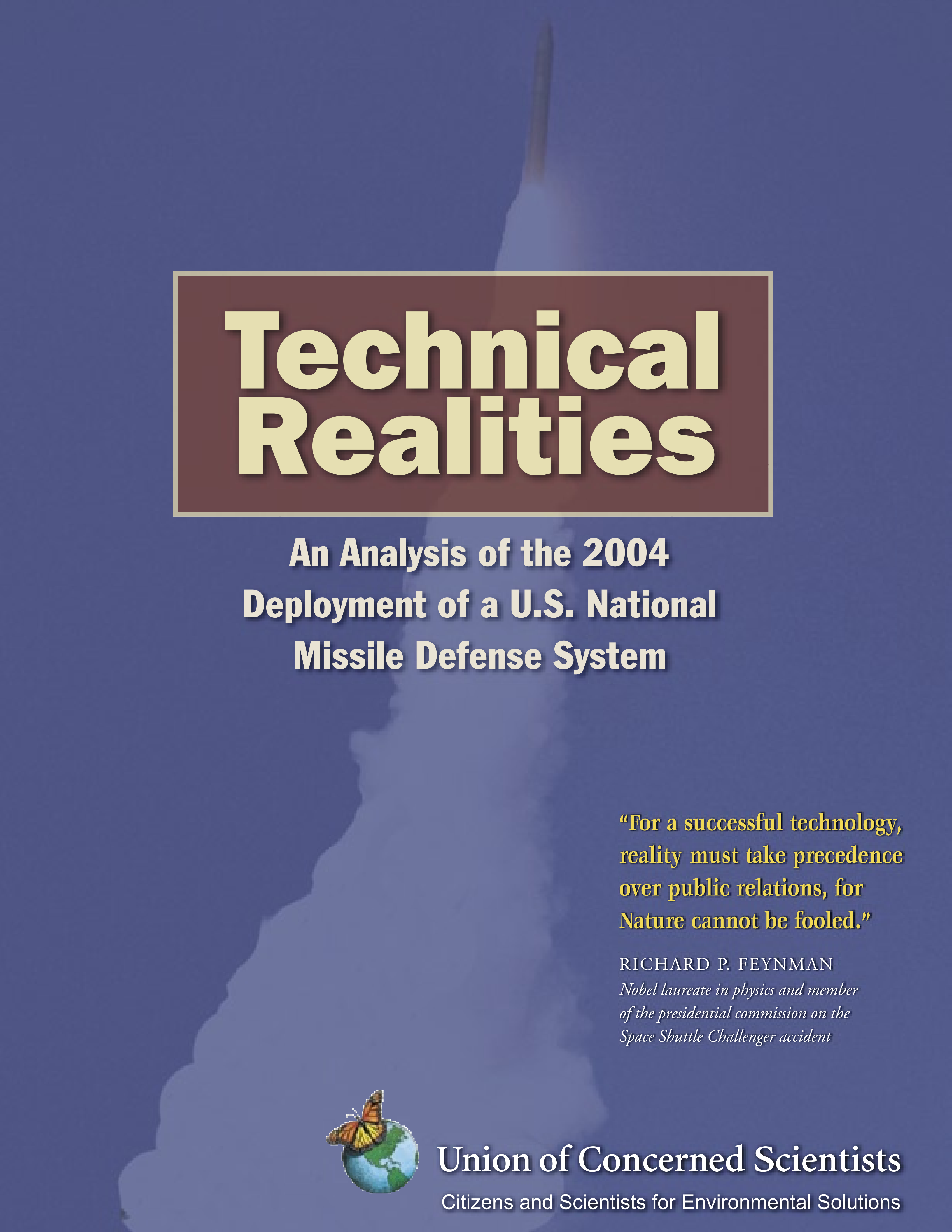

Technical Realities

An Analysis of the 2004 Deployment of a U.S. National Missile Defense System

> "For a successful technology, reality must take precedence over public relations, for Nature cannot be fooled."
>
> RICHARD P. FEYNMAN
> *Nobel laureate in physics and member of the presidential commission on the Space Shuttle Challenger accident*

Union of Concerned Scientists
Citizens and Scientists for Environmental Solutions

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An Analysis of the 2004 Deployment of a U.S. National Missile Defense System

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May 2004

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Executive Summary

The ballistic missile defense system that the United States will deploy later this year will have no demonstrated defensive capability and will be ineffective against a real attack by long-range ballistic missiles. The administration's claims that the system will be reliable and highly effective are irresponsible exaggerations. There is no technical justification for deployment of the system, nor are there sound reasons to procure and deploy additional interceptors.

The Missile Defense Agency should halt its deployment of the Block 2004 GMD system, and Congress should require that the system undergo operationally realistic testing before it is deployed.

On December 17, 2002, President Bush announced that he had directed the Secretary of Defense to begin fielding a ground-based missile defense that would achieve initial operational capabilities in 2004. The system is intended to defend the United States initially against attacks by long-range ballistic missiles North Korea might deploy in the future.

The general operating principles and many of the key components of the ground-based midcourse defense (GMD) system are based on technology developed under the Clinton administration's national missile defense (NMD) program. The GMD system will use ground-based interceptor missiles to launch "kill vehicles" that are intended to destroy their targets by colliding with them in the midcourse of their trajectory, outside Earth's atmosphere. The system will use ground- and sea-based radars to track the warheads and other objects released by attacking missiles, and the kill vehicles will use infrared sensors to home on their targets.

The Bush administration plans to deploy its missile defense systems in two-year blocks. The first, Block 2004, covers the years 2004 and 2005. It is the only block for which detailed information on planned deployments is publicly available, although some general information is available for Block 2006 and beyond. This report focuses on the Block 2004 GMD system.

The Missile Defense Agency (MDA) has been planning to make this system operational by September 30, 2004, with an initial deployment of 10 interceptors at Fort Greely, Alaska, and Vandenberg Air Force Base, California. More recently, the MDA has stated that the system could be operational as early as July 2004, when the first interceptor is deployed in its silo, but that only "several" interceptors would be deployed by the end of September. Current plans are to deploy a total of 20 interceptors at these two sites by the end of 2005, and Congress has already appropriated funds for these interceptors. However, the administration's FY05 budget includes funds to procure and deploy an additional 20 interceptors.

This report analyzes the defensive capabilities of the Block 2004 GMD system as it will initially be deployed and as it is planned to evolve through 2005. To do so, we examine the GMD test program in detail and assess what it has demonstrated about the capability of the system and its individual components. We also analyze the theoretical technical capabilities of the key system components—the radars and the kill vehicle—to determine how they would function in a hypothetical ballistic missile attack by North Korea. We ultimately assess the capability of the defense to defend Hawaii, Alaska, and the west coast of the United States from North Korean attacks. (The administration has stated that the system is also intended to defend against attacks from the Middle East, but this is irrelevant since no nations there could deploy a long-range missile by 2005. Moreover, the radars available to the GMD system are oriented in the wrong direction for attacks coming from the Middle East and look instead toward Russia and China. The MDA has not begun to upgrade the one radar oriented in the right direction, and it is unlikely to be available until the end of Block 2004, if then.)

Although the Pentagon has not publicly issued any detailed assessments of the defensive capability of the system it will deploy, several officials have made statements in congressional testimony indicating that the system will be highly effective. We discuss the assumptions underlying these statements and provide a critique of these assessments. We then discuss the policy implications of the Pentagon overestimating the defensive capability of the deployed GMD system.

We also assess the Defense Department's assertions that the deployment date is "event driven" rather than "schedule driven," i.e., that the date for deploying the system and making it operational depends on events in the development and testing program and not on external factors.

Finally, we recommend changes to the current and future U.S. program to develop defenses against long-range ballistic missiles.

Findings and Recommendations

1. The Block 2004 missile defense will have no demonstrated capability to defend against a real attack since all flight intercept tests have been conducted under highly scripted conditions with the defense given advance information about the attack details.

None of the system components to be deployed as part of the Block 2004 system—including the interceptors and radars—has been flight tested in its deployed configuration. It is possible that the new three-stage interceptor with the deployment version of the kill vehicle will be flight tested once before September, but that test is not scheduled to be an intercept test. According to the MDA, the Cobra Dane radar will be key to the operation of the Block 2004 system, but it will not take part in a flight or intercept test before 2007. Moreover, there will be no system-level flight or intercept test of the defense before its activation in September 2004.

Since 1997, the MDA has conducted 10 flight tests involving prototype or surrogate system components. Eight of these were intercept tests, five of which resulted in intercepts. All the flight tests have been research and development tests, which provide information for design modifications but do not assess the system's effectiveness under realistic operational conditions. In fact, the intercept tests to date have included many artificialities and limitations, as the MDA acknowledges.

First, the test conditions have not been varied: The test geometries and closing speed and angle have been nearly identical. The tests have occurred at the same time of day, even though the infrared signal of an object in space depends strongly on whether it is in sunlight or in shadow. And in each test the target cluster included the same or similar objects.

Second, the system's ability to discriminate the warhead from other elements in the target cluster has not been realistically tested: The mock warhead and balloons have had very different radar and infrared signatures. More important, the defense was provided with detailed a priori information about the characteristics and expected appearance of all the objects in the test. The radars that will be part of the Block 2004 system will not be able to discriminate warheads from other objects (decoys or debris), so discrimination will rely on the kill vehicle alone. Yet no tests in which the kill vehicle relies on its sensor to discriminate the warhead have been conducted, and none are planned through 2007.

The basic goal of these intercept tests has, according to the MDA, been to demonstrate hit to kill. But hit to kill was first demonstrated more than 20 years ago; the goal here should be to demonstrate hit to kill under conditions relevant to intercepting long-range missiles. These tests have not done so because the endgame conditions have been unrealistic. Since the tests used a prototype two-stage interceptor, the closing speed between the kill vehicle and mock warhead was artificially low by as much as a factor of two. The defense used information from either a GPS receiver or a C-band beacon on the mock warhead to determine its position, and this was used to provide the kill vehicle with very accurate tracking data.

The new Pacific test bed, coupled with the new three-stage interceptor, will allow the MDA to conduct tests under more realistic conditions. However, the test bed alone will not address the lack of realism in flight testing, nor is it needed to address the key realism issues: testing without a priori information, under unscripted conditions, and against realistic countermeasures. The MDA flight test program through September 2007 will not include countermeasures that the Pentagon's director of operational testing and evaluation has identified as simple for the enemy to implement.

In fact, the MDA has no current plans to conduct tests under unscripted conditions, nor is it clear that such operationally realistic testing will ever be conducted.

2. A technical analysis of the Block 2004 GMD system shows there is no basis for believing the system will have any capability to defend against a real attack.

Because the testing program has provided essentially no data about how the system or its components would perform in a real missile attack, this report analyzes the theoretical technical capabilities of the system to assess its defensive capability. Our judgment that the Block 2004 system will be ineffective against a real attack is based on two factors: the inability of the system to deal with unsophisticated countermeasures and, for attacks against Hawaii, the marginal tracking capability of the available radars.

Countermeasures. Unsophisticated countermeasures that could readily be implemented by countries such as North Korea remain an unsolved problem for midcourse defenses against long-range missiles. This problem has been identified in numerous government documents over the past several years.

Moreover, in 2000, a panel of independent scientists and engineers conducted a detailed technical assessment of the missile defense system under development by the Clinton administration. That system would ultimately have included up to nine X-band radars with very good discrimination capabilities as well as a constellation of satellite-based infrared sensors. The panel found that the fully deployed system would be rendered ineffective by unsophisticated but effective countermeasures.

Unlike the previously proposed system, the Block 2004 system will not include an X-band radar, and the radars available to it are not able to discriminate objects—warheads, balloons, debris—from one another. Nor will there be any satellite-based infrared sensors. Thus, any discrimination of the warhead must be performed by the infrared sensor on the kill vehicle. For this reason, the Block 2004 system will be vulnerable to even simpler countermeasures than those that would have defeated the Clinton system.

For example, by painting their surfaces, balloon decoys can be given the same infrared signature as a bare warhead. There are also several anti-homing countermeasures to prevent the kill vehicle from homing on the warhead. These include leaving the warhead attached to the final missile stage and thus forcing the defense to choose which end of the target to hit; enclosing the warhead in a large balloon so the kill vehicle could not determine its exact location; and tethering several balloons to the warhead at a distance of a few meters. The latter strategy could be especially effective if one or more of the balloons had a higher temperature and greater infrared signal than the warhead.

The MDA has conceded that midcourse countermeasures will present major difficulties for the GMD system, but argues that boost-phase defenses will solve the problem of midcourse countermeasures. But the United States will not have any boost-phase defenses ready for deployment until later this decade, if then.

Radar Tracking Capabilities. To defend Hawaii from North Korean attacks, the Block 2004 system will essentially rely on the Aegis SPY radar. This radar was designed for air defense and, despite various upgrades over the years, its ability to detect and track long-range missiles is quite limited.

Our analysis indicates that the radar would be able to track the warhead only for the first few tens of seconds of its flight or not at all, because it has a short detection range. Thus the Block 2004 system will be able to provide only limited tracking information about a missile attack by North Korea on Hawaii, resulting in a large uncertainty in the location of the threat cloud. In this case, the defense may not be able to direct the interceptor close to the threat cloud, and the kill vehicle could have a difficult time locating and homing on the target.

3. The Bush administration claims about the Block 2004 defense capability are misleading and unrealistic.

The administration has consistently claimed that the Block 2004 system will be highly effective against a small number of incoming missiles, even when it is initially made operational later this year. High-level Pentagon and MDA officials have asserted the following:

- The system to be deployed in 2004 would be 90 percent effective against a North Korean missile if it launched two interceptors.
- The first interceptor deployed will provide a defense of the United States.
- The system capability is limited only by the number of interceptors.

