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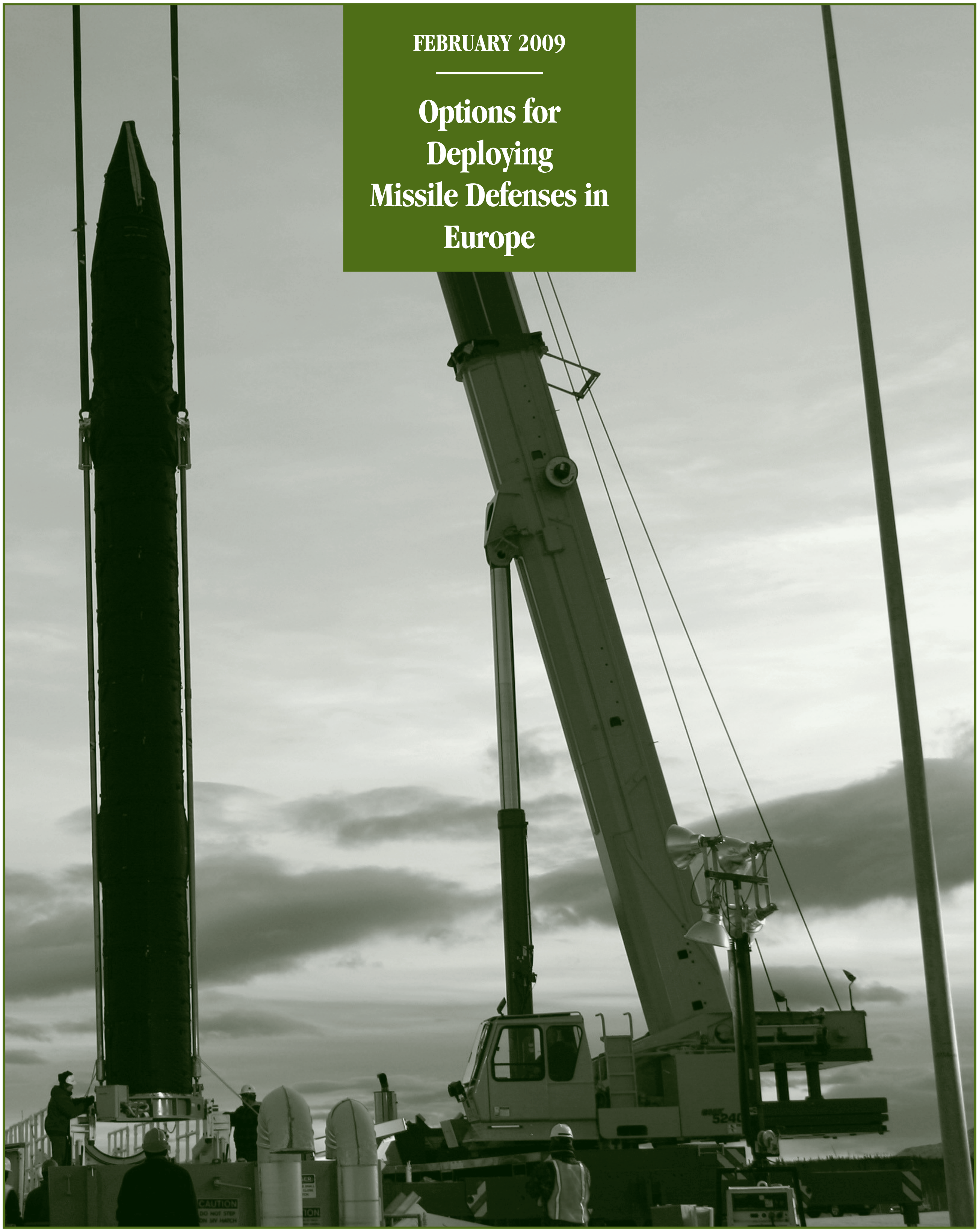

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Options for Deploying Missile Defenses in Europe

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The Congress of the United States ■ Congressional Budget Office

Notes

Unless otherwise indicated, all years referred to in this report are fiscal years, and all dollar amounts are in 2009 dollars.

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

Preface

Over the past decade, developing and fielding defenses against a ballistic missile attack have been significant priorities for the Department of Defense. The department's Missile Defense Agency (MDA), which directs the development of missile defenses, is fielding a Ground-Based Midcourse Defense (GMD) system that is intended to defend the United States against limited ballistic missile attacks from North Korea or Iran. The GMD system consists of interceptors (missiles designed to destroy other missiles) located at Fort Greely in Alaska and Vandenberg Air Force Base in California; radars in the United States, England, and Greenland; and an overarching command-and-control system. MDA plans to expand the GMD system to defend U.S. allies and deployed forces in Europe against Iranian missile threats. That expansion involves establishing an interceptor launch site in Poland, a high-resolution tracking radar in the Czech Republic, and a forward-based radar in another location yet to be specified.

This Congressional Budget Office (CBO) study—prepared at the request of the Chairman and Ranking Member of the House Armed Services Committee's Strategic Forces Subcommittee—examines the cost and potential defensive capability of the proposed European GMD system. It also explores alternative ways to provide some or all of the intended capabilities of that system. The alternatives that CBO considered include deploying sea-based interceptors around Europe or mobile land-based interceptors at existing U.S. bases in Europe. In addition, CBO examined the defensive capability that would be available if no dedicated missile defenses were fielded in Europe. In keeping with CBO's mandate to provide objective and impartial analysis, this report makes no recommendations.

Michael Bennett and Kevin Eveker of CBO's National Security Division performed the analysis and wrote the study under the general supervision of J. Michael Gilmore. Raymond Hall of CBO's Budget Analysis Division prepared the cost estimates under the general supervision of Sarah Jennings. David Arthur and Eric Labs provided thoughtful comments.

Christian Howlett edited the study, with the assistance of Sherry Snyder, and Christine Bogusz proofread it. Maureen Costantino designed the cover and, with the assistance of Carl Mueller and Donald Price, prepared the report for publication. Lenny Skutnik printed the initial copies, Linda Schimmel coordinated the print distribution, and Simone Thomas prepared the electronic version for CBO's Web site (www.cbo.gov).

Douglas W. Elmendorf

Douglas W. Elmendorf
Director

February 2009

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Summary

As part of ongoing efforts to protect the United States and its allies from attack by ballistic missiles, the U.S. Missile Defense Agency (MDA) is working to deploy a missile defense system in Europe. As proposed, the system would be fielded by 2013 and would include interceptor missiles in silos to be built in Poland, a tracking radar in the Czech Republic, and another radar at an unspecified location near Iran. The goal of the system, according to MDA, is to "defend [U.S.] allies and deployed forces in Europe from limited Iranian long-range threats and expand protection of [the] U.S. homeland."[1]

MDA's proposed system is controversial. Some critics argue that testing of the system to date has been insufficient to verify that it will function as intended. Other critics argue that even if the system performs according to expectations, it is unnecessary given the current status of Iranian missile development and the likelihood of an Iranian missile attack on Europe or the United States. The United States has signed agreements with Poland and the Czech Republic to host the missile defense system, but those agreements have been the subject of debate in the host nations and have not yet been fully ratified by their parliaments. The system as proposed would not be able to defend some areas—including parts of North Atlantic Treaty Organization (NATO) member Turkey—that are within striking distance of missiles that Iran has tested or claims to have developed. The Russian government has also sharply protested the deployment by the United States of missile defenses in eastern Europe.

In this study, the Congressional Budget Office (CBO) compares the potential cost and performance of MDA's proposed European system with the cost and performance of three other options for deploying missile defenses in Europe, as follows:

- Standard Missile-3 (SM-3) Block IIA interceptors located on U.S. Navy Aegis ballistic missile defense (BMD) ships operating at three locations around Europe, supported by two transportable forward-based radars (FBRs);
- Ground-based SM-3 Block IIA interceptors operating from mobile launchers located at two existing U.S. bases (Ramstein Air Force Base in Germany and Incirlik Air Force Base in Turkey), supported by two transportable forward-based radars; and
- Ground-based Kinetic Energy Interceptors (KEIs, a new high-acceleration interceptor MDA is developing that could be based either in silos or on mobile transporters), operating from mobile launchers located at two existing U.S. bases in Europe (Ramstein Air Force Base in Germany and Incirlik Air Force Base in Turkey), supported by two transportable forward-based radars.

CBO developed the alternatives using components that are already being planned rather than entirely new systems. Like MDA's proposal, the alternatives are all midcourse-phase defense systems, which would intercept an enemy missile after its rocket booster had burned out and the missile was "coasting" on a ballistic trajectory above the atmosphere. (For an introduction to ballistic missiles, see Appendix A.) CBO's analysis assumes that all the components of the proposed defenses and alternatives to them will perform according to MDA's current expectations. Many observers would argue that assumption is optimistic, however, because it has not been verified by testing.

1. Missile Defense Agency, *Fiscal Year 2009 Budget Estimates: Overview,* 08-MDA-3199 (January 23, 2008), p. 6.

Besides protecting parts of Europe, MDA's proposed European system is intended to give the United States an extra layer of defense against potential Iranian intercontinental ballistic missiles (ICBMs) beyond that provided by U.S.-based interceptors. CBO's analysis indicates that interceptors of the Ground-Based Midcourse Defense (GMD) system already in place at two bases in the United States—supported by radars currently slated to be incorporated into the system by 2012—would provide defensive coverage to more than 99 percent of the U.S. population against ICBMs from Iran. MDA's proposed European system would extend defensive coverage to the other 1 percent of the U.S. population. It would also provide redundant defense from a third interceptor site for all of the continental United States. Such redundancy gives system operators more flexibility: Interceptors launched from Europe against a U.S.-bound ICBM would engage the missile early in its trajectory, allowing operators to determine whether the intercept was successful and still have enough time to launch a second interceptor from the United States, if necessary.

CBO compared the proposed deployment and the alternatives to it on the basis of the defense of Europe that they would provide, the additional defense of the United States they would provide relative to the defense provided by the existing Ground-Based Midcourse Defense system, their costs, and when the alternatives could be available. Using those four criteria, CBO's analysis suggests the following:

- **Defense of Europe.** All of the alternatives CBO considered would provide defense of most of Europe roughly equivalent to the defense provided by MDA's proposal against most types of ballistic missiles that Iran is thought to have developed or could develop in the future. Because the alternatives CBO considered would locate interceptors closer to Iran than MDA's planned system, they would generally provide more extensive defense of southeastern Europe than would MDA's proposal. Moreover, because they would be composed of mobile or transportable components, deploying the alternative systems would not require building permanent facilities—including missile silos—at European sites. However, none of the systems that CBO analyzed, including the system proposed by MDA, would be capable of defending all of Europe against all of the threat missiles that Iran has either already tested or might develop.

- **Extended Defense of the United States.** MDA's proposed system would complement the coverage already available from U.S.-based interceptors by providing redundant defense from a third interceptor site for all of the continental United States. None of the alternatives considered by CBO provide as much additional defense of the United States. Deploying Kinetic Energy Interceptors would add defense from a third redundant interceptor site for about 75 percent of the U.S. population in range of ICBMs from Iran. Deploying land-based or sea-based Standard Missile-3 (SM-3) Block IIA interceptors would provide additional defense for about one-half or less of the U.S. population.

- **Costs.** For roughly the same cost as MDA's European system—a total of about $9 billion to $14 billion over 20 years—the United States could deploy either SM-3 interceptors or Kinetic Energy Interceptors at its existing bases in Germany and Turkey, supported by tracking radars in Azerbaijan and Qatar. At greater cost, the United States could deploy SM-3 interceptors on U.S. Navy ships and station them permanently at three locations in European waters. That system would cost almost twice as much as MDA's proposal—a total of about $18 billion to $26 billion over 20 years—largely because CBO assumed that the Navy would need to buy additional ships to operate it.

- **Availability.** The alternatives that CBO examined might not be available as early as MDA's proposed European system. MDA's plans call for that system to be fully fielded by 2013, although constraints that the Congress has placed on the availability of funds could delay its completion. Given the U.S. military's development schedules for various interceptors, the two alternative systems using SM-3 Block IIA interceptors could be available around 2015, but the system using Kinetic Energy Interceptors probably would not be available until sometime after 2018. Deploying the alternatives considered by CBO would require surmounting technical challenges similar to those associated with deploying MDA's proposed system.

MDA's Plans for European Missile Defenses

Developing defenses against ballistic missiles has long been a goal of the Department of Defense (DoD) and was particularly emphasized by the Bush Administration.

Early U.S. efforts at missile defense (such as the 1960s-era Nike-Zeus program) were aimed at countering the vast Soviet missile arsenal. Recent efforts are more modest in scope. The National Missile Defense Act of 1999 states, "It is the policy of the United States to deploy as soon as is technologically possible an effective National Missile Defense system capable of defending the territory of the United States against limited ballistic missile attack (whether accidental, unauthorized, or deliberate)."[2]

DoD's Missile Defense Agency has the mission of "develop[ing] and field[ing] an integrated, layered, ballistic missile defense system to defend the United States, its deployed forces, allies, and friends against all ranges of enemy ballistic missiles in all phases of flight."[3] In its budget request for fiscal year 2009, MDA divided its efforts to fulfill that mission into a series of "blocks," each based on a particular desired capability:

- Block 1.0—Defend the United States from limited North Korean long-range threats;
- Block 2.0—Defend allies and deployed forces from short- to medium-range threats in one region or theater;
- Block 3.0—Expand defense of the United States to include limited Iranian long-range threats;
- Block 4.0—Defend allies and deployed forces in Europe from limited Iranian long-range threats and expand protection of the U.S. homeland; and
- Block 5.0—Expand defense of allies and deployed forces from short- to intermediate-range threats in two regions or theaters.[4]

Block 1.0 is nearing completion, and most of the work on Blocks 2.0 and 3.0 is expected to occur over the next two years. The other blocks are mainly in the planning and development stages.

The Block 4.0 program centers on establishing a European Interceptor Site (EIS) in Poland, where silos would be constructed to hold 10 ground-based, midcourse-phase interceptors. The EIS would be supported by the European Midcourse Radar (EMR), an X-band tracking radar that is slated to be moved from its current location in the Pacific to the Czech Republic. MDA's plans also call for deploying a forward-based short-wavelength radar somewhere closer to Iran. That radar would provide tracking earlier in the trajectory of an enemy missile (usually referred to as a threat missile) and thus would extend the area defended by the interceptors. MDA has not specified a location for the forward-based radar in its public statements.

In the President's 2009 budget, MDA requested total funding of $3.9 billion over the 2008–2013 period for the Block 4.0 system, including operations and support in those years.[5] That budget request was based on a plan in which both the EIS and EMR become operational in 2012 and all of the interceptors are in place in Poland by 2013. However, limits on the availability of funding that the Congress included in the 2009 defense authorization bill could delay the fielding of the system. Those limits make funding contingent on final approval of missile defense agreements with the countries hosting facilities and on certification by the Secretary of Defense that the proposed interceptor has successfully completed "operationally realistic" flight testing.

Controversies About MDA's Proposed System

MDA argues that establishing a missile defense capability in Europe is necessary to address a ballistic missile threat that is "real and growing."[6] According to the agency's

2. Public Law 106-38, 113 Stat. 205.

3. Missile Defense Agency, "MDA Mission," www.mda.mil/mdalink/html/aboutus.html, accessed on April 18, 2008. The flight of a ballistic missile is generally separated into three phases. The boost phase lasts from launch until the missile's rocket engines have finished firing. After that, the missile enters the midcourse phase, when the payload (which may or may not have separated from the rocket booster) follows a ballistic trajectory outside the atmosphere. The terminal phase begins with the payload reentering the atmosphere and lasts until impact.

4. Missile Defense Agency, *Fiscal Year 2009 Budget Estimates.*

5. That total does not include approximately $200 million in development funding related to the European system that is included in the budget for Block 3.0. Part of that $200 million is intended to adapt MDA's current three-stage ground-based interceptor to the two-stage version that would be used in Europe.

6. Missile Defense Agency, *Proposed U.S. Missile Defense Assets in Europe,* 07-MDA-2650 (June 15, 2007), p. 1, www.mda.mil/mdalink/pdf/euroassets.pdf.

technical analysis, the proposed Block 4.0 system would provide additional defense of the United States against ICBMs launched from the Middle East and would defend most of Europe against medium- and intermediate-range missiles launched from the Middle East.[7] However, a number of observers have argued that the testing conducted to date has been insufficient to verify that the Block 4.0 system will function according to MDA's expectations.

Moreover, as proposed, the system would not defend some areas in southeastern Europe—including some member countries of NATO—against short- or medium-range missiles launched from Iran. Extending defensive coverage to those areas would require the United States or NATO to provide additional defensive systems. The Secretary General of NATO has emphasized the importance of complete coverage for NATO members, stating, "We have no A league or B league in NATO. Every NATO ally is entitled to the same kind of protection."[8] In a statement following the NATO summit in Bucharest in April 2008, NATO "recognise[d] the substantial contribution to the protection of Allies from long range ballistic missiles to be provided by the planned deployment of European based United States missile defence assets" but also called for developing "options for a comprehensive missile defence architecture to extend coverage to all Allied territory and populations not otherwise covered by the United States system."[9]

Russia has objected to the U.S. proposal to deploy missile defenses in Europe, questioning the immediacy of an Iranian threat and arguing that the proposed system is actually intended to defend against Russian missiles. The United States and Russia have held several rounds of high-level talks about the proposal. Those discussions have reportedly included the possibility of Russia's cooperation and the use of Russian radars in the system.[10] In April 2008, the two nations released a strategic framework declaration in which "the Russian side has made clear that it does not agree with the decision to establish" missile defense sites in Europe but that left open the door to negotiate about the issue and "to intensify our dialogue...on issues concerning [missile defense] cooperation both bilaterally and multilaterally."[11]

Although the U.S. Secretary of State signed an agreement with the Czech government in July 2008 to host the EMR and an agreement with the Polish government in August 2008 to host the EIS, neither of those agreements has been finalized. The parliaments of the Czech Republic and Poland need to ratify the agreements, and press reports indicate that a majority of the public in those countries opposes hosting the systems.[12] The agreement with the Polish government calls for basing a U.S. battery of Patriot Advanced Capability-3 (PAC-3) missiles in Poland; details about which existing PAC-3 battery will be moved to Poland have yet to be announced.[13]

Options for Missile Defenses in Europe

In this study, the Congressional Budget Office has attempted to address the following questions:

- How well does MDA's proposed system meet the agency's stated Block 4.0 goals?
- What other combinations of existing, planned, or potential missile defense systems could achieve all or part of those goals?

7. According to MDA's classification scheme, short-range ballistic missiles are those with a maximum range of 600 kilometers, medium-range ballistic missiles have a range of 600 to 1,300 kilometers, intermediate-range ballistic missiles have a range of 1,300 to 5,500 kilometers, and intercontinental ballistic missiles have a range of more than 5,500 kilometers.

8. "U.S. BMD [Ballistic Missile Defense] Plans Gain NATO's Endorsement but Not Russia's," *WMD Insights* (June 2008), pp. 26–35, www.wmdinsights.com/PDF/WMDInsights_Jun08Issue.pdf.

9. North Atlantic Treaty Organization, *Bucharest Summit Declaration* (April 3, 2008), www.nato.int/docu/pr/2008/p08-049e.html.

10. See, for example, "Moscow Rejects U.S. Written Proposals on Missile Defense, Downplays New Iranian Missile Test," *WMD Insights* (February 2008), pp. 38–44, www.wmdinsights.com/PDF/WMDInsights_Feb08Issue.pdf.

11. The White House, Office of the Press Secretary, *U.S.–Russia Strategic Framework Declaration* (April 6, 2008), www.cfr.org/publication/16193/usrussia_strategic_framework_declaration.html.

12. For a summary of public opinion in Europe, see "Special Report: The European Ballistic Missile Defense Dispute," *WMD Insights* (April 2007), pp. 1–15, www.wmdinsights.com/PDF/WMDInsights_Apr07Issue.pdf.

13. John Liang, "U.S. Official: A PAC-3 Battery in Poland Would Mean Moving an Existing Unit," *Inside Missile Defense* (August 27, 2008).

To answer those questions, CBO estimated the ability of the proposed system to defend both Europe and the United States against ballistic missiles fired from Iran and compared the system's cost and level of effectiveness with those of other defensive architectures that could be deployed in Europe. In addition, CBO examined the defensive capability that would be available from other systems that MDA is planning, even if no dedicated European missile defenses were deployed.

For the analysis, CBO assumed that the various systems would be capable of achieving their intended levels of operational effectiveness. However, a number of technical analyses have questioned the efficacy of planned systems, particularly if an adversary employs countermeasures designed to confuse missile defenses. CBO did not explicitly model the options' effectiveness when countermeasures are used. That issue and other caveats about the analysis are discussed at the end of the summary.

The results of the modeling described in this report depend on the assumptions that CBO made about the performance of the threat missiles and defensive systems and about the locations of components of those systems. Because many of the systems considered here are under development or are proxies for systems that could potentially be developed, their actual performance parameters are uncertain; different sets of assumptions would lead to different results. (For a discussion of the sensitivity of CBO's analysis to selected assumptions about performance, see Appendix B.)

Dedicated European Missile Defenses

To compare other systems with MDA's planned system, CBO constructed various alternatives that would use mobile interceptors located at sea or on existing U.S. bases in or around Europe. CBO designed the alternatives so that they would provide roughly equivalent levels of defense of Europe against most threats. The specifics of the four options that CBO analyzed are as follows:

- Option 1—The European capability proposed by MDA, consisting of 10 Ground-Based Interceptors permanently housed in silos to be constructed in Poland, an X-band radar in the Czech Republic, and a forward-based X-band radar at a location to be determined.[14] CBO assumed that the forward-based radar (FBR) would be located in Azerbaijan.[15] Current plans call for the system to be fully fielded by 2013.

- Option 2—A standing sea-based defense comprising Aegis ballistic missile defense ships of the U.S. Navy equipped with SM-3 Block IIA interceptors, which are slated to start entering the fleet around 2015. Those ships would maintain three stations—in the waters off Romania, eastern Italy, and Poland—and would be supported by forward-based transportable X-band radars in Azerbaijan and Qatar.

- Option 3—Land-based SM-3 Block IIA interceptors operating from mobile launchers at two existing U.S. bases: Ramstein Air Force Base in Germany and Incirlik Air Force Base in Turkey. Tracking would be provided by forward-based transportable X-band radars in Azerbaijan and Qatar. This system would be available around 2015.

- Option 4—Land-based Kinetic Energy Interceptors operating from mobile launchers at Ramstein and Incirlik Air Force Bases, supported by forward-based transportable X-band tracking radars in Azerbaijan and Qatar. Given the current development schedule for those interceptors, this system would probably not be available before 2018.

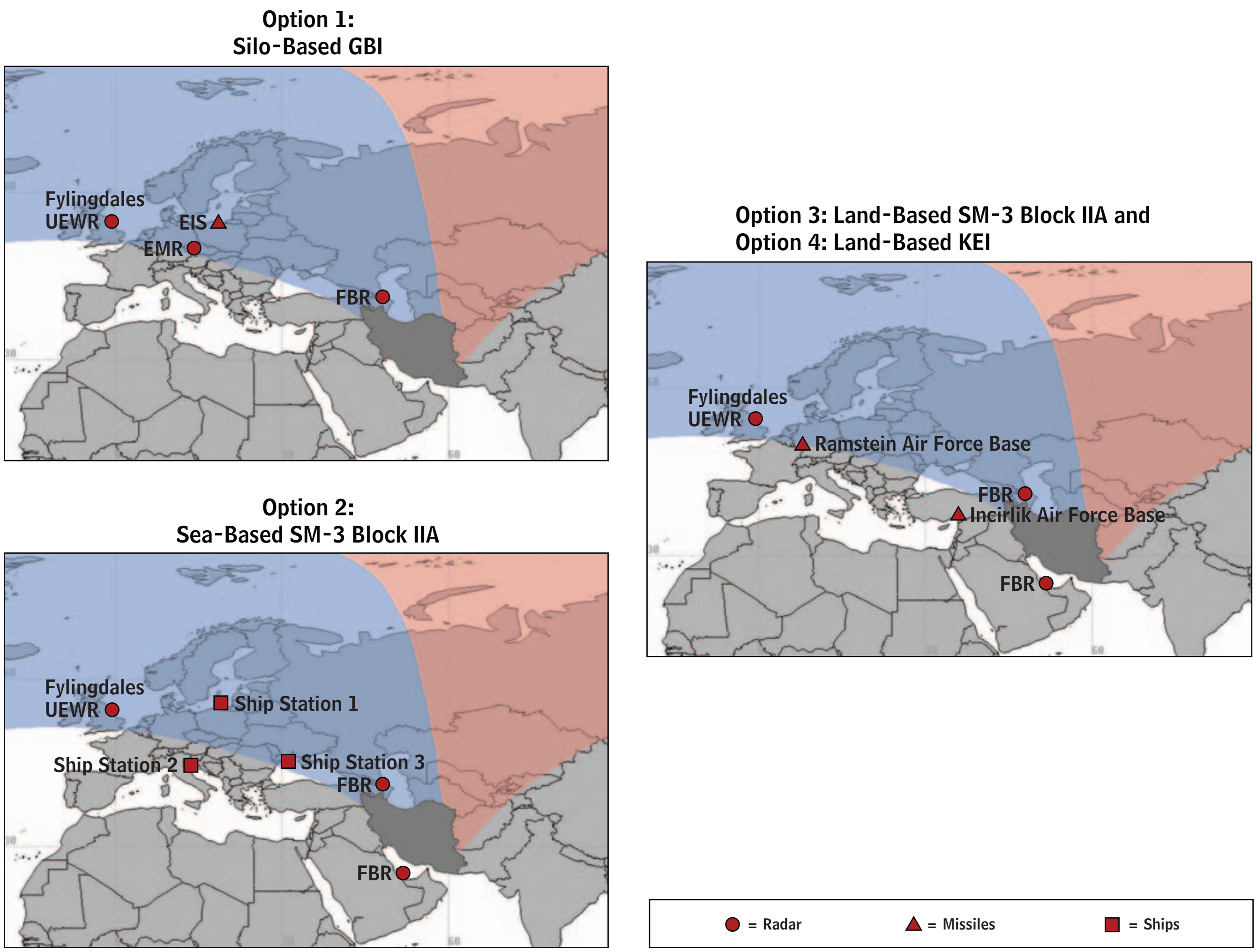
The location of the components of a missile defense system relative to the likely trajectories of enemy missiles is critical to the system's capability. In many cases, U.S.-bound missiles launched from Iran would fly over Russia rather than Europe (see Summary Figure 1)—for example, a trajectory from northwestern Iran to Los Angeles passes almost directly over Moscow. Placing the forward-based radar far enough east to track such trajectories is critical to providing defense of the western United States. CBO considered Azerbaijan a suitable location for an FBR for defense of both Europe and the United States, but using locations farther east (such as Afghanistan) could provide better tracking of ICBMs headed toward the United States. Interceptors located in Europe would generally have to fly north and/or east to intercept U.S.-bound missiles. The site of the intercept would vary

14. All of the options would also use the existing early-warning radar at Fylingdales, England, which was recently upgraded to improve its tracking capability for missile defense.

15. MDA has not designated a specific location for the FBR, but some press reports indicate that it has been considering the Caucasus region as a possible location. See, for example, Nathan Hodge, "Caucasus Considered as Base for U.S. Missile Sensor," *Jane's Defence News* (July 27, 2006).

Summary Figure 1.

Components of the Options for European Missile Defenses and Their Locations



Source: Congressional Budget Office.

Notes: Blue shading indicates the range of trajectories of intercontinental ballistic missiles from Iran to the continental United States. Red shading indicates the additional range of trajectories for missiles targeting all of the United States, including Alaska and Hawaii. Iran is shown in dark gray.

GBI = Ground-Based Interceptor; UEWR = upgraded early-warning radar; EMR = European Midcourse Radar; EIS = European Interceptor Site; FBR = forward-based radar; SM = Standard Missile; KEI = Kinetic Energy Interceptor.

according to the type of threat missile and interceptor; many potential intercepts would occur over Russia, Scandinavia, or the polar region.

Most European-bound missiles launched from Iran could be tracked by an FBR in Azerbaijan. However, that radar could not track missiles launched from southeastern Iran toward the southernmost parts of Europe, such as Spain, southern Italy, and Greece. In Option 1, tracking by the European Midcourse Radar in the Czech Republic could be used for some of those trajectories. In Options 2, 3, and 4, CBO added the forward-based radar in Qatar to provide early tracking for those trajectories. Compared with Iranian missiles bound for the United States, missiles targeting Europe would fly more directly toward the interceptors, so the interceptors would generally fly south and/or east to engage those threats. Intercepts would most likely occur over Europe or the Mediterranean Sea.

Non-European Missile Defenses

The primary goal of this study is to compare the cost and performance of options for deploying missile defenses in Europe. Even without such defenses, however, midcourse-phase systems that are being deployed mainly in the United States and aboard U.S. Navy ships would be capable of defending parts of both Europe and the United States against Iranian missiles. In addition to the options listed above, CBO modeled the defense available from two portions of the overall U.S. missile defense system that are scheduled to be available around 2012:

- The Block 3.0 Ground-Based Midcourse Defense system, which will consist of Ground-Based Interceptors at Fort Greely in Alaska and Vandenberg Air Force Base in California, supported by tracking radars at multiple locations around the world.

- The near-term "surge" capability of Navy ships equipped with the Aegis BMD system using SM-3 Block IB interceptors, which are slated to start entering the fleet around 2011. (That system is an earlier version of the system in Option 2, with less capable interceptors and limits on communications that would mean intercepts could occur only within range of shipboard radars. Those limits increase the number of ships required, so this capability probably represents a temporary crisis-response defense rather than a standing defense.)

Costs of the Missile Defense Options

To estimate the total costs associated with each of the four European-based options, CBO calculated the potential costs for research and development, production of interceptors and radars, construction of physical infrastructure at missile defense sites, and operations over the assumed 20-year lifetime of a system (see Summary Table 1).[16] Overall, CBO estimates, Option 1 would cost between $9 billion and $13 billion; Option 2, between $18 billion and $22 billion; Option 3, between $9 billion and $13 billion; and Option 4, between $10 billion and $14 billion. (Those and other cost estimates in this report are in 2009 dollars.) The low number in each range of estimates represents the total cost if few technical difficulties arise in making a system fully operational. The high number accounts for the risk of cost growth by factoring in the extent to which costs have typically grown for similar systems in the past.[17]

The estimates described above do not include development costs for system components (such as various radars or interceptors) that MDA already plans to develop for applications not specific to European defense. The estimates also do not include the costs of any defense assistance or equipment that the United States might provide to the nations hosting missile defense sites, beyond that associated with the direct construction and operation of the sites themselves.

Capabilities of the Missile Defense Options

To compare the defensive capabilities of the various missile defense options, CBO modeled their ability to intercept missiles launched from Iran. The modeling focused on two types of missile threats:

- Near-term threats—that is, missiles that Iran has tested or claims to have developed, such as the Shahab-3, Shahab-3A, and Ashura. All of those missiles have ranges of about 2,000 kilometers or less, meaning they can reach only the southeastern portion of Europe, including parts of Bulgaria, Romania, and Greece (see Summary Figure 2).

- Potential future threats—that is, missiles that Iran could potentially develop or acquire, such as a liquid-fuel intermediate-range ballistic missile (IRBM), with a range of about 5,000 kilometers, and liquid- or solid-fuel ICBMs, with ranges of about 18,000 and 12,000 kilometers, respectively. In its modeling, CBO used several existing missiles developed by other countries as proxies for those potential future threats. All of those missiles would be capable of reaching anywhere in Europe, and the modeled ICBMs would also be capable of reaching the United States (see Summary Figure 2).

16. The distinction between categories of costs is made only for the purposes of this study. Historically, funding for MDA, including funding for production and operations, has all come under the budget category of research, development, test, and evaluation. Recently, however, MDA's budget justification materials have designated some funds under the category of military construction.

17. For most components, the cost-risk factors that CBO used were developed by the RAND Corporation and were based on unpublished updates to Jeanne M. Jarvaise, Jeffrey A. Drezner, and Daniel M. Norton, *The Defense System Cost Performance Database: Cost Growth Analysis Using Selected Acquisition Reports,* MR-625-OSD (Santa Monica, Calif.: RAND, 1996).

Summary Table 1.

Estimated Costs and Components of the Options for European Missile Defenses

	Option 1		Option 2		Option 3		Option 4	
	Low	High	Low	High	Low	High	Low	High
	Estimated Cost (Billions of 2009 dollars)							
R&D[a]	0.4	0.5	0.2	0.3	0.5	0.7	0	0
Production	2.8	3.2	9.5	10.4	2.1	2.6	3.2	4.1
Construction	1.1	1.4	0.3	0.3	0.5	0.7	0.5	0.7
Operations[b]	5.0	7.6	8.3	10.9	5.9	8.8	5.9	8.8
Total	**9.2**	**12.8**	**18.3**	**21.9**	**9.0**	**12.8**	**9.6**	**13.6**
	Deployed Components							
Interceptors	10 two-stage GBIs in Poland		30 SM-3 Block IIAs on ships at three stations		20 SM-3 Block IIAs at Ramstein and Incirlik Air Force Bases		20 KEIs at Ramstein and Incirlik Air Force Bases	
Sensors	UEWR in Fylingdales EMR in Czech Republic FBR in Azerbaijan		UEWR in Fylingdales FBR in Azerbaijan FBR in Qatar		UEWR in Fylingdales FBR in Azerbaijan FBR in Qatar		UEWR in Fylingdales FBR in Azerbaijan FBR in Qatar	

Source: Congressional Budget Office.

Notes: The low estimates assume that few technical difficulties arise in making a system fully operational; the high estimates account for the extent to which costs have typically grown for similar systems in the past.

