both MDA and

47. See Office of the Secretary of Defense, *Missile Defense Review* (2019), p. 81, https://go.usa.gov/x7MQB (PDF, 27.3 MB).

48. See Thomas G. Roberts, *What Can 24 Satellites Do for U.S. Missile Defense?* (Center for Strategic and International Studies, October 2018), https://tinyurl.com/yy7qadfg.

Table 6.

Illustrative Costs to Build a Space-Based Interceptor System

Billions of 2020 Dollars

	CBO's 2004 Study			NRC's 2012 Study		
	Initial Development and Fielding	Average Annual Operations and Sustainment (Including Replacement Satellites)	Total 20-Year Costs[a]	Initial Development and Fielding	Average Annual Operations and Sustainment (Including Replacement Satellites)	Total 20-Year Costs[a]
Original Study (Adjusted to 2020 Dollars)	31 to 43	2.2 to 3.1	53 to 74	127 to 214	11.4 to 19.1	241 to 405
CBO's Adjustment of Original Cost Estimates Under a Scenario With Moderate Cost Reductions[b]	25 to 33	1.6 to 2.3	41 to 56	91 to 155	8.2 to 13.8	173 to 293
CBO's Adjustment of Original Cost Estimates Under a Scenario With Larger Cost Reductions[c]	23 to 30	1.4 to 2.0	37 to 50	78 to 133	7.3 to 12.3	151 to 256

Data source: Congressional Budget Office, using data from Congressional Budget Office, *Alternatives for Boost-Phase Missile Defense,* Option 4 (July 2004), www.cbo.gov/publication/15852; and National Research Council, *Making Sense of Ballistic Missile Defense: An Assessment of Concepts and Systems for U.S. Boost-Phase Missile Defense in Comparison to Other Alternatives,* SBI Options, Case 1 (National Academies Press, 2012), https://doi.org/10.17226/13189. See www.cbo.gov/publication/56949#data.

NRC = National Research Council.

Ranges in costs are from each original study and reflect the uncertainty about the costs of component systems and activities related to factors like the maturity of available technology, the complexity of manufacturing, and the potential cost growth experienced in many defense programs.

a. Total 20-year costs include 10 years for initial development, production, fielding, and operation of initial satellite constellation, and 10 years for ongoing replacement of satellites as each reaches the end of it's 7-year operational lifetime.

b. Kill vehicle costs are 25 percent lower; launch costs are $2,500 per pound.

c. Kill vehicle costs are 50 percent lower; launch costs are $1,200 per pound.

the new Space Development Agency are conducting initial research on missile tracking from LEO using a constellation of small satellites. MDA's effort, named the Hypersonic and Ballistic Tracking Satellite Sensor, would be a sensor (or sensors) capable of tracking missiles from LEO. Concurrently, the Space Development Agency is developing concepts for a constellation of about 200 small satellites in LEO to perform missile tracking. Those tracking satellites would be part of a larger architecture that includes a constellation of about 600 satellites to transfer data from satellite to satellite and from satellite to ground. Neither of those development programs is sufficiently detailed to allow CBO to estimate the costs.

Develop Defenses Against Hypersonic Missiles. Hypersonic missiles are a new and challenging threat to both the homeland and deployed forces (see Box 1 on page 8). The MDR directs DoD to identify the resources, testing, and personnel needed to defend against them.

MDA is currently working on a plan for hypersonic defenses. The agency recently selected several preliminary interceptor designs to continue to the next step of development. Some of the concepts being discussed involve improvements to existing regional ballistic missile defense systems. Those systems are designed to defend small areas, so a large number of them may be required if defense of large regions, like the U.S. homeland, is desired. However, the program is in the very early stages, and there is not yet enough information for CBO to produce an estimate of the costs of such a defense. Additionally, no analytical literature exists from which to draw estimates for comparison because the threat from hypersonic missiles is a recent development. It almost certainly would require a space sensor system like the ones discussed above.

List of Tables and Figures

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About This Document

This Congressional Budget Office report was prepared as directed in the Fiscal Year 2019 National Defense Authorization Act. In keeping with CBO's mandate to provide objective, impartial analysis, the report makes no recommendations.

Michael Bennett prepared the report, with guidance from David Mosher and Edward G. Keating. David Arthur assisted in the research. Corinne Kramer fact-checked the report.

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CBO continually seeks feedback to make its work as useful as possible. Please send any comments to communications@cbo.gov.

Phillip L. Swagel
Director
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