These statements are irresponsible. Underlying all of them is an assumption that the kill probability of the interceptors—the probability that an interceptor will hit its target—will be very high. There is no data to justify such an assumption. The kill probability depends as much on the characteristics of the attack—the warhead type and trajectory, the numbers and types of decoys, and the kind of countermeasures used—as it does on the performance of the defense components. Based on the poor defense capability in the face of unsophisticated countermeasures, the kill probability is likely to be on low, not high.

According to the General Accounting Office, while the MDA has assigned numerical values to the interceptor kill probability, it has not provided its assumptions about the attack characteristics that would affect the kill probability. In essence, the MDA appears to be picking numbers out of thin air.

The MDA has also claimed that its simulation software will provide valuable information about the effectiveness of the Block 2004 GMD system. This is not true. As the director of operational testing and evaluation noted in his FY03 report to Congress, “Due to the immature nature of the systems they emulate, models and simulations of the BMDS [ballistic missile defense system] cannot be adequately validated at this time.”

Finally, MDA officials have stated that the demonstration of hit to kill provides confidence that the system will work. However, the United States demonstrated that it could perform hit to kill more than 20 years ago. Being able to destroy a target is not the issue; the important question is whether it can do so under unanticipated conditions in a real attack. This was graphically demonstrated in the 1991 Gulf War when the Patriot missile defense failed to intercept almost all of the incoming Iraqi short-range missiles despite its successful performance in intercept tests (and early Pentagon claims of high effectiveness).

Such overstatements of the GMD system’s defensive capability could have serious repercussions. To the extent that policy makers believe such claims, they will affect decision making. According to administration officials, the president believes he will have “many more options” available if he has a limited operational defense. If the president is told that the system could reliably defend against a North Korean ballistic missile attack, he might be willing to accept more risks when making policy and military decisions. Similarly, a belief in the efficacy of the deployed defense could reduce the administration's motivation to try to address the North Korean missile program by other means, such as diplomacy. It is not difficult to find examples in which the perceptions of high-level policy makers differed starkly from the technical assessment of experts who were more familiar with the details. A striking example is the explosion of the space shuttle Challenger in 1986.

U.S. overstatements of the system effectiveness could also inspire overreactions on the part of Russia and China, which in turn could undermine U.S. security.

4. There is no justification for procuring and deploying additional interceptors over the next several years.

Deploying more interceptors will not address the fundamental limitations of the Block 2004 GMD system that severely constrain its effectiveness, nor will they improve its defense capability in a meaningful way. Because the system cannot counter threats that employ unsophisticated countermeasures, the kill probability will almost certainly be low. Consequently, more interceptors are largely irrelevant to system effectiveness.

Moreover, adding more interceptors in silos will not make intercept tests more realistic, and takes missiles away from the testing program.

5. There is no technical justification for deployment of the Block 2004 missile defense system.

The MDA claims that the program is "event driven," but while development and testing timelines continue to slip, the deployment schedule has moved up. The administration's goal is not the earliest possible deployment of a militarily effective capability, but simply of missile defense hardware. As physics Nobel laureate Richard Feynman wrote in the report of the presidential commission on the space shuttle Challenger accident, "For a successful technology, reality must take precedence over public relations, for Nature cannot be fooled."

6. The MDA should halt its deployment of the Block 2004 GMD system and Congress should require the MDA to conduct operationally realistic testing of the system before it is deployed.

For a defensive system to be useful to U.S. policy makers and military leaders, more must be known about its likely performance under operational conditions. As this report demonstrates, there are strong reasons to believe that the GMD system will not be effective, neither in its Block 2004 configuration, nor in future block iterations. It is essential that the GMD system be tested by an independent agency under operationally realistic conditions. Congress should insist that realistic testing be conducted to demonstrate system effectiveness under the types of operational conditions that would be encountered in actual battle, including a lack of prior information about the enemy missile, its warheads, and its flight path. Until such tests are performed, there is no justification for deployment of this system.

CHAPTER 1

INTRODUCTION

On December 17, 2002, President Bush announced that he had directed the secretary of defense to begin fielding a ground-based missile defense against long-range ballistic missiles that would achieve initial operational capabilities in 2004 (Bush 2002). The system is intended to defend the United States against attacks by missiles that North Korea might deploy in the future.[1]

A Pentagon press conference and press release provided further details about this system, known as the ground-based midcourse defense (GMD), including that 10 interceptors would be deployed by the end of 2004 (U.S. DOD 2002). It was subsequently revealed that the planned date for achieving a GMD initial operational capability was September 30, 2004 (see for example, U.S. Senate 2003). More recently, the Missile Defense Agency (MDA) has stated that initial operational capability could be as early as July 2004, when the first interceptor is deployed in its silo (Graham 2004a).

This report analyzes the defensive capabilities of the system as it will initially be deployed and as it will evolve through 2005. To do so, we examine the GMD test program in detail and assess what it has demonstrated about the capability of the system and its individual components. We also analyze the technical capabilities of the key system components—the radars and the kill vehicle—to determine how they would function in a hypothetical ballistic missile attack by North Korea. We ultimately assess the capability of the defense to defend Hawaii, Alaska, and the west coast of the United States from North Korean attacks. The administration has stated that the system is also intended to defend against attacks from the Middle East, but no nations in this region could deploy a long-range missile by 2005. Also, the available radars for the GMD system, Cobra Dane and Beale, are oriented in the wrong direction for attacks coming from the Middle East, and look instead toward Russia and China. The Fylingdales early warning radar in England, which could see an attack from this region, is scheduled to become operational by the end of Block 2004, but upgrades to the radar have not yet begun (GAO 2004, p. 15).

Although the Pentagon has not publicly issued any detailed assessments of the defensive capability of the system it will deploy, several officials have

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[1] North Korea does not currently have any long-range missiles capable of reaching the United States. It has maintained a moratorium on missile flight testing since 1998.

made statements in congressional testimony about the system's capabilities. We discuss the assumptions underlying these statements and provide a critique of these assessments.

The GMD System to Be Deployed

The general operating principles of the GMD system, and many of its key components, are based on technology and systems developed under the Clinton administration's national missile defense (NMD) program, which is reviewed briefly below.

The Clinton NMD system

On September 1, 2000, President Clinton announced that he had decided not to deploy the NMD system his administration had been developing, in effect passing this decision on to the next president (Schmitt 2000, p. 1). In announcing this decision, Clinton argued: "I simply cannot conclude with the information that I have today that we have enough confidence in the technology, and the operational effectiveness of the entire NMD system, to move forward to deployment." He specifically singled out the problem of countermeasures (steps the attacker could take to confuse, overwhelm, or otherwise defeat the defense), stating, "There are also questions to be resolved about the ability of the system to deal with countermeasures" (Clinton 2000).

Had he decided to begin deployment, the NMD system would have been fielded in three phases. As is standard practice for new military systems, specific requirements had been set for each phase of this system, although these were classified.

The first phase, the so-called Capability 1 (C-1) system, was planned for deployment in 2005, but its completion would probably have slipped to at least 2007 had deployment gone forward. This system would have deployed 20, and eventually 100, interceptors at Fort Greely in central Alaska.

The NMD system would have used a hit-to-kill interceptor that operates above the atmosphere and would have attempted to destroy an incoming missile warhead during the relatively long midcourse portion of its trajectory. This kill vehicle would have used infrared (and possibly visible-light) sensors to home in on its target. Ground-based radars and space-based early warning infrared sensors would have been used to detect, track, and discriminate potential targets. (See box 1.)

The key sensor for the C-1 system was to have been a ground-based X-band radar (GBX, so called because it would operate at a frequency of about 10 GHz, within the x-band frequency range from 8 GHz to 12 GHz). It would have been deployed on Shemya Island, Alaska, at the end of the Aleutian Islands chain. This X-band radar was specifically designed for the NMD system and emphasized precision tracking and decoy discrimination capabilities.

Box 1. How the Clinton C-1 Midcourse Defense Was Designed to Work

Under the C-1 system, if a long-range missile were launched at the United States, early warning satellites, which use infrared sensors to detect the hot plume of a missile in boost phase, would have provided initial notification of the target launch. Data from the satellites would then be provided to a nearby early warning radar, which would track the missile after its boost phase.

Sometime after the boost phase ended, the missile would release its warhead and any decoys it carried. These objects, along with any debris generated in this process and the deployment bus if one was used, would constitute the "target cluster."

The track data collected by the early warning radar early in the trajectory of the target cluster would be used to predict its future trajectory and estimate where the intercept would occur. In some cases, this information would then be used to formulate an initial "weapons task plan," specifying when and where the interceptor(s) should be launched to deliver the kill vehicle(s) to the right point in space at the right time.

The track information from the early warning radar would also cue the X-band radar, indicating the approximate location of the target cluster so that it begins searching the right vicinity. Concentrating this search on a small region of space would enable the radar to detect the target cluster at much longer distances than would otherwise be possible. Once the radar acquired the target cluster it would begin tracking the objects with high accuracy, refining the estimate of each object's future trajectory. The X-band radar would also attempt to determine which object was the warhead.

At the appropriate time, one or more interceptors would be launched. A few minutes after the interceptor's launch, it would release its kill vehicle. The kill vehicle would perform one or more "star sightings" to precisely determine its orientation, positioning itself so that its visible sensors observed the stars, then comparing its observations with a star map in its onboard computer.

While in flight, the kill vehicle would receive updates on its position and on the target's position from the X-band radar and space-based sensor system, via the nearest ground station. To receive these updates, the kill vehicle was designed so that it would need to orient itself with its antenna facing toward the ground station; once the kill vehicle oriented itself to detect the warhead with its onboard infrared sensors, it cannot receive updates from any ground-based sensors and could not operate on its own.

When close enough, the kill vehicle would detect the target cluster with its onboard infrared sensors and, based on discrimination information previously provided by the X-band radar, determine which object was the mock warhead and maneuver to collide with it.

The intended location of this radar was clearly chosen to track attacks from North Korea. Coverage for missiles approaching from other directions was to have been provided by upgrading five existing early warning radars (in Alaska, California, Massachusetts, Greenland, and England, known as upgraded early warning radars). Upgrading would have enabled them to track targets accurately enough to help guide interceptors, but not accurately enough to discriminate the warhead from other objects in the target cluster. However, these radars would still be far inferior to the X-band radar in both their tracking accuracy and discrimination capability. Existing defense support program (DSP) early warning satellites and their future replacements would have been relied upon for detecting missile attacks and cueing the radars. (See table 1.)

The full Clinton NMD system (Capability 3, or C-3), which would have become operational sometime after 2010, would have added a second interceptor site, most likely at the former Safeguard site in North Dakota. It would also have brought the total number of interceptors up to 250. Perhaps more importantly, it would have deployed as many as eight more X-band missile defense radars at sites spanning much of the northern hemisphere. It would also have deployed a space-based missile tracking system of infrared sensors (known as SBIRS-Low) consisting of some 24 satellites in low earth orbit. This system would have been able to provide track data that was accurate enough to guide interceptors, without assistance from other sensors. It would also assist with target discrimination by providing information on different features of the objects, such as their infrared signal and temperature.

The Bush Administration’s Approach to Missile Defense

As a presidential candidate, George W. Bush argued that the Clinton administration’s approach to NMD was “flawed—a system initially based on a single site, when experts say more is needed” (Bush 2000a). He further stated that the Clinton administration was “driving towards a hasty decision, on a political timetable.” Instead, he argued that “America must build effective missile defenses, based on the best available options, at the earliest possible date. Our missile defense must be designed to protect all 50 states—and our friends and allies and deployed forces overseas—from missile attacks by rogue nations or accidental launches.” Although President Bush entered office with a firm commitment to missile defense deployments, and NMD deployment in particular, the administration’s missile defense plans were not articulated until later.

By the summer of 2001, a general outline of the Bush administration’s approach to missile defense began to emerge through congressional testimony (see, for example, Wolfowitz 2001 and Kadish 2001). It envisioned a single integrated missile defense system that did not differentiate between theater and national missile defenses. The administration declared the goal of being able to shoot down enemy missiles of all ranges—short, medium, and long—in all phases of flight—boost, midcourse, and terminal—and to do this from interceptors on land, at sea, on aircraft (the Airborne Laser), and in space. This system would be layered, in order to provide "multiple engagement opportunities along the entire flight path of a ballistic missile" (Kadish 2001). The idea was that if one layer missed, another might not. The system would defend not only the United States but also allied countries and forces deployed overseas.

Unlike the Clinton NMD system, the Bush administration's missile defense system would not start out with a well-defined architecture. Rather, the acquisition process was to be "evolutionary, one that would allow us to field systems incrementally, once they are proven through realistic testing" (Kadish 2001). In particular, deployment would take place in two-year blocks, the first, Block 2004, covering the years 2004 and 2005. Nor would

Table 1. Interceptors and Sensors Included in the Initial and Final Block 2004 National Missile Defense Systems and the Clinton Administration's "C-1" System

		Bush Administration Initial Capability (Fall 2004)	**Bush Administration Block 2004 System (End of 2005)**	**Clinton Administration C-1 System (2005–2007)**
Interceptors		Fewer than 10[a] (AK & CA)	20 (AK & CA)	100 (AK)
X-band Missile Defense Radars		0	0	1 Shemya, AK
Upgraded Early Warning or Surveillance Radars		Cobra Dane, Shemya, AK Beale AFB, CA	Cobra Dane, Shemya, AK Beale AFB, CA Fylingdales, England	Clear, Alaska Beale AFB, CA Cape Cod, MA Fylingdales, England Thule, Greenland
DSP Early Warning Satellites		Yes	Yes	Yes
SBIRS-Low		No	No	No
Aegis SPY radars[b]	**on Aegis Surveillance and Tracking Destroyers**	1	10	No
	on Aegis Missile Defense Cruisers	No	3[c]	No

a. According to GAO 2000b, p 15: 5 interceptors will be deployed by September 2004 and 10 by February 2005.

b. The Aegis SPY radars are designed as part of a system to defend against aircraft, cruise missiles, and short-range missiles. They have limited utility as part of a defense against long-range missiles. For this reason, the Clinton administration did not incorporate them into its plans for a national missile defense system. The Bush administration is doing so because no X-band radar will be available for Block 2004.

c. These three ships would be armed with a total of "up to 10" SM-3 missile interceptors. These interceptors are not capable of intercepting intercontinental-range missiles targeted at U.S. territory. These ships are included here because their Aegis SPY radars might contribute to the NMD system's surveillance capabilities.

the missile defense system be hindered by “rigid military requirements” (Kadish 2001).