GBI = Ground-Based Interceptor; SM = Standard Missile; KEI = Kinetic Energy Interceptor; UEWR = upgraded early-warning radar; EMR = European Midcourse Radar; FBR = forward-based radar.

a. The estimates for research and development (R&D) do not include development costs for components that the Missile Defense Agency (MDA) already plans to develop for applications not specific to European defense. For Option 4, no Europe-specific R&D would be necessary because the system would rely on components that already exist or that MDA is developing for general use.

b. Costs are estimated over 20 years.

The primary measure of performance in CBO's analysis is the area that a given system would be able to defend against a particular type of missile. That defensive coverage is shown on maps that compare the areas defended by each option. CBO focused on two aspects of performance: defense of Europe against all modeled threats and defense of the United States against potential ICBM threats. (The methodology that CBO used to estimate the options' defensive capability is described in Appendix B.)

Defense of Europe

CBO's analysis supports the following observations about defending Europe against missiles launched from Iran:

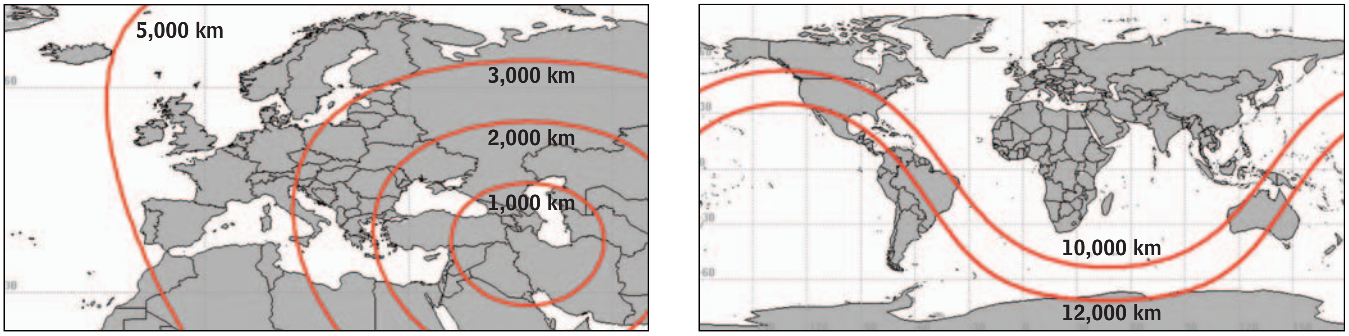
- Missiles that Iran has tested or claims to have developed (the near-term threats in this study) are capable of reaching only the southeastern portion of Europe. If Iran developed or acquired IRBMs or ICBMs with performance similar to those produced by several other countries, those missiles would be capable of reaching all of Europe.

- The U.S.-based GMD Block 3.0 system will not provide any defense of Europe against missiles launched from Iran (see Summary Figure 3).

- Aegis BMD ships equipped with SM-3 Block IB interceptors and stationed around Europe would be capable of defending some of Europe against Iranian missiles; the extent of the area defended would depend on the type of threat. That capability could be available before any of the options for dedicated defenses in Europe considered in this analysis. However, given MDA's current plans, the Aegis BMD system would be limited until around 2015 to engaging targets only when they were within range of the ships' onboard SPY-1 radars at the time of intercept. Thus, as many as

Summary Figure 2.

Distances from a Potential Missile Launch Site in Iran



Source: Congressional Budget Office.

Notes: The ranges shown are for launches from northwestern Iran.

The ballistic missiles that Iran is thought to possess now have a maximum range of about 2,000 kilometers (km).

seven ship stations would be required to provide defensive coverage of much of Europe (albeit with gaps in coverage against some threats). Because two or more ships would be necessary to maintain constant coverage at a given station, that level of presence would probably be sustainable only for short periods with the 18 total ships that MDA plans to outfit for Aegis ballistic missile defense.

- The European system proposed by MDA (Option 1) would cover most of Europe against Iranian missiles, with the extent of the defended area depending on the type of missile threat (see Summary Figure 4 for an IRBM threat). However, both CBO's and MDA's analyses indicate that the system's defense would generally not extend to all of southeastern Europe. Defending that area would require deploying additional systems.

- The other alternatives in this analysis (Options 2, 3, and 4) would provide broad defense of most of Europe against all modeled missile threats. All of those options include interceptor locations nearer to Iran than the proposed European Interceptor Site in Poland and thus would provide more extensive defense of southeastern Europe (see Summary Figure 4).

- None of the systems that CBO analyzed would be capable of defending all of Europe against all of the modeled threats.

(Detailed maps of the areas defended by the options and by a near-term Aegis BMD surge capability against all modeled threats are included in Chapter 3.)

Defense of the United States

CBO also modeled the capability of the four options to defend the United States against potential Iranian ICBMs. That defense would be redundant in the sense that it would be in addition to the defensive capability of the GMD Block 3.0 system, much of which is already in place and which MDA plans to complete by 2012.

CBO's analysis supports the following observations about defending the United States against missiles launched from Iran:

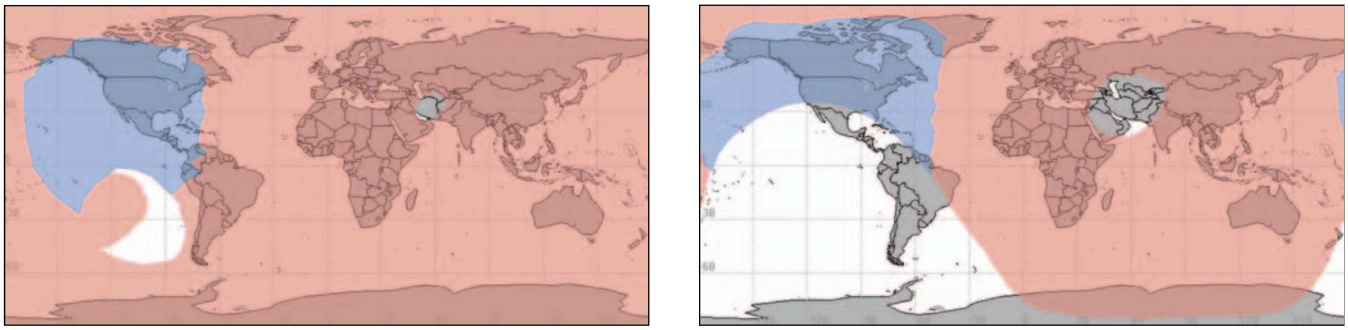
- None of the missiles that Iran has tested or claims to have developed are capable of reaching the United States. If Iran developed or acquired an ICBM with performance similar to those built by the United States or Russia, such a missile would be capable of reaching the United States.

- The GMD Block 3.0 system will provide defense for nearly 100 percent of the U.S. population within range of ICBMs from Iran (see Summary Table 2). In most cases, that defense will be redundant in that both the interceptor site at Fort Greely and the one at Vandenberg Air Force Base will be able to cover a given area.

Summary Figure 3.

Areas Defended by the GMD Block 3.0 System Against ICBMs from Iran

Liquid-Fuel ICBM | Solid-Fuel ICBM



Source: Congressional Budget Office.

Notes: Blue shading indicates the area defended against a given missile threat. Red shading indicates undefended areas within range of that threat.

GMD = Ground-Based Midcourse Defense; ICBM = intercontinental ballistic missile.

- Aegis BMD ships with SM-3 Block IB interceptors stationed around Europe would not provide any additional defense of the United States.

- The European system proposed by MDA (Option 1) would provide extra defense of the United States, extending coverage to the less than 1 percent of the U.S. population not covered by the GMD Block 3.0 system and providing defense from a third redundant interceptor site for most of the U.S. population (see Summary Figure 5). For ICBMs headed to the United States, engagement timelines would generally allow operators to assess the results of an attempted intercept from the European site before launching an interceptor from U.S. sites—a scenario referred to as "shoot-look-shoot."

- The options with sea-based and land-based SM-3 Block IIA interceptors (Options 2 and 3) would provide some additional defense of the United States against liquid-fuel ICBMs but none against solid-fuel ICBMs. Those options could provide about the same level of U.S. defense as MDA's proposed European system if they added launch sites for SM-3 Block IIA interceptors in the United States.

- Option 4, with its land-based Kinetic Energy Interceptors, would cover at least 75 percent of the U.S. population in range of ICBMs from Iran. With the modeled interceptor sites in Germany and Turkey, the additional U.S. defense provided by Option 4 would not be as extensive as that of MDA's proposed European system; using different or additional interceptor locations could change the area defended by Option 4. Intercept timelines would allow "shoot-look-shoot" between KEI intercepts from Europe and intercepts from existing GMD sites in the United States. Additionally, as modeled by CBO, the KEI would carry the Multiple Kill Vehicle, which MDA is currently developing to improve an interceptor's performance against countermeasures such as balloons or other mock reentry vehicles launched along with a threat warhead to act as decoys.[18]

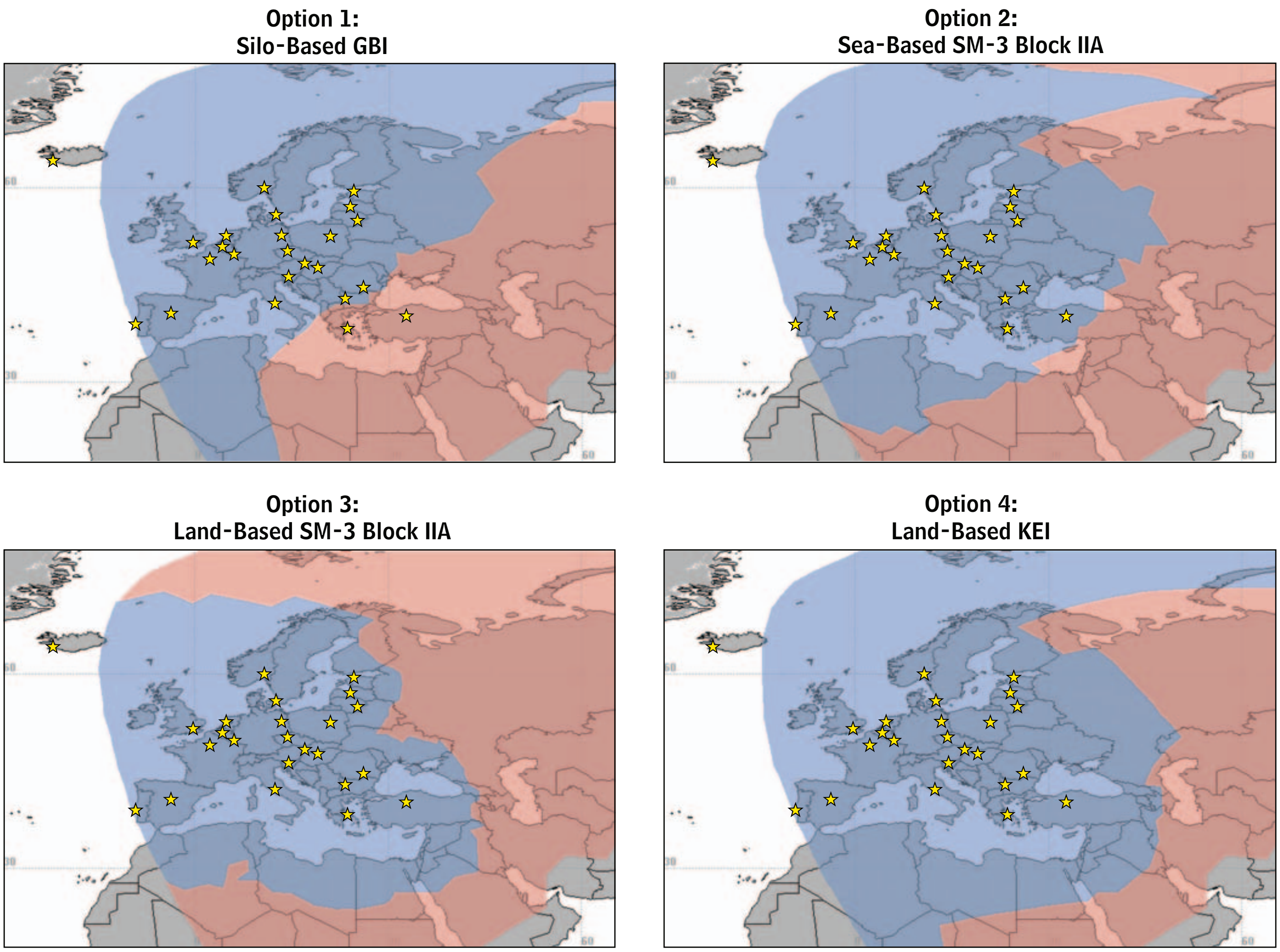
Issues Not Addressed in This Analysis

An analysis like the one CBO conducted for this study must necessarily include simplifying assumptions that limit the level of technical detail included in the model. Other issues, although relevant to the topic at hand, are beyond the scope of the analysis.

18. As the name implies, the Multiple Kill Vehicle would carry several kill vehicles (the section that separates from the interceptor booster and maneuvers to intercept the target) and thus would allow a single interceptor to engage more than one target—enhancing the probability of engaging the actual warhead in the presence of decoys.

Summary Figure 4.

Areas Defended by the Missile Defense Options Against IRBMs from Iran



Source: Congressional Budget Office.

Notes: Blue shading indicates the area defended against a given missile threat. Red shading indicates selected undefended areas within range of that threat. Yellow stars show the locations of NATO capitals.

IRBM = intermediate-range ballistic missile; GBI = Ground-Based Interceptor; SM = Standard Missile; KEI = Kinetic Energy Interceptor; NATO = North Atlantic Treaty Organization.

Technical Limitations

Some critics of proposed missile defense systems question their ability to reliably defend against missile threats from a determined adversary. One of the main issues in such criticisms is whether planned missile defenses will be able to overcome countermeasures. A 1999 National Intelligence Estimate on ballistic missile threats stated, "We assess that countries developing missiles also will respond to US theater and national missile defenses by deploying larger forces, penetration aids, and countermeasures.… These countries could develop countermeasures based on these [readily available] technologies by the time they flight test their missiles."[19] A number of more recent analyses argue that the current midcourse

19. National Intelligence Council, *Foreign Missile Developments and the Ballistic Missile Threat to the United States Through 2015,* unclassified summary of a National Intelligence Estimate (September 1999), www.dni.gov/nic/special_missilethreat1999.html.

Summary Table 2.

Summary of the Options' Defensive Capabilities

Type of Missile Threat	With No Dedicated Defenses in Europe: GMD Block 3.0 System (Three-stage GBIs at two bases in the United States)	With No Dedicated Defenses in Europe: Near-Term "Crisis Response" Defense (SM-3 Block IBs on ships in seven locations)	Options for Dedicated Defenses in Europe: Option 1 (Two-stage GBIs in Poland)	Option 2 (SM-3 Block IIAs on ships at three permanent stations)	Option 3 (SM-3 Block IIAs at two U.S. bases in Germany and Turkey)	Option 4 (KEIs at two U.S. bases in Germany and Turkey)
Defense of Europe (Percentage of threatened European NATO capitals defended)						
Shahab-3A (1 capital in range)	0	100	0	100	100	100
Ashura (3 capitals in range)	0	100	67	100	100	100
IRBM (23 capitals in range)	0	43	91	100	100	100
Liquid-Fuel ICBM (24 capitals in range)	0	71	75	88	46	71
Solid-Fuel ICBM (24 capitals in range)	0	63	92	100	100	100
Defense of the United States (Percentage of threatened U.S. population defended)						
Liquid-Fuel ICBM (100 percent in range)						
Stand-alone defense	100	0	99	58	24	77
Defense combined with GMD Block 3.0 system	100	100	100	100	100	100
Solid-Fuel ICBM (85 percent in range)						
Stand-alone defense	100	0	100	1	0	89
Defense combined with GMD Block 3.0 system	100	100	100	100	100	100

Source: Congressional Budget Office.

Notes: GMD = Ground-Based Midcourse Defense; GBI = Ground-Based Interceptor; SM = Standard Missile; KEI = Kinetic Energy Interceptor; NATO = North Atlantic Treaty Organization; IRBM = intermediate-range ballistic missile; ICBM = intercontinental ballistic missile.

interceptors and radars fielded by MDA would not be capable of overcoming such countermeasures.[20]

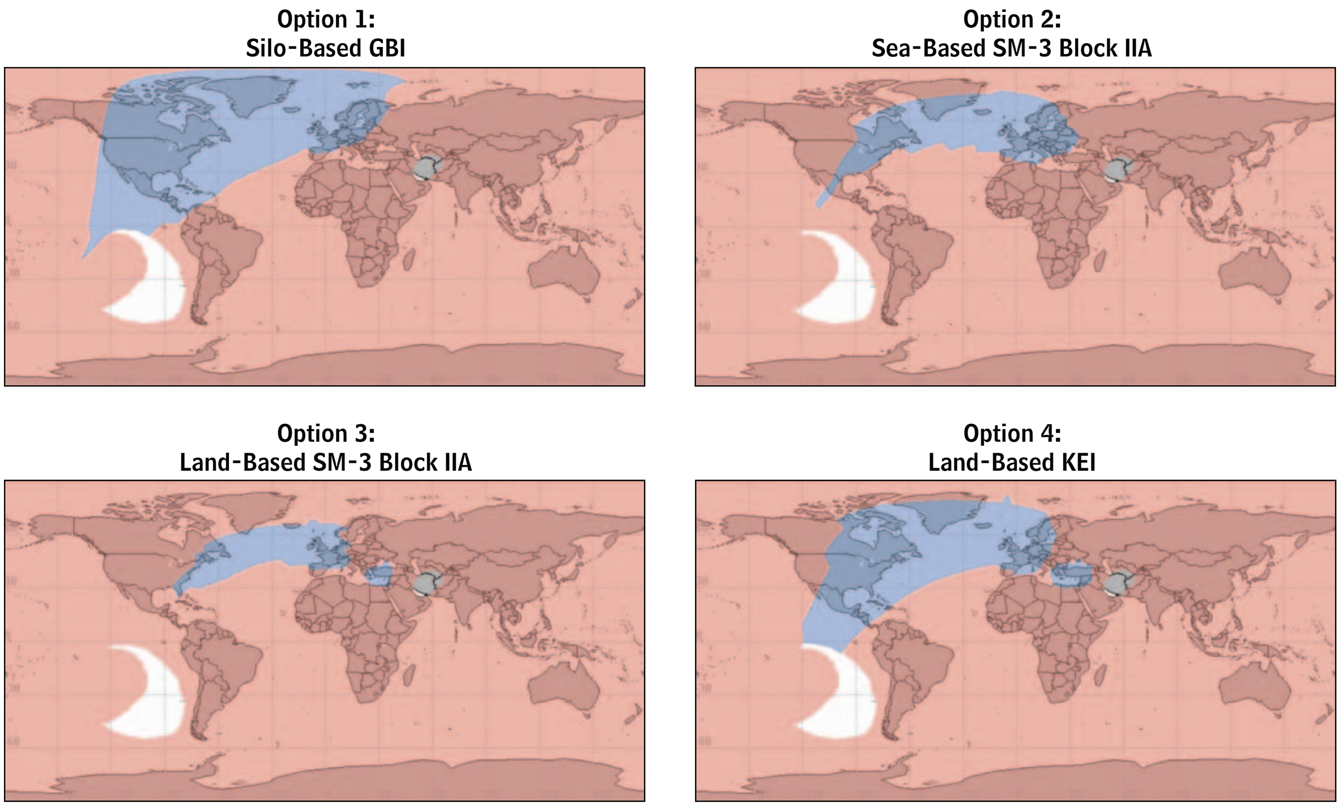
MDA is working on several projects to defeat countermeasures, including improving discrimination of actual weapon payloads from decoys and developing the Multiple Kill Vehicle to allow a single interceptor to engage several potential targets. Moreover, MDA is pursuing a layered defense, with systems designed to engage missiles during the boost, midcourse, and terminal phases of their flight. Since countermeasure techniques vary for different phases of flight, that approach is intended to reduce the susceptibility of the overall system to countermeasures and to allow multiple systems to engage the same threat missile, if necessary.

Because this report focuses on the proposed European midcourse-phase system, CBO considered only other midcourse systems as alternatives to limit the scope of the study. However, boost-phase and terminal-phase systems

20. See, for example, Lisbeth Gronlund and others, *Technical Realities: An Analysis of the 2004 Deployment of a U.S. National Missile Defense System* (Cambridge, Mass.: Union of Concerned Scientists, May 2004); and Richard L. Garwin, "Holes in the Missile Shield," *Scientific American* (November 1, 2004), p. 70.

Summary Figure 5.

Areas Defended by the Missile Defense Options Against Liquid-Fuel ICBMs from Iran



Source: Congressional Budget Office.

Notes: Blue shading indicates the area defended against a given missile threat. Red shading indicates undefended areas within range of that threat.

ICBM = intercontinental ballistic missile; GBI = Ground-Based Interceptor; SM = Standard Missile; KEI = Kinetic Energy Interceptor.

could also be used to achieve some of MDA's stated defensive goals. A previous CBO report examined missile defense with boost-phase interceptors.[21] Future CBO studies will also address boost-phase defense, including the Airborne Laser. Because of their nature, terminal-phase systems have a limited effective range and probably would be used as a supplement to boost- or midcourse-phase systems rather than as a sole defense.

For the midcourse architectures considered, CBO's technical analysis was based on unclassified performance parameters for the various radars and interceptors and assumed that the systems would work "as advertised." (A sensitivity analysis, which describes the extent to which the results would differ if actual performance deviated from the modeled parameters, is included in Appendix B.) In particular, CBO's estimation of whether an intercept could occur in a given scenario was based on a simulation of the ability of sensors to determine the ballistic trajectory of a threat missile (which, in CBO's model, requires only that the missile be within the sensor's assumed field of regard for a given length of time after the missile booster burns out) and the ability of the interceptor's booster to launch the kill vehicle onto a trajectory that passes close enough to the threat missile for an intercept to potentially occur (subject to constraints on intercept altitude and closing velocity). CBO did not model the detailed dynamics of the kill vehicle's maneuvers in the "end game" or the performance of the kill vehicle's sensor and guidance systems, nor did CBO estimate the probability of a successful intercept (beyond a

21. Congressional Budget Office, *Alternatives for Boost-Phase Missile Defense* (July 2004).

simple yes or no). Thus, CBO's analysis did not quantify the value of system features designed to defeat countermeasures, such as improved discrimination or multiple kill vehicles, although the report includes a qualitative discussion of how such features vary among the options.

The Severity of Missile Threats from Iran

Another question often raised about MDA's plans for European missile defense is the viability and urgency of the Iranian missile threat—in particular, the threat to the United States. Developing long-range missiles capable of traveling the 10,000 or more kilometers from Iran to the United States would be a technical challenge, as would developing a nuclear weapon. (Presumably, an Iranian ICBM attack on the United States would use a nuclear warhead or other weapon of mass destruction rather than a conventional warhead.) In a 2006 report, DoD's National Air and Space Intelligence Center stated that "Iran has an extensive missile development program and has received support from entities in Russia, China, and North Korea," concluding that "Iran could have an ICBM capable of reaching the United States before 2015."[22] Previous assessments by various organizations have reached similar conclusions.

A National Intelligence Estimate from November 2007 addressed the issue of potential Iranian nuclear weapons, concluding that "Iran probably would be technically capable of producing enough [highly enriched uranium] for a weapon sometime during the 2010–2015 time frame." That report also stated that until fall 2003, Iranian military entities were working to develop a nuclear weapon, but those programs were subsequently halted. However, the report also judged that "Iran has the scientific, technical and industrial capacity eventually to produce nuclear weapons if it decides to do so."[23] Combining those two components to form a viable nuclear ICBM threat would present additional challenges. Citing the difficulties in adapting a nuclear weapon from a laboratory environment "in a concrete tunnel, [with] no G-loading, no vibration, no temperature extremes" to an ICBM, a former commander-in-chief of U.S. Strategic Command stated, "I would submit that the miniaturization of a nuclear warhead is probably the most significant challenge that any proliferant would have to face."[24]

CBO modeled the defensive capability of various missile defense options against shorter-range missiles that Iran has reportedly tested or claims to have developed and against potential future Iranian IRBMs or ICBMs. However, CBO did not attempt to assess whether or when Iran might be technically capable of fielding such threats. CBO's analysis was based on technical descriptions of current Iranian missiles and of proxy missiles developed by other countries available in unclassified literature. The proxy missiles were chosen to represent the various types of missiles that exist and could potentially be fielded by an adversary (a liquid-fuel IRBM capable of reaching all of Europe and liquid- and solid-fuel ICBMs capable of reaching the United States), each of which would present different challenges to a missile defense system. Any actual missiles in those categories that Iran fielded in the future would most likely differ in detail from the proxies that CBO selected.

Finally, some analysts question the need for extensive systems to defend the United States against ballistic missiles in the face of other, arguably more likely, threats. A recent National Intelligence Estimate addressed the potential of nonmissile threats to the United States (using, for example, ships, trucks, or airplanes as delivery mechanisms). It stated that although "[n]onmissile means of delivering weapons of mass destruction do not provide the same prestige or degree of deterrence and coercive diplomacy associated with ICBMs," nevertheless "the Intelligence Community judges that US territory is more likely to be attacked with WMD [weapons of mass destruction] using nonmissile means."[25] That conclusion was based on the arguments that nonmissile means are less expensive than ICBMs; can be developed and deployed covertly in an attempt to evade retaliation; would avoid missile defenses; and, with expected technology over the next 15 years, would be more reliable and much more accurate than ICBMs. CBO has not tried to analyze Iran's strategy or the relative likelihood of various threats. Rather, the scope of this analysis is to compare the expected performance of various missile defense options against a posited Iranian missile threat.

22. National Air and Space Intelligence Center, *Ballistic and Cruise Missile Threat,* NASIC-1031-0985-06 (March 2006), pp. 9 and 17.

23. National Intelligence Council, *Iran: Nuclear Intentions and Capabilities,* National Intelligence Estimate (November 2007).

24. General Eugene Habiger, quoted in Joseph Cirincione, *The Declining Ballistic Missile Threat, 2005,* Policy Outlook (Washington, D.C.: Carnegie Endowment for International Peace, February 2005), p. 9.

25. National Intelligence Council, *Foreign Missile Developments and the Ballistic Missile Threat to the United States Through 2015,* unclassified summary of a National Intelligence Estimate (December 2001), p. 15.

CHAPTER

1

Ballistic Missiles: Threats and Defenses

With their ability to strike at long range and to carry devastating weapons, ballistic missiles are both an attractive military option and a feared threat for many nations. In combat, missiles have several advantages over manned aircraft for attacking an adversary: They can fly above traditional air defenses and attack over long distances very quickly. Moreover, even without being used, missiles pose a threat that gives their owners a means to deter or coerce enemies. Since World War II—when Germany ushered in the modern era of missile warfare by using V-1 and V-2 rockets to attack Britain—the development and use of missiles have become widespread. Today, more than 20 countries field ballistic missile systems. (For a discussion of what makes a missile "ballistic" and other basic concepts of missile defense, see Appendix A.)

To counter such threats, the Department of Defense (DoD) has long been working to develop defenses against ballistic missiles. Early U.S. efforts (such as the 1960s-era Nike-Zeus program) were aimed at countering the Soviet Union's vast arsenal of missiles. Recent efforts are more modest in scope. The National Missile Defense Act of 1999 states, "It is the policy of the United States to deploy as soon as is technologically possible an effective National Missile Defense system capable of defending the territory of the United States against limited ballistic missile attack (whether accidental, unauthorized, or deliberate)."[1]

DoD's Missile Defense Agency (MDA), which oversees those efforts, has broken its goals into a series of "blocks." It is fielding those blocks more or less sequentially, with each new block extending the capability of the overall system:

- Block 1.0—Defend the United States from limited North Korean long-range threats;
- Block 2.0—Defend allies and deployed forces from short- to medium-range threats in one region or theater;
- Block 3.0—Expand defense of the United States to include limited Iranian long-range threats;
- Block 4.0—Defend allies and deployed forces in Europe from limited Iranian long-range threats and expand protection of the U.S. homeland; and
- Block 5.0—Expand defense of allies and deployed forces from short- to intermediate-range threats in two regions or theaters.[2]

MDA's planned Block 4.0 program—which is the focus of this study—envisions putting a missile defense system in Europe by 2013 that could disable or destroy ballistic missiles launched from Iran. The system would consist of interceptor missiles based in Poland, supported by a tracking radar in the Czech Republic and another at an undetermined location closer to Iran. This analysis looks at how well the proposed system would meet MDA's Block 4.0 goals and whether other combinations of existing, planned, or potential missile defense systems could achieve all or some of those goals. Specifically, the Congressional Budget Office (CBO) estimated the ability of MDA's proposed system to defend both Europe and the United States against various types of ballistic missiles fired from Iran. CBO then compared the cost and effec-

1. Public Law 106-38; 113 Stat. 205.

2. Missile Defense Agency, *Fiscal Year 2009 Budget Estimates Overview,* 08-MDA-3199 (January 2008).

tiveness of that system with the cost and effectiveness of other defensive architectures that could be deployed.

Current and Potential Missile Threats from Iran

Iran has a history of pursuing ballistic missile programs dating back to the 1970s. Those programs have involved Iran's developing missile systems itself and acquiring them from other countries. Iran has also used its missiles in combat: During the Iran-Iraq "War of the Cities" in the mid-1980s, it reportedly fired more than 600 ballistic missiles. According to unclassified reports, the missiles that Iran has deployed or tested so far appear to have a maximum range of roughly 2,000 kilometers (km).[3] But Iran reportedly has several projects aimed at developing or acquiring longer-range missiles, and Iranian officials have publicly discussed plans to develop a space-launch vehicle for putting satellites into orbit. That vehicle supposedly underwent developmental testing in February 2008. Space-launch technology, if developed, could easily be adapted to offensive ballistic missiles. Several recent assessments by the U.S. intelligence community have judged that by about 2015, Iran could be capable of developing and testing a missile with a long enough range to reach the United States.

For this analysis, CBO considered two types of Iranian missile threats: near-term threats—missiles that Iran has tested or claims to have developed—and potential future threats. To approximate future threats, CBO examined several existing missiles developed by other countries; they are intended to represent the types of missiles that Iran might be able to develop or acquire.

Ballistic missiles are generally categorized by the range over which they can operate. Several classification schemes exist. This report follows the categories that MDA uses:

- Short-range ballistic missiles are those with ranges up to 600 km;
- Medium-range ballistic missiles are those with ranges up to 1,300 km;
- Intermediate-range ballistic missiles (IRBMs) are those with ranges up to 5,500 km; and
- Intercontinental ballistic missiles (ICBMs) are those with ranges greater than 5,500 km.

Near-Term Iranian Threats

Iran reportedly has at least three types of intermediate-range ballistic missiles: Shahab-3, Shahab-3A, and Ashura. Their ranges vary from 1,300 km to about 2,000 km, which means that if launched from northwestern Iran, they would be capable of reaching the Black Sea region of southeastern Europe, but not central or western Europe (see Figure 1-1).[4]

The Shahab-3 is a single-stage, liquid-fuel missile with an estimated maximum range of 1,300 km (see Table 1-1). Reportedly, the missile is similar in design to North Korea's No-Dong missile, with the two countries cooperating on at least part of the development process. In turn, the No-Dong is thought to derive from the Russian Scud-B missile. Iran's Shahab-3 is believed to be about 16.5 meters (m) in length and 1.4 m in diameter, with a payload of around 1,200 kilograms (kg). The first reported test of the Shahab-3 was in 1998. According to a recent intelligence report, the system is now operational, with a total inventory of less than 20 launchers fielded.[5]

Numerous reports suggest that Iran has tried to increase the range of the Shahab-3 by adjusting its design. A new version with a redesigned nose-cone shape was reportedly displayed by Iran in 2004. That variant, designated Shahab-3A, is believed to be about a meter longer than the original version and to have an estimated range of about 1,700 km. An intelligence report from 2006 concluded that the Shahab-3A was still in development and not yet fielded at that time.[6]

In November 2007, Iran announced that it had developed a new missile, called the Ashura. According to Iranian statements, the Ashura has a range of about

3. Dinshaw Mistry, "European Missile Defense: Assessing Iran's ICBM Capabilities," *Arms Control Today* (October 2007).

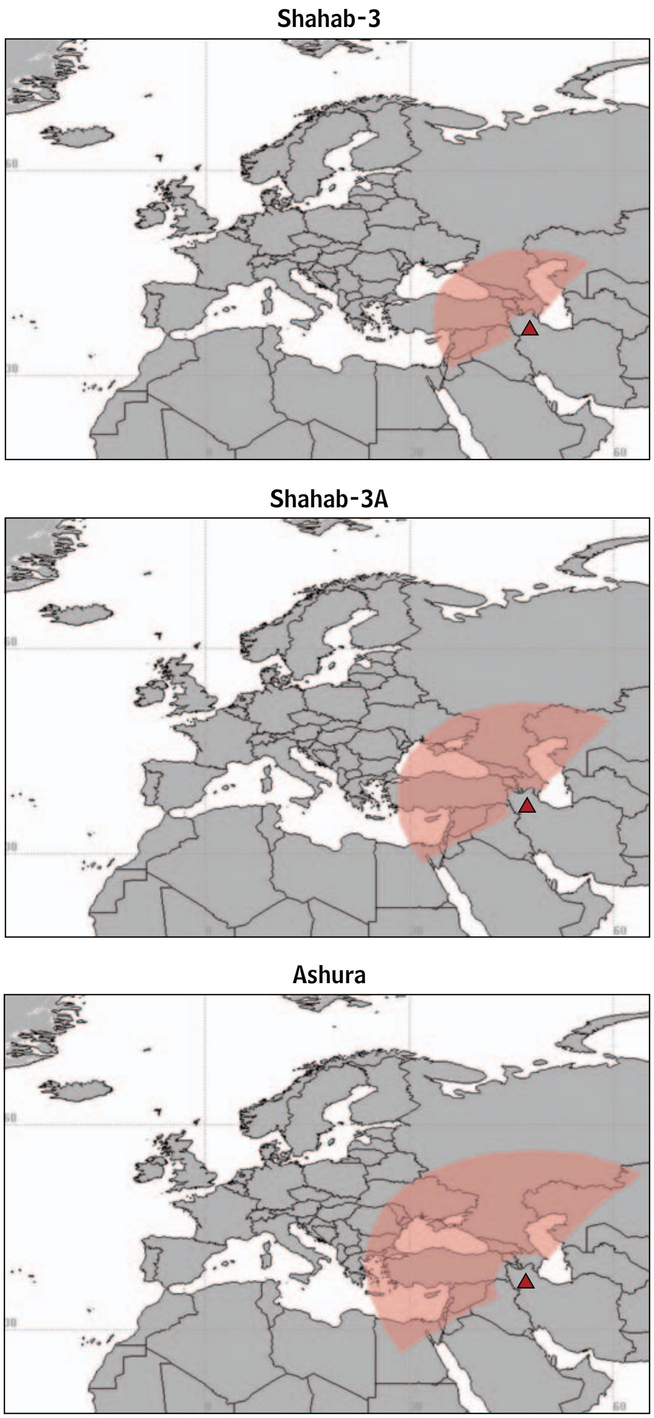
4. Technical descriptions, ranges, and even names of Iranian missiles vary considerably among different unclassified sources. Thus, the descriptions of specific missiles in this report may differ from descriptions elsewhere that are based on other sources.

5. National Air and Space Intelligence Center, *Ballistic and Cruise Missile Threat*, NASIC-1031-0985-06 (March 2006), p. 10.

6. Ibid.

Figure 1-1.

Areas Within Range of Near-Term Missile Threats from Iran



Source: Congressional Budget Office.

Note: Red shading indicates selected regions within range of a given missile launched from northwestern Iran. Missile symbol ▲ indicates the location of the modeled missile launch site in Iran.

2,000 km. The Ashura is thought to be a multiple-stage, solid-fuel missile, which represents a departure from the sort of incremental improvements previously made to the Shahab-3 to increase its range. Shortly after Iran announced that it had developed the Ashura, the director of MDA was quoted as saying that the Ashura was "different" and "surprises us."[7] To date, Iran has not claimed to have tested the Ashura, although some press reports indicate that an unsuccessful test occurred in November 2007.[8] In November 2008, Iran said that it had successfully tested a solid-fuel missile with the same range as the Ashura, although it referred to the missile as the Sejil.[9]

Because the claimed development of the Ashura is so recent, no unclassified source is available that gives technical parameters for the new missile. For the modeling in this analysis, CBO used an existing two-stage, solid-fuel missile with comparable range—the Chinese CSS-5—as a proxy for the Ashura.[10] Although that choice was primarily motivated by the availability of unclassified technical parameters for a missile of the same general description, it is possible that the Ashura and the CSS-5 share a common heritage. The 1998 Commission to Assess the Ballistic Missile Threats to the United States concluded that China had contributed extensively to Iran's solid-fuel missile program.

Another missile that might pose a near-term threat is the Musudan, a two-stage, liquid-fuel missile with an estimated maximum range of 3,000 km. The Musudan (also referred to as the BM-25) was developed by North Korea and reportedly was based on Russian R-27 missile technology. Some reports conclude that Iran acquired Musudan missiles from North Korea and may have carried out a flight test of them.[11] However, to date, Iran has not publicly claimed to have acquired or tested the Musudan.

7. Lt. Gen. Henry Obering as quoted in David Bond, ed., "Washington Outlook," *Aviation Week and Space Technology* (December 3, 2007).

8. See, for example, Peter Crail, "Iran Lauds Development of Solid-Fuel Missile," *Arms Control Today* (January/February 2008).

9. Nazili Fatahi and Alan Cowell, "Iran Claims Success in Tests Firing Long-Range Missiles," *New York Times*, November 13, 2008.

10. CSS-5 is a NATO designation; China refers to the missile as the DF-21. China was widely reported to have used that missile when it shot down an aging Chinese weather satellite in January 2007.

11. Daniel A. Pinkston, *The North Korean Ballistic Missile Program* (Carlisle, Pa.: Army War College, Strategic Studies Institute, February 2008).

Table 1-1.

Performance Parameters Assumed for Near-Term and Potential Future Missile Threats from Iran

	Number of Stages	Fuel Type	Maximum Burn Time (Seconds)	Nominal Maximum Burn-Out Velocity (Kilometers per second)	Nominal Maximum Range (Kilometers)
			Missiles Posing a Near-Term Threat		
Shahab-3	1	Liquid	98	3.4	1,300
Shahab-3A	1	Liquid	98	3.7	1,700
Ashura	2	Solid	72	3.8	2,100
			Missiles Posing a Potential Future Threat		
IRBM	2	Liquid	188	5.5	5,200
Liquid-Fuel ICBM	2	Liquid	329	7.6	17,800
Solid-Fuel ICBM	3	Solid	203	7.0	12,300

Source: Congressional Budget Office based on *Jane's Strategic Weapons Systems* (Coulsdon, Surrey, United Kingdom: Jane's Information Group, 2008); and Steven J. Isakowitz and others, *Space Launch Systems*, 4th ed. (Reston, Va.: American Institute for Aeronautics and Astronautics, 2004).

Note: IRBM = intermediate-range ballistic missile; ICBM = intercontinental ballistic missile.

CBO did not specifically look at how well possible missile defenses in Europe would defend against the Musudan. With its 3,000 km range, the Musudan would threaten more of central Europe than the near-term threats that CBO did examine, although it would not be capable of reaching most of western Europe (see Summary Figure 2 on page xvii). As a multiple-stage, liquid-fuel missile, it is similar to the potential future intermediate-range ballistic missile that CBO included in this analysis (see below). However, because the Musudan reportedly has a comparable burn time but a 2,000 km shorter range than that notional missile, it would probably present a less challenging threat to midcourse-phase missile defenses.

Potential Future Iranian Threats

None of the missiles that Iran has claimed to have developed or tested is capable of threatening the northwestern half of Europe or the United States. To assess the capability of missile defenses to defend all of Europe and the United States, CBO posited three types of threats that Iran could field in the future:

- A liquid-fuel intermediate-range ballistic missile capable of reaching all of continental Europe, the United Kingdom, and Ireland;
- A liquid-fuel intercontinental ballistic missile capable of reaching all of the United States; and
- A solid-fuel ICBM capable of reaching most of the United States (see Figure 1-2).

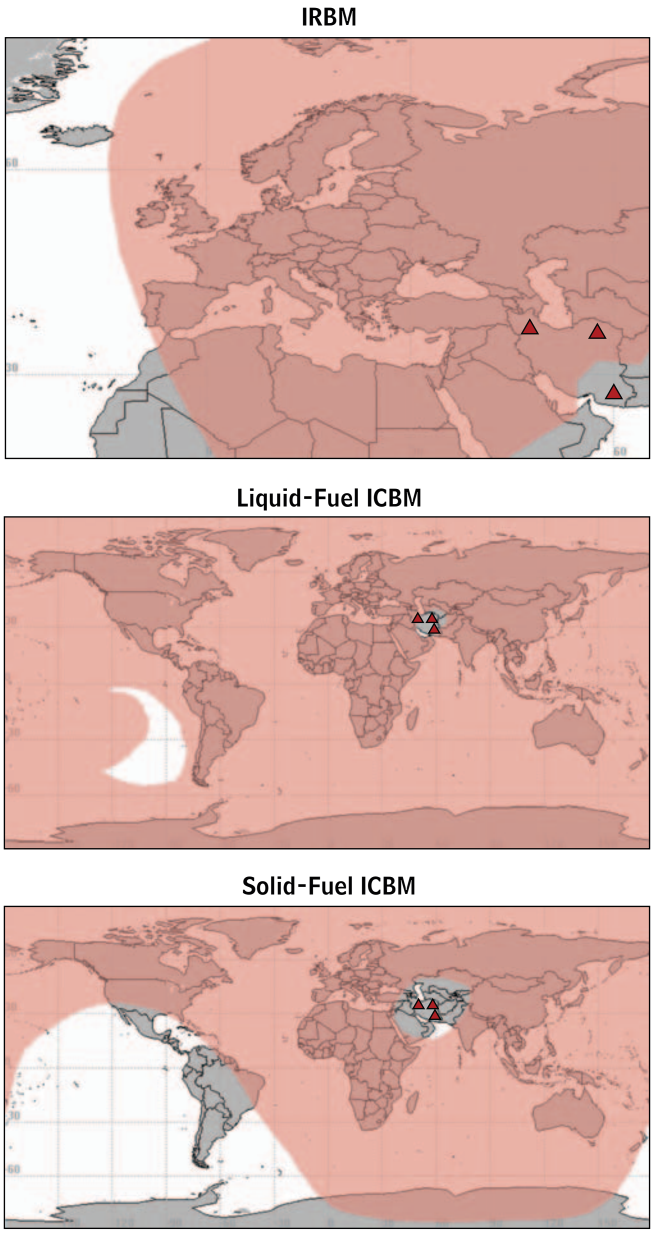
In all of those cases, CBO used as proxies existing missiles that fit the general description. It did not attempt to assess when or whether Iran might be able to actually field such missiles.

As a stand-in for a potential Iranian IRBM threat to Europe, CBO used the Taepo-Dong 2 (also referred to as the Paektusan 2), a North Korean two-stage, liquid-fuel missile with a maximum range of more than 5,000 km. The Taepo-Dong 2 failed after about 40 seconds during its only known flight test, which was part of multiple missile launches that North Korea conducted in July 2006.

As a proxy for a potential Iranian liquid-fuel ICBM, CBO chose the Titan II, a two-stage missile first fielded by the United States in the early 1960s. Originally intended to serve as a nuclear-capable ICBM, the Titan II was later adapted as a space-launch vehicle for putting spacecraft into orbit. In CBO's modeling, the Titan II is assumed to have a payload of 3,700 kg and a maximum range of more than 17,000 km, making it capable of reaching almost anywhere on Earth.

Figure 1-2.

Areas Within Range of Potential Future Missile Threats from Iran



Source: Congressional Budget Office.

Notes: Red shading indicates regions within range of a given missile launched from any of the three modeled missile launch sites in Iran. Missile symbols ▲ indicate the locations of all of the missile launch sites in Iran used in this analysis.

IRBM = intermediate-range ballistic missile; ICBM = intercontinental ballistic missile.

As a stand-in for a potential Iranian solid-fuel ICBM, CBO used the SS-25, a missile first fielded by the Soviet Union in the late 1980s. It is a road-mobile missile that is launched from a transporter-erector-launcher vehicle. As modeled by CBO, this missile has an estimated payload of 1,000 kg and a maximum range of around 12,000 km—capable of reaching most of the United States from Iran.

The Debate About Ballistic Missile Defenses

When faced with an adversary that possesses, or has indicated the intention to possess, ballistic missiles, nations have historically responded in various ways. For example, in the 1970s and 1980s, the United States and the Soviet Union negotiated agreements about the extent or capability of their inventories of ballistic missiles, such as the Intermediate-Range Nuclear Forces Treaty and agreements from the Strategic Arms Limitation Talks. In addition, nations that possess missile or warhead technology have negotiated agreements to refrain from sharing that technology with countries that do not already possess it. Examples of such agreements include the Missile Technology Control Regime and the Nuclear Non-Proliferation Treaty.

Another approach that nations have followed is trying to deter an adversary militarily from using (or perhaps even from fielding) ballistic missiles, either through conventional armed forces or through the deployment of a countering ballistic missile force. The ultimate example of that approach is the strategy of mutually assured destruction that the United States and the Soviet Union pursued during the Cold War. Another military option is to destroy or neutralize an adversary's missiles before they can be used. For example, U.S. and allied special forces reportedly captured Iraq's Scud missile sites before the main invasion of Iraq in 2003 so those missiles could not be used in combat.[12]

12. Fred Barnes, "The Commander," *The Weekly Standard* (June 2, 2003).

The approach that this study focuses on is fielding ballistic missile defenses to destroy an enemy missile after it is fired. The primary example of such defenses being employed in combat is the United States' use of Patriot missile interceptors against Iraqi Scud missiles during Operation Desert Storm in 1991.

Historically, the development of missile defenses has often been controversial. Advocates argue that the threat from ballistic missiles is growing despite efforts to control it through diplomacy. The United States' nuclear arsenal and conventional forces provide some measure of deterrence by enabling the country to make a devastating response to the launch of an enemy missile. But missile defenses are touted as a supplement to that deterrent: They could provide a means of defense against the potentially catastrophic effects of even a single missile attack, should deterrence fail. Moreover, some people argue that deterrence may not entirely succeed against threats from rogue nations, which seek to use missiles not "as operational weapons of war" but "primarily as weapons of coercive diplomacy, to complicate U.S. decision-making or limit our freedom to act in a crisis."[13] In such cases, advocates argue, the presence of missile defenses would give U.S. leaders more flexibility in their actions and perhaps discourage adversaries from pursuing offensive missiles in the first place.

Critics of missile defenses make a number of arguments against developing such defenses, including their potential to complicate deterrence and arms control agreements. The 1972 Anti-Ballistic Missile (ABM) treaty between the United States and the Soviet Union sought to reduce the effect of missile defenses on the deterrence calculus by limiting the number and nature of missile defenses that each country could field. In particular, the treaty outlawed any system with full national coverage, limiting each nation to a single missile defense site with a maximum of 100 ground-based interceptors.[14] No land-mobile, sea-based, or space-based interceptors were permitted. During the late 1990s—when the first tests of what would become the current Ground-Based Midcourse Defense (GMD) system were taking place—efforts were made to design a system that would be close enough to existing ABM treaty limitations on location and scope of coverage to fit within an amended treaty. Reportedly, one concern during that process was that if the United States withdrew from the ABM treaty, the Russians or Chinese might respond by expanding or improving their nuclear forces, which in turn could trigger expansion or improvement of India's and Pakistan's arsenals.[15] Nevertheless, the United States withdrew from the treaty, effective in June 2002, citing a need to "defend its homeland, its forces and its friends and allies" against missile threats from "terrorists and rogue states."[16] More recently, in response to the proposal to deploy a missile defense system in Europe, Russian leaders reportedly threatened to withdraw from some arms control treaties, such as the Intermediate-Range Nuclear Forces Treaty. They also pledged to move short-range missiles closer to the interceptor site in Poland if the defense system was deployed.[17]

Besides concerns about arms control, critics of missile defenses often cite the high cost of such systems and the technical challenges they must overcome to operate effectively. Since 1985, appropriations for MDA and its predecessor missile defense organizations have totaled about $144 billion, an average of $6.0 billion per year (in 2009 dollars). Since 2002, after the U.S. withdrawal from the ABM treaty, annual appropriations for MDA have averaged about $9.0 billion. President Bush's 2009 budget request called for the average level of annual spending to rise slightly, to $9.2 billion, through 2013. Developing cost-effective missile defenses is also technologically challenging, particularly when the missiles being targeted are equipped with countermeasures designed to foil defense systems. The various technical obstacles that different kinds of missile defense systems face are described in more detail below.

13. John Holum, senior advisor for arms control and international security at the State Department, in a March 2000 speech, as quoted in Bradley Graham, *Hit to Kill* (New York: Perseus Books Group, 2001), p. 164.

14. The original agreement limited each party to two interceptor sites, but a 1974 protocol changed that to a single site.

15. For a detailed account of the debate within the Clinton Administration about missile defenses, see Graham, *Hit to Kill*.

16. Department of State, *ABM Treaty Fact Sheet* (December 13, 2001), http://2001-2009.state.gov/t/ac/rls/fs/2001/6848.htm (accessed June 25, 2008).

17. Richard Weitz, "Special Report: The European Ballistic Missile Defense Dispute," *WMD Insights* (April 2007), p. 2; and Steve Gutterman, "Medvedev: Russia to Deploy Missiles near Poland," *Washington Post*, November 5, 2008.

Technical Challenges to Ballistic Missile Defenses

Missile defense systems are generally categorized by where in a missile's flight they are designed to engage the missile. Missile flight is generally split into three phases:

- The **boost phase**, which lasts from launch until the booster stops firing (and generally separates from the weapon payload). The length of this phase can vary from one minute or less for short- and medium-range ballistic missiles to several minutes for intermediate-range and intercontinental ballistic missiles.

- The **midcourse phase**, during which the payload coasts on a ballistic trajectory, usually outside the atmosphere, toward its target. This phase is by far the longest and can last from less than 10 minutes to about 40 minutes, depending on the range of the missile.

- The **terminal phase**, which begins when the payload reenters the atmosphere (nominally at an altitude of 100 km) on its way toward the target. This phase generally lasts for less than a minute.

The U.S. missile defense systems now under development generally use one of two technological approaches to engaging enemy missiles: directed-energy (laser) beams or interceptor missiles. Laser-based systems are designed to engage the booster of an enemy missile (usually referred to as a threat missile) by burning a hole in its outer casing. Thus, such systems are limited to boost-phase defense, before the payload separates from the booster. (A payload typically includes a warhead encased in a reentry vehicle. Because such vehicles are hardened to resist the heat of reentering the atmosphere at high speed, destroying them with a laser beam would be very challenging.)

Interceptors, by contrast, can engage threat missiles during any phase of flight, either by striking the booster or the payload directly (referred to as hit-to-kill or kinetic kill) or by causing a high-explosive or nuclear detonation near the missile. Intercepting a missile during its boost phase has the advantage that the booster is still attached to the payload and is still burning, presenting a relatively large, hot target that is easy for both radar and infrared sensors to detect. However, because the boost phase is short, interceptors need to have high acceleration and be located close to the launch site of the missile they are targeting.

Intercepts in the midcourse phase have the advantage of a longer time frame, so interceptors can be launched from locations farther from the launch site of the threat missile and still be able to reach the missile in time. However, once the payload separates from the booster, it is considerably smaller than the full missile, presenting a more challenging target for hit-to-kill interceptors and making tracking with radar more difficult. In addition, nations have developed numerous countermeasures to foil midcourse defenses. They include deploying decoys to confuse interceptors; encasing the warhead in a balloon or an oversized reentry vehicle to hide it (also potentially to cool it and mask its thermal signature); deploying jammers, chaff, or flares to reduce sensors' ability to track the warhead; splitting the warhead into numerous submunitions to make complete destruction more difficult; and enabling the reentry vehicle to maneuver so it can depart from the expected ballistic trajectory. Some current or planned midcourse-phase defense programs include, or intend to develop, various means to address countermeasures. The efficacy of such counter-countermeasures has not yet been evaluated with flight tests against target missiles equipped with countermeasures.

Intercepts in the terminal phase have the advantage that many of those countermeasures will not survive reentry into the atmosphere. In addition, terminal-phase interceptors are deployed near the areas being protected rather than the potential launch sites of enemy missiles, reducing the political and logistical issues associated with basing defenses in other countries. However, the time scale for intercept during the terminal phase is very short, and the warhead is moving very fast.

Although each phase of a missile's flight presents unique challenges to missile defenses, all types of defenses must go through several critical steps before actually engaging a missile. First, the defense must become aware that the threat missile has been launched. U.S. systems generally detect launches by using infrared sensors on satellites, although land- or air-based infrared sensors or radar might also be used.

Second, the defense must determine the trajectory of the threat missile. That knowledge allows operators to predict the intended target, the flight time of the missile, and its position as a function of time along the trajectory. The missile's trajectory is generally measured with radar, although infrared satellites can provide some tracking capability, particularly during the boost phase. Before the missile's booster burns out, predictions of the full trajectory are very uncertain.[18] The velocity and acceleration of the missile can change quickly as stages burn out and new ones start to fire, so predicting the trajectory even on short time scales is difficult. Once the booster has burned out and the missile has entered the ballistic (midcourse) phase, its future position can be estimated much more reliably. Nevertheless, because of the inherent limitations of sensors operating over long range, there is always some uncertainty in the predicted position of the missile. To reduce that uncertainty, most missile defense systems are designed to allow communication between the tracking sensors and the engagement system, so the trajectory prediction can be refined during the engagement. Generally, the interceptor itself carries some sensors, often contained in a so-called kill vehicle that separates from the interceptor booster and maneuvers to adjust the trajectory to the intercept.[19]

Third, on the basis of the predicted trajectory of the threat missile, operators must choose the parameters of the defensive engagement. Because most U.S. missile defense systems use interceptors, this step consists of determining the optimum trajectory for the interceptor to intersect with the trajectory of the threat missile. That choice is constrained by the time required for the interceptor to fly to the intercept point. It may also be restricted by the interceptor's or kill vehicle's limits on intercept altitude (both maximum and minimum intercept altitudes are possible) and by constraints on the intercept geometry (such as limits on the relative velocity between the interceptor and the threat missile that is required to make a kinetic kill or on the angle between the trajectories that will allow the interceptor's sensors to operate).[20] For directed-energy weapons, such as the Airborne Laser, other criteria go into selecting the optimum engagement position. They include constraints on the distance to the threat missile, the angle between the laser beam and the missile's body, and the altitude of the engagement.

The timeline for the three steps described above—and the time available for the engagement itself—depends on the type of missile being targeted, the phase of flight in which the engagement will occur, the location of the missile defense system's components relative to the launch site, and the range over which the components can operate effectively. The various types of missiles with which Iran might pose a threat to Europe or the United States vary widely in their burnout times, total flight times, and distances flown during those times (see Figure 1-3). Thus, the placement of the sensors and interceptor launch sites is critical to a system's ability to engage all types of threat missiles.

- Sensors need to be close enough to the launch site to begin tracking a missile early in its trajectory. But ideally, they should not be so close that a longer-range missile passes through and out of the sensors' field of regard before its booster burns out.

- Sites for launching interceptors need to be far enough away from the potential launch sites of threat missiles that the defense has time to react and the interceptor has time to fly to the intercept point before the threat missile has passed too far beyond the interceptor launch site. (Such "tail-chase" engagements put the defense at a disadvantage unless the interceptor is significantly faster than the threat missile.) However, for boost-phase intercepts, interceptor launch sites must be close enough to the launch sites of threat missiles that an interceptor can fly out to engage a missile before the missile's booster has burned out.

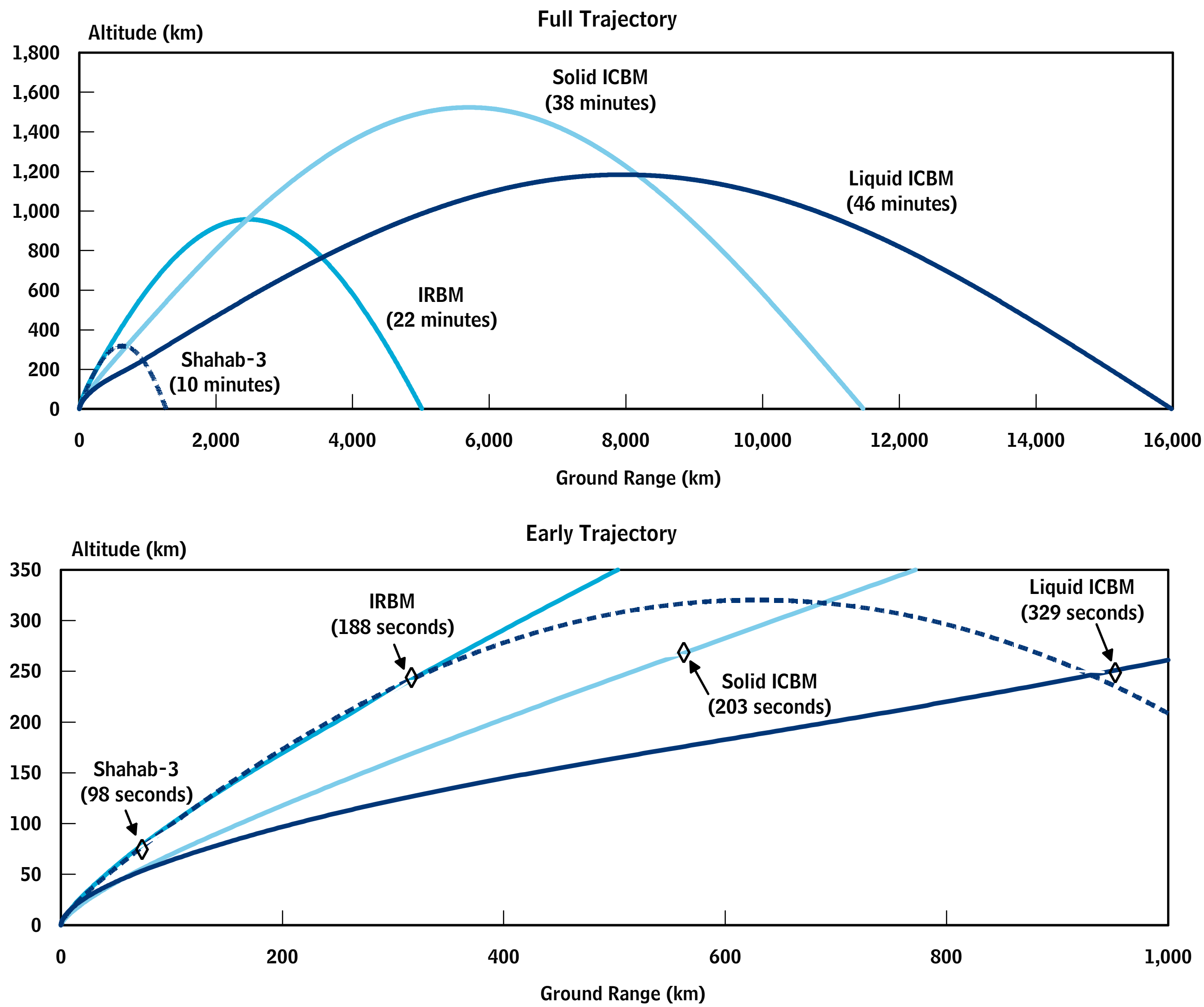
18. For example, with the solid-fuel ICBM that CBO included in this analysis, if the thrust is terminated just 5 seconds short of the full 203-second burn time, the location of final impact changes by more than 2,000 km from that of a full-burn trajectory.

19. The amount of maneuverability that the kill vehicle has, usually quantified as the total change in velocity (delta-V) of which it is capable, varies by the phase of flight. Boost-phase intercept kill vehicles may require several kilometers per second of delta-V, whereas midcourse intercept kill vehicles, which operate during the more predictable ballistic portion of the trajectory, can have considerably less. However, a relatively high delta-V could be required for midcourse intercepts if the threat warhead was capable of maneuvering during the midcourse phase.

20. Hit-to-kill interceptors rely on the kinetic energy of the collision with a target to destroy the target. Since kinetic energy is proportional to the square of the relative velocity between the colliding bodies, there is some minimum value of relative velocity that will ensure that the collision is sufficiently violent to destroy the target. For this study, CBO assumed a minimum relative velocity of 3 km per second; the rationale for that value is discussed in Appendix B.

Figure 1-3.

Altitude Versus Ground Range for Various Types of Missile Threats



Source: Congressional Budget Office.

Notes: The upper panel shows the full trajectories and total flight times for the various types of missiles; the lower panel shows detail of the missiles' trajectories near the launch site as well as their burnout times and position at burnout (diamond-shaped symbols).

km = kilometers; IRBM = intermediate-range ballistic missile; ICBM = intercontinental ballistic missile.

To meet their defensive goals, both boost-phase and midcourse-phase missile defenses may need to cover threat-missile trajectories with a wide range of azimuth angles (the angle of the trajectory relative to north). For missiles launched onto trajectories that point away from the interceptor site, a trade-off comes into play: If the interceptor site is too close to the launch site, the interceptor may not have time to reach those trajectories before the threat missile passes the interceptor site, resulting in a tail-chase engagement. But if the interceptor site is too far away from the threat missile's launch site, the interceptor may not have enough range or speed to reach the missile. If the range of azimuths that threat missiles could use is sufficiently large, multiple interceptor sites may be needed to defend the full desired area.

Current and Planned Components of U.S. Missile Defenses

Under the ABM treaty, defenses against long-range missiles were limited to one fixed, land-based interceptor site, with no land-mobile, sea-based, or space-based interceptors allowed. Limits were also placed on the location, number, and sensitivity of radars supporting missile defenses. Since the United States withdrew from the ABM treaty in 2002, the Missile Defense Agency has pursued research and development efforts into many of the formerly prohibited approaches to fielding missile defenses. The goal of MDA's efforts is to construct a layered defense—one capable of engaging enemy missiles during all phases of their flight—by combining disparate sensors and systems aimed at particular phases of flight with an overarching command, control, battle management, and communications system.

Work on midcourse-phase and terminal-phase defenses is farthest advanced. Two terminal-phase systems, both operated by the Army, are currently being fielded—the Patriot Advanced Capability-3 (PAC-3) system has more than 500 operational interceptors, and the Army activated its first Terminal High-Altitude Area Defense (THAAD) battery in May 2008. Two midcourse-phase systems—the Ground-Based Midcourse Defense system (operated by the Army) and the Aegis ballistic missile defense (Aegis BMD) system (operated by the Navy)—have also begun to be fielded. Development efforts are continuing on those and numerous other missile defense systems, as well as on a variety of sensors to detect and track threat missiles.

Boost-Phase Defenses

MDA is pursuing several programs that would use lasers or interceptors to engage a threat missile while its booster was still firing.

The Airborne Laser system consists of a highly modified Boeing 747 aircraft that contains a high-power chemical laser, several lower-power lasers to aid in pointing and focusing the high-power laser, and various sensors. Design of the Airborne Laser (in its current form) began in 1996, and the first developmental aircraft is scheduled to conduct a shoot-down test in 2009. Current plans, which are contingent on the outcome of that test, call for building a second developmental aircraft for continued testing from 2009 to 2018 and then procuring seven operational aircraft.

MDA is also developing a land-mobile interceptor system called the Kinetic Energy Interceptor (KEI). That program is currently focusing on midcourse intercepts, but the system is also being designed to intercept missiles during their boost phase. The first flight test of the system's high-acceleration booster is scheduled for 2009, and developers are aiming to have the KEI ready for operations sometime after 2015. They also envision developing a sea-based version of the KEI in the future.

MDA is in the early stages of research on other potential boost-phase intercept systems. One concept being explored is air-launched interceptors, using several different combinations of aircraft platforms and interceptors. Another effort, the Space Test Bed, is investigating the idea of space-based interceptors.

Midcourse-Phase Defenses

MDA is continuing its development efforts to expand or improve systems that are designed to engage threat missiles after the booster burns out but before the warhead reenters the atmosphere.

The Ground-Based Midcourse Defense system is intended to defend the United States against long-range missiles. It uses three-stage Ground-Based Interceptors (GBIs) located in silos at Fort Greely in Alaska and Vandenberg Air Force Base in California. The first phase of fielding the system (called the initial defensive capability) was completed in December 2005, with eight GBIs at Fort Greely and two at Vandenberg. By the end of 2007, the number of interceptors at those sites had increased to 21 and 3, respectively. MDA's planned Block 4.0 program for missile defenses in Europe would add a third interceptor site, currently slated for Poland, to the GMD system. That site would use a two-stage version of the GBI rather than the three-stage version used in the United States. (Plans for expanding the GMD system to Europe are described in more detail in Chapter 2.)

Another current midcourse-phase defense, the Aegis BMD system, is designed to use the SPY-1 radar installed on many Navy warships to track missiles and a modified version of the Navy's Standard Missile (SM) to intercept them. The most recent version of the interceptor is the SM-3 Block IA, but further upgrades are being developed. The SM-3 Block IB, with an improved kill vehicle, is slated to start entering the fleet in 2011; the SM-3 Block IIA, with a larger second stage for higher burnout velocity and further improvements to the kill vehicle, is expected to be ready for deployment in about 2015. As of the end of 2007, 10 Navy ships were capable of tracking threat missiles and launching Aegis BMD interceptors, and another 7 ships were capable of performing only the radar-tracking portion of the BMD mission. MDA's plans call for outfitting a total of 18 ships for the full Aegis BMD mission.

In addition, the Kinetic Energy Interceptor that is under development is being considered for midcourse intercepts. The KEI program is pursuing a common booster that could be used for land-mobile, land-fixed (silo-based), and sea-mobile launches for either midcourse- or boost-phase intercepts. For midcourse-phase intercepts, plans call for the KEI to be capable of carrying the Multiple Kill Vehicle, which would allow a single interceptor to launch several kill vehicles and thus increase the probability of engaging the actual warhead if decoy countermeasures were present. Variants of the Multiple Kill Vehicle, which is still being developed, could also potentially be carried by the GMD system's ground-based interceptors or by a later, post-Block IIA version of the Aegis system's SM-3 interceptor.

Terminal-Phase Defenses

The United States currently has two land-based defense systems designed to engage threat missiles after their warheads have reentered the atmosphere. MDA is also pursuing a sea-based terminal-phase missile defense.

The Patriot Advanced Capability-3 system is intended to provide terminal-phase defense against short- and medium-range missiles. The Army is responsible for the system, which is now operational. PAC-3 is eventually supposed to be supplemented by the Medium Extended Air Defense System (MEADS), a joint U.S. venture with Italy and Germany, which will use an improved version of the PAC-3 interceptor.

The other land-based system, the Terminal High-Altitude Area Defense, is a deployable terminal-phase defense that consists of an X-band tracking radar, a mobile launcher capable of carrying eight interceptors, and associated fire control and communications.[21] The Army recently activated the first THAAD unit, with 24 THAAD interceptors on three launchers, based at Fort Bliss, Texas.

A new addition to MDA's terminal-phase defense portfolio is the Sea-Based Terminal program, which is intended to use the architecture of the midcourse Aegis BMD system. As now envisioned, the Sea-Based Terminal program would first develop a near-term capability using a modified version of the SM-2 Block IV interceptor and then develop a far-term capability based on a new interceptor.