The Bush missile defense program sought to pursue a wide range of potential missile defense technologies, including those developed during the Clinton administration and others that had not been pursued by that administration. This effort was to be supported by significantly increased funding. (The FY01 budget for missile defense was $4.8 billion, the last year of the Clinton administration. Under the Bush administration, the FY02, FY03, and FY04 budgets have been $7.8 billion, $7.4 billion, and $9.1 billion, respectively. For FY05, President Bush has requested more than $10 billion for missile defense, and the administration plans to spend well over $55 billion over the next six years.) The restrictions on the system imposed by the 1972 Anti-Ballistic Missile (ABM) Treaty were to be removed, either by negotiation with Russia or by withdrawing from the treaty.

A notable feature of this program is that it was designed so that “in an emergency and, if directed, we might quickly deploy test assets to defend against a rapidly emerging threat” (Kadish 2001). Finally, “the new testing program will incorporate a larger number of tests than in the past” and these tests “will employ more realistic scenarios and countermeasures” (Kadish 2001).

On December 13, 2002, President Bush announced that the United States would exercise its option to unilaterally withdraw from the ABM Treaty by giving six months notice of its intention to do so (Mufson and Milbank 2001). The U.S. withdrawal from the treaty officially took effect on June 13, 2002 (Milbank 2002).

The Missile Defense Test Bed

A key step toward the deployment of the GMD system was the Bush administration’s decision to establish a missile defense test bed involving the construction of facilities in Alaska and elsewhere. The Bush administration argued that this test bed, due to be completed by the end of 2004, was necessary for more realistic testing, but also stated that it could be used as an “emergency defense” system against North Korea.

This test bed incorporated many existing U.S. missile and missile defense test facilities, including those at Kwajalein test range on Kwajalein atoll in the Marshall Islands, at Vandenberg Air Force Base in California, and in Hawaii, as well as the DSP early warning satellites. (For a more detailed description of the test bed, see Gronlund and Wright 2001, pp. 3–9.) However, the test bed was also to incorporate a number of significant new facilities, including

- Five interceptor silos, to be built at Fort Greely in central Alaska. The interceptors to be placed in these silos would use a test version of the exoatmospheric kill vehicle.

- Upgrades to the Cobra Dane phased array radar on Shemya Island in the western Aleutians to enable it to provide more accurate track information on incoming warheads, and to do so in real time.

- Upgrades to the existing PAVE PAWS early warning radar at Beale Air Force Base in California to enable it to provide more accurate track information on incoming warheads.

- Two interceptor launch silos, to be built on Kodiak Island, Alaska.

- Battle management and communication facilities.

As noted above, Bush administration officials argued that although the test bed was needed to improve the realism of the testing program and was in fact responding to criticisms of the NMD testing program, it could also be used as an operational defense. Even before preliminary construction on the new test bed facilities had begun, in February 2002, the MDA had established a goal of having this test bed completed and able to provide a contingency missile defense capability by the end of September 2004 (Duffy 2002).

Critics of the test bed argued that it was in large part a deployment program disguised as a test program. In particular, they pointed out that the silos at Fort Greely could not be used for testing, because of range safety issues. In addition, they noted that the Cobra Dane radar, a large fixed radar, pointed away from the test range instead of toward it.[2] However, this radar was well situated to detect and track ballistic missiles launched from North Korea toward the continental United States. Thus, they argued, the new test bed appeared to be the "stealthy" beginning of missile defense deployment rather than only an effort to improve the quality of missile defense testing (Gronlund and Wright 2001).

On June 15, 2002, two days after the U.S. withdrawal from the ABM Treaty went into effect, construction of the missile interceptor silos at Fort Greely in Alaska began (Ground Broken 2002).[3]

The Bush GMD System

As noted above, the Bush administration's missile defense system is to be deployed in two-year blocks. The first block, called Block 2004, covers the years 2004 and 2005. It is the only block for which detailed information on planned deployments is publicly available, although some general information is available for Block 2006 and beyond. This report focuses on Block 2004, and the only system intended to provide a national defense: the GMD system.

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[2] In 2003 testimony, Thomas P. Christie, director of operational test and evaluation, U.S. Department of Defense, stated: "I would say that, yes, the Cobra Dane radar, as we know it now, will not be able to—because of the way it's pointed will—you know, except in an operational situation, we will not be able to use it in testing." After being informed that some of the senators could not hear his statement, he repeated: "We will not be able to use the Cobra Dane radar that is presently there to test with because we would have to be launching from, you know, the direction west of that into its envelope" (Christie 2003).

[3] Some preliminary clearing and infrastructure work that did not violate the ABM Treaty had already begun several months earlier.

The Bush Block 2004 GMD system builds directly on the previously announced test bed, using the test bed as its core but adding additional interceptors and sensors. As originally announced, 10 ground-based interceptor missiles would be deployed when the GMD system was declared operational, by the end of September 2004: six at Fort Greely, Alaska, and four at Vandenberg Air Force Base in California. This initial operational capability would rely on a sensor network consisting of the existing DSP early warning satellites, the upgraded Cobra Dane radar, and the upgraded PAVE PAWS early warning radar at Beale Air Force Base in California. A U.S. Navy Aegis surveillance and tracking destroyer would be deployed in the Sea of Japan to provide radar information on missiles launched from North Korea toward Hawaii. In addition, various command-and-control and communication facilities would be deployed.

By the end of Block 2004 (the end of 2005), an additional 10 interceptors were to be deployed at Fort Greely, bringing the total number deployed to 20, and a sea-based X-band missile defense radar (SBX) would have been deployed. In addition, the existing early warning radars in England and Greenland were to be upgraded and integrated into the system (assuming England and Denmark granted permission). Additional Aegis ships would be upgraded so that a total of 15 U.S. Navy Aegis surveillance and tracking destroyers would provide forward-based surveillance in support of the GMD system. Three Aegis missile defense cruisers were also to have their radars modified and would be armed with as many as 20 sea-based interceptors. (These interceptors were intended to provide defense against shorter-range missiles, not the long-range missiles the GMD is to counter.)

Since this initial announcement, a number of changes have occurred. Several planned components have slipped in time and some have slipped entirely out the Block 2004 time frame (that is, until 2006 or later). The objective of having 10 interceptors deployed by September 30 now appears unlikely; the head of the MDA stated recently that 5 will be in place by September (Graham 2004). The upgraded early warning radar in Greenland will no longer be available in Block 2004. Planned Aegis deployments by the end of 2005 have been reduced from 15 to 10 surveillance and tracking destroyers, and the number of Aegis interceptors to be deployed has dropped from 20 to 10. Although the SBX is planned for deployment as a test asset in December 2005, it would not become part of the operational system until 2006. A plan to have the Airborne Laser available as a contingency boost-phase system has also been delayed beyond the end of 2005. On the other hand, current plans now call for the GMD system to be declared operational as soon as the first interceptor is deployed and upgrades to the Cobra Dane radar are complete, which could occur as early as July 2004 (Graham 2004a).

Thus under current plans, the GMD could be declared operational in the summer of 2004, when only a single interceptor has been deployed. By the fall of 2004, several interceptors might be operational, with sensor information provided by DSP early warning satellites, the upgraded Cobra Dane radar on Shemya Island, the upgraded early warning radar in California, and the radar on a forward-deployed Aegis surveillance

Box 2: Components of the Block 2004 System

Early Warning Satellites (DSP/SBIRS-High). U.S. early warning satellites are designed to detect the launch of a ballistic missile and to provide a rough location of the missile launch and limited information about the trajectory of the missile. The current early warning satellites are known as defense support program (DSP) satellites. They are scheduled to be supplemented and eventually replaced by five or six new SBIRS-High early warning satellites; however, the first SBIRS-High satellite will not be launched until at least 2007. All these early warning satellites use infrared sensors to detect the hot plume of the missile during its boost phase. After the missile has stopped burning and the warhead is released, the satellites can no longer see the missile or its warhead.

Ground-based Interceptor (GBI). The GMD interceptor is essentially the same as that of the Clinton NMD system. It consists of an exoatmospheric kill vehicle (EKV) on top of a booster. The booster will be a three-stage missile based in an underground silo. It will boost the kill vehicle to a speed of 7–8 km/s before releasing the kill vehicle. The kill vehicle will be capable of intercepting a target outside Earth's atmosphere. It will first use infrared seekers to home on its target. The kill vehicle, built by the Raytheon Corporation, uses "hit to kill," destroying its target by direct impact with it. The kill vehicle can maneuver in a lateral direction using small side thrusters to collide with its target.

Upgraded Early Warning Radars (UEWRs). The United States deploys early warning radars at several locations worldwide. They are designed to track incoming missiles and warheads in flight after the early warning satellites can no longer do so. The early warning radars currently in operation consist of two ballistic missile early warning system (BMEWS) radars in Greenland and England and three PAVE PAWS radars in Alaska, California, and Massachusetts. These radars are currently not able to track targets with high enough accuracy to guide interceptors, but can be upgraded to give them this capability. Under the Bush GMD plan, the radars in California, England, and Greenland would be upgraded, although the one in Greenland would not be available in Block 2004.

Cobra Dane. Cobra Dane is a large phased-radar on Shemya Island at the western end of the Aleutian Islands chain. It was originally built to gather intelligence on Soviet ballistic missile flight tests. It operates in L-band, between about 1.1 GHz and 1.3 GHz. Cobra Dane, modified for target tracking and interceptor guidance, will be the primary radar for the GMD system when it is declared operational. However, even after upgrade it will not have discrimination or tracking capabilities comparable to those of the planned X-band radars, and its fixed orientation is not optimal (for example, it is not well positioned to see missiles launched from North Korea toward Hawaii).

SPY Radars on U.S. Navy Aegis Ships. Under current plans, up to 18 U.S. Navy Aegis-equipped ships will be upgraded to allow their SPY-1 radar system to contribute sensor information to the GMD system. Fifteen Aegis destroyers would receive such upgrades and would be known as Aegis surveillance and tracking destroyers, although only 10 would be upgraded during Block 2004. These ships, which would be forward-deployed near suspected launch sites, are intended to provide the GMD system with information on the early phases of an attacking missile's trajectory. Three Aegis cruisers will receive similar upgrades and will be known as Aegis missile defense cruisers. They will also carry a small number of ballistic missile interceptors for use against short- and medium-range missiles (not the long-range missiles the GMD system is intended to counter).

Command-and-Control Facilities. The GMD system will have command-and-control nodes in Colorado and at the interceptor launch site at Fort Greely. The command facilities and the various other system components will be interconnected by several communication systems, including a fiber-optic wire network.

and tracking destroyer. (According to the General Accounting Office, three such destroyers would be available at this time, which would allow one to be kept forward deployed).

By the end of Block 2004 (end of 2005), additional components are to be deployed. More ground-based interceptors would be deployed, bringing the total to 20. The upgraded early warning radar at Fylingdales in England is scheduled to become operational, providing sensor coverage for missiles approaching the eastern United States from the Middle East. Up to 10 U.S. Navy Aegis destroyers and 3 Aegis cruisers may have their radar systems modified so that they might be able to contribute sensor data to the GMD system. (And up to 10 sea-based interceptors could be deployed on the cruisers for use against short- and medium-range ballistic missiles.) A sea-based X-band radar (SBX) could be deployed by December 2005, but would not be operational for missile defense purposes until 2006.

Beyond Block 2004

Details of what is planned for the GMD beyond Block 2004 are sketchy, but appear to include the deployment of a second SBX sea-based radar, and up to 20 additional interceptors, 10 of which might be deployed at a third site, possibly outside the United States.

Overview of the Report

In the following chapter, this report examines the GMD test program in detail and assesses what it has demonstrated about the capability of the system and its individual components. Chapter 3 analyzes the technical capabilities of the key Block 2004 GMD components—the radars and the kill vehicle—to determine how they would function in a hypothetical ballistic missile attack by North Korea. It uses this analysis to assess the capability of the Block 2004 GMD system to defend Hawaii, Alaska, and the west coast of the United States from North Korean attacks.

The report goes on to consider the administration's statements about the capability of the Block 2004 system and the motivation for the deployment decision. Chapter 4 provides a critique of the administration's capability assessments, and discusses the assumptions underlying these statements. Chapter 5 assesses the administration's claim that its deployment decision is "event driven" and not schedule driven.

CHAPTER 2

DEMONSTRATED CAPABILITY

Since 1997 the Missile Defense Agency (MDA) has conducted 10 flight tests of the ground-based midcourse defense (GMD) system involving prototype or surrogate system components. A significant amount of ground testing has also taken place, but flight intercept tests are the best way of demonstrating and confirming the capabilities of the individual components and the integrated system. All the flight tests conducted have been research and development tests, which are intended to provide information to allow design modifications to the system and not to assess the system's effectiveness under realistic operational conditions. Nonetheless, these tests provide the best data currently available.

This section assesses what information the flight test program has provided about the defensive capability of the Block 2004 GMD system. **This assessment shows that the system remains in an early stage of development, and that the testing program has provided essentially no data about how the system would perform in a real missile attack.**

The Testing Program to Date

To date, the GMD system has undergone 10 flight tests, of which eight were intercept tests. Five of these resulted in intercepts. (Details about how the United States conducts these intercept tests are provided in box 3 on p. 12.)