Sensors

The ability to detect and track threat missiles is critical to the success of any missile defense program. MDA's plans for a layered ballistic missile defense envision using a variety of existing or planned sensors:

- Upgraded early-warning radars—existing early-warning radars whose hardware and software have been upgraded to enhance their tracking capabilities. Those radars are located at Beale Air Force Base in California; Fylingdales, England; Thule, Greenland; and Shemya, Alaska. Other radars in Clear, Alaska, and Cape Cod, Massachusetts, will be integrated into the ballistic missile defense system once the Air Force finishes upgrading them.

- The European Midcourse Radar—an X-band radar designed for tracking missiles and discriminating between warheads and decoys. The radar, previously deployed on Kwajelein Atoll in the Pacific, is to be moved to the Czech Republic as part of MDA's plans for a European missile defense capability.

- The Sea-Based X-Band Radar—a high-power radar designed for tracking and discriminating between warheads and decoys. The radar is mounted on a movable sea platform and has participated in tests at several locations. After testing, it is to be stationed offshore at Adak, Alaska.

21. The THAAD interceptor is capable of engagements both inside the atmosphere (endoatmospheric) and outside the atmosphere (exoatmospheric) and thus could be considered both a terminal-phase and a late midcourse-phase defense system.

- The AN/TPY-2—a transportable X-band radar based on the radar of the THAAD system.[22] One AN/TPY-2 has been deployed to Shariki, Japan, and MDA plans to use another as the forward-based radar for the proposed European missile defense system.

- The Space Tracking and Surveillance System (STSS)—a planned constellation of infrared satellites.[23] Two STSS demonstration satellites are slated to be launched in 2009. The size and satellite design for the operational STSS constellation (referred to as STSS Follow-On) is still being determined. The goal of the system is to track threat missiles during their entire trajectory.

- The Defense Support Program and the Space-Based Infrared System–High—constellations of Air Force surveillance satellites that are intended to provide infrared detection of missile launches.

22. The AN/TPY-2 was formerly known as the Forward-Based X-Band Transportable radar.

23. STSS was originally referred to as the Space-Based Infrared System–Low.

CHAPTER

2

Options for Missile Defenses in Europe

The Missile Defense Agency's planned Ground-Based Midcourse Defense Block 4.0 system has two stated goals: to defend U.S. allies and deployed forces in Europe against limited threats from Iranian long-range missiles and to expand protection of the United States against those threats. Deploying that system would involve placing interceptors and radars in various European countries. MDA hopes to have the system operational by 2013.

How well would the proposed GMD Block 4.0 system achieve its stated goals? Could other current or proposed missile defense systems meet the same objectives, perhaps from existing U.S. bases or at a lower cost? To answer those questions, the Congressional Budget Office examined four options for basing missile defenses in Europe and modeled their ability to meet the Block 4.0 goals. Option 1 corresponds to the European system proposed by MDA. The other three options—which CBO designed to provide roughly the same level of European defense as the GMD Block 4.0 system against most types of threats—would use various systems that MDA has already developed or proposed. To limit the scope of this study and allow for a more direct comparison among the alternatives, only midcourse-phase defense systems were included in the analysis.

Any of those options for missile defenses in Europe would supplement other midcourse-phase defenses—specifically, the U.S.-based GMD Block 3.0 system and Aegis ballistic missile defense ships—that the Department of Defense plans to have in place at various locations around the world by about 2012. CBO also modeled the ability of those systems to defend Europe and the United States against missiles launched from Iran. This chapter describes those existing defenses as well as the components and costs of the four options for deploying missile defenses in Europe. Chapter 3 explores in detail how much defensive coverage of Europe and the United States the various alternatives would provide against different types of missile threats.

Existing Midcourse-Phase Defenses

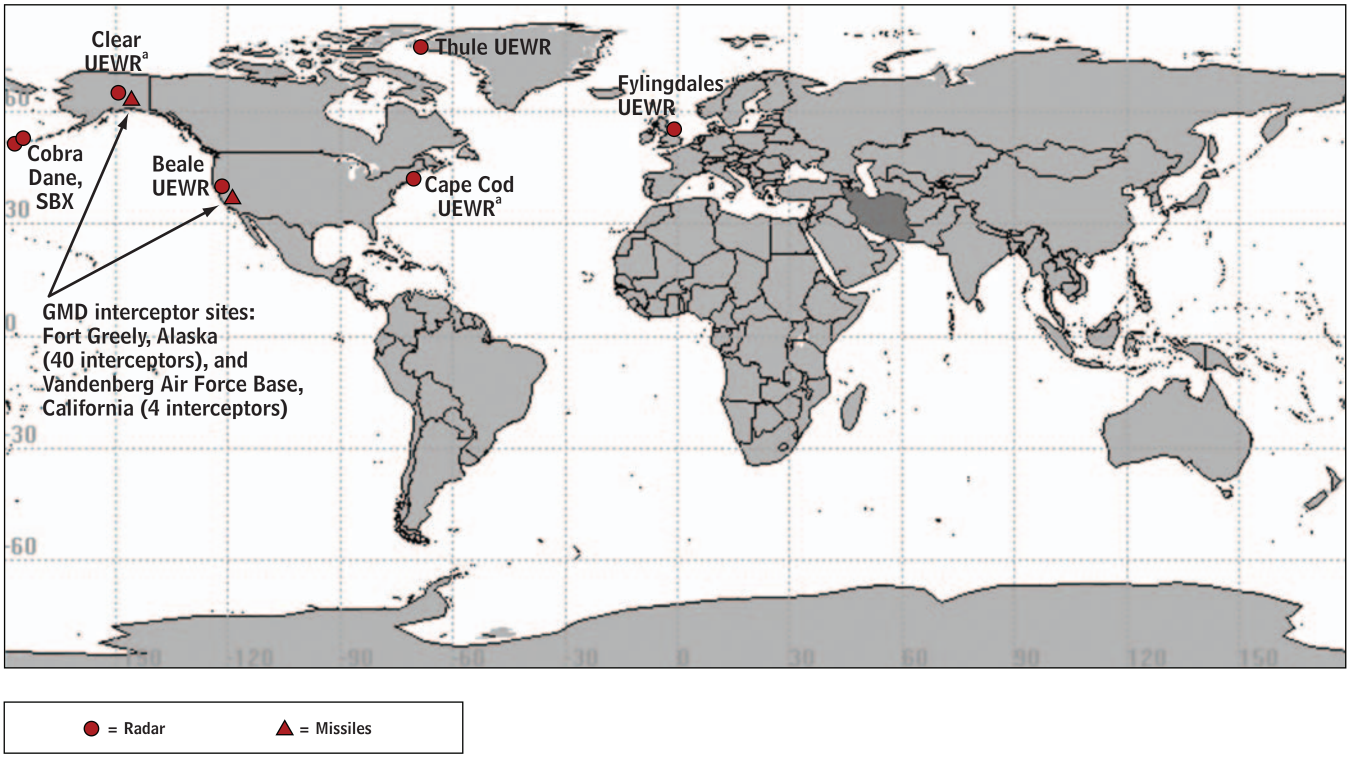
To help meet its Block 3.0 goal (expanding defense of the United States to include limited Iranian long-range threats), MDA is continuing to add capability to the GMD system that has been operating since the end of 2005. The GMD Block 3.0 system, which is scheduled to be in place by 2012, will include 44 interceptors launched from silos: 40 at Fort Greely in Alaska and 4 at Vandenberg Air Force Base in California.[1] It will also include several radar installations and a command, control, battle management, and communications system to link the various components (see Figure 2-1).

The GMD system uses three-stage, solid-fuel Ground-Based Interceptors. Each GBI consists of an Orbital Boost Vehicle booster and an Exoatmospheric Kill Vehicle (EKV) that is capable of engaging a single target. MDA is also developing the Multiple Kill Vehicle (MKV), which would be able to engage multiple targets as a way to counter decoys deployed by an enemy missile. Designers envision that the GBI will eventually carry the MKV. However, in this analysis, CBO modeled only the EKV version of the ground-based interceptor. The MKV would presumably be heavier than the EKV, which would reduce the burnout velocity of the interceptor and thus its range.

1. Vandenberg also has a fifth silo that is designated for testing purposes.

Figure 2-1.

Components of the GMD Block 3.0 System and Their Locations



Source: Congressional Budget Office.

Notes: Iran is shown in dark gray.

GMD = Ground-Based Midcourse Defense; UEWR = upgraded early-warning radar; SBX = Sea-Based X-Band Radar.

a. The Clear and Cape Cod UEWRs will be added to the Block 3.0 system after the Air Force finishes upgrading them.

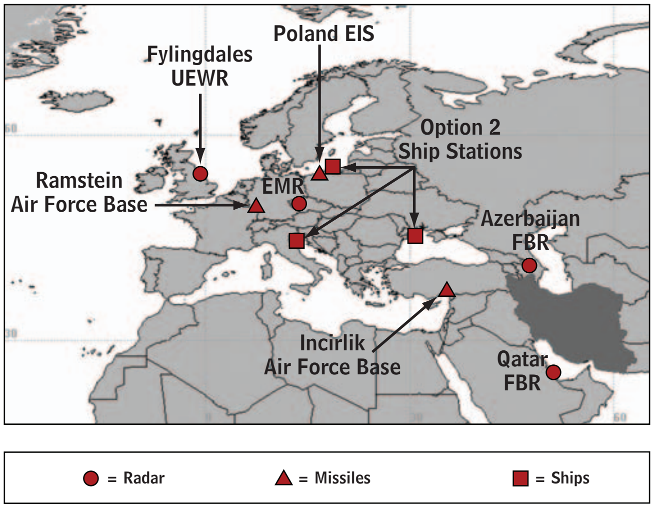
A variety of sensors can or will provide tracking for the GMD system, including upgraded early-warning radars (UEWRs) in Fylingdales, England; Thule, Greenland; Beale, California; Clear, Alaska; and Cape Cod, Massachusetts.[2] UEWRs have a very long range (about 5,000 kilometers). However, they operate in the ultrahigh frequency (UHF) range with wavelengths of about 70 centimeters (cm), which limits their spatial resolution and thus their ability to see fine detail to distinguish actual targets from decoys. The longest range radar available to the GMD system is the Cobra Dane radar located in Shemya, Alaska, which operates in the L-band at a shorter wavelength (about 20 cm), allowing better spatial resolution. The highest resolution is provided by the Sea-Based X-Band Radar (SBX), a mobile long-range radar that operates at wavelengths of about 3 cm and that will be based at Adak, Alaska. (The modeled performance characteristics of those and other sensors included in CBO's analysis are shown in Appendix B.)

In addition to the GMD system, Navy ships equipped with the Aegis ballistic missile defense system could be available to respond to Iranian missile launches. The Missile Defense Agency envisions equipping 18 ships with the Aegis BMD capability, including having a total inventory of 52 Block IB interceptors available by 2014. However, 18 ships would probably not be enough to maintain a large Aegis BMD presence in Europe over extended periods. Thus, this system would most likely be a "crisis response" defense—to be used for a limited time during periods of heightened tensions—rather than a standing defense. (The form that such a defense might take and

2. The Clear and Cape Cod UEWRs are supposed to be incorporated into the missile defense system after the Air Force finishes upgrading them.

Figure 2-2.

Components of the Options for European Missile Defenses and Their Locations



Source: Congressional Budget Office.

Notes: Iran is shown in dark gray.

UEWR = upgraded early-warning radar; EIS = European Interceptor Site; EMR = European Midcourse Radar; FBR = forward-based radar.

the defensive capability it could provide are described in Chapter 3.)

Four Alternatives for Missile Defenses in Europe

To supplement those existing defenses, CBO examined four possible options for deploying missile defenses in Europe, with components located at various places in Europe and the Middle East (see Figure 2-2). MDA's plan to base missile defense facilities in Europe (Option 1 in this analysis) has entailed lengthy negotiations with host nations. To potentially simplify such negotiations, the other options that CBO developed would locate interceptors and radars either at sea or on existing U.S. bases in Europe and the Middle East (a forward-based radar, or FBR, is assumed to be located in the Caucasus region). At a Congressional hearing in April 2008, the director of MDA indicated that European nations might be more open to hosting interceptors that were mobile instead of deployed in fixed silos.[3] Thus, the land-based options that CBO developed (Options 3 and 4) would use mobile interceptors instead of the fixed ones that MDA plans to deploy.

Option 1: MDA's Planned European System

The first option corresponds to the GMD Block 4.0 European capability proposed by MDA. It comprises interceptors in Poland, an X-band radar in the Czech Republic, and a forward-based radar at a location to be determined. In line with MDA's plans, that system is assumed to be fully deployed by 2013.

The interceptors in Option 1 would be located at Redzikowo air base in northern Poland, where 10 silos, each holding one interceptor, would be built. The interceptors would be two-stage versions of the GBI, with the third stage of the booster removed to increase acceleration (see Box 2-1). Those interceptors would initially carry the EKV, although they could be adapted to carry the antidecoy MKV once it was developed.

MDA's GMD Block 4.0 system would also include an X-band radar—called the European Midcourse Radar (EMR)—to be located in Brdy, Czech Republic. In July 2008, the U.S. Secretary of State and the Czech Foreign Minister signed an agreement for the Czech Republic to host the EMR; as of December 2008, however, the agreement had been approved by the upper house of the Czech parliament but not yet by the lower house. The EMR is an existing X-band radar that would be moved to Europe from Kwajalein Atoll in the Pacific, where it has been used to support missile testing. For this analysis, CBO modeled the range of the EMR using technical descriptions of the Kwajalein radar available in unclassified sources.[4] However, some recent studies have concluded that the radar's effective range may be considerably less than modeled by CBO.[5]

MDA's plans also call for deploying a forward-based radar, although the location and description of the radar have not yet been specified. For this analysis, CBO assumed that the radar would resemble an AN/TPY-2

3. Dave Ahern, "Allied Nations Interested in Buying THAAD Ballistic Missile Defense Systems," *Defense Daily* (April 22, 2008).

4. J.F. Crawford and others, "Ground Based Radar—Prototype (GBR-P) Antenna," *IEE National Conference on Antennas and Propagation: 30 March–1 April 1999*, Conference Publication No. 461 (London: Institution of Electrical Engineers, 1999), p. 249; and "Ground-Based Midcourse Defense (GMD) Segment," *Jane's Strategic Weapons Systems* (Coulsdon, Surrey, United Kingdom: Jane's Information Group, 2007).

5. George N. Lewis and Theodore A. Postol, "The European Missile Defense Folly," *Bulletin of the Atomic Scientists,* vol. 64, no. 2 (May/June 2008), p. 32.

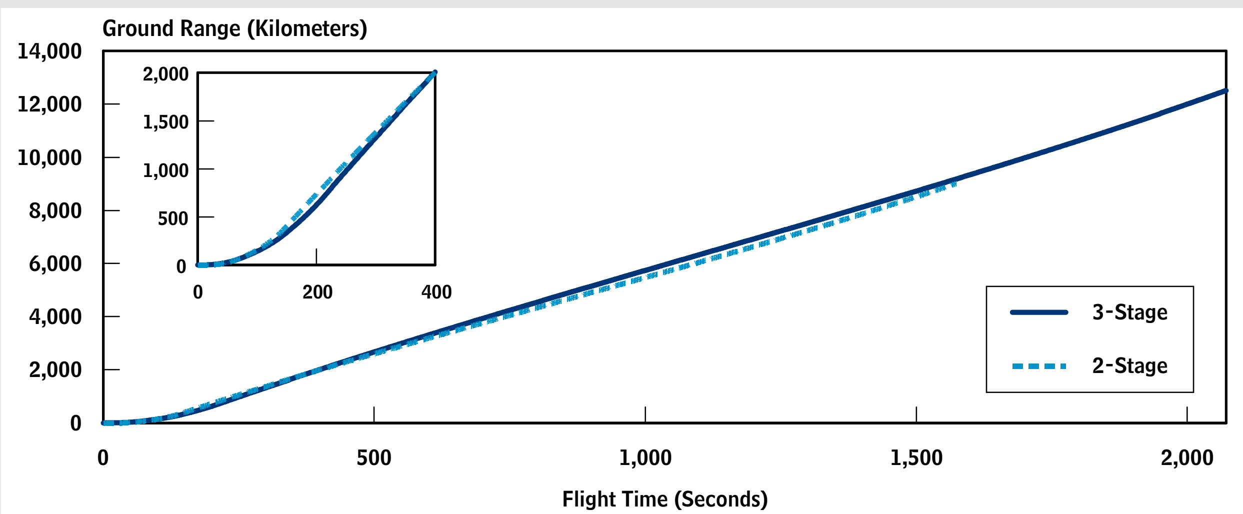
Box 2-1.

Two-Stage and Three-Stage Ground-Based Interceptors

The Missile Defense Agency (MDA) is planning to field a two-stage version of its current ground-based interceptor in Europe rather than the three-stage version used at the U.S.-based launch sites of the Ground-Based Midcourse Defense system. According to MDA, the two-stage interceptor will be very similar to the original version, with the same overall dimensions (16.6 meters long and 1.3 meters in diameter). However, the third and final stage of the interceptor's booster will be removed, and modifications will be made to the avionics module and the guidance and control software. MDA has budgeted a total of about $120 million to develop the two-stage version and integrate it into the command-and-control architecture of the overall missile defense system.

Those design modifications are necessary because European interceptors will be located closer to the potential launch sites of threat missiles than U.S.-based interceptors are, and they will need to be able to reach the intercept points sooner. Removing the third stage reduces the overall mass of the booster by about 1,000 kilograms. Because the first two stages will not have to lift that extra mass, the interceptor will accelerate more quickly. However, since the interceptor will no longer have the thrust provided by the third stage, its final burnout velocity—and thus its maximum range—will be lower than for the three-stage version (see the figure, below).

Ground Range Versus Flight Time for Two- and Three-Stage Versions of the Ground-Based Interceptor



Source: Congressional Budget Office.

Note: The trajectories shown are for an interceptor's full burn time at a sample elevation angle. The inset shows detail for the earliest portion of the flight.

transportable X-band radar with a range of 1,000 km. Press reports suggest that MDA has considered a location in the Caucasus region for the FBR; in this study, CBO assumed that the radar would be located in Azerbaijan. (That location was used in all four of the options.) The antenna of the AN/TPY-2 has a field of regard of 120 degrees in azimuth, with electronic steering available to move the radar beam quickly within that field. However, a mechanical steering kit is being developed to allow physical movement of the antenna, so that a single radar antenna can be extended to a full 360-degree field of regard in azimuth. CBO assumed that mechanical steering kits would be used for all of the AN/TPY-2 radars in this study.

The siting of a forward-based radar is critical to successful missile defense in Europe. The earlier the trajectory of a threat missile can be determined, the more time will be available for interceptors to fly to distant intercept points, expanding the area that can be defended. CBO chose Azerbaijan as the notional location for a forward-based radar because it is near Iran and would allow early tracking of the midcourse phase of missiles launched from both northern and southern Iran toward northern Europe and the continental United States. Trajectories of intercontinental ballistic missiles heading for Alaska or Hawaii would be out of range of the radar as modeled, however, as would missiles launched from southern Iran toward southern Europe. (Proposals have been made to use Russian radars in the GMD Block 4.0 system; for more details, see Box 2-2.)

Option 2: A Ship-Based European Missile Defense

The second alternative envisions using an upgraded version of the current ship-based Aegis BMD system to provide a standing missile defense (rather than merely a crisis-response defense) in Europe. The ships would be permanently stationed at three locations in waters around Europe. They would each carry 10 of the planned SM-3 Block IIA improved interceptors. Given MDA's schedule for deploying those interceptors, this option would be available sometime after 2015. MDA also intends that by that time, the Aegis BMD system will be able to use remote radars (those other than the ships' onboard SPY-1 radars). Remote radars would provide initial tracking of a threat missile to determine, just before an interceptor is launched, what initial trajectory the interceptor should take (referred to as launch on remote). Those radars will also provide data for in-flight tracking updates to the interceptor (referred to as engage on remote). The Aegis BMD system in this option is assumed to have that capability and to be supported by two forward-based radars and the existing UEWR in Fylingdales, as well as the ships' SPY-1 radars.

In designing this option, CBO assumed that the three ship stations would be located in the northwest Black Sea near the coast of Romania, in the northern Adriatic Sea off the coast of Italy, and in the Baltic Sea just north of Poland (see Figure 2-2). CBO selected those locations to minimize the number of stations that would be necessary to provide roughly the same defensive coverage of Europe as the other options. CBO's cost estimate for Option 2 (described later in this chapter) is based on the assumption that this system would be used as a standing defense, requiring continuous operations and enough ships to maintain the three stations indefinitely. However, other than the two forward-based radars, this option could also represent a future crisis-response capability if no dedicated missile defenses were fielded in Europe.[6]

Treaty constraints could make it difficult to keep a U.S. missile defense ship in the Black Sea indefinitely. The Montreux Convention, which has been in force since 1936, establishes Turkish control over the flow of ships between the Mediterranean and the Black Sea. Under the convention, warships of non-Black Sea nations are not supposed to remain in the Black Sea for more than 21 days at a time.[7] Thus, if Option 2 was implemented, the ship assumed to be on station in the Black Sea might be able to stay at that location only part of the time and might need to spend the rest of the time in other, nearby locations. CBO modeled the effect of different ship locations on the defensive capability of Option 2 (as discussed in Chapter 3). Alternatively, similar defensive capability could be achieved without triggering the constraints of the Montreux Convention by replacing the Black Sea ship station in this option with a ground-based site for SM-3 Block IIA interceptors in the Black Sea region.

6. It is also possible that the forward-based radars could be deployed in times of crisis, since the type of radar envisioned in this option (the AN/TPY-2) is transportable. However, establishing the required communications and integrating the radars into the overall command-and-control system on short notice could be difficult.

7. For more information about the Montreux Convention, see www.ntip.navy.mil/montreux_convention.shtml.

Box 2-2.

Using Russian Radars for Ballistic Missile Defense in Europe

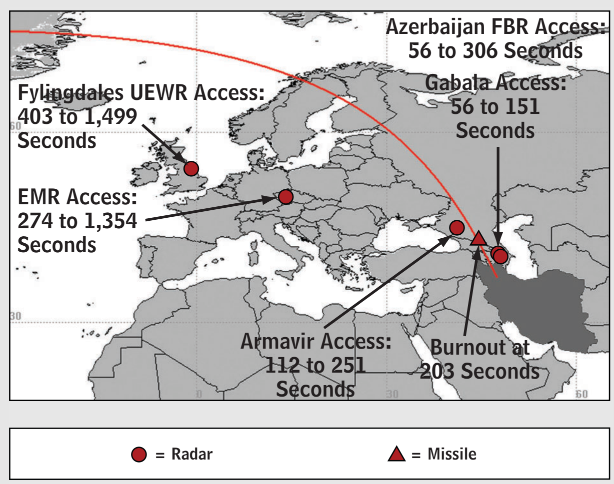
To make the proposed European missile defense system a more cooperative effort, proposals have reportedly been made to integrate Russian radars into the system. Two radars in particular have been mentioned:

- A very high frequency (VHF)-band radar in Gabala, Azerbaijan—built by the former Soviet Union and now operated by Russia—that is based on the Daryal radar design; and

- An ultrahigh frequency (UHF)-band radar in Armavir, in the Krasnodar region of Russia, that is based on the Voronezh-DM radar design.

Those radars would have both advantages and disadvantages for European missile defense. On the plus side, they are located closer to Iran than the upgraded early-warning radar in Fylingdales, England, or the proposed European Midcourse Radar in the Czech Republic. Thus, they could begin tracking missiles launched from Iran earlier in the missiles' trajectories. On the minus side, according to unclassified descriptions, both of the Russian radars operate at longer wavelengths—and therefore have lower spatial resolution—than the U.S. radars that have been proposed for use in the European defense system. Moreover, the Russian radars have a fixed field of regard that is optimized for detecting missiles headed toward Russia as the missiles clear the horizon. According to unclassified reports, the radars' azimuthal coverage (about 110 to 220 degrees for the Gabala radar and about 120 to 300 degrees for the Armavir radar) and their range of elevation angles (from just above the horizon to about 50 degrees for both radars) are appropriate for that original purpose. But those parameters are not ideally suited for tracking missiles launched from Iran toward Europe or the United States. Such missiles would tend to fly through and out of the Russian radars' field of regard very early in their trajectories (see the figure, below).

Radar Access Times for a Sample ICBM Trajectory



Source: Congressional Budget Office.

Notes: Trajectory and radar access are shown for a solid-fuel ICBM launched from northwestern Iran toward Los Angeles.

ICBM = intercontinental ballistic missile; UEWR = upgraded early-warning radar; EMR = European Midcourse Radar; FBR = forward-based radar.

The ships used in Option 2 would be dedicated to the missile defense mission full time. Because the Navy's Aegis BMD ships are multipurpose vessels that fulfill a variety of other missions, CBO assumed that maintaining three ship stations indefinitely would not be possible with the existing or planned fleet. Thus, CBO's cost estimate for this option includes funds to procure nine ships (three for each station) that would be dedicated to missile defense. Because those ships would not be serving other missions (besides self-defense), they would not need to be as capable as the destroyers or cruisers that now perform the Aegis BMD mission. For costing purposes, CBO assumed that the new ships would be littoral combat ships (like the recently commissioned LCS 1) with a specially developed Aegis BMD module. Research and development funds to create that module are included in the option's estimated costs.

For tracking, this system would use two forward-based AN/TPY-2 radars: one in Azerbaijan (as in Option 1) and one in Qatar. The SM-3 Block IIA is not as fast as the ground-based interceptor used in Option 1, so early launch of the interceptor would be more critical. Putting a forward-based radar in Qatar would allow for early tracking of missiles launched from southern Iran.

CBO did not include the European Midcourse Radar in Options 2, 3, and 4, because each of those alternatives would use two forward-based AN/TPY-2 radars. The combined field of regard of the Fylingdales radar and the two forward-based radars would provide enough tracking coverage that adding the EMR would not change the areas that could be defended, according to CBO's modeling. However, CBO's model does not quantitatively estimate the probability of successfully intercepting and destroying the threat warhead. With its high spatial resolution, the EMR is intended to better discriminate between warheads and decoys, potentially improving the probability of successfully engaging a threat missile that deploys decoys. If that capability was desired, the EMR could be added to Options 2, 3, and 4 at an additional cost.

Option 3: SM-3 Interceptors at U.S. Bases in Europe

The third alternative would use the same type of interceptor as Option 2, the SM-3 Block IIA, but based on land rather than at sea. The interceptor launch sites would be located at two U.S. bases—Ramstein Air Force Base in Germany and Incirlik Air Force Base in Turkey—with 10 interceptors at each site. Given the development schedule for the SM-3, this option could be available around 2015 (the same time as Option 2 and two years later than MDA's planned European capability).

The interceptor sites would be supported by new forward-based AN/TPY-2 radars in Azerbaijan and Qatar as well as by the existing Fylingdales UEWR. As in Option 2, the EMR was not assumed to be part of this alternative; if its extra tracking and discrimination were required, the EMR could be added to this missile defense system (at an additional cost) without significantly changing the system's defense coverage as modeled by CBO.

MDA is not currently pursuing the idea of basing SM-3 interceptors on land (although it is considering the concept as a risk-reduction alternative in the joint U.S.-Israeli Arrow interceptor program).[8] For this option, CBO assumed that the Vertical Launch System used to launch interceptors on Aegis BMD ships would also be used with the land-based version. However, in place of the SPY-1 radar that sends tracking updates during interceptor flights in the Aegis BMD system, CBO assumed that this option would employ a conventional antenna, similar to the In-Flight Interceptor Communications System (IFICS) used in the GMD system. CBO's cost estimate for Option 3 includes research and development funding to develop and field the land-based version of the SM-3, including an analog to the IFICS.

Option 4: Kinetic Energy Interceptors at U.S. Bases in Europe

The final alternative in this analysis would be very similar to Option 3 except that it would use the Kinetic Energy Interceptor instead of the SM-3 Block IIA. The KEIs would be launched from truck-based mobile launchers at Ramstein and Incirlik Air Force Bases. CBO assumed that there would be two missiles per launcher and that each launch site would have 10 interceptors and 5 launchers. CBO also assumed that the KEI would carry the Multiple Kill Vehicle to engage multiple targets in case a threat missile was carrying decoys. Based on the current development schedules of the KEI and MKV, this option would probably not be available before 2018, making it the latest of the alternatives that CBO examined.

Estimated Costs of the Options

To estimate the total costs of the four missile defense systems described above, CBO divided the costs into four categories:

- Research and development (R&D)—the engineering activities needed to design and develop interceptor boosters, kill vehicles, and other supporting components and infrastructure;
- Production—the manufacturing of interceptors and associated equipment (and, in the case of Option 2, the purchasing of ships);
- Construction—the activities required to build the physical infrastructure that supports a given missile defense system; and

8. Missile Defense Agency, Systems Engineering and Integration, "U.S. and Israel Upper Tier Ballistic Missile Defense Element Options for Defense of Israel" (briefing provided to the Congressional Budget Office, May 5, 2008).

- Operations—the routine efforts to operate and maintain the system over a nominal 20-year lifetime.[9]

Estimates of costs for systems that are defined only conceptually or that depend on the development of new technologies involve more uncertainty than do estimates for well-defined programs that are based on proven technologies. To account for the potential effects of such uncertainty, CBO estimated a range of costs for the four missile defense options. In each case, the low estimate represents what a system might cost if few technical difficulties arose in making it fully operational. The high estimate takes into account the risk of cost growth by factoring in the extent to which costs have typically grown for similar systems in the past.[10]

Overall, CBO estimates that the planned GMD Block 4.0 system in Europe (Option 1) would cost a total of $9 billion to $13 billion (in 2009 dollars) over 20 years. A system using land-based SM-3 Block IIA interceptors at U.S. bases in Germany and Turkey (Option 3) would cost about the same amount, and a system of Kinetic Energy Interceptors at those bases (Option 4) would cost slightly more: between $10 billion and $14 billion. A permanent ship-based European missile defense (Option 2) would be more expensive—between $18 billion and $22 billion over 20 years—in part because of the costs of building new ships (see Table 2-1).

Research and Development Costs

In CBO's estimates, R&D costs include only those activities and associated costs that would be incurred specifically for missile defenses in Europe. No R&D costs have been included for systems that MDA is developing for general use. For example, development costs for the SM-3 Block IIA interceptor and the KEI have not been included because their development is not specific to European defenses. But the costs associated with developing a two-stage version of the three-stage ground-based interceptor have been included because that version is being developed specifically for deployment in Europe. No R&D costs have been included for systems that have already been developed, such as the AN/TPY-2 and EMR radars.

For the GMD Block 4.0 system in Option 1, CBO estimates that developing the two-stage version of the GBI and performing required software upgrades would cost about $400 million, based on information provided by MDA. For Option 2, CBO estimates that about $200 million would be needed to develop a missile defense module for the littoral combat ship (LCS), consistent with past module-development costs for the LCS. For Option 3, CBO estimates that a total of $400 million would be needed—about $300 million to develop the land-based SM-3 missile defense capability, consistent with an MDA estimate for the Arrow risk-reduction concept, and $100 million to develop an in-flight interceptor communications system. All of those estimates include a factor of 40 percent to account for the costs of integrating the components into the existing infrastructure. For Option 4, no Europe-specific R&D would be necessary because the system would rely on components that already exist or that MDA is developing for general use.

To account for cost risk, CBO increased each of those low estimates by a factor of 48 percent to produce the high estimates shown in Table 2-1. The 48 percent factor is consistent with past cost growth for comparable systems.

Production and Construction Costs

Manufacturing interceptors, radars, ships, and other equipment for the four options would cost a total of about $2 billion to $10 billion, depending on the option, CBO estimates. Building the necessary physical infrastructure at the interceptor launch sites and radar sites would cost another $0.3 billion to $1.1 billion (not including possible cost growth).

Interceptors. When designing the options for this analysis, CBO assumed that 10 interceptors would be deployed at each launch site. Because the number of launch sites varies among the options, however, the total number of deployed interceptors also varies. In addition to deployed interceptors, CBO included spare interceptors in each option's inventory, with the number of spares equaling 20 percent of the number deployed. Thus, Option 1 includes a total of 22 interceptors: 10 installed

9. The distinction between those categories of costs is made only for the purposes of this study. Historically, funding for MDA, including for production and operations, has all come under the budget category of research, development, test, and evaluation, although recently some funds have come under the budget category of military construction.

10. Those cost-risk factors, developed by the RAND Corporation, are based on unpublished updates to Jeanne M. Jarvaise, Jeffrey A. Drezner, and Daniel M. Norton, *The Defense System Cost Performance Database: Cost Growth Analysis Using Selected Acquisition Reports,* MR-625-OSD (Santa Monica, Calif.: RAND, 1996).

Table 2-1.

Cost Estimates for the European Missile Defense Options

(Billions of 2009 dollars)

	Option 1		Option 2		Option 3		Option 4	
	Low	High	Low	High	Low	High	Low	High
Research and Development[a]								
Interceptors	0.3	0.4	0.2	0.2	0.4	0.5	0	0
Radars	0	0	0	0	0	0	0	0
System integration	0.1	0.2	0.1	0.1	0.1	0.2	0	0
Subtotal	0.4	0.5	0.2	0.3	0.5	0.7	0	0
Production								
Interceptors	1.2	1.2	2.1	2.8	0.7	1.0	1.9	2.5
Radars	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Ships	0	0	5.9	5.9	0	0	0	0
Ground equipment	0.6	0.8	0	0	0.2	0.3	0.2	0.3
Communication sets	0.4	0.4	1.0	1.2	0.5	0.6	0.5	0.6
Other	0.3	0.4	0.2	0.2	0.3	0.4	0.3	0.4
Subtotal	2.8	3.2	9.5	10.4	2.1	2.6	3.2	4.1
Site Construction	1.1	1.4	0.3	0.3	0.5	0.7	0.5	0.7
Operations (Over 20 years)								
Routine operations	4.6	6.8	3.2	4.7	5.9	8.8	5.9	8.8
Ship operations	0	0	5.1	6.2	0	0	0	0
Operational testing	0.4	0.8	0	0	0	0	0	0
Subtotal	5.0	7.6	8.3	10.9	5.9	8.8	5.9	8.8
Total	**9.2**	**12.8**	**18.3**	**21.9**	**9.0**	**12.8**	**9.6**	**13.6**

Source: Congressional Budget Office.

Notes: Option 1 = silo-based GBI; Option 2 = sea-based SM-3 Block IIA; Option 3 = land-based SM-3 Block IIA; Option 4 = land-based KEI.

The low estimates assume that few technical difficulties arise in making a system fully operational; the high estimates account for the extent to which costs have typically grown for similar systems in the past.

GBI = Ground-Based Interceptor; SM = Standard Missile; KEI = Kinetic Energy Interceptor.

a. The estimates do not include development costs for components that the Missile Defense Agency (MDA) already plans to develop for applications not specific to European defense. For Option 4, no Europe-specific R&D would be necessary because the system would rely on components that already exist or that MDA is developing for general use.

in silos in Poland, 2 spares, and 10 for testing (assuming one test every two years over the 20-year lifetime of the system). Costs for test interceptors were included in Option 1 because the two-stage GBI is specific to the European system; no test interceptors were included in the other options because both the SM-3 Block IIA and the KEI are being developed for general use, and testing stock will presumably be part of their overall programs. Option 2 includes a total of 72 interceptors: 10 each for six ships (assuming that, consistent with current practice, missiles can be transferred between ships in port but not on station) and 12 spares. Options 3 and 4 each include a total of 24 interceptors: 10 apiece at the launch sites in Germany and Turkey plus 4 spares.

To calculate total production costs for each option's interceptors, CBO used a two-step approach. It estimated the costs of producing the first unit of each component of an interceptor and of assembling those components into the first interceptor off the production line. It then estimated costs for further purchases of the same type of interceptor by using learning-curve methods, which account for the fact that later units of something tend to have lower per-unit production costs than earlier units.

An interceptor consists of several parts: the booster, the booster's avionics (electronic communications and navigation systems), the kill vehicle, and, for mobile interceptors, the launch canister. CBO used various methods to estimate the costs of purchasing the first units of those components:

- Booster costs were estimated with a model developed by the technical consulting firm Technomics; the model uses a cost-estimating relationship based on the total impulse (thrust multiplied by burn time) of each stage of a booster and other technical parameters to calculate the cost of the first production model of the booster.

- Costs for the booster's avionics and the kill vehicle were estimated with the Unmanned Spacecraft Cost Model developed by Tecolote Research. That model uses cost-estimating relationships based on the mass of various types of components. As inputs to the model, CBO estimated the mass of the different components using information from MDA and other unclassified sources.

- Canister costs were based on estimates from MDA.

Integrating and assembling the components would add 12 percent to the total cost of an interceptor, CBO estimated, and government systems engineering and project management would add another 30 percent. Those percentages are consistent with Tecolote's cost-estimating relationship for such work. On the basis of those calculations, CBO estimated that the first two-stage GBI off the production line would cost about $66 million, the first SM-3 Block IIA interceptor would cost about $37 million, and the first KEI would cost about $94 million.

As with previous estimates, CBO accounted for cost risk by applying factors to those low estimates that reflect historical cost growth for comparable systems. The high estimates assume that production costs for the boosters, avionics, and canisters could grow by about 38 percent and that production costs for the kill vehicle could rise by about 19 percent. However, CBO assumed that no cost risk would be associated with the two-stage GBI because that interceptor is a very close variant of the three-stage GBI that is currently deployed.

Costs for the remaining interceptors that would be purchased under each option were estimated by analyzing trends in actual costs for the ground-based interceptors that MDA recently purchased. CBO's analysis suggests that doubling the number of interceptors being purchased reduces the average cost per interceptor by about 5 percent. Buying the 22 interceptors envisioned in Option 1 would result in an average per-unit cost of slightly over $55 million, CBO estimates, meaning that total interceptor production costs under Option 1 would amount to about $1.2 billion (with no significant risk of cost growth). CBO assumed that other interceptors would show a similar trend of cost declining as quantity increased, so producing 72 SM-3 Block IIA interceptors for Option 2 would cost between $2.1 billion and $2.8 billion, and producing 24 of the same interceptors for Option 3 would cost between $0.7 billion and $1.0 billion. Producing 24 Kinetic Energy Interceptors for Option 4 would cost between $1.9 billion and $2.5 billion.

Radars and Other Equipment. CBO's estimates of production costs for radars were based on information from MDA. Those costs total roughly $300 million for each of the options, with the European Midcourse Radar and AN/TPY-2 radar both estimated to cost about $150 million apiece. Option 3 also includes about $100 million to pay for an in-flight interceptor communications system that would transmit tracking updates from the available radars to interceptors in flight.

Cost estimates for Option 1 for ground equipment, communications equipment to link the facilities of the European defense system, site security, and construction of the facilities were based on information provided by MDA. CBO adapted those estimates as necessary for Options 2, 3, and 4.

Ships. CBO assumed that nine new ships would have to be procured under Option 2 so that three ship stations could be maintained indefinitely as a standing defense. Rather than purchasing more of the current multimission Aegis warships, CBO assumed that the Navy would use dedicated missile defense ships modeled on the littoral combat ship. A missile defense LCS would have a total unit cost of about $650 million, CBO estimates: $560 million for the ship itself (based on an earlier CBO estimate of average LCS costs) and the remainder for the missile defense module, including a SPY-1 radar and Vertical Launch System cells. CBO assumed that production costs for the ships would not grow significantly beyond the margins already included in that $650 million estimate. Total costs would be about $5.9 billion.

The Navy could, however, choose to use upgraded versions of its existing and planned Aegis-capable surface combatants to provide missile defense for Europe. In that case the Navy would forgo performing the missions those ships now perform, but a substantial portion of the $5.9 billion in funding for constructing new dedicated missile defense ships would be unnecessary.

Operations Costs

According to the Missile Defense Agency, each of the locations of the proposed European defense system—interceptor site, EMR site, and FBR site—will cost about $70 million to operate in 2013, the year they are scheduled to become operational. All told, operations costs for the system will total about $230 million per year, MDA estimates. CBO assumed that operations costs would continue at that level throughout the nominal 20-year lifetime of the system. Thus, CBO estimates total costs of routine operations for Option 1 at about $4.6 billion over that period, not counting possible cost growth. For the other land-based systems, Options 3 and 4, CBO used the same $70 million per-site estimate of annual operations costs for each of the four locations (two interceptor sites and two FBR sites). As a result, estimated operations costs for those options total about $5.9 billion over 20 years. Likewise, Option 2 would require about $3.2 billion to operate its two FBR sites over 20 years. In addition, the nine missile defense ships would each cost about $30 million per year to operate, CBO estimates, for total ship operations costs of about $5.1 billion (without cost growth). For that estimate, CBO used actual average operating costs for Navy frigates as a proxy for the littoral combat ship.

To account for the possible growth of operations costs, CBO increased those low estimates by 50 percent for radar and ground-based interceptor sites and by 20 percent for ships.

CBO assumed that only Option 1 would conduct additional interceptor tests beyond those already planned under current or projected MDA schedules. In general, operational tests of missile defenses have three components: target missiles that are launched to simulate enemy missiles, interceptors that are fired at those targets, and analysis of the data from the test. CBO assumed that MDA would conduct one test every two years, for a total of 10 operational tests over the 20-year period. The costs of the 10 interceptors used in those tests are included in the production costs for Option 1. The remaining costs for those tests would total about $40 million per test, CBO estimated on the basis of information from MDA—about $20 million for the target missiles and their launch and another $20 million for the data analysis. Thus, 10 operational tests over 20 years would cost $0.4 billion. For the high estimate, CBO assumed that the costs of the targets and data analysis could increase twofold, to about $0.8 billion in all.

CHAPTER

3

Defensive Capabilities of Alternative Midcourse-Phase Missile Defenses

To compare the defensive capabilities of the various missile defense systems described in Chapter 2, the Congressional Budget Office modeled the ability of those systems to intercept missiles launched from Iran. The analysis covered both near-term threats (the shorter-range Shahab-3, Shahab-3A, and Ashura missiles that Iran has tested or claims to have developed) and potential future threats from Iran (including liquid-fuel intermediate-range ballistic missiles and both liquid- and solid-fuel intercontinental ballistic missiles). The primary measure of defensive capability that CBO computed is the area defended against a given type of missile, which is presented in maps comparing those areas. To make the options easier to compare, CBO also computed two summary measures: the number of European NATO capitals and the fraction of the U.S. population that a given system would defend.

The area threatened by a missile—and the ability of missile defenses to engage threats—depends strongly on the locations of the launch sites for both the threat missile and the interceptor. CBO considered three launch sites in Iran: one each in the northwestern, northeastern, and southeastern "corners" of the country. Those locations do not correspond to any specific known Iranian missile sites; rather, they are intended to explore the effect of geography on defensive capability by choosing extreme points from the range of potential launch sites. In each case, CBO chose a launch site that is at least 200 kilometers from the Iranian border or coastline in all directions, on the assumption that missile stations would be placed away from borders to avoid direct attack. Given their shorter range and the emphasis on European defense in this study, near-term threat missiles were assumed to be launched only from the northwestern site. For the potential future threats, all three Iranian launch sites were included in CBO's modeling. For an area to be considered defended against a given missile, it must be defended against launches from *all* of the sites that are capable of reaching it with that missile.

In this analysis, CBO assumed that the various missile defense systems would be able to achieve their intended level of operational effectiveness. However, a number of technical analyses have questioned the efficacy of the planned systems, particularly if an adversary uses countermeasures. CBO did not explicitly model the systems' effectiveness in the presence of countermeasures, but that issue is discussed in Box 3-1.

The analytic results shown in this report depend on the assumptions that CBO made about the performance of the threat missiles and the defensive systems and about the locations of the components of those systems. Because many of the systems in this analysis are under development or are proxies for systems that could potentially be developed, their actual performance parameters are still uncertain. Different sets of assumptions would lead to different results. (For a discussion of the sensitivity of CBO's analysis to selected performance assumptions, see Appendix B.)

The U.S.-Based GMD Block 3.0 System

Before considering the capability of dedicated missile defenses in Europe, it is useful to look at the capability that would be available if no dedicated European defenses were fielded. The Missile Defense Agency plans to have the Ground-Based Midcourse Defense Block 3.0 system—comprising three-stage Ground-Based Interceptors in Alaska and California and tracking radars at various

Box 3-1.

Capabilities Against Countermeasures

Along with developing missiles, some nations have worked to develop countermeasures that could hinder missile defense systems. Common countermeasures include decoy warheads that are deployed to confuse interceptors; jammers, chaff, or flares that are designed to disrupt sensors trying to track a threat warhead; and maneuverable warheads that can change their trajectory during flight.

Each of the options that the Congressional Budget Office (CBO) modeled for this analysis consists of existing or planned systems that use techniques intended to mitigate the effects of countermeasures. (Those techniques are summarized in the table at right.) CBO's model does not estimate the probability of a successful intercept, and thus it does not quantify the relative value of the various approaches to deal with countermeasures.

One type of countermeasure commonly discussed in the missile defense literature is the deployment of decoys. Potential ways of handling decoys include deploying sensors that can distinguish the actual warhead from surrounding decoys (usually referred to as discrimination) and deploying multiple kill vehicles on a single interceptor with the aim of engaging all of the objects that could be warheads. In an ideal case, those two techniques would be combined to increase the chance of successfully engaging the warhead. As modeled, none of the options in this study would use both techniques; however, all of them could potentially do so.

For these options, the optimum way to use radar to discriminate between warheads and decoys is to have continuous tracking with high-resolution X-band radar from the time that the decoys and warheads are deployed (shortly after the booster burns out) until the intercept. Continuous tracking is also critical to engaging warheads that can maneuver during the midcourse phase of flight. Option 1, with both the European Midcourse Radar (EMR) and a forward-based radar (FBR), would have the most X-band radar coverage over the engagement portion of a threat missile's trajectory. It would also be capable of tracking missiles from burnout to intercept for many (though not all) trajectories. However, constraints on steering both the FBR and the EMR could preclude full tracking for multiple, widely separated missiles launched at about the same time (see Box 3-2 on page 30). Continuous tracking for multiple missiles and for all trajectories would require additional radars beyond those included in Option 1.

Options 2, 3, and 4 are assumed to include two FBRs but not the EMR, so high-resolution tracking would be available only for the early portion of a threat missile's trajectory. Tracking later in the trajectory would come from the lower-resolution Fylingdales or SPY-1 radars. Adding the EMR to those options (at an extra cost of about $600 million to procure and install the radar and about $70 million per year to operate it) would improve the discrimination capability to match that of Option 1, with little change to the area that could be defended.

Continued

locations—operational by about 2012.[1] Thus, the capability of any dedicated European defenses that were fielded after that time would supplement the defensive capability provided by the Block 3.0 system.

The GMD Block 3.0 system is intended to defend the United States against limited long-range threats from Iran. Because its interceptor sites are far from Europe, the system will not provide any defense of Europe against Iran's near-term or potential future threats. However, according to CBO's modeling, the Block 3.0 system will be able to defend almost all of the United States (including Hawaii) and much of Canada against liquid- or solid-fuel ICBMs launched from Iran (see Figure 3-1). The

1. For more details about the components of the Block 3.0 system and the other missile defense systems described here, see Chapter 2.

Box 3-1. **Continued**

Capabilities Against Countermeasures

As modeled, only Option 4 is assumed to incorporate the planned Multiple Kill Vehicle (MKV), which is intended to allow a single interceptor to engage multiple objects. Future plans call for deploying the MKV on Ground-Based Interceptors, so that kill vehicles could be added to Option 1 at some point. However, the extra mass of the MKV would reduce the area that could be defended under Option 1. During development of the Standard Missile-3 (SM-3) Block IIA interceptor, the Missile Defense Agency considered the possibility of having it carry the MKV (perhaps a variant of the one modeled here), but the agency recently decided to stick with a unitary warhead for that version of the interceptor. However, a possible follow-on version of the interceptor, sometimes referred to as the SM-3 Block IIB, might carry the MKV. How that would affect the area defended would depend on the mass of the MKV and the modifications made to the interceptor.

Summary of Techniques Used to Mitigate the Effect of Countermeasures

Technique	Desired Effect	Option 1	Option 2	Option 3	Option 4
High-Resolution X-Band Radar	Discriminate between warhead and decoys	Yes (FBR and EMR)	Partial (FBR only, as modeled)	Partial (FBR only, as modeled)	Partial (FBR only, as modeled)
Multiple Kill Vehicle	Engage multiple targets to reduce the effect of decoys	Not as modeled	Not as modeled	Not as modeled	Yes
Radar Wavelength Diversity	Reduce susceptibility to chaff and jammers	Yes (X-band and UHF)	Yes (X-band, UHF, and S-band)	Yes (X-band and UHF)	Yes (X-band and UHF)
Two-Color Infrared Sensor on Kill Vehicle	Reduce susceptibility to infrared stealth, improve kill vehicle's discrimination between warhead and decoys	Yes	Yes	Yes	Yes

Source: Congressional Budget Office.

Note: FBR = forward-based radar; EMR = European Midcourse Radar; UHF = ultrahigh frequency.

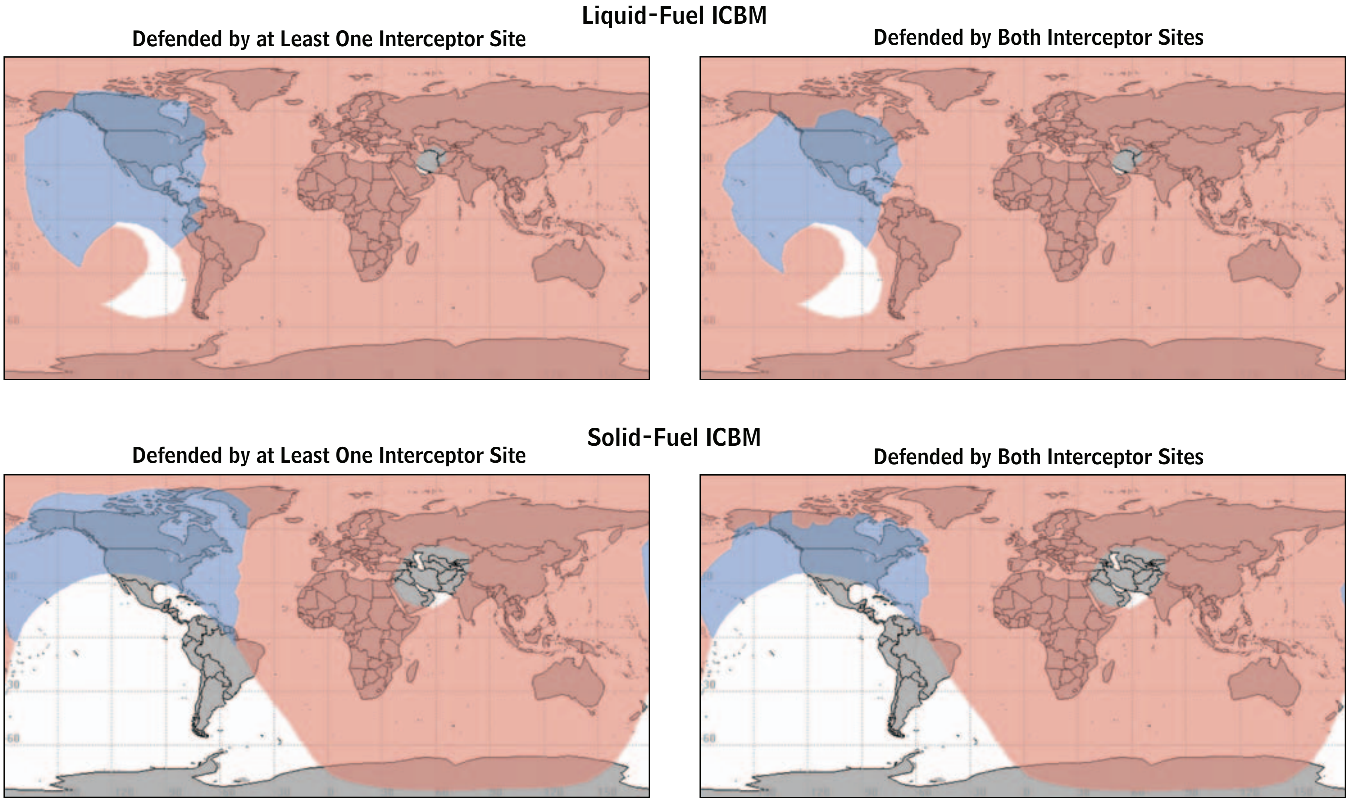
exception is that Alaska will be defended against solid-fuel ICBMs but not liquid-fuel ICBMs.

Most of the Block 3.0 system's defense is redundant—in other words, each of the system's interceptor launch sites is capable of defending almost the entire continental United States (see the right-hand panels of Figure 3-1). Intercept timelines would not allow an interceptor to be launched from the second site if the initial interceptor from the first site was unsuccessful (a practice known as shoot-look-shoot; see Box 3-2). Thus, the full potential value of having redundant interceptor sites would not be realized. But the redundancy provides some protection against the temporary loss of one site—for example, because of natural disasters or equipment failure.

To intercept U.S.-bound missiles from Iran, the GMD Block 3.0 system will rely on tracking from radars in Fylingdales, England, and Thule, Greenland. However, it will not be capable of defending those radar sites against

Figure 3-1.

Areas Defended by the GMD Block 3.0 System Against ICBMs from Iran



Source: Congressional Budget Office.

Notes: Blue shading indicates the area defended against a given missile threat. Red shading indicates undefended areas within range of that threat.

Interceptor sites for the Block 3.0 system are located at Fort Greely in Alaska and Vandenberg Air Force Base in California.

GMD = Ground-Based Midcourse Defense; ICBM = intercontinental ballistic missile.

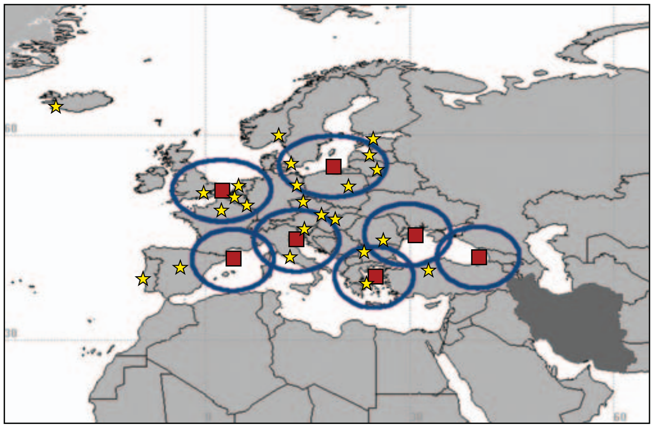
Iranian missiles, which makes the system vulnerable to attacks in which multiple missiles first target the radars and then target the United States. That vulnerability could be removed by using local defenses to protect the radars—say, Aegis ballistic missile defense ships or terminal-phase systems such as the Terminal High-Altitude Area Defense or Medium Extended Air Defense System.

A Potential Crisis-Response Defense

Another system that would be available in the absence of dedicated European missile defenses is Aegis BMD ships equipped with Standard Missile-3 Block IB interceptors. Those interceptors are scheduled to start being deployed in about 2011. At that point in the Aegis BMD development plan, the missile defense system would have to use onboard SPY-1 radars to track threats. Because Aegis ships can communicate with each other, the BMD system could use SPY-1 radars on a network of ships to provide tracking throughout the engagement with a threat missile. However, although the system could use other radars (such as an upgraded early-warning radar) to provide initial tracking of the threat missile, it would not be able to use those radars to provide tracking updates after the interceptor was launched. Thus, the number of ships required to provide defense over a broad area would depend mainly on the field of regard of the SPY-1 radar rather than on the performance of the interceptor. (The Aegis BMD system in Option 2, by contrast, would use Block IIA interceptors, which are more advanced, and external radars throughout the engagement; it would not be available until around 2015.)

Figure 3-2.

Radar Footprint for Aegis BMD Ships



☆ = NATO Capitals ■ = Ships

Source: Congressional Budget Office.

Notes: Dark blue outlines indicate the footprint of Aegis ships' SPY-1 radars at an altitude of 400 kilometers for the seven ship locations that CBO modeled. Iran is shown in dark gray.

BMD = ballistic missile defense; NATO = North Atlantic Treaty Organization.

CBO modeled the defensive capability provided by Aegis BMD ships with SM-3 Block IB interceptors operating around Europe. For its modeling, CBO assumed that seven ships would be operating in different locations: two in the Black Sea, one in the Adriatic Sea, one in the Aegean Sea, one in the western Mediterranean, one off the coast of Poland, and one in the English Channel (see Figure 3-2). With SPY-1 radars, that distribution of ships would provide radar access over a large fraction of Europe at engagement altitudes, although there would be gaps in the radar access in some locations. Those gaps correspond to regions where late tracking updates would not be available to interceptors. Intercepts that occurred in those regions might have less-up-to-date tracking information than intercepts in other areas and thus might have a lower probability of success. However, for any given trajectory of a threat missile, an interceptor generally has a range of possible intercept locations, which means that the gaps in radar access could be avoided in many cases. Consequently, those gaps might have little impact on the overall area defended.

To provide continuous missile defense for an extended period, additional ships would have to be available to rotate periodically to the seven locations. (A typical multiplier for Navy operations calls for having three to four ships for each long-term station.) Currently, MDA plans to outfit a total of 18 Aegis BMD ships, most of which will be based in the Pacific, where transit times to Europe are longer than for Atlantic-based ships. Because not enough ships are likely to be available to maintain that capability indefinitely, it would probably be used only during periods of heightened tension.

Against near-term threats from Iran, most of the defensive coverage provided by this crisis-response system would come from the ships in the Black Sea. That coverage would extend into threatened regions adjacent to the Black Sea, including parts of Turkey (see Figure 3-3). In the case of IRBMs, some of the trajectories that a missile could fly would be beyond the range of SPY-1 radars on the nearest ships. If that happened, the IRBM's track could not be determined until it had flown within radar range of one of the ships farther from Iran, reducing the time available for intercept and resulting in scattered areas of defensive coverage. ICBMs on trajectories with shortened burn times would fly at a lower altitude than IRBMs and could be visible to the SPY-1 radars sooner, so the area defended against ICBMs would have fewer gaps. However, that defense would not extend to all of Europe. In addition, this crisis-response system with Aegis SM-3 Block IB interceptors located around Europe would not provide any additional defense of the United States against Iranian ICBMs.

CBO's Four Options for Deploying Standing Missile Defenses in Europe

CBO also analyzed the extent to which Europe and the United States could be defended by the four options described in Chapter 2: MDA's proposed European capability (Option 1), SM-3 Block IIA interceptors deployed on Aegis BMD ships at three stations (Option 2) or on land at U.S. Air Force bases in Germany and Turkey (Option 3), or Kinetic Energy Interceptors located at those bases (Option 4). According to CBO's modeling, Option 4 would provide nearly complete coverage of the parts of Europe within range of near-term Iranian threats, and Options 2 and 3 would provide coverage of most, but not all, of those areas. Option 1 would offer the least defense of areas within range of near-term Iranian threats. All of the alternatives would provide substantial coverage of Europe against IRBMs and solid-fuel ICBMs launched from Iran. With its interceptors located farther northwest

Box 3-2.

Attacks with Multiple Missiles and Shoot-Look-Shoot Defense

The estimates of defensive capability presented in this study are based on the assumption that a missile defense system will be dealing with a single threat missile at a time. However, an adversary could try to overwhelm missile defenses by launching multiple missiles. In recent years, both North Korea and Iran have conducted missile tests in a salvo configuration, with several missiles launched at roughly the same time.

Launching multiple missiles almost simultaneously on divergent trajectories could reduce the ability of the modeled options to provide tracking. Both the European Midcourse Radar and the forward-based radar would be capable of tracking missiles over a wide range of azimuth angles, through a combination of electronically steering the radar beam within the instantaneous field of view and mechanically steering the antenna to move that field of view.[1] Although steering electronically between multiple targets is essentially instantaneous, steering the antenna mechanically is relatively slow. Thus, if targets were far enough apart to be outside the same instantaneous field of view, the radar's ability to mechanically steer quickly enough to maintain tracking could limit the ability of a defense system to engage multiple missiles at the same time.

The total number of threat missiles (whether fired singly or in a salvo) that the options in this study could handle would depend on the guidelines for launching interceptors—that is, the firing doctrine. To increase the likelihood of successfully destroying a given missile, more than one interceptor could be fired at it. The director of the Missile Defense Agency was recently quoted as saying that "salvo launching [of interceptors] makes sense for...systems where you don't have a lot of battlespace and you want to get off two shots to make sure of your intercept.... [It does not] make as much sense for the long-range system... normally you would fire, determine if you are successful, and if you are not, you fire again."[2] The latter approach is known as shoot-look-shoot.

The Congressional Budget Office (CBO) analyzed the possibility of using the shoot-look-shoot approach with the missile defense options in this study. For threat missiles launched at European targets, the extent to which the options would be capable of shoot-look-shoot defense varies considerably depending on the type of missile and its launch location. For example, Options 1, 2, and 4 would provide shoot-look-shoot defense for large parts of Europe against intermediate-range ballistic missiles (IRBMs) launched from all three modeled locations in Iran. Option 3 would offer shoot-look-shoot defense for about half of Europe against IRBMs launched from

1. The Congressional Budget Office assumed that both radars would be able to operate over the full 360-degree range of azimuth (the direction of the trajectory relative to north).

2. Thomas Duffy, "MDA Reconsidering Ground-Based Midcourse Salvo Tests," *Inside Missile Defense* (April 9, 2008).

Continued

than the others, however, Option 1 would leave parts of Greece, Turkey, and other areas of southeastern Europe undefended against those missiles (unless other resources were added to MDA's proposed system). Against the more challenging liquid-fuel ICBMs, all of the options would leave large parts of Europe undefended.

In addition to their coverage of Europe, some of the alternatives could offer another layer of defense to protect the United States from potential Iranian ICBMs. (That defense would be in addition to the coverage offered by the U.S.-based GMD Block 3.0 system.) Option 1 would provide the most extensive coverage of the United States against ICBMs, defending all of the continental United States. Option 4 would offer substantial defense of the United States but would still leave large areas undefended. Options 2 and 3 would cover little or none of the United States unless interceptor sites were added on U.S. soil.

Box 3-2. Continued

Attacks with Multiple Missiles and Shoot-Look-Shoot Defense

northeastern and southeastern Iran, but for only a small portion of southern Europe against IRBMs launched from northwestern Iran. In the case of liquid-fuel intercontinental ballistic missiles (ICBMs), shoot-look-shoot defense would not be available in any of the options for substantial parts of Europe against ICBMs launched from northwestern Iran; Options 3 and 4 would provide no shoot-look-shoot defense anywhere in Europe against those threats.

In the absence of other supporting defenses, operators would presumably launch two interceptors against any threat missile determined to be headed for European targets where shoot-look-shoot was not possible. They might opt for a single interceptor if shoot-look-shoot was considered feasible. CBO's cost estimates for the four options assume an inventory of 10 interceptors at each launch site, so each site would be able to handle between 5 and 10 threat missiles targeted at Europe. (Conclusions about the maximum number of targets that could be engaged do not take into account any possible constraints that the sensors might place on the number of targets engaged at the same time or any limits that the interceptor launch systems might impose on how closely in time interceptor launches can occur.)

If the options in this study were supported by more forward-based defenses—particularly a future boost-phase defense system—shoot-look-shoot between the options and those supporting defenses could allow for a more economical use of midcourse interceptors. In some cases, midcourse interceptors would engage only targets that the forward-based defenses failed to destroy. Similarly, if the options were supported by terminal-phase systems (such as the Terminal High-Altitude Area Defense) in specific locations, threat missiles headed for those locations might be engaged with a single midcourse interceptor, and the local terminal-phase system would serve as backup if the intercept failed. In that case, the options would perhaps use a single interceptor per engagement and thus each interceptor site could handle up to 10 threat missiles launched at European targets.

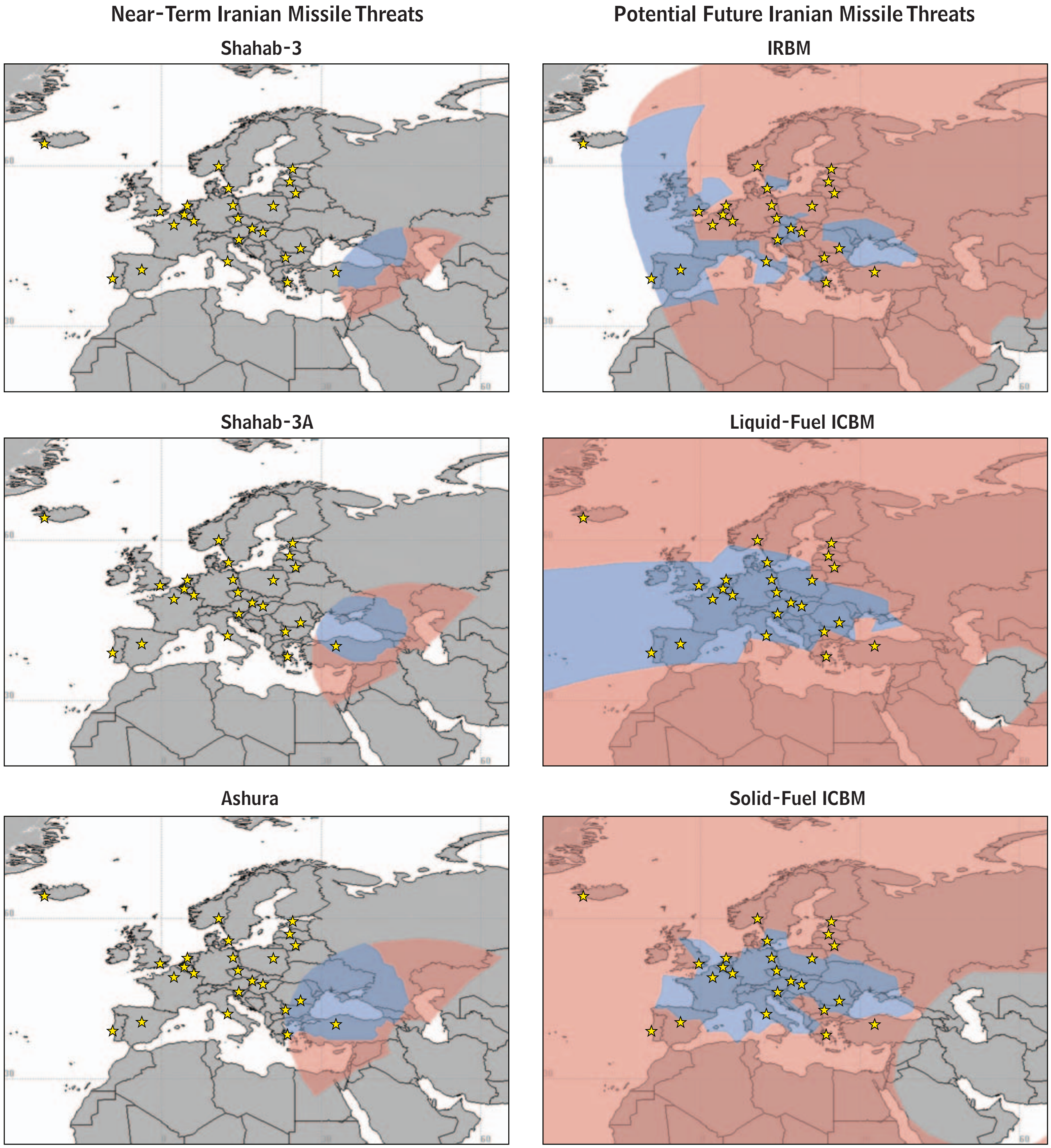
For ICBMs launched at the United States, none of the options by themselves would be capable of shoot-look-shoot defense against missiles launched from all of the modeled locations in Iran—although Options 1 and 2 would provide some shoot-look-shoot defense for portions of the United States against ICBMs launched from northeastern or southeastern Iran. However, all four of the options, to the extent they could defend regions of the United States, would be capable of shoot-look-shoot in those regions if the second interceptor came from one of the Ground-Based Midcourse Defense system sites in Alaska or California. Thus, for threat missiles that were determined to be heading toward the United States, it is possible that operators of the midcourse defenses in Europe might elect to fire a single interceptor at each missile, allowing the maximum of 10 threat missiles to be engaged per European interceptor site.