As the MDA acknowledges, these tests have included many limitations and artificialities, and they have not used the interceptors or radars that will be part of the Block 2004 deployed system.

The artificialities fall into three general categories, which are discussed below. First, there was essentially no variation in the engagement conditions in these tests. Second, they did not realistically test the discrimination capabilities of the defense. Third, although these were basically tests of the kill vehicle's performance during the endgame, even the endgame was not conducted under operationally realistic conditions.

1. Lack of Variation in Test Conditions

The first eight flight intercept tests have essentially been repeats, with additional components added as the tests proceeded. They were essentially identical in the test geometries, the closing speed and angle, and the time of day.

Box 3. The Anatomy of an Intercept Test

In the eight flight intercept tests of the midcourse system conducted to date, the interceptors have been launched from the Ronald Reagan Ballistic Missile Defense Test Site, located on Kwajalein atoll in the Marshall Islands. In addition to an interceptor launch site, this facility includes an X-band radar, which is a one-third-scale prototype of the missile defense X-band radar that is the key sensor to be used in the GMD system. Other radars and sensors—originally built to monitor U.S. ballistic missile flight tests, but now also used to monitor the GMD intercept tests—are located on Kwajalein.

In these eight tests, a three-stage target missile carrying a mock warhead was fired toward the Kwajalein test facility from Vandenberg Air Force Base in California, some 7,500 km away. The missile then released the bus (a small maneuvering platform designed to release objects on a precise trajectory), which in turn released the mock warhead and one or more spherical balloons. These objects, along with any debris, formed the target cluster in the tests.

Because no radars were in the right location to track the warhead, unlike what would be expected in the operational system, the warhead carried a GPS receiver and transmitter and/or a C-band beacon that allowed a C-band radar on Hawaii to track the warhead. Data from these instruments provided the defense with the location of the warhead, which was used to command the interceptor launch and provide initial guidance information to the interceptor. The X-band radar on Kwajalein provided updates to the interceptor later in flight.

The United States has recently added another launch site on Kodiak Island in Alaska; some future tests will use this facility to launch target missiles or interceptors. In addition, a second launch silo has been constructed at Vandenberg Air Force Base in California to allow tests against two target missiles; such tests are not scheduled until FY07. Interceptor silos are also being built at Vandenberg.

Identical Test Geometries. The same test geometry has been used in all of the tests. The trajectories of the target and interceptor missiles, as well as the planned intercept point, have been nearly identical. In each test, a target missile carrying a mock warhead was fired from Vandenberg Air Force Base in California toward the Kwajalein test facility in the Marshall Islands, 7,500 km away. Some 20 minutes later, the interceptor was launched from the Kwajalein atoll and released the kill vehicle, which traveled north to an intercept point roughly 700 km from Kwajalein and at an altitude of 230 km.

The intercept altitude of 230 km was reportedly chosen to minimize the spread of debris on the ground and in space. However, to intercept warheads in their midcourse, an operational system should be able to intercept at altitudes above 1,000 km.[4] Moreover, the MDA has stated that its goal is to eventually intercept at altitudes as low as 130 km.

Identical Closing Speed and Angle. Because the same test geometry has been used in all the tests, there has been no significant variation in the closing speed or angle of the hit-to-kill endgame. These are important variables and could significantly affect the probability of intercept.

Same Time of Day. With the exception of integrated flight test 10 (IFT-10, which failed), all the tests have been conducted at essentially the same time of day—with the planned intercept occurring two to four hours before local sunset at Kwajalein. This means that the sun was in a similar location for each test and illuminated the mock warhead and other objects from behind the kill vehicle. As a result, the illumination of the objects was similar in each test and the kill vehicle approached the objects with the sun to its back. The time of day at which the test occurs is relevant in part because the infrared signature of an object in space depends strongly on whether the object is in sunlight or in Earth's shadow (at night), as well as on how long it is in sunlight (Sessler et al. 2000, pp. 87–89 and app. A).

IFT-10 was conducted so that the intercept would have taken place at night in Kwajalein. However, the test was not completed because the kill vehicle failed to separate from the interceptor booster. Thus, no data is available for intercepts at other times of day.

2. Ability to Discriminate Not Realistically Tested

One of the key functions the defense system would need to perform in a real attack is to discriminate the warhead from other objects—including decoys and debris from the bus or final stage of the booster—that may be deliberately or inadvertently created when the warhead and decoys deploy. Several aspects of discrimination need to be tested and demonstrated:

- The defense sensors' ability to measure various characteristics of the objects in the target cluster (e.g., radar cross section, physical shape, and infrared signature)

- The battle management system's ability to use the radar measurements to discriminate the warhead from the other objects under different conditions (both when the battle management system has advance intelligence information about the appearance of the objects, and when it does not)

- The kill vehicle's ability to discriminate the warhead from the other objects under different conditions (when the kill vehicle receives

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[4] For example, Dr. John Peller, then NMD program manager at Boeing, the prime contractor for the system, described a simulated intercept of a missile launched by North Korea toward Alaska in testimony to the Subcommittee on Strategic Forces of the Senate Armed Services Committee on February 24, 1999. This intercept would occur at an altitude of roughly 1,100 km.

discrimination information from the radars and when it does not, and when the defense does and does not have advance information about the appearance of the objects)

It will also be important to know that the system can handle instances where the advance intelligence information is misleading or incorrect.

Same or Similar Objects in the Target Cluster. The objects released by the target missile were the same for the first three intercept tests, IFT-3, IFT-4, and IFT-5. They consisted of a mock warhead, which is conical in shape, and a large balloon, which were spherical and had a diameter of 2.2 m.[5] The bus that released the warhead and balloon were also part of the target cluster. For the next three intercept tests, IFT-6, IFT-7, and IFT-8, the large spherical balloon had a diameter of 1.7 m.[6] Despite the change in diameter, the warhead and balloon remained very different in appearance, making them easier to distinguish. For IFT-8, two small balloons, probably about 0.6 m in diameter, were added to the target suite (Sirak 1999).[7]

IFT-9 used the same balloons as IFT-8, but a different mock warhead described as "smaller" than the "medium reentry vehicle" (MRV) used in previous tests. Lt. Gen. Ronald Kadish, the MDA director, stated that the new mock warhead had "a different set of characteristics" than the MRV, adding, "These targets are relatively small. It will be difficult for the system in different ways." These statements may mean that the physical size of the new mock warhead was slightly smaller than the MRV used in previous tests, or that the same warhead was being used but with a different surface coating that decreased the infrared signature to be detected by the kill vehicle's sensors.

Mock Warhead and Balloons Had Very Different Characteristics.[8] The Pentagon has stated that the mock warhead and large balloons look very different from one another to the missile defense sensors. In particular, it has stated that the balloon appears much brighter (i.e., it has a stronger infrared signature) to the kill vehicle than does the warhead.

In the first three intercept tests, the large balloon appeared about six times brighter to the kill vehicle's infrared sensor than did the MRV used in

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[5] The mock reentry vehicle is roughly 1.8 m in height and has a base diameter of roughly 0.75 m.

[6] The 2.2 m balloon was an existing balloon that the Ballistic Missile Defense Organization (BMDO) had in its inventory. The agency reportedly intended to switch to the 1.7 m balloon when it depleted its inventory of the larger one. In the original plans, the new balloon was to have been used first in IFT-7. However, the 2.2 m balloon used in IFT-5 did not inflate properly, and the BMDO may have decided not to use the last balloon of this size because of reliability concerns.

[7] Unlike the large balloon, the small balloons reportedly contain "sophisticated instruments that collect flight data."

[8] More details are available in two UCS technical working papers: Wright 2002 and Wright and Gronlund 2002.

those tests.[9] We estimate that the large balloon used in IFT-6, IFT-7, and IFT-8 appeared more than three times brighter than the MRV.[10] For this reason, the kill vehicle could easily distinguish the balloons from the reentry vehicle. Indeed, a Pentagon briefing about IFT-3 stated that the kill vehicle first saw the large balloon by itself and recognized that it was the balloon rather than the warhead. This means that "discrimination" was not even based on comparing the relative brightness of the two objects, but on the absolute brightness of the balloon itself (U.S. DOD 2000).

The two small balloons added to IFT-8 were much dimmer than the warhead—one-half to one-third as bright as the MRV.[11] It is interesting to note that after the test, Deputy Secretary of Defense Paul Wolfowitz stated that this was the first test in which balloons had looked like the mock warhead.[12] This claim was later corrected by Kadish, who stated that the balloons did not look like the warhead (Wall 2002, p. 28).

There is no public information about the infrared signature of the mock warhead in IFT-9. However, the X-band radar should have had little difficulty in distinguishing the different shapes and radar cross sections of the warhead and balloons.

In contrast, a real attack should be expected to involve decoys that closely resemble a warhead, or warheads whose appearance has been disguised and decoys that appear similar to the disguised warhead. The MDA apparently assumes that certain signatures will correspond to either a warhead or a decoy. According to Maj. Gen. Willie Nance, who was then program executive officer for the ground-based missile defense segment, the defense will "use physics-based information about objects" and "will recognize that there are certain features that are associated with certain objects" (Nance 2001).[13] But in fact, there is no reason to assume that either

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[9] This figure comes from comparing the central values of the predicted one-sigma ellipses for the infrared intensity of the objects for one of the sensor bands, as shown in Tsai et al. 1988, fig. 5. Theodore Postol, personal communication, February 2002.

[10] The 1.7 m balloon apparently has a uniform surface. If this balloon has the same average surface properties as the original 2.2 m balloon, then based on the ratio of cross-sectional areas of the two balloons, it would appear more than three times brighter than the MRV used in those tests.

[11] The small spherical balloons were apparently similar to those that were used in the fly-by tests IFT-1A and IFT-2 (Lt. Col. Richard Lehner, personal communication, March 2002). If these balloons had roughly the same surface coating as the 2.2 m balloon, then their brightness relative to that balloon would suggest they had a diameter of 0.5–0.6 m, in good agreement with their actual size (Tsai et al. 1988, fig. 5).

[12] Wolfowitz stated, "I'll say right off the bat before some critic discovers it, this was not a, quote, 'realistic' test of exactly what intercepts would have to do. But it's the first time we have had anything that looked like a decoy warhead, and it picked out the real warhead from the decoys" (Novak 2002).

[13] Physics-based information refers to features such as the size, temperature, absorptivity, reflectivity, and emissivity of an object as well as features of its motion, including its coning, wobbling, precessing, tumbling, and spinning motions, and the angle between its trajectory and body axis.

the warhead or decoys will have unique characteristics that can be determined by the available sensors alone.[14]

Detailed a Priori Information. Not only has the appearance of the warhead been significantly different from the other objects in these tests, but the defense system has been told what to look for. The defense was given detailed information in advance on the anticipated appearance (i.e., the radar and infrared signatures) of the warhead and other objects. The defense then matched the measured signatures to the expected signatures. As a result, these tests did not assess the ability of the defense to discriminate the warhead from other objects under conditions in which it does not have this a priori information.

The importance of this a priori information to the performance of the defense during these intercept tests is underscored by Kadish's reaction during IFT-5. When told that the balloon did not deploy properly, he responded, "The decoy is not going to look exactly like what we expected. This presents a problem for the system that we didn't expect" (60 Minutes 2000). The test was later aborted when the kill vehicle failed to separate from its booster, so it was not able to provide information on the extent to which this posed a problem for the defense.

There is no reason to assume that such a priori information will be available to the defense before an attack. Because emerging missile states will not extensively flight test their ballistic missiles, the United States is unlikely to have much information about the appearance of its warheads or decoys. Moreover, such countries would take strict precautions to keep this information secret.

These artificialities mean that the eight intercept tests revealed very little about the discrimination capabilities of the defense system. Indeed, Nance stated, "I will tell you that these are not stressing discrimination tests. We don't intend that. These tests are principally focused on demonstrating we could do hit to kill" (Nance 2001).

If that is the goal of these intercept tests, it is important to understand how realistic the endgame of these tests has been and to what extent they have demonstrated hit to kill under operational conditions. As discussed next, the test endgames also included significant artificialities.

3. Unrealistic Endgame Conditions

Although five of the first eight intercept tests resulted in successful intercepts, all the intercept attempts were made under endgame conditions that were—in several ways—unrealistic for a defense against long-range missiles. In particular, the closing speed was low; the target cluster was manipulated to keep it in the kill vehicle's field of view; and the kill vehicle was provided with very accurate track data.

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[14] For a detailed discussion of how an attacker could use "antisimulation" to make a warhead appear like a decoy, see Sessler et al. 2000, chap. 8.

Low Closing Speed. One of the most important parameters for any exoatmospheric hit-to-kill missile defense system is the closing speed at which it will have to make its intercept. The task that the MDA faces is not to demonstrate that hit to kill is feasible, which has been done (e.g., for ERIS and the Homing Overly Experiment), but to do so under realistic conditions, one aspect of which is realistic closing speeds.

In the tests, the closing speed was roughly 7.4 km/s. In a real attack, the operational system would need to function at closing speeds nearly twice that large. This is important, since the time available for homing depends on the distance at which the kill vehicle can detect the target, and on the closing speed. Doubling the closing speed would cut the time available for homing in half, for a given detection range.

The primary reason for the artificially low closing speeds is that all these tests have used a two-stage surrogate booster in place of the three-stage booster planned for the interceptor. As a result, the speed of the kill vehicle has been much lower than would be expected in the operational system. Currently the interceptor has a top speed of about 2.2 km/s, compared with a planned speed of greater than 7 km/s for the operational interceptor.

A surrogate booster has been used in all eight intercept tests because the interceptor booster being developed for the operational system is significantly behind schedule. The new booster is scheduled to be used for the first time in test IFT-13C in late July 2004. However, it is not clear why—until now—the MDA has chosen to use a two-stage surrogate booster rather than a faster three-stage booster. A three-stage booster has launched the target complex from Vandenberg in the same tests.