Ability to Defend Europe

The areas within range of near-term Iranian missiles extend to central Turkey and the Caucasus in the case of the Shahab-3 and Shahab-3A, and beyond the Black Sea into southeastern Europe in the case of the Ashura (see Figure 3-4). Option 1, with a single interceptor site in Poland, would provide the least defensive coverage of those regions (none at all for areas within range of the Shahab-3). That conclusion from CBO's model is consistent with the results of modeling by MDA. (The agency has indicated that other resources would be required to defend those regions.) The other three options include interceptor sites in the Black Sea or eastern Mediterranean regions and thus would be able to defend more of the areas within range of those near-term threats. Given the high acceleration of Kinetic Energy Interceptors,

Figure 3-3.

Areas Defended by Aegis BMD Ships Using SM-3 Block IB Interceptors



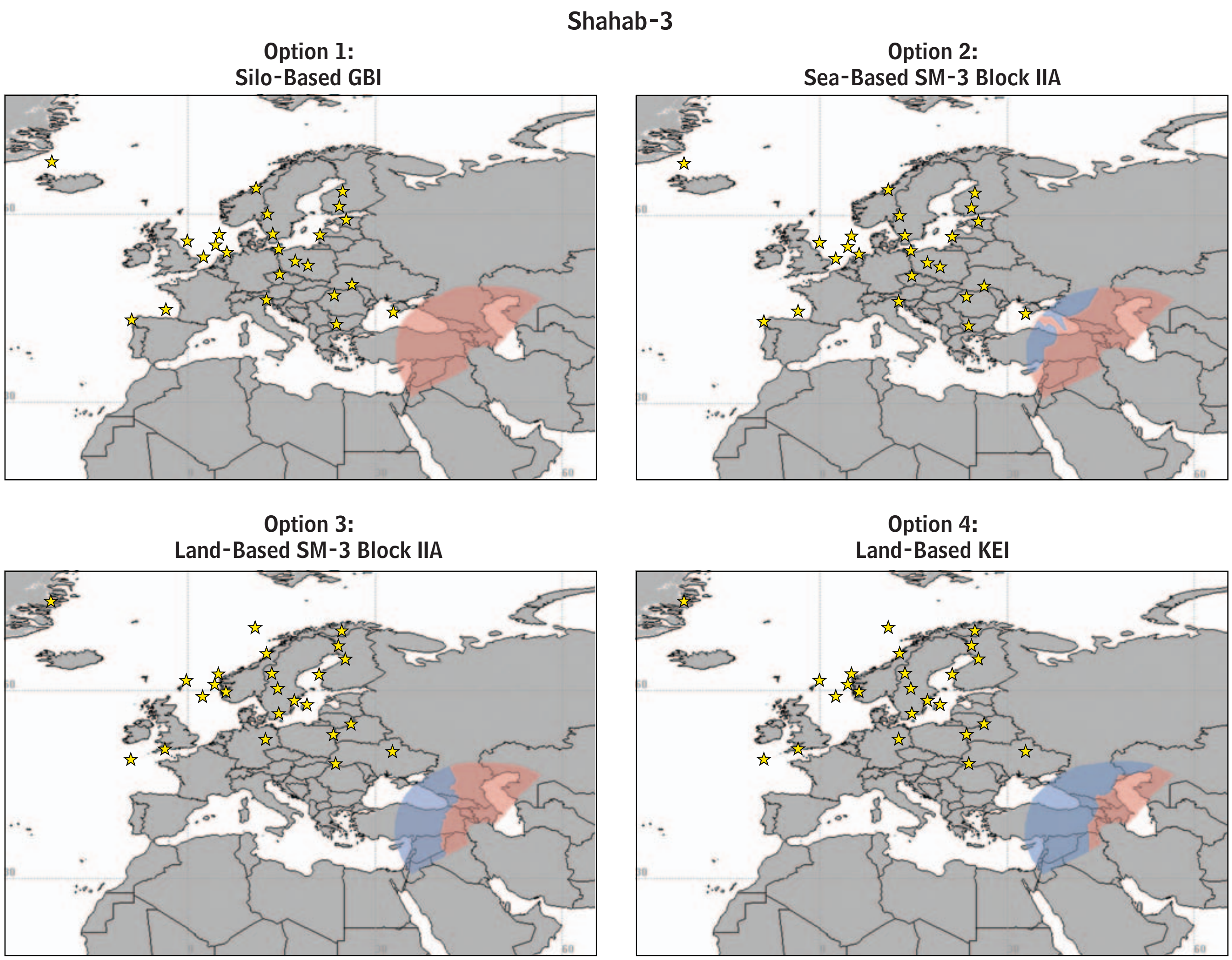
Source: Congressional Budget Office.

Notes: Blue shading indicates the area defended against a given missile threat by Aegis ships using SM-3 Block IB interceptors deployed in the seven locations shown in Figure 3-2. Red shading indicates undefended areas within range of a given threat. Yellow stars show the locations of NATO capitals.

BMD = ballistic missile defense; SM = Standard Missile; IRBM = intermediate-range ballistic missile; ICBM = intercontinental ballistic missile; NATO = North Atlantic Treaty Organization.

Figure 3-4.

Areas Defended by the Missile Defense Options Against Near-Term Threats from Iran



Continued

Option 4 would provide the most extensive defensive coverage against those missiles.[2]

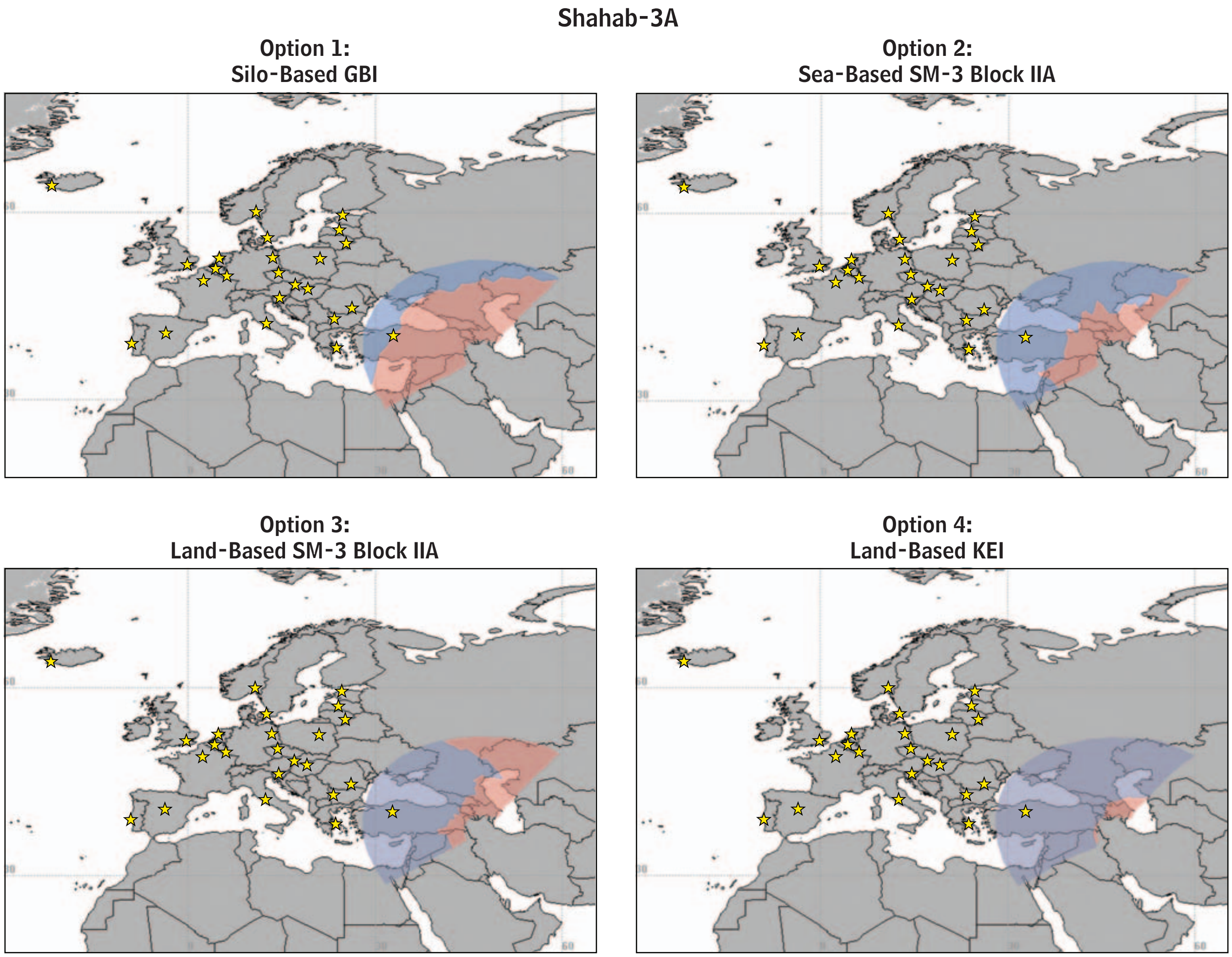
The potential future Iranian IRBM that CBO modeled would be capable of reaching all of continental Europe, the United Kingdom, and Ireland. All four options would have substantial capability to defend Europe against that IRBM threat, although only Option 4 would completely cover the threatened portions of NATO countries (see Figure 3-5).

As with the near-term threats, Options 2, 3, and 4 would offer more extensive coverage of southeastern Europe against IRBMs than MDA's proposed system would because those options would have interceptor sites closer to that region. Option 1 would need additional resources to defend that area. As an example of how the defensive capability of MDA's proposed system might change if

2. As described in Chapter 2, CBO assumed in its modeling that near-term threat missiles would be launched from northwestern Iran to maximize their reach into Europe. In some cases, however, the same missiles launched from other parts of Iran might be able to reach portions of Europe and could be more difficult for some of the options to defend against.

Figure 3-4. **Continued**

Areas Defended by the Missile Defense Options Against Near-Term Threats from Iran



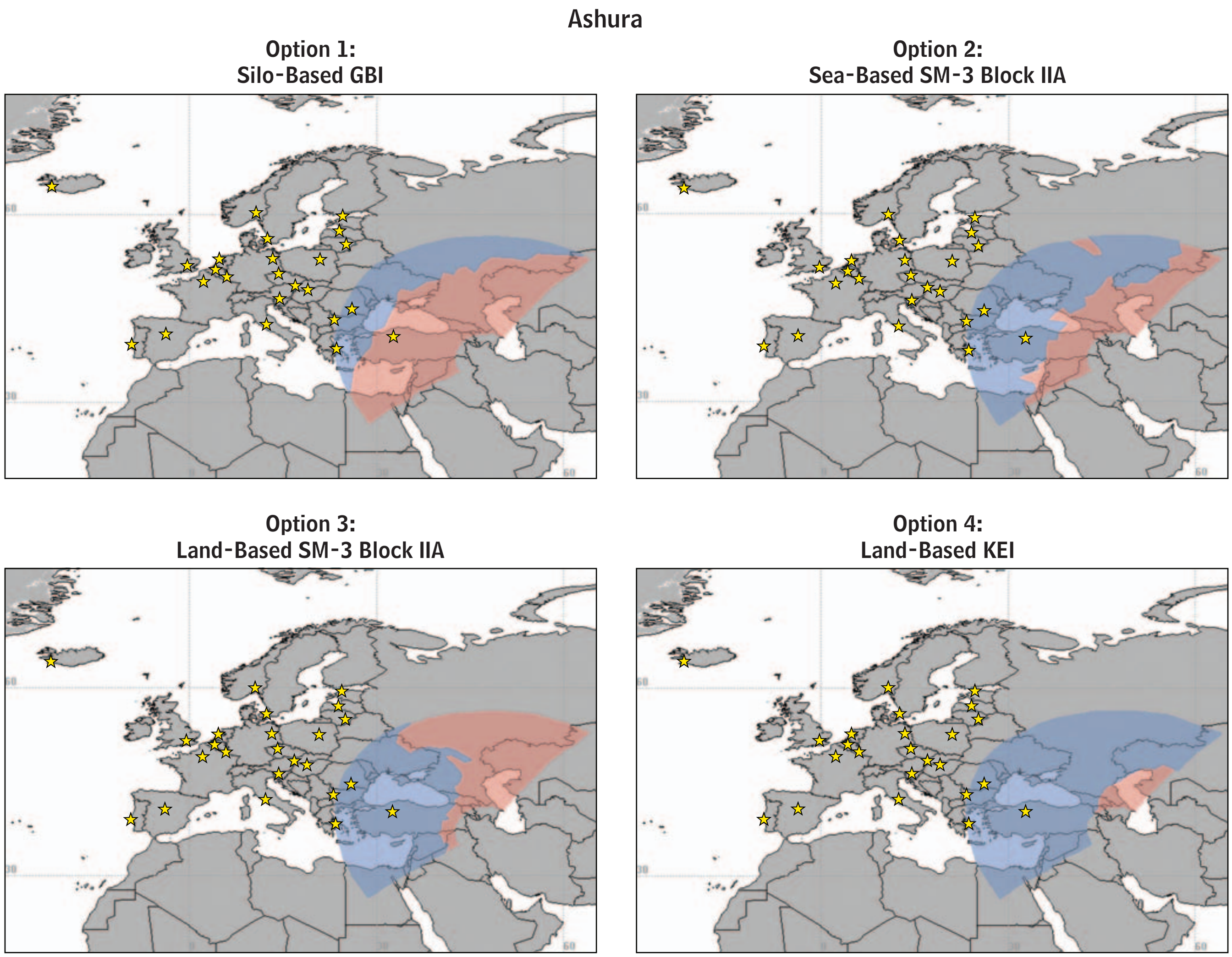
Continued

more resources were available, CBO modeled the extra coverage provided by adding a single station for Aegis BMD ships with SM-3 Block IIA interceptors in the northwestern Black Sea (see the area outlined in blue in the Option 1 panel in Figure 3-5). Other possibilities for expanding coverage exist, such as using THAAD or MEADS batteries to provide area defense in selected locations. CBO's cost estimate for Option 1 (described in Chapter 2) does not include additional resources to expand coverage of southeastern Europe. If land-based SM-3 Block IIA interceptors were available, adding a second interceptor site would cost a total of about $2.1 billion, CBO estimates: $700 million to procure the equipment and $1.4 billion to operate the site over 20 years. If a sea-based Aegis BMD system was used, the incremental cost of a second interceptor site would depend on whether the Navy employed existing ships and how the ships were operated.[3]

3. Those possibilities for expanding Option 1's coverage of southeastern Europe do not use additional two-stage Ground-Based Interceptors because those interceptors accelerate too slowly to be useful closer to the launch sites of Iranian missiles.

Figure 3-4. Continued

Areas Defended by the Missile Defense Options Against Near-Term Threats from Iran



Source: Congressional Budget Office.

Notes: Blue shading indicates the area defended against a given missile threat. Red shading indicates undefended areas within range of that threat. Yellow stars show the locations of NATO capitals.

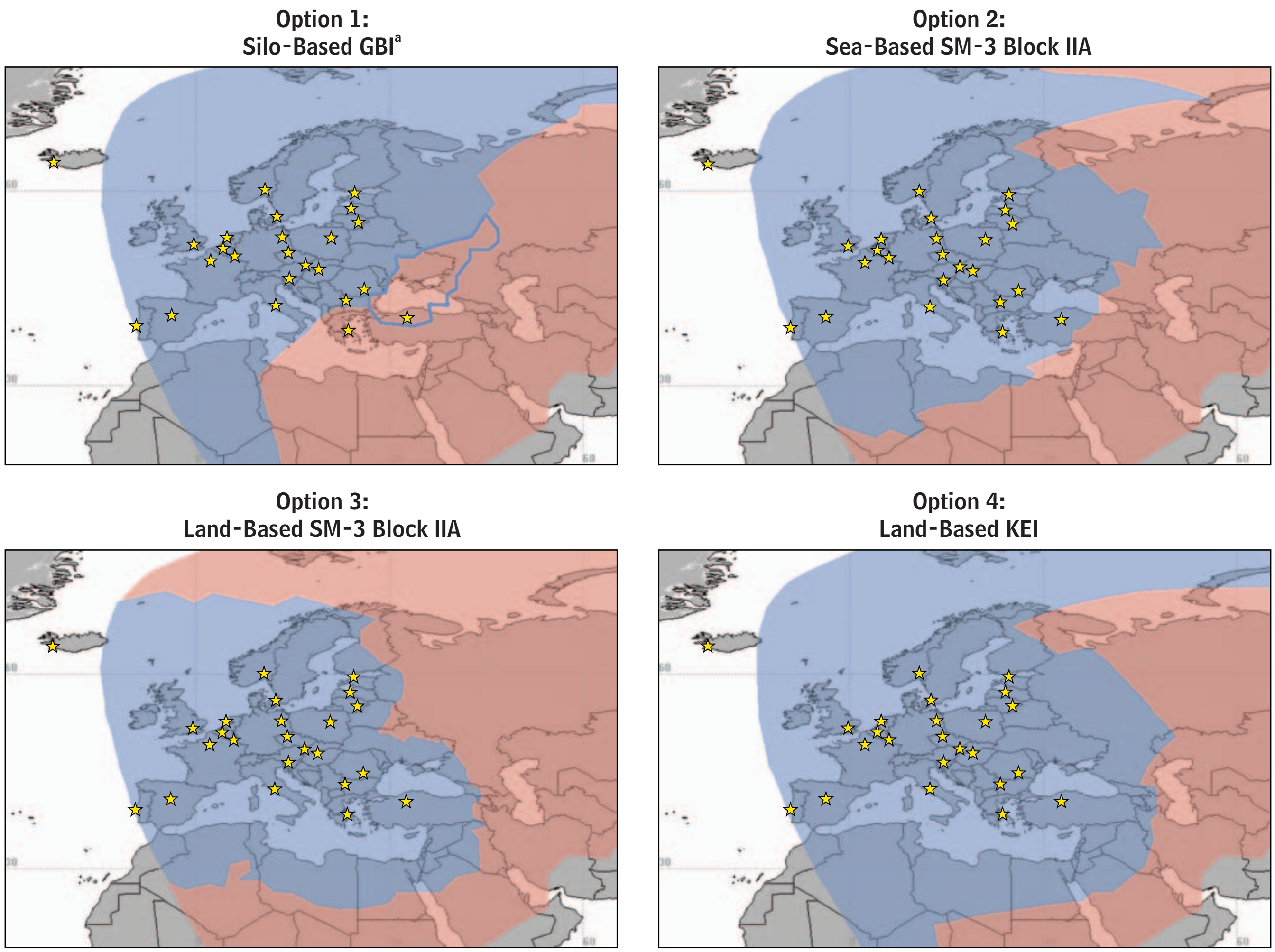
GBI = Ground-Based Interceptor; SM = Standard Missile; KEI = Kinetic Energy Interceptor; NATO = North Atlantic Treaty Organization.

Against solid-fuel ICBMs, each option would provide much the same coverage of Europe as it would against IRBMs. Liquid-fuel ICBMs, however, present a more challenging threat because they have a longer burn time and fly at lower altitudes to European targets than IRBMs or solid-fuel ICBMs. All of the options would leave substantial portions of Europe undefended against liquid-fuel ICBMs (see Figure 3-6). Some potential adversaries might view attacking Europe with an ICBM—which would be capable of a much longer range—as an in efficient use of missile technology and development resources, especially if an IRBM was available. Nevertheless, the prospect presents a challenge to European missile defenses as modeled in this study.

Given that challenge, planners might choose to add more interceptor sites to improve their ability to defend Europe against liquid-fuel ICBMs. For example, adding one

Figure 3-5.

Areas Defended by the Missile Defense Options Against IRBMs from Iran



Source: Congressional Budget Office.

Notes: Blue shading indicates the area defended against a given missile threat. Red shading indicates undefended areas within range of that threat. Yellow stars show the locations of NATO capitals.

IRBM = intermediate-range ballistic missile; GBI = Ground-Based Interceptor; SM = Standard Missile; KEI = Kinetic Energy Interceptor; NATO = North Atlantic Treaty Organization.

a. The area outlined in blue indicates additional coverage that would be provided if a site for ship-based SM-3 Block IIA interceptors was added in the northwestern Black Sea.

interceptor site in Poland and another in Romania to Option 3—in addition to the sites in Germany and Turkey—would significantly expand the area defended (see the area outlined in blue in the Option 3 panel in Figure 3-6). Even so, a few parts of Europe (such as the southern halves of Italy and the Iberian Peninsula) would remain vulnerable. CBO estimates that adding land-based SM-3 Block IIA interceptor sites to Option 3 would cost a total of about $2.1 billion per site: $700 million for the equipment and $1.4 billion for operations over 20 years.

Option 2's defensive coverage is based on the assumption of maintaining three ship stations, including one in the northwestern Black Sea. As noted in Chapter 2, treaty constraints could make it difficult to keep a missile defense ship stationed in the Black Sea indefinitely, in which case the ship would have to spend part of the time at other, nearby locations. CBO analyzed how Option 2's coverage would change if the ship station in the Black Sea was replaced with one in the eastern Mediterranean or the Aegean Sea. Against near-term threats, a BMD ship stationed in the eastern Mediterranean would provide less defensive coverage of southern Russia and the Caucasus region, but slightly more coverage of Turkey and the Middle East, than a ship stationed in the Black Sea. A ship stationed in the Aegean would provide far less coverage of Turkey against near-term threats than one in the Black Sea. Against a potential IRBM, both alternative ship locations would offer overall defensive capability similar to that of a Black Sea location, although with less coverage of the Black Sea and eastern Ukraine. In addition, a ship stationed in the Aegean would defend only half as much of Turkey against IRBMs as a ship in the Black Sea or eastern Mediterranean. In the case of solid-fuel ICBMs, moving ship stations would have little effect on Option 2's defensive coverage. The largest change would involve defensive capability against liquid-fuel ICBMs: Both alternative ship locations would lessen coverage of southeastern Europe (including Ukraine, Romania, and Bulgaria) against those missiles.

None of the options, as modeled, would be able to defend all of the capital cities of European NATO countries against all of the types of missiles in this analysis that could potentially reach them. Only one NATO capital (Ankara, Turkey) is within range of the Shahab-3A missile, and only three (Ankara; Athens, Greece; and Bucharest, Romania) are within range of the Ashura. Options 2, 3, and 4 would be capable of defending those cities against those threats, but Option 1's defensive coverage would not extend to Ankara (see Figure 3-7). Likewise, Options 2, 3, and 4 could defend all of the European NATO capitals within range of potential Iranian IRBMs or solid-fuel ICBMs, whereas Option 1 would not defend Ankara or Athens. Against potential Iranian liquid-fuel ICBMs, however, all of the options would leave a significant fraction of threatened capitals undefended.

The various analyses above apply to threat missiles flying minimum-energy trajectories (flight paths that would give them the maximum range for a given total amount of fuel), with the range reduced to hit the desired target by reducing the amount of fuel burned. In some cases, however, missiles on lofted or depressed trajectories could present a more challenging threat to defenses—especially IRBMs or ICBMs aimed at Europe (see Appendix A).[4] To explore that possibility, CBO modeled how the options' ability to defend Europe would change if faced with IRBMs flying depressed trajectories. With such trajectories, the area that could be defended would be reduced along the edge nearest the launch site of the threat missile. For example, in the case of an IRBM launched from northwestern Iran, the southeastern edge of the area of defensive coverage would move northward by at least 500 kilometers. The actual extent of the reduction in coverage would depend on the design of the threat missiles. When missiles fly depressed trajectories, they remain in the atmosphere longer, subjecting them to greater structural stresses than missiles on minimum-energy trajectories. Thus, trajectories that are substantially depressed may not be physically possible.

Ability to Defend the United States

The only missiles in this analysis that could reach the United States from Iran are ICBMs. The four options for European missile defenses would, to varying degrees, defend the United States against the potential ICBM threats modeled by CBO (see Figure 3-8 on page 41). Because the GMD Block 3.0 system is assumed to be in place by the time the options become operational, the options' defensive coverage of the United States would be in addition to the nearly complete defense of the United States available from the Block 3.0 system.

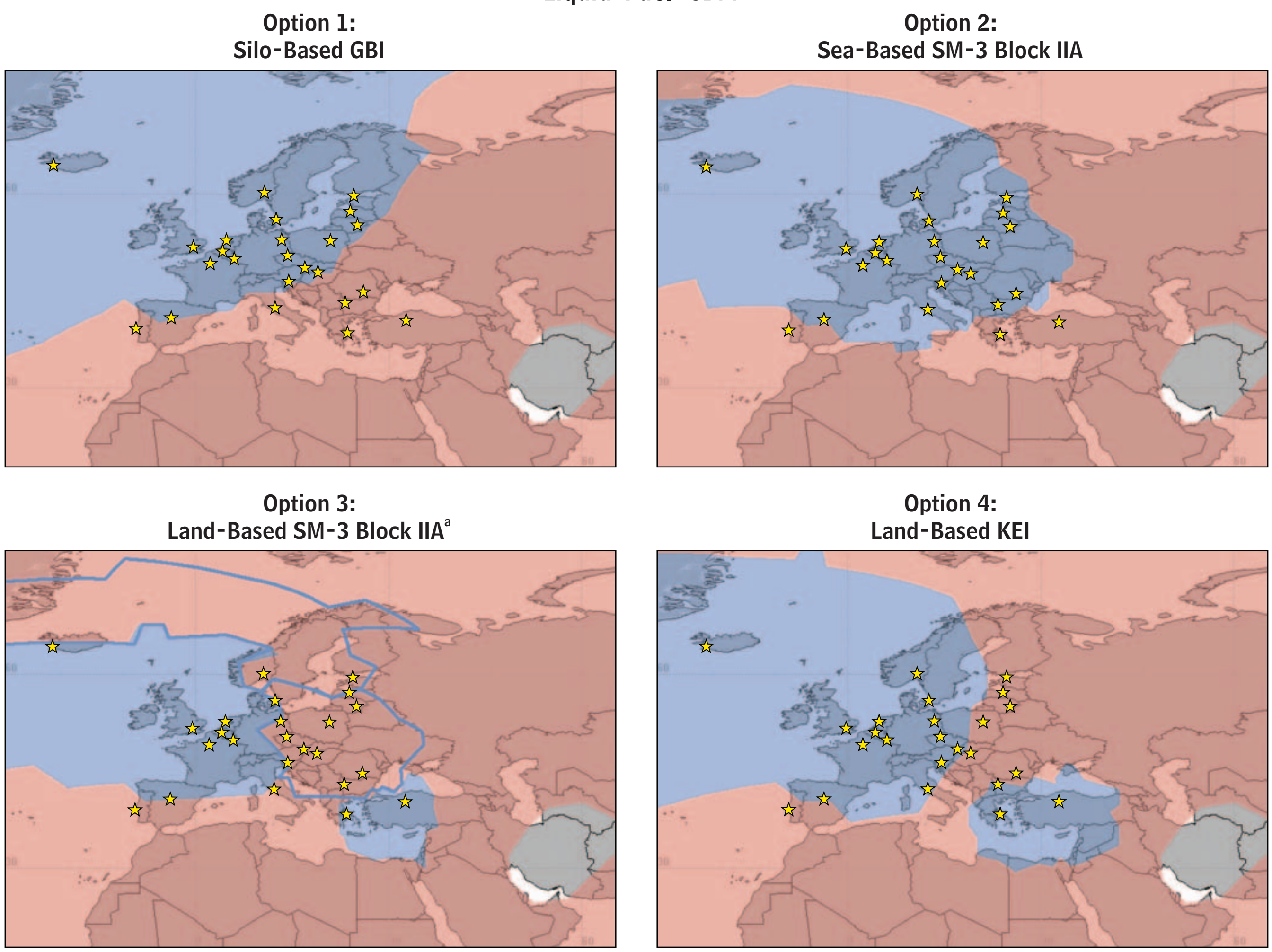
Of the modeled options, MDA's proposed European system would provide the most extensive defense of the United States, covering the entire continental United States against liquid-fuel ICBMs and covering all of the threatened portion of the continental United States plus part of Alaska against solid-fuel ICBMs. (That coverage would be reduced if the system used a forward-based radar located in Israel instead of the Caucasus; see Box 3-3 on page 44.) Option 4, with its Kinetic Energy Interceptors, would also provide substantial added coverage of the United States, particularly against solid-fuel ICBMs. The systems using SM-3 Block IIA interceptors (Options 2 and 3) offer the least additional defense of the United States: almost none against solid-fuel ICBMs and coverage of only parts of the northeastern (and, in the case of Option 2, central) United States against liquid-fuel ICBMs.

4. Lofted or depressed trajectories would not be a problem with ICBMs aimed at the United States from Iran because those missiles would have to travel trajectories close to minimum energy to be able to reach the United States.

Figure 3-6.

Areas of Europe and the Middle East That the Options Would Defend Against ICBMs from Iran

Liquid-Fuel ICBM



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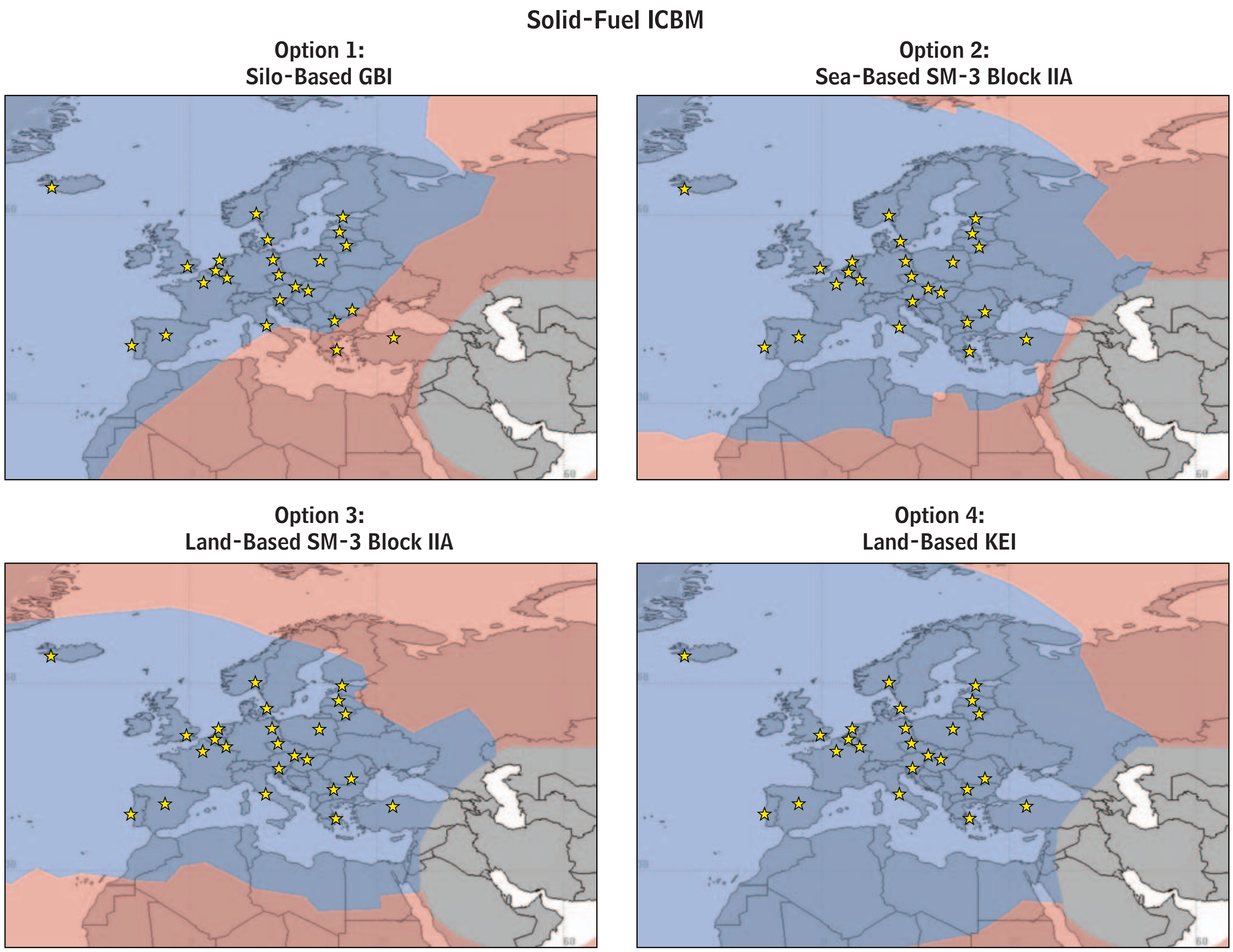
U.S. defense could be expanded under Options 2 and 3 by adding an interceptor site in the United States. For example, with an extra launch site for SM-3 Block IIA interceptors in Cape Cod, Massachusetts—supported by UEWRs in Cape Cod, Thule, and Fylingdales—Option 3 could defend the eastern half of the threatened portion of the United States (see Figure 3-8 on page 41). The expansion of coverage would be similar under Option 2 with a sea-based interceptor site near Cape Cod. If additional coverage of the western United States was required, a second interceptor site could be added in the northwestern part of the country. For that site, however, the engagement geometry and sensor coverage against Iranian threats would be essentially the same as for the existing GMD sites in the western United States, and the proximity of the interceptor sites would preclude shoot-look-shoot defense, so the value of adding that redundant SM-3 defense on the West Coast would be questionable. Such a site might be able to defend parts of the United States against attack by sea-based missiles off the West Coast that would be out of range of the GMD sites, but analyzing such a threat is beyond the scope of this study. As with a supplemental site in Europe, adding a land-based SM-3 Block IIA site in the United States would cost about $700 million for procurement and about $1.4 billion for operations over 20 years, CBO estimates.

Figure 3-6. **Continued**

Areas of Europe and the Middle East That the Options Would Defend Against ICBMs from Iran



Source: Congressional Budget Office.

Notes: Blue shading indicates the area defended against a given missile threat. Red shading indicates undefended areas within range of that threat. Yellow stars show the locations of NATO capitals.

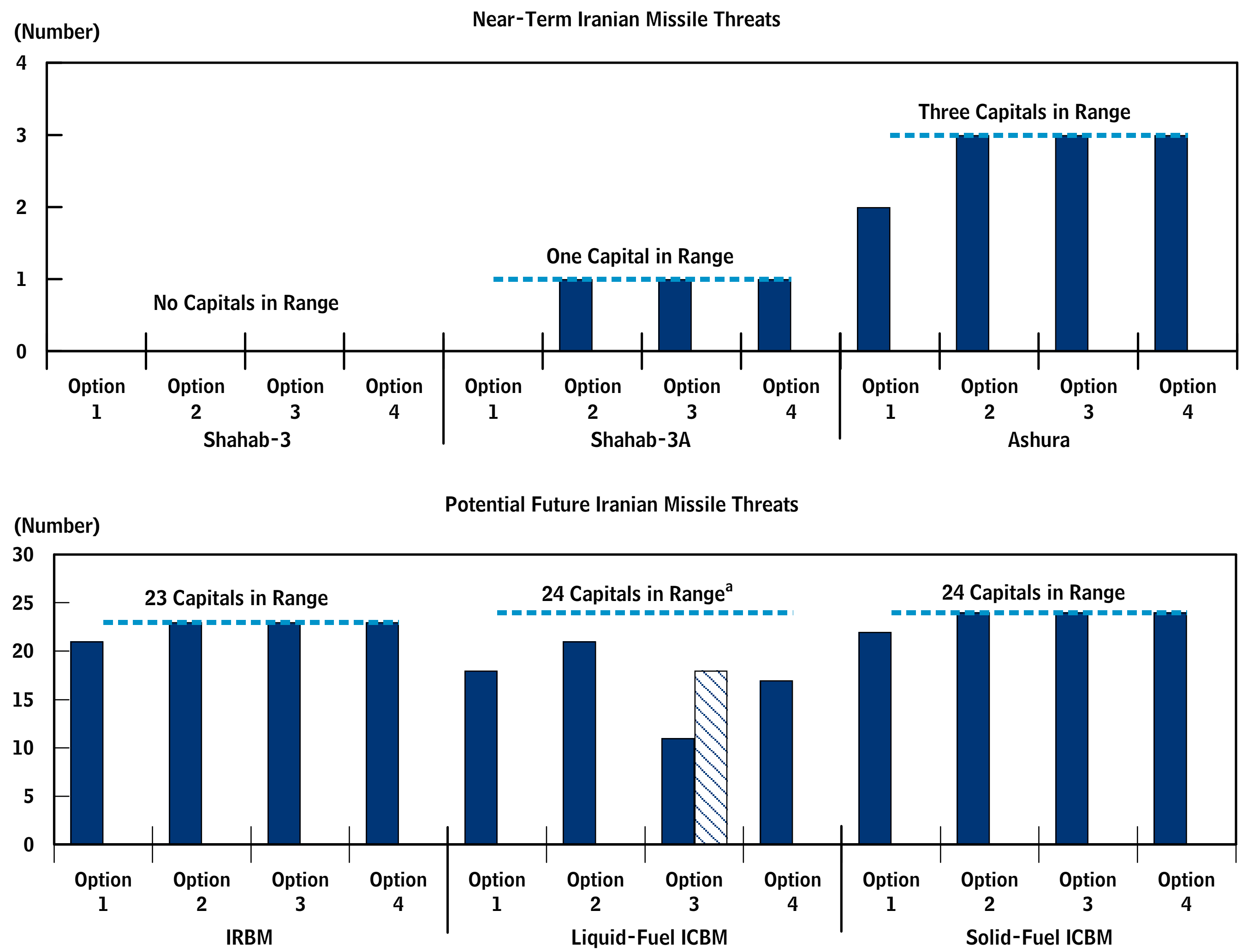
ICBM = intercontinental ballistic missile; GBI = Ground-Based Interceptor; SM = Standard Missile; KEI = Kinetic Energy Interceptor; NATO = North Atlantic Treaty Organization.

a. The areas outlined in blue indicate additional coverage that would be provided if sites for land-based SM-3 Block IIA interceptors were added in Poland and Romania.

As a summary measure, CBO analyzed the level of redundancy of the U.S. defense against Iranian ICBMs in terms of the number of interceptor sites providing defense as a function of the percentage of the U.S. population defended. Nearly all of the U.S. population potentially within range of an Iranian liquid-fuel ICBM will be covered by at least one of the GMD Block 3.0 system's two interceptor sites, and 97 percent will be covered by both sites (see Figure 3-9 on page 43). Option 1 would supplement the coverage of those two sites with its interceptor site in Poland, with the result that more than 95 percent of the threatened U.S. population would be defended by three interceptor sites. Likewise, Option 4's additional coverage would mean that about 75 percent or

Figure 3-7.

Number of European NATO Capitals That the Options Would Defend Against Various Missile Threats



Source: Congressional Budget Office.

Notes: Option 1 = silo-based GBI; Option 2 = sea-based SM-3 Block IIA; Option 3 = land-based SM-3 Block IIA; Option 4 = land-based KEI.

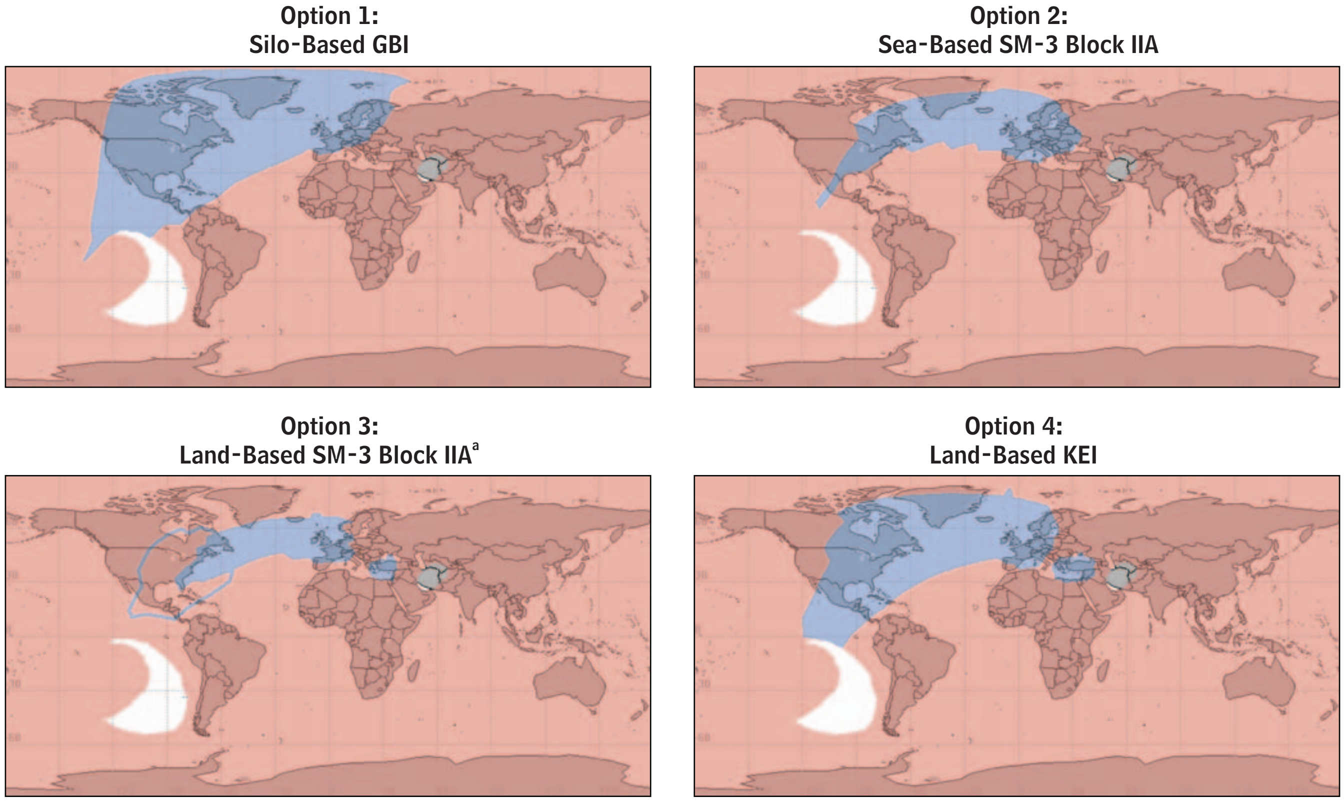
NATO = North Atlantic Treaty Organization; IRBM = intermediate-range ballistic missile; ICBM = intercontinental ballistic missile; GBI = Ground-Based Interceptor; SM = Standard Missile; KEI = Kinetic Energy Interceptor.

a. The striped column for Option 3 against liquid-fuel ICBMs indicates additional coverage that would be provided if interceptor launch sites were added in Poland and Romania.

Figure 3-8.

Total Area That the Options Would Defend Against ICBMs from Iran

Liquid-Fuel ICBM



Continued

more of the threatened U.S. population would be defended by three interceptor sites.[5] Such redundant defense is desirable as a hedge against attacks with multiple missiles, natural disasters, or technical problems that could disable an interceptor site. Further, the additional U.S. coverage provided by all of the options, when combined with that of the GMD Block 3.0 system, would allow for the use of shoot-look-shoot defense (see Box 3-2 on page 30), which could improve the efficiency with which interceptors were used to engage threats.[6] (Shoot-look-shoot defense is not possible between the two Block 3.0 sites alone.)

5. All of that additional coverage would come from the KEI site in Germany; the site in Turkey would not provide any coverage of the United States.

6. CBO has not modeled the possibility of shoot-look-shoot between an SM-3 Block IIA site in the eastern United States and the GMD sites on the West Coast.

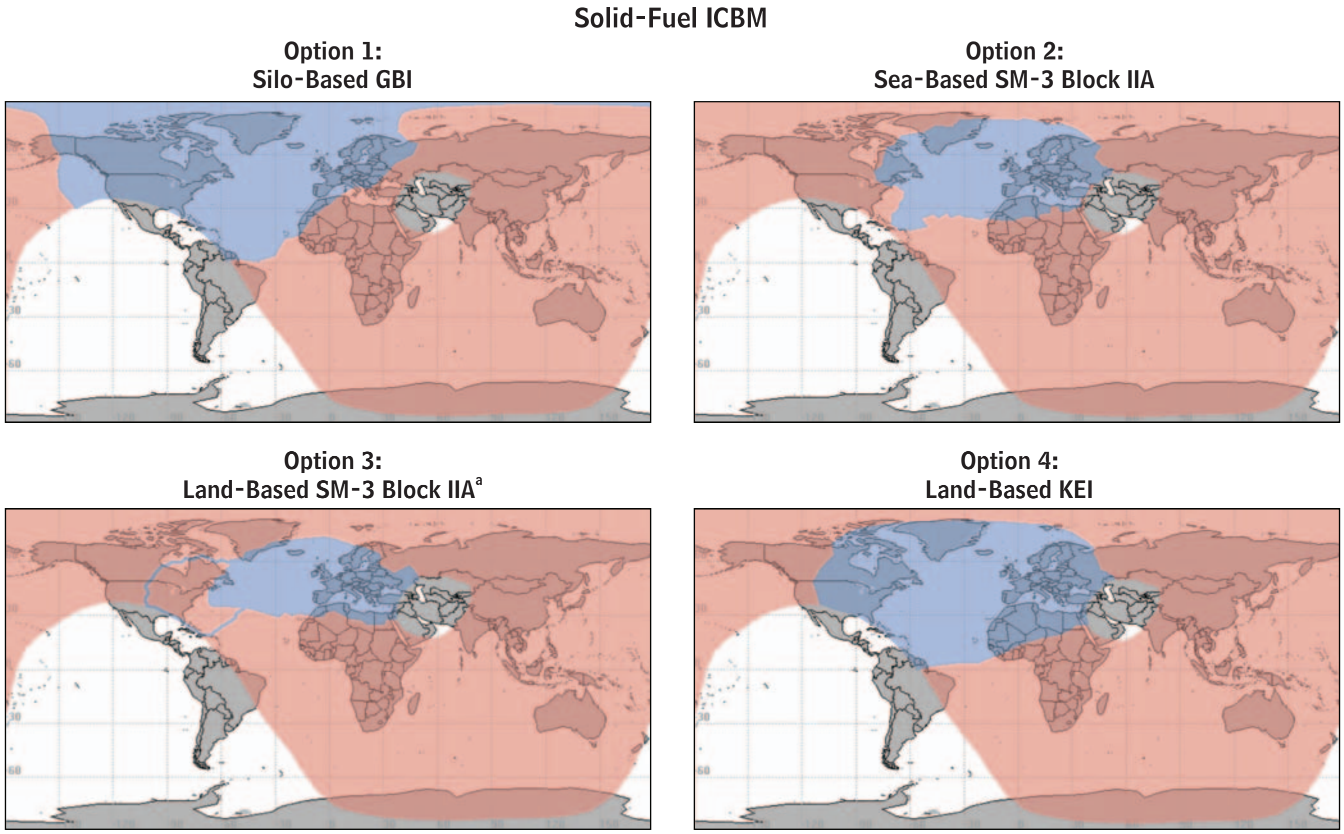
Ability to Intercept Russian ICBMs

The question of whether MDA's proposed European system could be used to intercept Russian ICBMs has been the subject of some debate. Russian officials, expressing doubt about the imminence of the missile threat from Iran, have argued that the Block 4.0 system is actually intended to defend against Russian missiles. However, given the large number of missiles that Russia possesses compared with the number of interceptors in the planned system, it is clear that the European capability—as proposed—could be easily overwhelmed by missiles launched from Russia.

The question of whether the Block 4.0 system could be used to intercept a single Russian missile has also been debated in the press. MDA has presented analysis that the system would not be able to intercept an ICBM launched from a base in western Russia, but some critics of MDA's plans have published studies indicating that it would be

Figure 3-8. **Continued**

Total Area That the Options Would Defend Against ICBMs from Iran



Source: Congressional Budget Office.

Notes: Blue shading indicates the area defended against a given missile threat. Red shading indicates undefended areas within range of that threat.

ICBM = intercontinental ballistic missile; GBI = Ground-Based Interceptor; SM = Standard Missile; KEI = Kinetic Energy Interceptor.

a. The area outlined in blue indicates additional coverage that would be provided if a site for land-based SM-3 Block IIA interceptors was added in the Cape Cod, Massachusetts, region.

possible to engage Russian ICBMs with interceptors in Poland.[7]

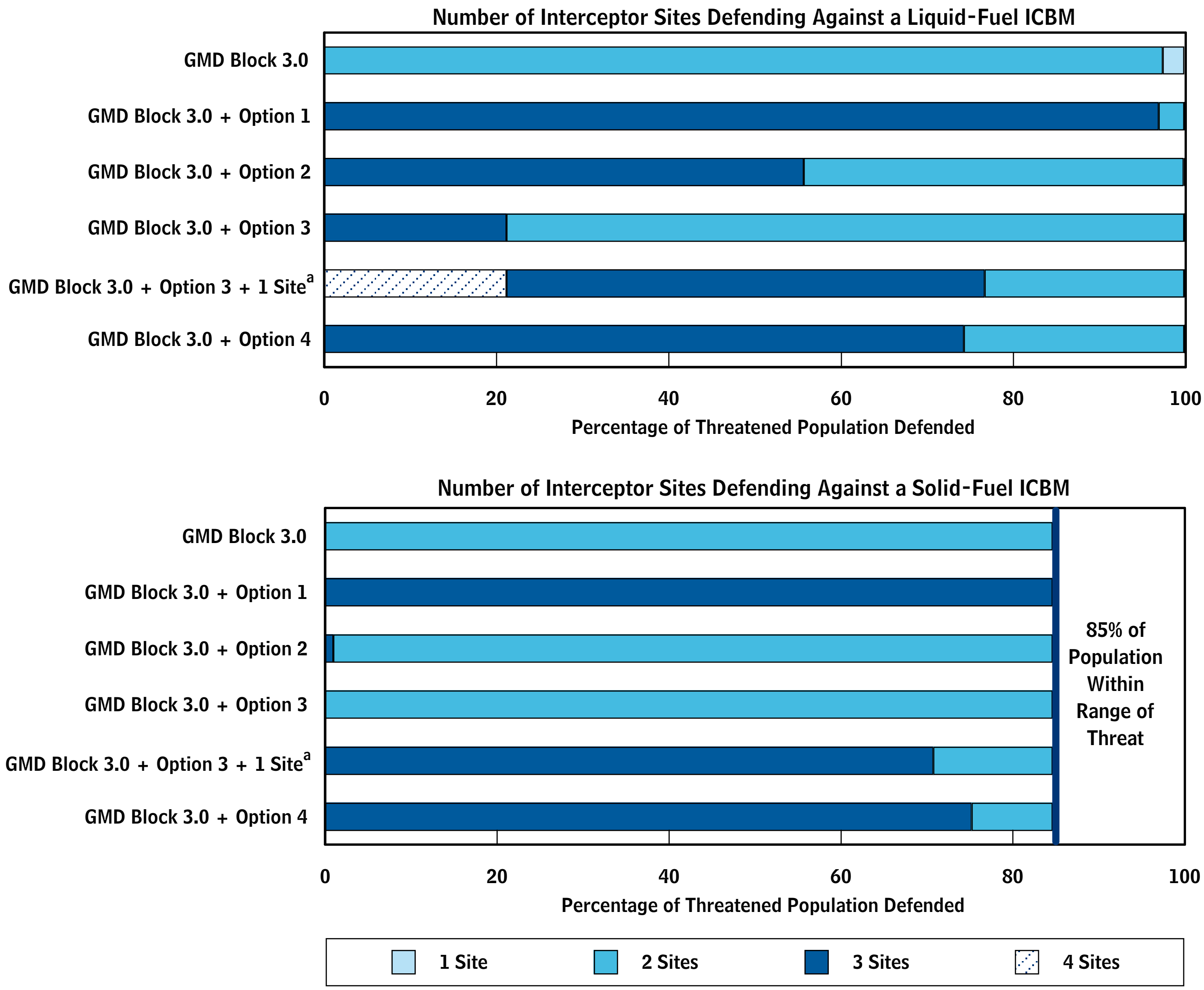
CBO has analyzed the defensive capability that the European Block 4.0 system would provide against a Russian ICBM—specifically, an SS-25 (the same missile that CBO used as a proxy for a potential Iranian solid-fuel ICBM). In its modeling, CBO assumed that the ICBM would be launched from the Yoshkar-Ola base east of Moscow. Missiles launched from that base toward the United States would fly trajectories that passed over Scandinavia, presenting advantageous engagement geometry for interceptors based in Poland. ICBMs launched from Russian bases farther east, such as Novosibirsk, would fly more directly over the North Pole and thus would be more challenging for interceptors in Poland to engage.

Before looking at the defense added by the European system, it is useful to consider the capability of the U.S.-based GMD Block 3.0 system against Russian missiles. Using existing radars, that system would provide complete coverage of the United States against the modeled

7. See, for example, George N. Lewis and Theodore A. Postol, "European Missile Defense: The Technological Basis of Russian Concerns," *Arms Control Today* (October 2007), www.armscontrol.org/act/2007_10/LewisPostol.

Figure 3-9.

Level of Redundant Defense of the United States Provided by the Missile Defense Options



Source: Congressional Budget Office.

Notes: Option 1 = silo-based GBI; Option 2 = sea-based SM-3 Block IIA; Option 3 = land-based SM-3 Block IIA; Option 4 = land-based KEI.

GMD = Ground-Based Midcourse Defense; ICBM = intercontinental ballistic missile; GBI = Ground-Based Interceptor; SM = Standard Missile; KEI = Kinetic Energy Interceptor.

a. Indicates additional coverage that would be provided if a site for land-based SM-3 Block IIA interceptors was added in the Cape Cod, Massachusetts, region.

Box 3-3.

Placing a Forward-Based Radar in Israel

Recently, the United States deployed an AN/TPY-2 radar to Israel to support Israeli missile defense efforts there. According to press reports, some U.S. officials have proposed connecting that radar to the Missile Defense Agency's planned Block 4.0 European system.[1] To evaluate the effect of such a radar placement, the Congressional Budget Office (CBO) modeled how the defensive capability of Option 1 would change if the Block 4.0 system used a forward-based radar (FBR) near Tel Aviv, Israel, rather than one in Azerbaijan (the location that CBO assumed for Option 1 in this analysis). The rest of the Block 4.0 system would remain the same: two-stage Ground-Based Interceptors in Poland supported by the European Midcourse Radar (EMR) in the Czech Republic.[2]

CBO's modeling indicates that replacing an FBR in Azerbaijan with one in Israel would reduce the portion of eastern Europe that could be defended against intermediate-range ballistic missiles and liquid- or solid-fuel intercontinental ballistic missiles (ICBMs) launched from Iran (see the figure at right). The reason is that many likely trajectories of Iranian missiles bound for eastern Europe would be outside the field of regard of the Israeli radar, which would be located more than 1,500 kilometers (km) southwest of an FBR in Azerbaijan and more than 1,000 km from the Iranian border. Such missiles could only be tracked once they came within range of the EMR, which would reduce the time available for intercepting them and thus reduce the area defended. Moreover, the EMR would generally not be able to observe those missiles at the time of burnout, which could lessen the system's ability to discriminate between actual warheads and any decoys that might be deployed.

ICBMs headed for the western United States from Iran would also fly outside the field of regard of an FBR in Israel. Consequently, Option 1's Poland-based interceptors would provide less defensive coverage of the United States with an FBR in Israel than with one in Azerbaijan.

Interceptors in Poland would not be able to defend Israel against the missiles that Iran claims to have now or could develop in the future. Moving the FBR to Israel would not change that situation, because the interceptor launch site in Poland is about 2,500 km from Israel, whereas missiles from Iran would need to travel as little as about 1,000 km to reach Israel. However, Options 2, 3, and 4 in this analysis, which would include interceptors in locations closer to Iran, could defend Israel against some of those threats.

1. See, for example, Dave Ahearn, "U.S. Lawmakers Urge Putting Radar in Israel, to Be Tied in with European Missile Defense," *Defense Daily* (May 13, 2008).

2. Including an FBR in Israel along with the one in Azerbaijan (rather than replacing the FBR in Azerbaijan) would increase the defensive capability of the proposed Block 4.0 system by adding any new areas defended (as shown in the figure here) to those defended with the original, single FBR.

Continued

Russian ICBM (see the upper panel of Figure 3-10 on page 46). Most of the radar tracking of such a missile would come from the Fylingdales and Thule UEWRs. However, those radars themselves could not be defended against a Russian ICBM by interceptors launched from the United States.

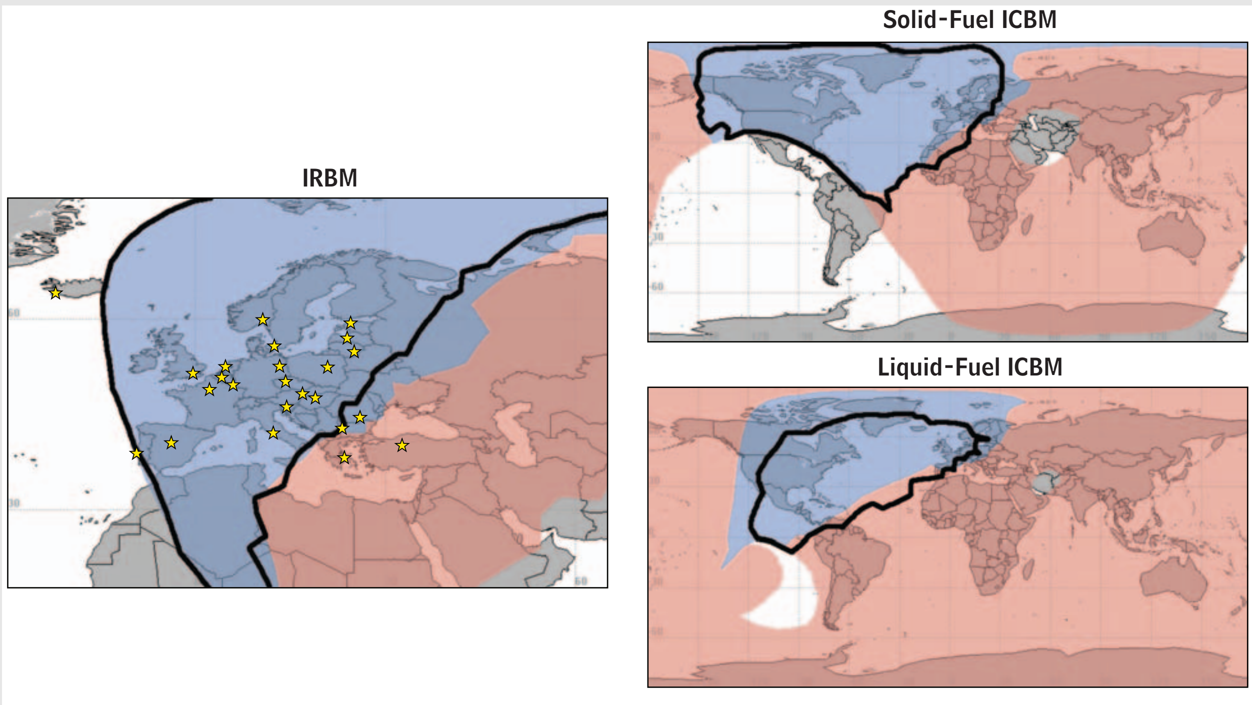
Adding the European Midcourse Radar in the Czech Republic, even without deploying interceptors in Poland, would slightly expand the area of northeastern Canada that could be defended by the U.S. GMD sites (see the lower panel of Figure 3-10). The main potential benefit of the EMR, however, is the addition of an X-band radar to the tracking system. The short wavelength—and thus the high spatial resolution—of X-band radar could improve the fidelity of tracking and enhance the ability to distinguish an actual warhead from decoys.

Deploying two-stage Ground-Based Interceptors in Poland, supported by the EMR, would defend the entire

Box 3-3. **Continued**

Placing a Forward-Based Radar in Israel

Option 1's Defensive Coverage with Different FBR Locations



Source: Congressional Budget Office.

Notes: Blue shading indicates the area defended against a given missile threat with an FBR in Azerbaijan. Black outline indicates the area defended with an FBR near Tel Aviv, Israel. Red shading indicates undefended areas within range of a given threat. Yellow stars show the locations of NATO capitals.

FBR = forward-based radar; IRBM = intermediate-range ballistic missile; ICBM = intercontinental ballistic missile; NATO = North Atlantic Treaty Organization.

threatened portion of Europe, as well as eastern Canada, against a Russian ICBM (see the upper panel of Figure 3-11). That additional defensive coverage would not extend into the United States, but it would come very close to the United States, so changes in the modeling assumptions could alter those results.

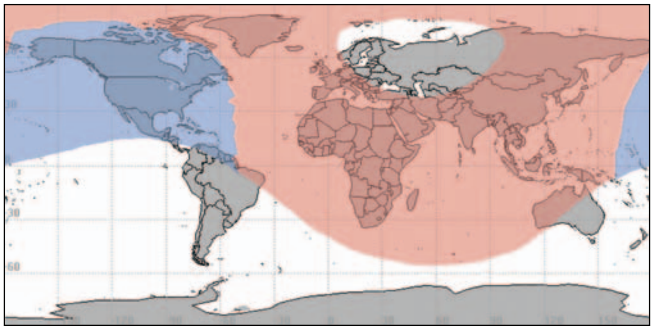
To explore the sensitivity of the results, CBO constructed alternate assumptions for the two-stage GBI using information available in public sources about the components of the interceptor.[8] CBO's alternate version of the GBI is based only on the technical parameters of the rocket stages as described for satellite launch applications, with no additional weight added to account for expanded avionics and communications capabilities that might be needed to use the rocket for an interceptor. The total mass of the alternate version is about 20,850 kilograms—roughly 3 percent (or 600 kg) lighter than the original version that CBO used in its modeling. With the reduction in mass, the alternate two-stage GBI has a higher velocity at burnout, which substantially expands the area it can defend (see the lower panel of Figure 3-11). In the case of a Russian ICBM launched from Yoshkar-Ola, that coverage area includes roughly half of the United States.

8. Steven J. Isakowitz and others, *International Reference Guide to Space Launch Systems,* 4th ed. (Reston, Va.: American Institute of Aeronautics and Astronautics, 2004).

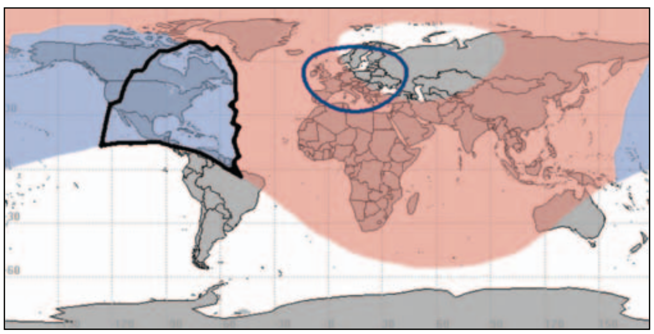
Figure 3-10.

Areas Defended by the GMD Block 3.0 System Against a Solid-Fuel ICBM from Russia

Using Only the Block 3.0 System's Sensors



Using the Block 3.0 System's Sensors and the EMR[a]



Source: Congressional Budget Office.

Notes: Blue shading indicates the area defended by GMD Block 3.0 interceptors launched from Fort Greely, Alaska, against an SS-25 missile launched from the Yoshkar-Ola base in Russia. Red shading indicates undefended areas within range of the Russian missile.

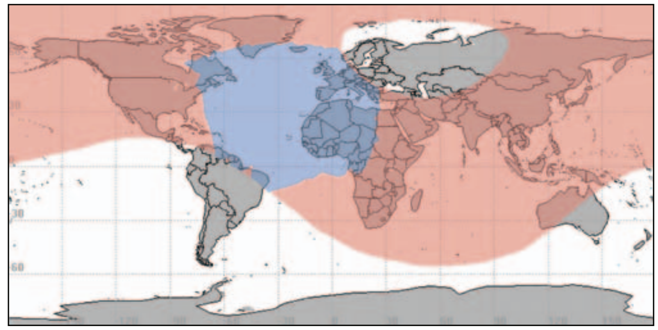
GMD = Ground-Based Midcourse Defense; ICBM = intercontinental ballistic missile; EMR = European Midcourse Radar.

a. Dark blue outline shows the EMR's footprint at an engagement altitude of 400 kilometers. Black outline indicates the portion of the defended area for which the EMR could be used to track the incoming missile.

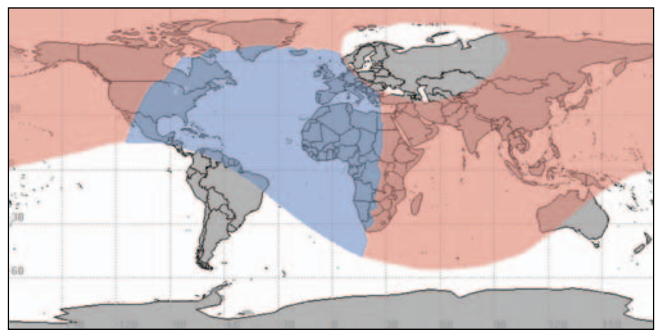
Figure 3-11.