Objects in Target Cluster Simultaneously in Kill Vehicle Field of View. The BMDO briefing on IFT-6 (Nance 2001) was the only one to provide detailed information about the location of all the objects as they approached the kill vehicle. This information indicates that the warhead, balloon, and bus all remained simultaneously in the kill vehicle's field of view until very late in homing process (Theodore Postol, personal communication, October 2001). Because every aspect of these tests is carefully controlled, it is very likely that the test was designed so that this would be the case. To achieve this, the bus would be programmed to release the warhead and balloon so that these three objects are all roughly lined up along the direction of sight of the kill vehicle's sensors. (Doing so is similar to releasing several independently targeted warheads—or MIRVs—from a missile.)

As a consequence, although the warhead and balloon were separated by 5.5 km shortly before intercept, to the kill vehicle they appear to have a cross-range separation of less than a kilometer. Similarly, the bus appears within about a kilometer of the other objects even though its actual spatial separation is greater.

Information about the locations of the objects in the target cluster is not available for the other tests, so we do not have evidence that the objects were arranged this way in those cases. However, doing so has a clear advantage.

Lining the objects up in this way allows the kill vehicle to collect data on them simultaneously. Otherwise, it would have to maneuver to rotate its sensors' field of view from one object to another. Since the kill vehicle's infrared sensors have a field of view of one degree, then two objects separated by 5.5 km could not be seen simultaneously when the kill vehicle was closer than about 300 km. If the objects were separated by 1 km, they could be seen simultaneously until they were within 60 km of the kill vehicle. (See figure 1.)

This special arrangement therefore simplifies the job of the kill vehicle and allows it to collect data on the objects for a longer time. This situation could obviously not be expected in general. Indeed, in an actual attack, one might expect that the attacker would consciously try to separate some of the objects in the target cluster far enough to make observing them more difficult for the kill vehicle. Moreover, this problem becomes more severe at the higher closing speeds appropriate to an operational system, since the kill vehicle would then have less time to collect data on the objects in the target cluster. Since using the operational booster could lead to a closing speed that is twice as large as that in current tests, this could cut in half the time available for the kill vehicle to view the objects.

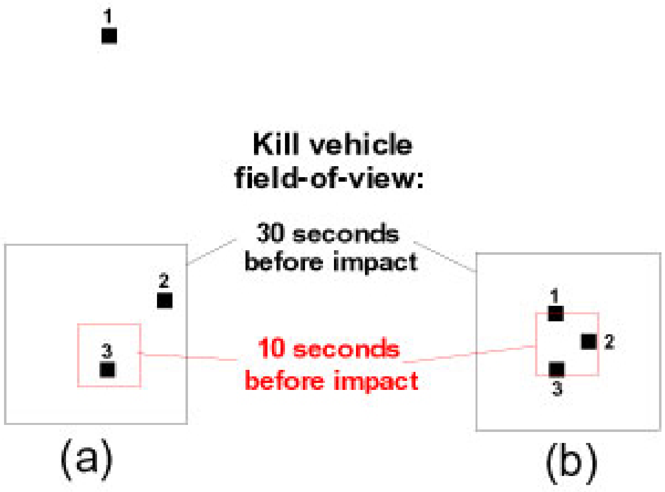

Figure 1. Kill Vehicle Field of View
This figure shows the same arrangement of objects in the target set in test IFT-6 from two different directions. Object 1 is the balloon decoy, Object 2 is the mock warhead, and Object 3 is the bus that released them. The kill vehicle is assumed to be approaching the objects in the direction you are looking at the figure. In part (a) of the figure, the target set is oriented in such a way that the objects appear so widely spaced that the sensors on the kill vehicle could not see the objects simultaneously as it approached impact. This is illustrated in the figure by the fact that the field of view of the kill vehicle's sensors (shown by the inner and outer squares) cannot contain all of the objects at the same time. In IFT-6, the objects were instead released so that the kill vehicle approached them from the top in part (a). From this direction, the objects are lined up with one another and appear to the kill vehicle to be much closer together, as shown in part (b) of the figure. As a result, they all remain simultaneously in the kill vehicle's field of view until very late in the homing process. This figure assumes a one-degree field of view for the kill vehicle's sensors, and a closing speed of 7.4 km/s, which was the speed in IFT-6.

Kill Vehicle Provided with Very Accurate Tracking Data. In all the intercept tests, the mock warhead carried a GPS transmitter and/or a C-band beacon, which appears to have provided the defense with high quality tracking information on the location of the warhead—possibly higher than would be provided by an X-band radar. This allowed it to launch the interceptor on a trajectory that was aimed essentially directly at the warhead, rather than toward a larger basket that included the full target cluster. Consequently, the kill vehicle did not need to maneuver much to hit the target.

Moreover, this test situation is only relevant to the case in which the radars have already discriminated the warhead prior to the launch of the interceptor booster. If this is not possible, the kill vehicle itself must discriminate.[15] In this case, the kill vehicle would be launched toward a basket containing the full target cluster, which could easily be tens of kilometers across, and homing would require much more maneuvering than is demonstrated in the current tests. In fact, none of the radars that will be available for use by the Block 2004 GMD system will be able to discriminate, leaving that task to the kill vehicle.

Because of this set of endgame artificialities, the intercept tests should not be construed as demonstrating the capability of the system under operationally realistic conditions, which would be considerably more demanding.

What the Tests Have Not Demonstrated

The limitations, artificialities, and scripting of the GMD intercept tests discussed above, coupled with the decision to deploy the system this year, have led to the situation where key components and capabilities of the system have not yet been demonstrated, and many will not be by September 2004 or well after that.

The MDA argues that building the Pacific test bed is necessary for rigorous and more realistic testing of the system. (See box 4 on p. 20.) Demonstrating some of the capabilities will require or be facilitated by the new test bed. However, many could be demonstrated with the test facilities already used for the first eight intercept tests. The fact that such testing has not been conducted is due to factors other than limitations of the existing test facilities—including the early stage of development of the system and the schedule slips discussed in chapter 5.

The discussion below highlights key components and capabilities and the extent to which they have been demonstrated in flight intercept tests. In sum, according to a February 2004 General Accounting Office (GAO) report:

> None of the components of the initial defensive capability to be fielded in September 2004—interceptors, fire control

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[15] This is called a Category B test. "The GMD system is designed to launch interceptors under one of three 'categories' of operation: (A) when a threat reentry vehicle has been tracked and discriminated by ground-based radars, (B) when ground-based radars have a track of the threat complex but discrimination is either incomplete or unavailable, or (C) when space-based sensors provide an early track of the boosting missile" (GAO 2004a, p. 6).

Box 4. More Interceptors Are Not Needed in Silos

On the grounds that the GMD weapon system is unique, the MDA has turned on its head the “Fly Before You Buy” requirement that any new weapon system undergo realistic operational testing to assess its effectiveness before procuring more than a small number of weapons for testing.* Instead, the MDA is arguing that the system must be built before rigorous and more realistic testing of the system can take place.

According to Kadish, the main reason for building the Fort Greely site was to allow for more realistic flight testing (Graham 2004). Moreover, the MDA includes the Fort Greely site as part of its new Pacific test bed. However, the Fort Greely interceptors will not be used for testing, but only as part of the Block 2004 operational system.

For safety reasons, the United States does not launch intercontinental-range missiles from an inland site. In response to critics pointing this out, the Ballistic Missile Defense Organization has stated that it might try to change the regulations so interceptors could be launched from Fort Greely. However, this would require a new environmental impact report. Moreover, there is no compelling reason to launch interceptor missiles from Fort Greely rather than Kodiak for a research and development test program: launches from Kodiak could address many of artificialities discussed in this chapter by facilitating intercept tests at longer ranges and higher speeds.

Even if there were a testing purpose to putting one or two interceptors at Fort Greely—for example, to facilitate training soldiers—there is no reason to deploy five, or ten, or more interceptors. Yet in the FY05 budget, the MDA has requested funds to build and field an additional 20 interceptors at Fort Greely and perhaps a third site, bringing the total deployed to 40 interceptors.

Despite the MDA’s contentions, it is clear that buying 20 additional interceptors for deployment in silos is irrelevant to the MDA’s flight test plans or capabilities. Moreover, while Kadish argues that he needs to buy in order to fly, this argument is disingenuous. It makes no sense to buy large numbers of interceptors before they have been tested and shown to work.

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* In this case, the weapons affected by the law would be the interceptors.

> nodes for battle management and execution, upgraded radars [Cobra Dane and the Beale radar], and forward-deployed Aegis radars on Navy cruisers and destroyers—has been flight-tested in its deployed configuration. . . . [The] MDA does not plan to conduct a system-level demonstration of the initial defensive capability in flight testing before September 2004 (GAO 2004a, p. 4).

Key Capabilities Not Demonstrated for Block 2004 GMD

- **The MDA will not conduct flight tests using the Cobra Dane radar before September 2004.** Although the Cobra Dane radar on Shemya has been identified by the MDA as a critical sensor for the defense system, Cobra Dane "will not actively participate in integrated flight tests at least through September 2007" (GAO 2004a, p. 6).

- **The MDA will conduct no flight tests by September 2004 of the new surveillance and tracking software being developed for the Aegis SPY radar** (GAO 2004b, p. 53). The reliability of communications links with the Aegis radar is also uncertain (GAO 2004b, p. 68). (The test bed is not required for these tests.)

- **The MDA has not tested the three-stage interceptor boosters being developed for the deployed system in an intercept attempt.** The first intercept test using one of these boosters is IFT-14, which is currently planned for mid-September 2004. Interception is not a goal of IFT-13C, currently scheduled for July 31, 2004, but may be attempted.[16] (The test bed is not required for these tests.)

- **The MDA has not used the deployment version of the kill vehicle in an intercept attempt.** IFT-13C would be the first flight test of a version of the Initial Block Exoatmospheric Kill Vehicle (IBEKV). Even this vehicle will not be the same as the kill vehicle intended for deployment; Pentagon documents say the test will use a kill vehicle that is "approximately 95 percent representative" of the kill vehicle to be used in the initial deployment (U.S. DOD 2003). (The test bed is not required for these tests.)

- **The MDA has not conducted any intercept tests in which one of the radars in the defense system provided the target information to launch and guide the interceptor and apparently does not plan to do so before September 2004.** The target tracking information used to launch the interceptor in all the intercept tests that have been conducted has come from artificial sources—either a GPS receiver or C-band beacon on the mock warhead. This will continue in IFT-13C and IFT-14 (GAO 2000a, p. 8) and apparently for the foreseeable future: in Senate testimony in March 2004, Kadish implied this artificiality would

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[16] IFT-13C and IFT-14 are scheduled to use the Orbital Sciences booster. The other booster, being developed by Lockheed Martin, will not be used in an intercept test until 2005 at the earliest.

continue for "18 to 24 months" (U.S. Senate 2004). In particular, no tests have been conducted in which the interceptor is launched using data from either the Cobra Dane radar or the Aegis SPY radar, which would be the sensors available for target tracking in an actual engagement. (This test could be done using a SPY radar without requiring the test bed.)

- **The MDA has not conducted any "Category B" tests, in which the kill vehicle is given only track information on the threat cloud and not specifically on the warhead, and must make the discrimination itself. Yet this is what the Block 2004 system will require, since neither the SPY, Cobra Dane, nor Beale radars will be able to discriminate the warhead from other objects (see footnote 15). No such test is scheduled before September 2004, and when the first such test will be conducted remains undecided.**

  Test IFT-15, which has slipped into FY-2005 from July 2004, was until recently intended to be a Category B test, but the MDA now says that the timing for such a test is under review. Neither the Cobra Dane radar nor the upgraded early warning radar in Beale, California, has the resolution needed to perform target discrimination, so "the kill vehicle itself must perform final target selection during the endgame." (GAO 2004a) The same is true for the Aegis SPY radar. However, identification of balloons and warhead by the kill vehicle has never been demonstrated without giving the kill vehicle detailed a priori information about the objects. As discussed above, discrimination by the kill vehicle is further complicated if the objects in the target set are separated widely enough that they are not all in the kill vehicle's field of view as it approaches the objects. In that case, the kill vehicle will need to physically turn its sensors to view one object after another rather than seeing them all at the same time. (The test bed is not required for these tests.)

- **The MDA has not conducted an intercept test with a closing speed comparable to what would be encountered in a real engagement.** As discussed above, the intercept tests that have been conducted have used a slow, two-stage surrogate interceptor booster with a speed of roughly 2.2 km/s, leading to closing speeds of somewhat over 7 km/s. In a real engagement using the deployed three-stage booster, closing speeds could be up to twice that value. Faster closing speeds reduce the time the kill vehicle has to acquire, track, discriminate, and maneuver to home on the target. IFT-14 is the first planned intercept with a more realistic closing speed, and this test may not occur until after September 2004.[17] (The test bed is not required for these tests.)

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[17] IFT-13C may attempt an intercept in late July, but an intercept is not scheduled.

- **The MDA has not conducted intercept tests at different times of day, under different solar conditions, and apparently does not plan to before September 2004.**[18] The location of the sun relative to the target set and the kill vehicle can significantly change the brightness of the objects and therefore affects how well the kill vehicle's optical sensor will detect the objects. If the attack took place at night with the trajectory in Earth's shadow, the optical sensors would not be useful (Sessler et al. 2000, pp. 87–89). Moreover, whether the engagement takes place in daylight or darkness can have a large effect on the relative temperatures of the objects in the target set, and thus how they would appear to the kill vehicle's infrared sensors (Sessler et al. 2000, appendix A). These issues are particularly important since, as noted above, in the Block 2004 system discrimination will have to be done by the kill vehicle's sensors. (The test bed is not required for these tests.)

- **The MDA has not conducted any intercept tests against a tumbling warhead and does not currently have plans to do so.** A tumbling warhead is a likely occurrence in a real attack since tumbling is a natural consequence of not controlling the separation of the warhead from the missile body. Thus, demonstrating the defense capability against such a target should be a high priority. A tumbling warhead would present a significantly different signal to the kill vehicle, since its motion would create significant fluctuations in its infrared signature, which the kill vehicle uses for detection. Moreover, such a fluctuating signal could be difficult to distinguish from other tumbling objects in the target cluster, such as the bus and separation debris, or from balloons that give a similarly varying signal from, for example, stripes or some otherwise varying surface coating. (The test bed is not required for these tests.)

- **The MDA has not conducted any intercept tests against targets with countermeasures of the kind that would be expected in a real attack.** Several of the past intercept tests have included one or three balloons along with the mock warhead as part of the target set, but as the MDA has acknowledged, these were not intended as decoys.[19] As discussed in chapter 3 of this report, several authoritative reports have discussed the kinds of simple but effective countermeasures that could be built by a country capable of acquiring a long-range missile and nuclear warhead. The MDA has admitted that its initial system cannot deal with such countermeasures, but argues unconvincingly that it believes missile attacks from a country like North Korea would not include countermeasures. (The test bed is not required for these tests.)

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[18] Test IFT-10 was scheduled at night, but the test failed because the kill vehicle did not separate from the interceptor booster, so it did not produce any useful information.

[19] These balloons have been easily distinguishable from the warhead, and the defense has been given detailed information in advance about what each object would look like (Wright 2002; Wright and Gronlund 2002.).

Moreover, if discrimination is based only on the infrared sensors on the kill vehicle, the types of countermeasures used can be even simpler than would be required if a radar could aid in discrimination. Infrared sensors are easily fooled by decoys designed to have different temperatures, which can be achieved by simply varying the surface properties of objects—by, for example, painting them (Sessler et al. 2000).

- **The MDA has not conducted any intercept tests of multiple interceptors against multiple targets, and no such tests are scheduled until FY2007** (GAO 2004a, p. 7). In a real attack, the attacker would be expected to launch several missiles at the same time to stress the defense, and the defense plans to fire several interceptors at each incoming warhead. In this highly probable scenario, the defense must be capable of handling more than one target at the same time, perhaps with overlapping clusters of targets, debris, and decoys. Such an engagement would be much more difficult than the scenarios currently being tested against.

- **The MDA has not conducted intercept tests in severe weather conditions to understand how this would affect system performance.** Previous flight tests have been conducted under fair conditions or "limited adverse conditions (light rain)" (GAO 2004a, p. 7). (The test bed is not required for these tests.)

- **The MDA has not conducted any flight tests under unrehearsed and unscripted conditions, and has no plans to do so** (GAO 2004a, p. 9). Even more important, the MDA's plans do not include independent testing under operationally realistic conditions, as would normally be conducted by the director, Operational Testing and Evaluation (see box 5). Only independent operational testing can demonstrate that the GMD system has any defensive capability under real-world conditions.

Without demonstrating these key capabilities in tests under realistic conditions and without a priori information about the attacking missile and its warhead and decoys, the MDA has no basis for believing that its deployed system will have any defensive capability.

Box 5. The MDA Has No Plans for Independent, Operationally Realistic Testing

To prevent the costly and dangerous procurement and deployment of military systems that did not work as intended, Congress passed a law more than 20 years ago—often referred to as the "Fly Before You Buy" law—establishing the office of the Director, Operational Testing and Evaluation (DOT&E) in the Department of Defense. The DOT&E reports both to the Secretary of Defense and to Congress, and oversees the operational testing programs for all major military systems.

The most operationally relevant data about overall system effectiveness comes from realistic operational testing. It is intended to be as realistic as possible: for example, the system is operated under operationally realistic conditions, including at night and in bad weather; soldiers rather than contractors operate the system; they are given only that minimum warning about the time or conditions of the attack necessary to organize and safely conduct the test; and expected enemy countermeasures are employed. Operational tests use production representative components that will be deployed as part of the system, and not prototypes or surrogates. Most important, these tests are conducted by the Service Operational Test Agencies and overseen by the DOT&E—independently of the program that is developing the weapon system.

Operational testing follows a series of development tests that are used to learn about basic system performance parameters, to uncover problems, and to refine the system development plans. As development testing progresses, the tests generally incorporate more operational realism, but operational tests are qualitatively different because they simulate as closely as possible actual usage.

Under this law, a major defense acquisition program may not produce weapons at more than a low rate (referred to as "going beyond a low rate of initial production (LRIP)) until realistic operational testing has been conducted and the DOT&E issues a report (called a "beyond-LRIP report") stating whether (1) the tests and evaluation performed were adequate, and (2) the results of such test and evaluation confirm that the items or components actually tested are effective and suitable for combat. While Congress and the Pentagon may decide to go into full production even if the conclusions of this report are negative, usually they do not until system improvements have been made.

Although the MDA will deploy 20 GMD interceptors by the end of 2005 and has requested funding for an additional 20, the GMD system remains in the early stage of its development testing. The MDA argues that its plans are not covered by this part of the Title X law because the GMD program is a research and development program and not an acquisition program.

Far more significant is that for the next decade or more, the MDA's plans do not include any operational testing. At a recent congressional hearing, Thomas Christie, the current DOT&E, was asked by Senator Carl Levin (D-MI) about plans for operational testing of the GMD system. He replied, "As far as dedicated operational testing that I'm in control of right now, that's not in the plan, for the foreseeable future" (Christie 2004).

At one point in the test planning for the GMD system, a series of "pop quizzes" were included. Such tests would begin to capture the surprise and lack of a priori information expected in realistic engagements. However, those pop quizzes have been indefinitely postponed as well.

Without independent testing under operationally realistic conditions, no one—including the MDA, the military, the administration, Congress, and the American public—will have the information needed to demonstrate that the GMD system has any defensive capability under real-world conditions.

CHAPTER 3

A TECHNICAL CAPABILITY ASSESSMENT

As we discuss in chapter 2, few of the capabilities required for an effective defense have been demonstrated to date, and most will not be for some time. Given such limited information about the system's ability to intercept a long-range missile, any assessment of its potential effectiveness must be based on the theoretical capability of the system's components against an array of attacks under various conditions. This is the methodology we use below.

The Block 2004 system is intended to defend against attacks from North Korea, should it acquire a long-range missile capability, and the plausible targets are Hawaii, Alaska, and the west coast of the United States.[20] We discuss each of these cases separately because the differences in their locations relative to the radars and interceptor bases pose different challenges. First, however, we discuss what is arguably the most important challenge to system capability: countermeasures.

Countermeasures

The most detailed publicly available official document discussing countermeasures is the unclassified summary of the September 1999 *National Intelligence Estimate (NIE) on the Ballistic Missile Threat to the United States Through 2015*, a consensus document of the U.S. intelligence agencies. This document states that emerging missile states would probably rely on "readily available technology . . . to develop . . . countermeasures" and that they could do so "by the time they flight test their missiles." Moreover, it lists several readily available technologies that emerging missile states could use to develop countermeasures (NIC 1999).

An April 2000 report co-authored by 11 independent scientists and engineers, *Countermeasures: A Technical Evaluation of the Operational Effectiveness of the Planned U.S. National Missile Defense System,* analyzed several countermeasures that would be available to any attacker capable of building a long-range missile, such as North Korea. It further analyzed the capability of the Clinton administration's planned "Capability-3" (C-3) system and found that the fully deployed system would be rendered ineffective by these unsophisticated but effective countermeasures (Sessler et al. 2000). The countermeasures considered in detail in the report were anti-simulation balloon decoys (in which the warhead would be placed in a

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[20] The system will include no radars that can observe an attack from the Middle East and will not until the Fylingdales radar is updated, a process that has not begun.

balloon as well to appear as a decoy), a cooled shroud to defeat infrared homing, and submunitions for chemical and biological weapons. (See box 6.)

As is shown in table 2 below, the C-3 system would have included 250 interceptors, 9 X-band missile defense radars, and a satellite-based system of infrared sensors. By contrast, when fully deployed, the Block 2004 system will include 20 interceptors, no X-band radar, and no space-based infrared

Box 6. The MDA's Assessment of Midcourse Countermeasures

The Missile Defense Agency (MDA) has conceded that midcourse countermeasures present major difficulties for the ground-based midcourse defense (GMD) system.

In its February 2004 report, the General Accounting Office (GAO) noted that the MDA's current test plan, which goes through intercept flight test 26 (IFT-26) and FY2007, includes no intercept tests "to address the challenge posed by an enemy's use of unsophisticated but more challenging counter-measures" (GAO 2004a, p. 13). Instead, MDA officials told the GAO that the MDA is analyzing the technical challenges posed by such countermeasures, and that they "may be" included in flight tests at a later time.

Even more indicative of the MDA's thinking about midcourse countermeasures is their formal response to the GAO report, which concluded that the MDA was not adequately addressing the countermeasures issue. The MDA response states:

> Another key point overlooked in the August 2000 DOT&E report, and now the subject [of the] GAO report, is the inherent robustness of the envisioned layered BMD [ballistic missile defense] system relative to midcourse countermeasures. The GAO report correctly identifies the challenges any of our midcourse defensive weapons and sensor systems would face in the presence of various decoys and countermeasures. But the BMD program will evolve to include employment of layered sensors and boost-phase intercept capabilities as an effective means to defeat midcourse countermeasures, sophisticated or otherwise, by destroying the adversaries' [sic] ballistic missile prior to the deployment of the enemy warhead and accompanying countermeasures. The value in this strategy must be factored in when making investment decisions for all available counter-countermeasures programs (GAO 2004a, p. 23).

The MDA is asserting that the solution to the midcourse countermeasure problem will be the addition of boost-phase defenses, which will not be ready for initial deployment for at least several years. The boost-phase defense that is furthest along in development is the Airborne Laser, which is facing cost, schedule, and technical problems and would not be deployed until Block 2006 or, more likely, much later.

Table 2. Interceptors and Sensors Included in the Initial and Final Block 2004 National Missile Defense Systems and the Clinton Administration's "C-3" System

		Bush Administration Initial Capability (Fall 2004)	**Bush Administration Block 2004 System (End of 2005)**	**Clinton Administration C-3 System (After 2010)**
Interceptors		Fewer than 10* (AK & CA)	20 (AK & CA)	250 (125 AK, 125 ND)
X-band Missile Defense Radars		0	0	Shemya, AK Clear, AK Beale AFB, CA Cape Cod, MA Fylingdales, England Thule, Greenland Grand Forks, ND Hawaii South Korea
Upgraded Early Warning or Surveillance Radars		Shemya, AK	Shemya, AK Fylingdales, England	Clear, AK Beale AFB, CA Cape Cod, MA Fylingdales, England Thule, Greenland South Korea
DSP Early Warning Satellites		Yes	Yes	Yes
SBIRS-Low		No	No	Yes
Aegis SPY radars[b]	**on Aegis Surveillance and Tracking Destroyers**	1	10	No
	on Aegis Missile Defense Cruisers	No	3[c]	No

a. According to GAO 2004b, p. 15: 5 interceptors will be deployed by September 2004 and 10 by February 2005.

b. The Aegis SPY radars are designed as part of a system to defend against aircraft, cruise missiles, and short-range missiles. They have limited utility as part of a defense against long-range missiles. For this reason, the Clinton administration did not incorporate them into its plans for a national missile defense system. The Bush administration is doing so because no X-band radar will be available for Block 2004.

c. These three ships would be armed with a total of "up to 10" SM-3 missile interceptors. These interceptors are not capable of intercepting intercontinental-range missile targeted at U.S. territory. These ships are included here because their Aegis SPY radars might contribute to the NMD system's surveillance capabilities.

sensors. Thus it would be far less capable than the nominal C-3 system, which *Countermeasures* demonstrated would be ineffective against attacks using these countermeasures. It follows that the Block 2004 system would be even more vulnerable to countermeasures, thereby negating its more limited defensive capability.

In fact, the Block 2004 system would be vulnerable to even simpler countermeasures than those considered in *Countermeasures*. Because the C-3 system included X-band radars, which have very high discrimination capabilities, and infrared sensors, effective countermeasures would have had to address both types of sensors. In contrast, the radars available to the Block 2004 system are not able to discriminate the warhead from other objects in the threat cloud released by the attaching missile.[21]

None of the radars that will be part of the Block 2004 system—Cobra Dane, the Beale upgraded early warning radar (UEWR), or the Aegis SPY radar—have high enough resolution to provide the discrimination capabilities necessary to locate the warhead in a threat cloud. As shown in table 3, the range resolution of these radars, which varies from 4 m to 30 m, is large relative to a warhead-sized object.

In its assessment of the GMD system, the GAO made this same point, stating:

> A notable limitation of system effectiveness is the inability of system radars to perform rigorous target discrimination. The Cobra Dane radar and the upgraded early warning radar in California can perform rudimentary target discrimination, but the kill vehicle itself must perform final target selection during the endgame (GAO 2004a, p. 4).

Thus, countermeasures that defeat only the infrared sensors on the kill vehicle would be an effective option for an attacker facing the Block 2004 defense. Such countermeasures would be simpler to build than ones designed to defeat two types of sensors. Below we consider the capabilities of the kill vehicle's infrared sensor, and discuss several examples of countermeasures that would be effective against the Block 2004 system.

Capabilities of the Infrared Sensor on the Kill Vehicle

The kill vehicle will use a long-wave infrared (LWIR) sensor to detect and, if necessary, discriminate its warhead target. It also has a visible light sensor, but at least in the initial flight tests, it was used only for a star sighting to better determine the kill vehicle's position and orientation.

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[21] The sea-based X-band radar (SBX) currently under construction has the high resolution required for discrimination, as the ground-based X-band radars planned for C-3 would have. Its roughly 15-cm range resolution is much smaller than a warhead-sized object of roughly 2 m in dimension and thus would allow it to determine the object's approximate size and shape. (See table 3.) However, this radar will not be ready for deployment as part of the Block 2004 system.