Areas Defended by Option 1 Against a Solid-Fuel ICBM from Russia

Using CBO's Modeled Version of the Two-Stage GBI



Using a Two-Stage GBI with a Higher Burnout Velocity



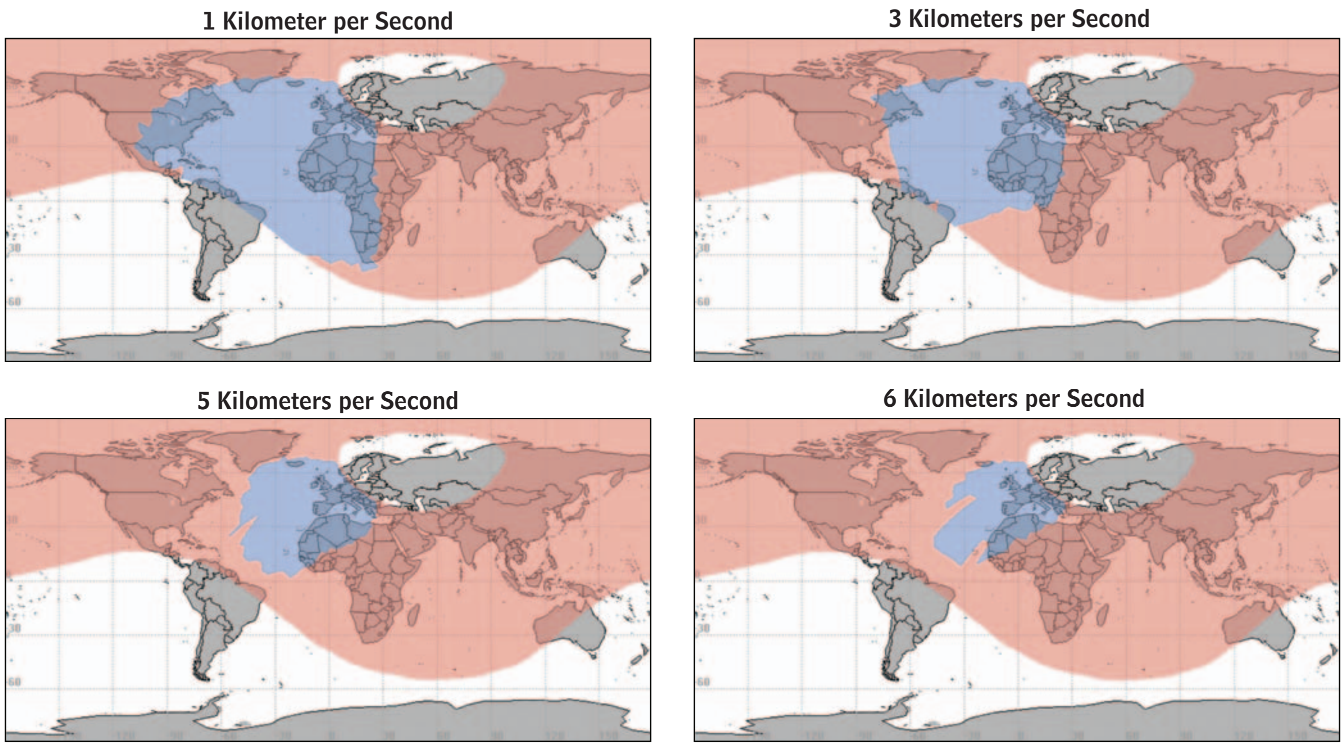
Source: Congressional Budget Office.

Notes: Blue shading indicates the area defended by the Missile Defense Agency's proposed European system (Option 1, silo-based GBI) against an SS-25 missile launched from the Yoshkar-Ola base in Russia. Red shading indicates undefended areas within range of the Russian missile.

ICBM = intercontinental ballistic missile; GBI = Ground-Based Interceptor.

Figure 3-12.

Sensitivity of Option 1's Defensive Coverage Against a Russian ICBM to Various Assumptions About Minimum Relative Velocity



Source: Congressional Budget Office.

Notes: Blue shading indicates the area defended by the Missile Defense Agency's proposed European system (Option 1, silo-based GBI) against an SS-25 solid-fuel missile launched from the Yoshkar-Ola base in Russia. Each panel is based on a different assumption about the minimum relative velocity between the interceptor and the threat missile required for a successful intercept. In its modeling for this study, CBO used a value of 3 kilometers per second.

ICBM = intercontinental ballistic missile; GBI = Ground-Based Interceptor.

Defensive coverage also depends on other parameters of CBO's modeling. For midcourse-phase intercepts, CBO assumed that the ballistic trajectory of a threat missile would have to be determined before an interceptor was launched. If interceptors were launched before the threat missile's booster burned out, the potential area of defensive coverage could be much larger—but the probability of a successful intercept could be substantially lower because of the greater uncertainty in the projection of the threat missile's trajectory. In the particular case of ICBMs launched from western Russia and interceptors based in Poland, the size of the defended area is very sensitive to the relative velocity required for a successful intercept.[9] In that case, the trajectories of the ICBMs would pass close to the interceptor site, but the timing is such that the missiles would have gone beyond the interceptor site by the time of engagement. Thus, the interceptor would be approaching the threat missile from the rear at a fairly low relative velocity.

In its modeling, CBO required a minimum relative velocity of 3 kilometers per second for a successful intercept. However, lower or higher values could also be valid—in particular, low relative velocities might suffice if the kill vehicle hit the ideal aim point with sufficient accuracy or

9. Relative velocity is the velocity of one object (the interceptor) as seen by another object (the threat missile). It depends on the speed of each of the missiles and the directions they are flying. Like cars driving on a two-way highway, objects heading in opposite directions have higher relative velocity, and objects heading in the same direction have lower relative velocity.

if the threat missile contained a salvage-fused warhead, which is designed to detonate if struck by an antimissile weapon. Conversely, higher relative velocities might be necessary to ensure complete destruction of the warhead if submunitions were used.

To explore how sensitive the area of defensive coverage is to the required relative velocity, CBO modeled intercepts of Russian ICBMs at various minimum relative velocities: 1 km/sec, 3 km/sec, 5 km/sec, and 6 km/sec. At a low required relative velocity (1 km/sec), interceptors in Poland would be capable of defending much of the United States as well as Europe against Russian ICBMs (see Figure 3-12). A higher requirement for relative velocity would shrink the area of defensive coverage to Europe and parts of the eastern Atlantic Ocean.[10] (For further discussion of relative velocity and the sensitivity of CBO's analysis to various assumptions, see Appendix B.)

10. The analysis of defense against missiles launched from Iran is less sensitive to the cutoff for minimum relative velocity because of the locations of the launch sites for threat missiles and interceptors in that case.

APPENDIX

A

Ballistic Missile Basics

Ballistic missiles, in the simplest sense, have two main parts: a rocket and a weapon payload. The rocket provides a brief burst of power (a "boost" that typically lasts for a few minutes) and guidance in order to place the payload on a specific trajectory. The payload then coasts on that "ballistic"—unpowered and free-flying—trajectory to its target. The maximum range over which the rocket (or booster) can deliver the payload depends on the amount of force (thrust) it can provide, how long it provides that thrust (the burn time), and the mass of the payload. Small changes in payload mass can produce large changes in range, so great effort goes into reducing the mass of the payload. Because the body of the rocket that encases the fuel also acts as a sort of payload, boosters are often split into stages. The dead weight of the structure for each stage can be jettisoned when that stage has finished firing, reducing the total mass that the booster has to lift and thereby increasing the range.

Solid Versus Liquid Fuel

Rockets provide thrust by burning propellant, which can be liquid, solid, or a mixture of the two (referred to as hybrid). Within those broad categories, many different varieties of propellant exist. Propellant typically has two components—fuel and oxidizer—which react to form a hot gas. The gas is expanded through a nozzle at the end of the rocket, pushing the rocket forward. The thrust that an engine generates depends on the amount of hot exhaust gas produced per unit of time and the velocity of the gas as it exits the rocket. Exhaust velocity is usually stated in terms of the specific impulse parameter (I_{sp}), which has units of seconds and equals the exhaust velocity divided by the gravitational acceleration at sea level (g). The specific impulse of a given rocket stage depends primarily on the type of fuel used, although the physical design of the engine and operational conditions also play a role.

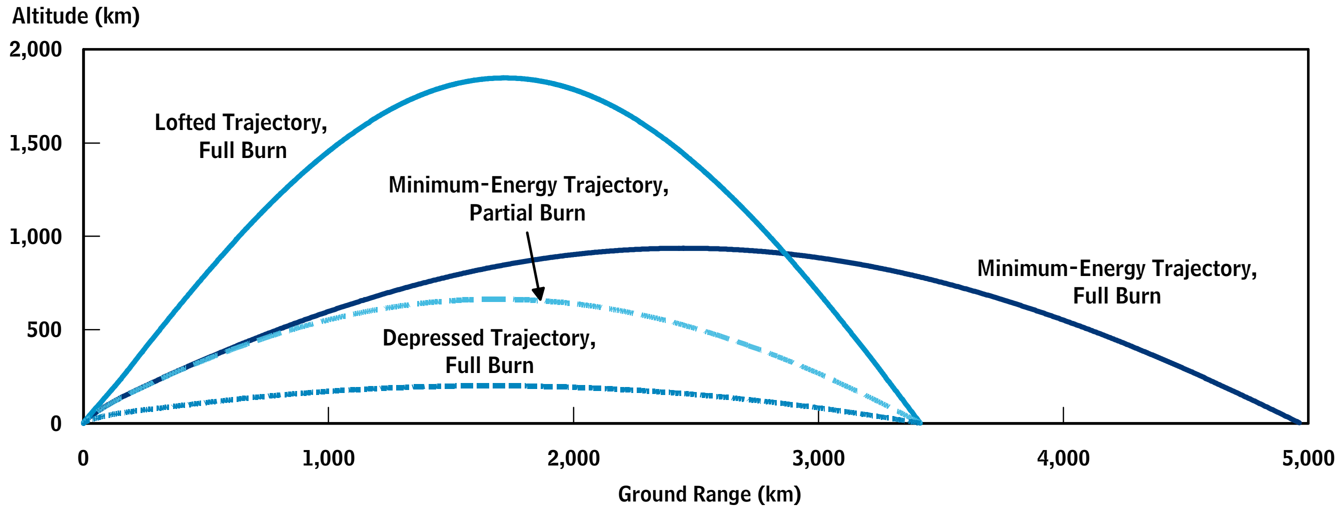
Solid and liquid fuels offer different advantages to missile designers. Liquid fuels are generally capable of higher I_{sp} than solid fuels. However, liquid propellants can be difficult to work with. For example, they can be extremely toxic and in some cases require cryogenic temperatures. Those properties make liquid fuels less than ideal for road-mobile missile systems (although some do exist, including Iran's Shahab-3 and Shahab-3A).

Solid fuels are generally more stable and easier to work with, a distinct advantage for road-mobile and ship-based systems. In addition, solid-fuel missiles can usually be launched on shorter notice than liquid-fuel missiles, which require time to load fuel into the missile. Faster launches increase responsiveness (which commanders desire in military systems) and reduce the time available for enemy surveillance to become aware of an imminent launch.

The biggest disadvantages of solid fuels relate to the nature of their combustion. Once a solid-fuel engine has begun to fire, it will continue to burn along the entire exposed surface of the fuel until all of the fuel is expended. The thrust from a solid-fuel engine can be made to vary over the course of the burn by customizing the shape in which the fuel is cast when the engine is constructed. However, that thrust profile cannot be adjusted while the engine is firing or be stopped and restarted, whereas liquid-fuel engines allow for more precise control. Also, because combustion occurs along an extended surface, the entire casing of a solid-fuel engine must be sturdy enough to withstand high pressures, which increases the structural "dead weight" that the rocket has to carry. For a given range, solid-fuel missiles generally have shorter burn times than liquid-fuel missiles, so missile defense systems have less time available to engage a solid-fuel missile in the boost phase (while its booster is still firing). However, the shorter burn time means that solid-fuel missiles enter the ballistic portion of flight

Figure A-1.

Altitude Versus Ground Range for Various IRBM Trajectories



Source: Congressional Budget Office.

Note: IRBM = intermediate-range ballistic missile; km = kilometers.

earlier, so defense systems that target missiles during that midcourse phase may have more time to engage them.

Range

The maximum range that a particular missile can attain depends on the velocity of the payload at the end of the boost phase, referred to as the burn-out velocity (V_{bo}). A reasonable estimate of V_{bo} can be made with just a few operational parameters: the mass of the payload, the total mass of each of the stages, the mass of the propellant in each stage, and the I_{sp} for each stage. The actual V_{bo} will also be determined by the aerodynamic properties of the missile and the specific trajectory flown.

For a given flight of a ballistic missile, range depends on the trajectory on which the booster places the payload. Ballistic missiles are usually launched from a vertical position. After a short period of vertical thrust, the booster is generally made to tilt (pitch over) slightly from the vertical. After that pitch-over maneuver, the thrust is usually realigned with the body of the missile. Because the thrust is no longer aligned with the (vertical) gravitational force, the missile will begin to turn toward the horizontal, a phenomenon referred to as a gravity turn. Missiles generally use a gravity turn to steer themselves onto a trajectory that has the desired angle with respect to the horizontal (known as the flight-path or elevation angle), after which the thrust is redirected to stop the gravity turn. There is an optimal flight-path angle that will maximize the range of the missile; that trajectory is referred to as a minimum-energy trajectory because it allows the maximum range for a given amount of fuel.

Of course, missiles need to be able to hit targets that are closer than their maximum range. Several ways exist to reduce the range from the maximum. One approach is to follow the same flight profile as a minimum-energy trajectory but terminate the thrust early. That is straightforward for liquid-fuel missiles but more complicated for solid-fuel missiles because they generally burn until all of their fuel is spent. However, a solid-fuel missile can reduce forward thrust by venting its exhaust gases out the sides of the missile or by executing a maneuver (called a generalized energy management, or GEM, maneuver) to waste some of the fuel—the missile equivalent of driving around in circles. Besides terminating thrust, range can also be reduced by using a different flight profile (see Figure A-1), at either a higher elevation angle (lofted trajectory) or a lower elevation angle (depressed trajectory). Generally, missiles have limits on what trajectories they can fly because of their minimum burn time and other design constraints, so there is a minimum range over which a given missile can be used to strike.

In some cases, lofted or depressed trajectories may be more challenging for missile defenses than minimum-energy trajectories. A lofted trajectory, which resembles a lob shot in tennis, may allow a missile to fly above the range of sensors or interceptors, thereby evading or delaying detection or engagement. However, at higher altitude, the missile may clear the horizon and thus become visible to a given sensor earlier than with a minimum-energy trajectory; the missile is also in the air longer, potentially affording more time for engagement. Lofted trajectories can be more challenging to defenses that target missiles in the terminal phase of their flight, because the payload travels closer to vertical and is in the atmosphere for a shorter time after reentry.

Depressed trajectories, by contrast, require more fuel than minimum-energy trajectories. But, like a baseball pitcher's fastball, a missile on a depressed trajectory travels a more direct line to the target and reaches the target faster, which can reduce the amount of time available for intercept. Also, at lower altitude, the missile may be able to remain below the horizon of a given sensor longer and thus delay or evade detection.

A wide range of possibilities exist for combining thrust termination with various angles of lofted or depressed trajectories, so an exhaustive analysis of the capabilities of a missile defense system would require extensive resources. For this report, the Congressional Budget Office assumed that enemy missiles would be flying minimum-energy trajectories, with thrust termination used to reduce the range from the maximum.

APPENDIX

B

Analytic Methods and Sensitivity of the Results to Changes in Assumptions

To estimate the defensive capability of a given missile defense system, the Congressional Budget Office (CBO) began by simulating the possible trajectories that threat missiles with minimum-energy flight profiles (see Appendix A) could take from each of the three hypothetical launch sites in Iran. The area threatened by a particular missile—that is, the region between the missile's minimum and maximum ranges—was split into a grid by varying azimuth angles and booster burn times (and thus range) over small intervals throughout the full range. For shorter-range missiles, CBO considered only the set of azimuth angles that threatened Europe, consistent with the scope of this study. For intercontinental ballistic missiles (ICBMs), CBO considered the full 360-degree range in azimuth.

For the next step—modeling the ability of a given interceptor at a given location to defend against threats—CBO first created a fan of possible interceptor trajectories by varying the initial azimuth and elevation angles by small intervals over the full range. Then, for each threat trajectory in the grid, CBO determined which combinations of initial azimuth and elevation angles for the interceptor would produce a trajectory that intersected with the chosen threat trajectory. Any trajectory that came within 100 kilometers (km) of the threat trajectory at the closest point of approach was considered to have intersected the threat and thus to be a potential intercept trajectory.[1] In general, multiple combinations of azimuth and elevation angles yielded potential intercept trajectories for each threat trajectory.

Criteria for a Successful Intercept

For a potential intercept trajectory to be considered as a successful intercept, it had to meet certain criteria in terms of the geometry and the timeline of the intercept. All of the interceptors that CBO modeled are designed to conduct exoatmospheric intercepts (that is, to intercept missiles outside the atmosphere). Thus, in its modeling, CBO included a requirement that the altitude of the threat missile at the intercept point be at least 100 km in all cases. In addition, the Standard Missile-3 (SM-3) Block IB interceptor requires tracking updates from the SPY-1 radar during an engagement, so the intercept must occur inside the radar's field of regard. To meet that requirement, CBO limited the altitude of the threat missile to no more than 650 km at the point of intercept for engagements with SM-3 Block IB interceptors.

All of the interceptors that CBO considered in this study use hit-to-kill technology, destroying a threat warhead through the kinetic energy of the collision. A minimum kinetic energy is required to ensure destruction of the warhead, which translates to a minimum allowable relative velocity between the interceptor and the threat warhead. Little information about the requirements for a kinetic kill is available in unclassified literature. One detailed study estimated that a direct hit from a kill vehicle weighing 40 kilograms (kg) would require a relative velocity of about 1.5 km per second (sec) to ensure destruction.[2] Greater kinetic energy expands the volume

1. The value of 100 km was chosen to be consistent with the size of the intervals used for elevation and azimuth angles. In general, it would be possible to determine a "firing solution" (the actual choice of angles that a real intercept attempt might make) with a smaller separation by choosing angular values lying between the intervals that CBO selected. The intent of CBO's approach was to determine, with a reasonable amount of computation, the range of values for elevation and azimuth angles within which it would be possible to obtain a firing solution.

2. Richard M. Lloyd, *Physics of Direct Hit and Near Miss Warhead Technology*, vol. 194 of Paul Zarchan, ed., *Progress in Astronautics and Aeronautics* (Reston, Va.: American Institute of Aeronautics and Astronautics, 2001).

of the region damaged by the collision, which can help correct for an impact that is slightly off from the ideal hit point. The same study found that for an impact that is offset by 20 centimeters (cm), the required velocity for a 40 kg kill vehicle is estimated at 2.5 km/sec, whereas an offset of 30 cm necessitates 3.0 km/sec. If the warhead contains submunitions, a relative velocity of 6 km/sec or more may be needed to ensure a high probability of complete destruction. For this analysis, CBO assumed that a relative velocity of at least 3.0 km/sec would be necessary to destroy a threat warhead.

The most limiting requirement on potential intercept trajectories is the timeline available for intercept. The interceptor's flight time (from launch to the closest point of approach to its target) must be sufficiently less than the flight time of the threat missile to allow for detecting the launch, tracking the threat missile, and deciding on the optimum intercept trajectory.

After the launch of a threat missile, the defense system must become aware of the launch, nominally through infrared satellites—known as overhead nonimaging infrared (ONIR) satellites. After being cued by that detection, tracking radars will begin to measure the trajectory of the threat missile as soon as the missile enters their field of regard. For the midcourse-phase intercepts modeled in this study, CBO required that the ballistic trajectory of the threat missile (its trajectory after its booster has burned out) be determined before an interceptor is launched. To allow for that determination, CBO required a lead time of 30 seconds after burnout for the ONIR satellites to detect that burnout has occurred, followed by 5 seconds of access from a tracking radar and then 30 seconds for deciding on the defensive strategy and launching the interceptor. In some cases, if a radar is near the launch site of the threat missile, the missile may be within the radar's field of regard at burnout, and the 5 seconds of access may occur directly after the alert of burnout from the ONIR satellites. In other cases, the threat missile may fly farther along its trajectory before it enters the field of regard of the tracking radar, requiring more lead time for an engagement.

In all, the available lead time—equivalent to the flight time of the threat missile to the closest point of approach minus the flight time of the interceptor to the same point—must be equal to or greater than the sum of the following elements:

- The threat missile's burn time,
- Thirty seconds for an ONIR satellite to determine that the missile has burned out,
- Any delay before the missile enters the field of regard of a tracking radar (the delay may be zero with optimal radar placement),
- Five seconds of access by the tracking radar to determine the missile's ballistic trajectory, and
- Thirty seconds for decisionmaking and the interceptor launch process.

Sensitivity to Modeled Performance Parameters

In its modeling, CBO used performance parameters from unclassified sources for the interceptors and threat missiles. In some cases, those parameters could differ to some degree from the actual performance of the missiles. In particular, two types of interceptors—the SM-3 Block IIA and the Kinetic Energy Interceptor (KEI)—are still in the development stages, and the performance of the actual production versions could differ from the ones modeled in this study. To explore the sensitivity of the model's results to variations in performance, CBO constructed alternate models for the interceptors with different performance parameters. It also examined the effects of altering the assumed ranges of various tracking radars.

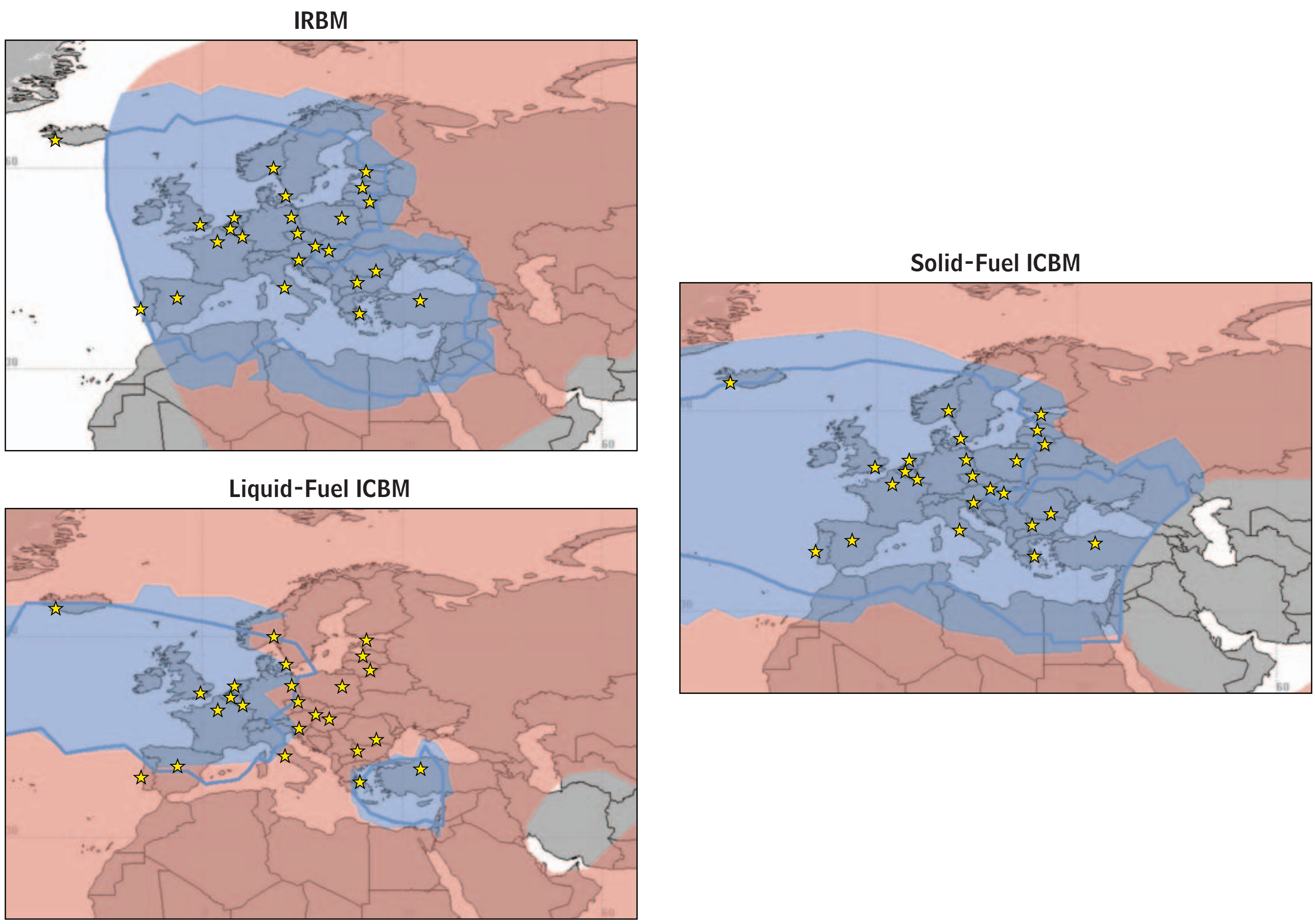
Burnout Velocity

An important parameter of an interceptor is its velocity when its booster burns out, which largely determines the interceptor's range. For its sensitivity analysis, CBO varied the burnout velocity of the SM-3 Block IIA and the KEI by 10 percent from the values modeled in the rest of the study. For the SM-3, burnout velocity was decreased by 10 percent from the nominal value; for the KEI, it was both increased and decreased by 10 percent.[3] Such changes in burnout velocity could result if the total mass of the interceptor (including the kill vehicle) or the specific impulse of the rocket motors differed from the assumed values.

3. Because the Block IIA is an upgrade of an existing missile with well-known performance characteristics, its burnout velocity is unlikely to substantially exceed the expected value.

Figure B-1.

Sensitivity of Option 3's Defensive Coverage to Various Assumptions About the Burnout Velocity of the Interceptor



Source: Congressional Budget Office.

Notes: Option 3 places land-based SM-3 Block IIA interceptors at two existing U.S. bases in Europe.

Blue shading indicates the area defended against a given missile threat. Blue outlines show the area defended if Option 3's SM-3 Block IIA interceptors had a burnout velocity 10 percent lower than the nominal value. Red shading indicates undefended areas within range of a given threat. Yellow stars show the locations of NATO capitals.

IRBM = intermediate-range ballistic missile; ICBM = intercontinental ballistic missile; SM = Standard Missile; NATO = North Atlantic Treaty Organization.

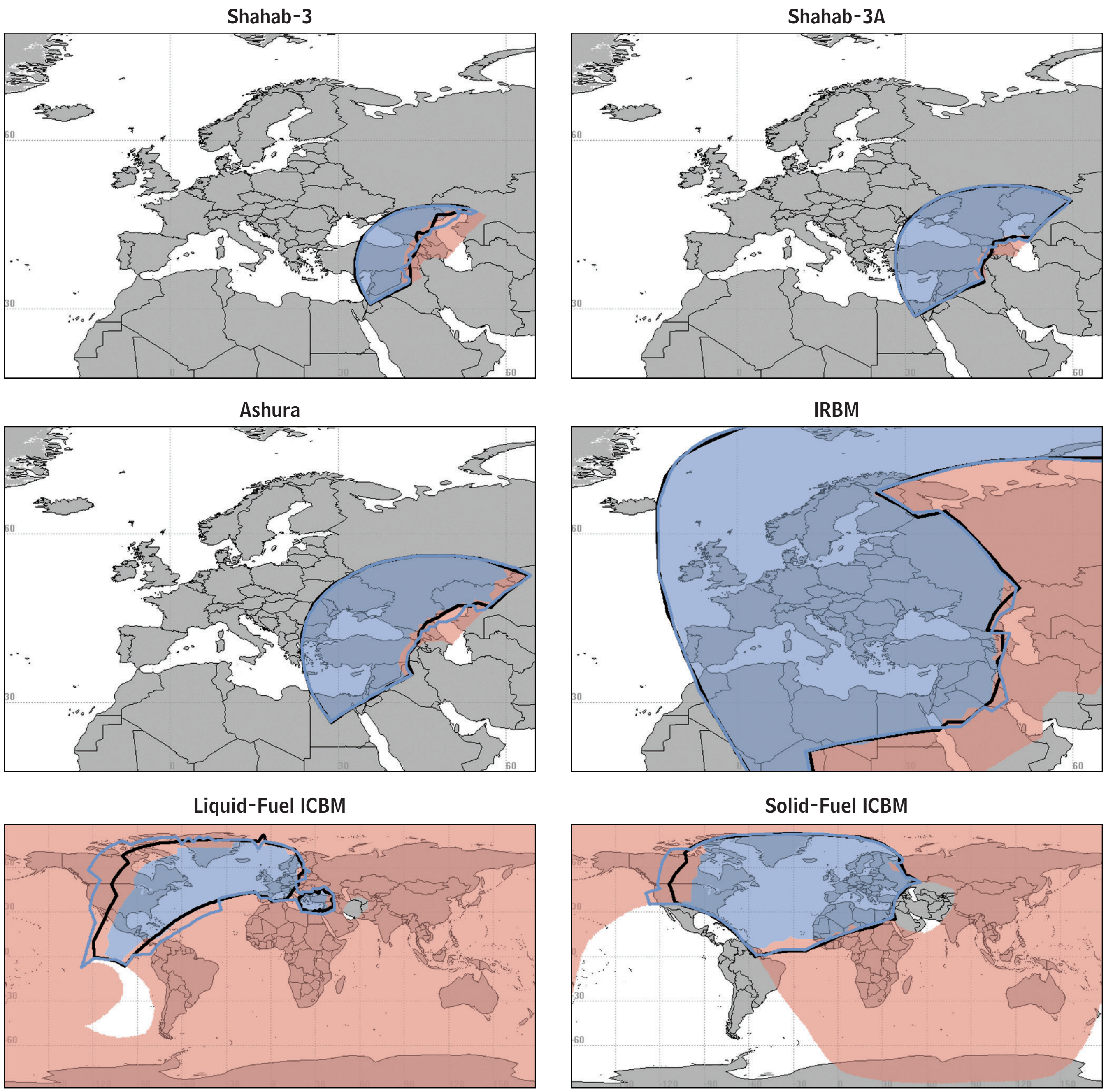
In the case of both interceptors, defensive coverage of Europe does not change substantially with those differences in burnout velocity. The largest change involves the SM-3's defensive capability against an Iranian intermediate-range ballistic missile: Some portions of eastern Europe that would be defended with the higher assumed velocity would not be defended with the lower velocity (as an example, see Figure B-1, which shows how coverage would change for Option 3). Defensive coverage of the United States against potential ICBMs is much more affected by changes in burnout velocity, especially for the KEI (see Figure B-2).

Radar Range

Another possible source of variation in performance is the effective range of the tracking radars. Recent studies have concluded that the range at which the European Mid-course Radar (EMR) could track reentry vehicles and discriminate between them and decoys would be much shorter than the ranges assumed by the Missile Defense

Figure B-2.

Sensitivity of Option 4's Defensive Coverage to Various Assumptions About the Burnout Velocity of the Interceptor



Source: Congressional Budget Office.

Notes: Option 4 places land-based KEIs at two existing U.S. bases in Europe.

Blue shading indicates the area defended against a given missile threat if Option 4's KEIs had a burnout velocity 10 percent lower than the nominal value of 3 kilometers per second. Black outlines show the area defended if the KEIs had the nominal burnout velocity, and blue outlines show the area defended if the KEIs had a burnout velocity 10 percent higher than the nominal value. Red shading indicates undefended areas within range of a given threat.

IRBM = intermediate-range ballistic missile; ICBM = intercontinental ballistic missile; KEI = Kinetic Energy Interceptor.

Table B-1.

Performance Characteristics Assumed for the Radars Used in the Missile Defense Options

Radar	Band	Wavelength (cm)	Range (km)	Elevation Angle (Degrees)		Azimuth Angle (Degrees)	
				Minimum	Maximum	Minimum	Maximum
Fylingdales	UHF	67	4,820	3	85	0	360
Thule	UHF	67	5,555	3	85	297	177
Clear	UHF	67	4,910	3	85	170	110
Cape Cod	UHF	67	5,555	3	85	347	227
Cobra Dane	L	23	48,000	1	80	259	19
EMR	X	3	5,000	1	90	0	360
SBX	X	3	5,000	2	90	0	360
SPY-1	S	9	650	1	90	0	360
FBR	X	3	1,000	1	90	0	360

Source: Congressional Budget Office based on information from the Missile Defense Agency; *Jane's Strategic Weapons Systems* (Coulsdon, Surrey, United Kingdom: Jane's Information Group, 2008); David Vallado, *Fundamentals of Astrodynamics and Applications*, 2nd ed. (El Segundo, Calif.: Microcosm Press, 2001); J.F. Crawford and others, "Ground-Based Radar-Prototype Antenna" (paper presented at the National Conference on Antennas and Propagation, York, United Kingdom, March 30–April 1, 1999); Dean Wilkening, "Airborne Boost-Phase Ballistic Missile Defense," *Science and Global Security*, vol. 12 (2004), pp. 1–67; Larry Chasteen, *National Missile Defense and Early Warning Radars: Background and Issues*, CRS Report for Congress RL30654 (Congressional Research Service, August 2000).

Note: cm = centimeters; km = kilometers; UHF = ultrahigh frequency; EMR = European Midcourse Radar; SBX = Sea-Based X-Band Radar; FBR = forward-based radar.

Agency or used in this study.[4] In CBO's model, the only requirement for radar coverage is that the ballistic trajectory of a threat missile spend 5 seconds in the field of regard of a tracking radar to determine the trajectory. In most cases, that initial tracking is provided by the forward-based radar (FBR). In the few cases in which the initial tracking is provided by the EMR, the time at which access begins is limited primarily by the horizon, so a reduction in range would generally not change the defended area. The main impact of a reduction in the EMR's range would be to decrease the area over which the radar could provide updated trajectories after an interceptor was launched and could discriminate decoys, potentially reducing the probability of a successful intercept for trajectories not within range of the EMR. CBO did not quantitatively model the probability of a successful intercept. Thus, the analysis is not sensitive to the impact of a shorter range for the EMR.

Changes in the range of the FBR, however, could affect the modeled results. CBO assumed that the AN/TPY-2 (the radar system used for the FBR) would have a range of 1,000 km (see Table B-1). Future upgrades have been proposed to increase the range of that radar through the use of an adjunct sensor. CBO estimated that increasing the range to 2,000 km would allow the FBR at the modeled location in Azerbaijan to observe many of the more easterly ICBM trajectories heading from Iran to the United States that are currently out of range. Such a change would expand the defensive coverage of Option 1, for example, west to include Alaska and portions of Russia.[5] Extending the range of an FBR in Azerbaijan beyond 2,000 km, however, would not increase its defensive capability against Iranian missile threats.

4. George N. Lewis and Theodore A. Postol, "The European Missile Defense Folly," *Bulletin of the Atomic Scientists,* vol. 64, no. 2 (May/June 2008), p. 32.

5. Option 1 consists of two-stage Ground-Based Interceptors in silos and X-band radars in two locations.

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