Table 3. Characteristics and Measurement Capabilities of Block 2004 Radars
For comparison, the table also includes the properties of the sea-based X-band radar currently under construction, which is planned for the Block 2006 system, and the ground-based X-band radar that the Clinton administration had planned to deploy.

	Upgraded PAVE PAWS (Beale AFB, CA)	Upgraded BMEWS (Fylingdales, England)	Cobra Dane (Shemya Island, AK)	AEGIS SPY	Sea-based X-Band	Clinton System X-Band
Frequency	420–450 MHz	420–450 MHz	1.175–1.375 GHz	3.1–3.5 GHz	10 GHz	10 GHz
Wavelength	67–71 cm	67–71 cm	~ 22–25 cm	~ 8.6–9.7 cm	3 cm	3 cm
Antenna Diameter (D)	22.1 m	25.6 m	29 m	~ 3.75 m	8.9 m[a]	12.5 m
Antenna Aperture[b]	384 m^2	515 m^2	660 m^2	12 m^2	62.2 m^2	123 m^2
Average Power (per face)	150 kW	255 kW	920 kW	32/58/77 kW[c]	133 kW	205 kW
Angular Beamwidth (θ_{BW})	2.2° (0.038 radians)	2.0° (0.035 radians)	~ 0.46° (0.0081 radians)	~ 1.5° (0.024 radians)	0.19° (0.0034 radians)	0.14° (0.0024 radians)
Cross-range Resolution (at 2,000 km)	75 km	70 km	16 km	48 km	6.8 km	4.8 km
Bandwidth (β)	≤ 30 MHz	≤ 30 MHz	5 MHz/ 200 MHz[d]	40 MHz[e]	1 GHz	1 GHz
Range Resolution	≥ 5 m	≥ 5 m	30 m/ 1.1 m	3.75 m	15 cm	15 cm

a. Based on a circular aperture with an area of 62.2 m^2.

b. The antenna apertures are taken to be πr^2, except for Aegis.

c. These figures are for SPY-1A, SPY-1B/D (cited in text), and SPY-1D (V)(estimated), respectively.

d. The 200 MHz applies only within ± 22 degrees of the radar's boresite.

e. Maximum bandwidth for SPY-1B/D. Bandwidth and range resolution may be better for SPY-1D(V) and ships modified for missile defense.

The infrared sensor on the kill vehicle uses a telescope to focus radiation from an object onto an array of small detectors, called pixels. When the kill vehicle's infrared sensor first detects an object, the radiation from that object will fall on a single pixel, and it will appear as a tiny dot of light with no distinct features.[22] A warhead-sized object of roughly 2 m in size will occupy

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[22] If the kill vehicle's aperture is 20 cm, then with a LWIR wavelength of 10 microns the diffraction-limited angular resolution would be roughly 0.00001/0.2 = 0.05 milliradians. The kill vehicle uses a 256 x 256 array and has just under a 1 degree

more than one pixel only at a distance of 30 km, which would be roughly 3 seconds prior to intercept. As a result, the kill vehicle can extract little information about the size or shape of an object before it must decide which object to intercept.[23] (See figure 2.)

The kill vehicle can measure the infrared intensity of the object in several infrared bands, thereby estimating its temperature. It can also measure how the infrared signal varies with time (which would occur, for example, if the object changes temperature or if an object that does not have a uniform spherical surface is tumbling).[24] However, the infrared signal of the warhead and decoys can be manipulated by the attacker to fool the system, as discussed below, to prevent their use for discrimination.

Therefore, in the absence of a radar with good discrimination capabilities, objects of different shapes and roughly comparable sizes will be indistinguishable to the Block 2004 defense. As a result, the defense will not be able to identify the warhead in order to fire a kill vehicle at it.

Infrared Decoys

The temperature and infrared signature of a warhead or decoy can be easily manipulated by the attacker, particularly if the attack takes place so that these objects are illuminated by the sun. For example, by simply changing the surface coating of an object (e.g., by painting its surface), its infrared signal can be changed by more than a factor of 10 (Sessler et al. 2000, p. 122, table A1). An attacker could make the temperature of each object in the package of decoys and warheads different from the others or make them nearly identical. In either case, the kill vehicle would be unable to determine which object was the warhead.[25]

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field of view, so each pixel corresponds to an angle of 0.0175/256 = 0.07 milliradians, or slightly greater than the diffraction limit. Using this value, we see that at a range of 500 km, each pixel corresponds to an azimuthal width of 35 m.

[23] The pixel resolution will not reach the size of a warhead, 2 m, until the range is just under 30 km. Even then, each warhead will occupy at most one or two pixels. In order to get any information on the shape of warhead-sized objects, a resolution that is a fraction of the object's dimensions is needed. For example, if the required resolution is a quarter of the warhead size, or 0.5 m, then this will not be achieved until the warhead is within about 7 km of the target. At this point there would be 0.5 to 1.0 second left to intercept the target. Moreover, at this point the kill vehicle's field of view is only about 120 m across. If the potential targets are more widely separated, than the kill vehicle will not be able to determine anything about the shape of all the objects because there will not be time to maneuver to view each object individually. In this case, the kill vehicle will have to decide which object to attempt to intercept without knowing anything about all their shapes, or even their relative shapes.

[24] If the kill vehicle has an estimate of the distance to the object, it can also estimate its infrared brightness and emissivity-area product.

[25] Unlike the case for decoys designed to fool both an X-band radar and infrared sensors, there would be no need to place the warhead itself in a balloon.

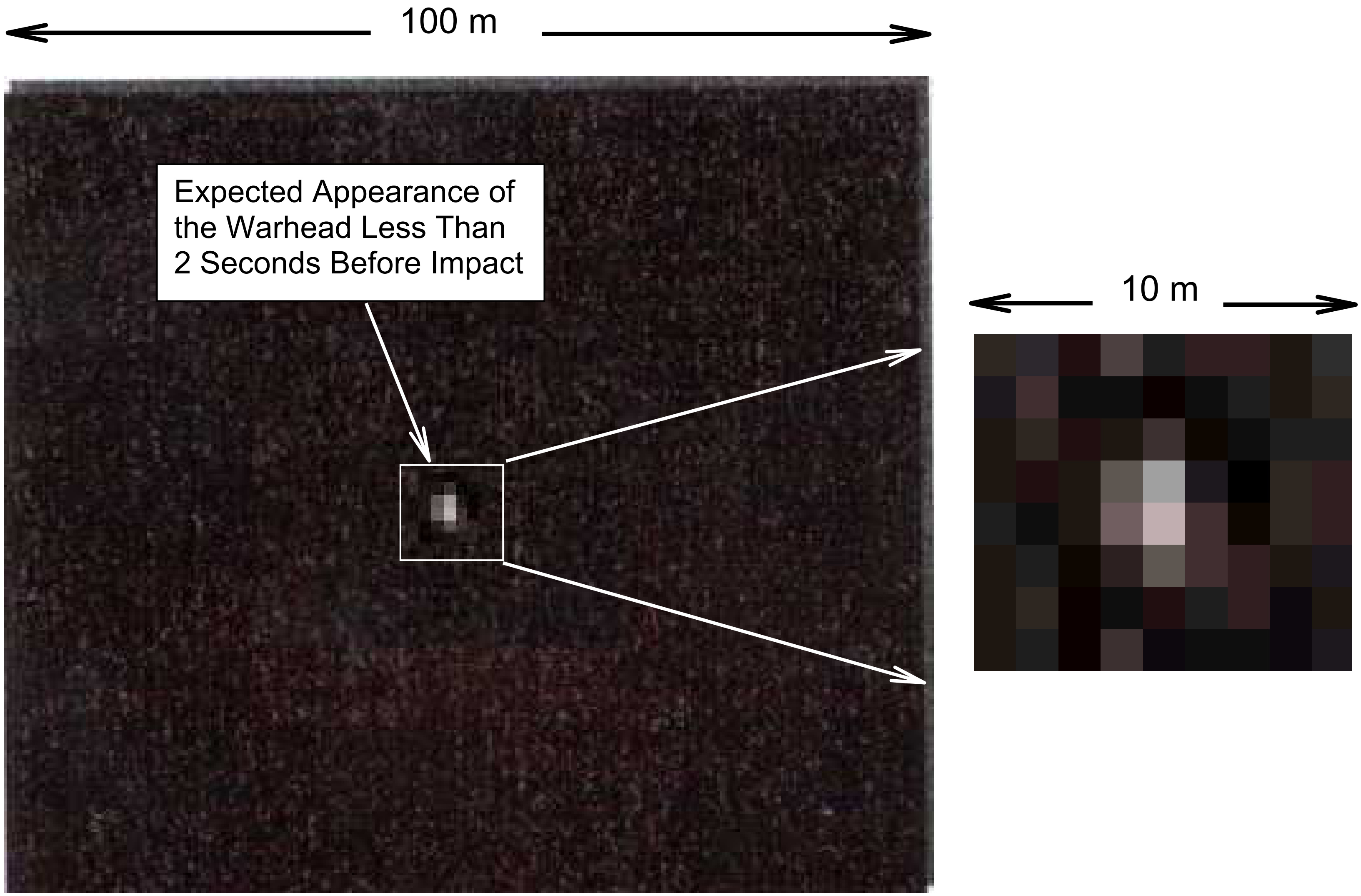

Figure 2. How Objects Appear to the Kill Vehicle
It shows a portion of the field of view of the kill vehicle’s infrared sensor when the kill vehicle is about 16 km from an object of roughly 2 m size, comparable to a warhead or decoy. Impact would occur in about a second and a half. The small light and dark squares represent the individual pixels of the infrared detector array. Even at this short range, the object only covers a small number of pixels, which appear lighter than the others (a blow-up of the center of the image is shown on the right). This illustrates that the kill vehicle will not be able to get information about the shape of objects in the threat cloud until it is too late to use for discrimination. (The kill vehicle’s sensor uses a 256 x 256 element array.) (Source of figure: Theodore Postol, MIT.)

If the attacker did not take measures to spin stabilize the warhead—as might well be the case for a country with an early generation missile—the warhead would tumble as it traveled through space. The infrared sensor would see a fluctuating signal as it viewed different parts of the tumbling warhead. However, a balloon decoy could also be made to show a time-varying infrared signal by painting stripes or markings on its surface, so that the infrared sensor will detect different signals as the decoy rotates.

The 2003 request for proposals for the MDA's small business innovation research program noted the difficulty of infrared (IR) discrimination and sought technical ideas to solve it, stating:

> Missile guidance sensors need to discriminate among targets, decoys, and penetration aids in an extremely short detect-to-kill time. Feature differences among decoys, penetration aids, and targets are not adequate for discrimination by current passive IR missile sensors (David Ruppe, personal communication, February 2004).

Countermeasures to Defeat Infrared Homing

Another class of countermeasures is designed to prevent the kill vehicle from homing on and hitting the warhead even if it can identify it. One example discussed in detail in *Countermeasures* is the use of an actively cooled shroud to reduce the infrared signal of the warhead so that the kill vehicle would not be able to detect the warhead in time to home on it. However, even purely passive cooling techniques could reduce the kill vehicle's detection range by a factor of 10 or more, which could lead to a failure to successfully home (Sessler et al. 2000, p. 47). Other antihoming countermeasures include leaving the warhead attached to the final missile stage and thus forcing the defense to choose which end of the target to hit; enclosing the warhead in a large balloon so the kill vehicle could not determine its exact location; and tethering several balloons to the warhead at a distance of a few meters. The latter strategy could be especially effective if one or more of the balloons had been painted so it would have a higher temperature and greater IR signal than the warhead.

The Role of the GMD System Radars

The above discussion makes clear that an attacker's use of unsophisticated countermeasures will seriously degrade the defensive capability of the Block 2004 system. But the inability of the system to address countermeasures is not the only its technical limitation; the radars have additional limitations.

Radars must both detect a missile when it is launched, and track the threat cloud, which includes the deployed warhead and other objects, such as debris and decoys. The radars must track long enough and with sufficient accuracy to allow the defense to determine the future location of the threat cloud with enough certainty to fire the interceptor toward a predicted intercept point. If poor track data results in large uncertainties in the warhead's future location, the interceptor may not be able to engage the warhead (see box 7).

The Cobra Dane radar was built to observe Soviet missile tests, and the Beale radar was built to provide early warning of incoming ballistic missile warheads. Both radars can track at long distances and appear able to provide relatively accurate track data if the object they are tracking remains in their field of view for a sufficiently long time. However, the Aegis SPY radar has much more limited detection and tracking abilities, as discussed below.

The Tracking Capability of the Aegis SPY Radar

The SPY radar was designed for air defense, i.e., to detect and track large, slow-moving aircraft at relatively short distances (a few hundred kilometers). Long-range missiles and their warheads travel much faster, have much smaller radar cross sections, and must be tracked long distances to

Box 7. The Consequence of Tracking Uncertainties

Tracking information provides an estimate of the warhead's trajectory. Uncertainties in the position and speed of the warhead depend on how precisely the radar can track the warhead and the length of time the radar is able to track it. Once the warhead flies out of radar's tracking range, the defense uses the estimated trajectory to predict the future path of the warhead. The uncertainty in the warhead's future position grows with time and, depending on the uncertainties in the initial tracking, the uncertainties may be very large late in flight when the kill vehicle attempts to intercept it.

The warhead's future position and the time it will be at a given location must be predicted in order to launch the interceptor on the proper trajectory. The interceptor launches the kill vehicle toward a predicted "basket" in space, and the kill vehicle must arrive in that basket at the right time to intercept.

Before it can home on the warhead, the kill vehicle must search the area in the basket and detect the warhead with its onboard sensors. The distance at which the kill vehicle's sensors can first detect the warhead is called the detection range. If the estimated position of the warhead is very uncertain, the basket will be large and this search process might take a significant amount of time. Since the warhead and kill vehicle are moving toward each other at a speed of about 10 km/s while this search takes place, the search process can significantly reduce the detection range. A short detection range means that the kill vehicle will have less time to maneuver to intercept the warhead. As a result, if the uncertainty in warhead position is large, the kill vehicle may not have enough time to change its course to reach the warhead.

accurately determine their trajectory.[26] Despite various upgrades over the years, the Aegis radar's capability to detect and track long-range missiles is quite limited. It is included in the Block 2004 system simply due to the lack of other radars, especially radars that can observe attacks by North Korea on Hawaii.

The MDA plans to station an Aegis ship with a SPY radar close enough to the launch site of an attacking missile (within several hundred kilometers) to allow the radar to detect and track the relatively large missile during its boost phase. The radar would attempt to track the warhead after the booster stops burning and drops off, but this is difficult for two reasons. First, warheads have a small radar cross section, so the range over which the radar can track the warhead is relatively short. Second, since the warhead would rise very quickly during the early part of its flight, our analysis suggests that it would fly out of the radar's range within a matter of seconds or might not be seen at all. Thus, the Aegis radar will at best provide tracking for only the very early part of the warhead's flight.

Using public information about the Aegis SPY radar and a knowledge of radar systems and operation, it is possible to model the SPY radar. The model we developed is described in appendix A. We emphasize that the results of our analysis are estimates based on this model, so that the actual numbers might differ somewhat from our results. However, this analysis raises serious questions about the capability of SPY to be used for these missions.

Based on our model of the SPY radar, we estimate that it would be able to detect a large missile booster early in flight at a range of 700–800 km.[27]

Tracking to determine the trajectory of the warhead cannot begin until the warhead is released at the end of boost phase, since the warhead is being accelerated while the missile is boosting. But the warhead is expected to have a significantly smaller radar cross section than the missile body, so the range at which the SPY radar can track the warhead is considerably shorter. In particular, our calculations suggest that the radar can only track the warhead at a distance of 400–500 km.

If correct, these numbers mean that the radar's tracking capability is marginal. If the detection range is near the low end of this range (400 km), the radar may not be able to track the warhead at all. If it is near the high end of this range (500 km) it would be able to track the warhead only for the first few tens of seconds of its flight. Because of the resolution of the radar, and because this tracking would be done for a relatively short time near the limit of radar's tracking range, the quality of the track data may be relatively poor.

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[26] The approximate radar cross section for a warhead is 0.001–0.01 m^2; for a large missile booster, it is 0.5–1 m^2; and for an aircraft, the cross section is 5–10 m^2. Aircraft speed is typically less than < 0.5 km/s, while a warhead on a long-range trajectory will have a speed of roughly 7 km/s.

[27] This figure assumes a radar cross section of 0.5 m^2.

Implications for Attacks on Alaska and the West Coast

A missile trajectory from North Korea to Alaska would pass through the central part of the Cobra Dane radar (see figure 3). The radar should therefore be able to provide relatively good tracking data on the threat cloud.

A missile trajectory from North Korea toward the West Coast of the United States could be tracked early in flight by Cobra Dane (see figure 3), and the Beale radar in California would be able to track the threat cloud as it approached the United States.

In both cases, the tracking information should be good enough to allow the defense to fire interceptors at the threat cloud. In these cases, it appears that system performance will be limited by countermeasures but not by the tracking capability of the radars.

Implications for Attacks on Hawaii

Because of the curvature of the earth, the Beale radar in California is unable to see warheads launched from North Korea to Hawaii unless they fly highly lofted trajectories.

The Cobra Dane radar in Alaska faces a fixed direction, so it has minimal ability to detect a missile on a trajectory from North Korea to Hawaii. While the trajectory flies through the edge of Cobra Dane's coverage (see figure 3), the radar's ability to track the warhead will be limited for several reasons. Roughly the first third of the trajectory within Cobra Dane's field of view occurs during the missile's boost phase, before the radar can start tracking the warhead. Moreover, because of the curvature of the earth, much of the trajectory that appears to be in the field of view actually lies below the radar's horizon, so the radar cannot observe it. For a standard trajectory, only about the last sixth of that part of the trajectory that appears in Cobra Dane's field of view would actually be visible to the radar, so that it could only track the threat cloud for a few tens of seconds.

The Aegis SPY radar, as discussed above, has limited tracking ability. The optimum placement of the ship would be in the Sea of Japan perhaps 600 km from the launch site, located so that the trajectory would essentially pass over the ship. If the missile flew on a standard trajectory, the radar might be able to track it for roughly 20 seconds if the tracking range were 400 km and 50 seconds if the tracking range were 500 km. So, as with Cobra Dane, the time available for tracking would be short.

Initially, only one Aegis radar is planned for deployment, with additional ships to follow by the end of 2005. As figure 3 shows, the trajectories from North Korea to Hawaii and to Los Angeles lie in different directions over the Sea of Japan, so the ship would have to be stationed between these two trajectories to optimize coverage of both. This would increase the distance from the radar to the warhead and reduce the tracking time by 10 to 20 seconds.

Apparently, then, the Block 2004 system will be able to provide only very limited tracking information about a missile attack by North Korea on Hawaii, resulting in a large uncertainty in the location of the threat cloud. If these uncertainties are large enough, the kill vehicle could have a difficult time locating and homing on the target cloud.

Figure 3. Field of View of Cobra Dane Radar

This figure shows the region in which the Cobra Dane radar can detect and track objects, which is the area between the dark "V" centered on the Alaskan island where Cobra Dane is located. The narrower fan in the center labeled "high-quality tracking" is the region over which the radar is said to have the best tracking capability. The figure also shows the ground tracks of missile trajectories from North Korea to Fairbanks, Los Angeles, and Honolulu. (The outer edges of the field of view are from Englander 2001.)

While the Aegis radar was used to observe the target missile launches in the last two GMD intercept tests in the fall of 2002, and has observed other missile launches, the Pentagon still appears to question SPY's ability to provide track data if Hawaii were attacked. During a recent congressional hearing, Senator Daniel Akaka (D-HI) asked Thomas Christie, director of operational test and evaluation, "Should I feel confident that the state of Hawaii will be protected by this system starting in September?" Christie responded, "We have not done the thorough analysis. That's one of the scenarios that we're looking at. And at this point in time, I can't say one way or another" (U.S. Senate 2004).

Because we do not have enough details about the radars involved, we cannot quantify this problem or reach a definitive conclusion. However, the ability of the SPY radar to track well enough to allow the GMD system to launch interceptors toward the warhead appears to be a real concern, and we urge Congress to look into this issue in more detail.

Based on the technical capabilities and limitations of the Block 2004 GMD system components, we conclude that there is no technical basis for believing the system will have *any* defensive capability in a real-world attack. In particular, unsophisticated countermeasures pose an insurmountable problem for this system.

The Probability That an Interceptor Will Hit Its Target

One way to characterize the defensive capability of a missile defense system is to assign a probability that an individual interceptor will intercept the target it is fired at—the so-called "kill probability." Indeed, the kill probability is the key performance metric used by the MDA to describe the anticipated defensive capability of the Block 2004 system (GAO 2004b, p. 27).

However, the kill probability is not an inherent property of the interceptor or kill vehicle but depends on the performance of all the other components of the system and—most importantly—on the characteristics of the attack. For this reason, it is not possible to assign one number to the kill probability.

The kill probability will depend on the successful completion of several tasks (none of which have been demonstrated for the GMD system under realistic flight conditions):

- The system radars' successful tracking of the warhead, decoys, and debris with enough accuracy to generate a "task plan" to launch an interceptor toward the right point in space
- The radars' successful discrimination of the warhead from the other objects
- The communication of this information to the interceptor so it can be launched, followed by track updates to the interceptor and kill vehicle as they are in flight
- The successful launch of the interceptor booster
- The successful separation of the kill vehicle from the interceptor booster
- The successful detection by the kill vehicle of the target cluster and discrimination of the warhead, either for comparison with or in lieu of discrimination data provided by the radars
- The successful homing by the kill vehicle

Because the Block 2004 GMD system is in the early stage of its development, the MDA has not had the opportunity to discover and address the various technical problems that inevitably arise as a development program progresses and increasingly difficult tests are conducted. Thus, it is reasonable to expect that the system performance will be less than it would be for a fully developed system using the same components.

Even what may appear to be the most straightforward of these tasks will have an associated probability of less than 100 percent. For example, the probability of a successful missile launch from a silo is likely to be less than 90 percent. Unlike the situation for a space launch, or a flight test, when the launch can be delayed by minutes or days if necessary, a GMD interceptor would need to be launched immediately regardless of any problems. In this case, it could be much less than 90 percent, since the GMD interceptor booster is essentially untested.

The probability of the successful separation of the kill vehicle from the interceptor booster is also likely to be less than 90 percent. In the eight flight intercept tests to date, two have failed because the kill vehicle failed to separate from the booster, including the most recent one. Thus, in the tests, the probability has been 75 percent. And again, every detail was examined prior to these tests, which would not be the case when an interceptor is launched to counter an attack.

Other parts of the system will also undergo random failures, which will affect the probability that the other tasks listed above will be successfully completed.

Moreover, the use of countermeasures would result in systematic errors and, for some tasks, significantly lower the probability of success. For example, the use of balloon decoys would prevent discrimination by the kill vehicle. The best the defense can do in the absence of discrimination is to fire interceptors at the target complex in the hope that one of them will hit the warhead. The kill probability will be based simply on the odds of randomly hitting the right object. For example, if the target complex contained 20 objects, the kill probability of the first interceptor (or all the interceptors launched in a salvo) will be 1 out of 20, or 5 percent, assuming all the other tasks are successfully completed. Successive interceptors could have slightly—but not significantly—higher kill probabilities, since the defense will not have dozens of interceptors to launch at the objects deployed by one incoming missile.

If the target complex included more than 20 objects, as could well be the case, the kill probability would be even smaller.

If the attacker used an antihoming countermeasure, the probability that the kill vehicle would successfully home on its target could be very low. In this case, the kill probability will remain at the same low value for each interceptor regardless of how many interceptors are launched.

Thus, taking into account all these factors, we conclude that the kill probability of a Block 2004 GMD interceptor in an actual engagement is likely to be very low.

CHAPTER 4

THE MDA'S CAPABILITY ASSESSMENT

> As of today the projected effectiveness would be in the 90 percent range.
>
> *—Edward "Pete" Aldridge, U.S. undersecretary of defense for acquisition, technology and logistics, in response to a question about how successful the October 2004 GMD system would be against a North Korean missile (U.S. Senate 2003a)*

While MDA officials are often careful to use the phrases "limited," "modest," and "very basic" to describe the defensive capability of the Block 2004 system, they also often imply that the capability would be significant. In particular, the MDA has repeatedly discussed the Block 2004 capability relative to that of an imaginary system that is 100 percent effective, giving the strong impression that the effectiveness would be close to 100 percent. Such comparisons also imply that criticisms of this deployment are based on the fact that the system will not be 100 percent effective, which is not the case.

For example, in recent testimony, Kadish stated, "We are no longer compelled to pursue a 100 percent solution for every possible attack scenario before we can provide any defense at all." Echoing the same theme, he later asked the rhetorical question, "Defenseless in the face of unpredictable threats, which would we rather have—some capability today or none as we seek a 100 percent solution?"

However, no one has argued that the Block 2004 should not be deployed because it is not 100 percent effective. Rather, opposition has focused on the Block 2004 system's marginal capability against real-world attacks.

This false notion that the 2004 system will provide a significant defensive capability has been reinforced by numerous statements by high-level Pentagon officials. Below we analyze some of the administration claims about the system capability and its limitations, then discuss the implications of these assessments for U.S. policy.

- ***"The system will be 90 percent effective."***

Perhaps the most unequivocal statement by a Pentagon official about the effectiveness of the deployed GMD system in the event of an actual attack is the one quoted above by Aldridge. In congressional testimony, Senator Evan

Bayh (D-IN) asked him how effective the system to be deployed in 2004 would be against a North Korean missile launched at the United States. His response was, "As of today the projected effectiveness would be in the 90 percent range."

The senator followed up,

> If you're advising the president of the United States, and there is a possibility of the North Koreans hitting Los Angeles or San Francisco with a nuclear warhead, you are advising him that we would have a 90 percent chance of taking that down before it can get there, as early as the end of fiscal year 2004, and if millions of lives depend on it, that's your answer.

"Yes sir," Aldridge responded (U.S. Senate 2003a). Aldridge also stated, "The way you could achieve these rates is you don't have to fire just one interceptor per target, you could fire two, as we do in PAC-3." Senator Carl Levin (D-MI) responded by saying,

> Number one, I am surprised that you even answered this in an unclassified setting. But number two, I'm surprised at your answer because I know the classified number. . . . I just think you better go back . . . and check the classified numbers [for] the probability of success of this '04 system. . . . I think you'll want to correct the record after you read the classified numbers.

Two days later, Aldridge defended his assessment in testimony to the House Armed Services Committee (Ruppe 2003). In response to a question by Representative Curt Weldon (R-PA) about whether his estimate was "in fact your belief based on 42 years of experience," Aldridge cited his long experience and stated,

> I had been asked to comment on a particular scenario of which North Korea would launch a missile, a single missile into San Francisco. And, given the fact that we would have a deployment system in the 2004–2005 timeframe with 20 interceptor missiles, what would I advise the president as to how effective that missile defense would have been against that single attack. Based upon my judgment, I would say given the fact that we could launch one, or two, or three missiles against that target, the effectiveness would be in the 90 percent range.

Such a statement is irresponsible. Claims about the performance of a weapon system must be based on the results of a rigorous test program, not the personal beliefs of any individual in the absence of such data.

Later a reporter from *Defense News* asked Kadish about Aldridge's assessment. Instead of clarifying the situation by correcting Aldridge's statement, Kadish added his voice to the confusion by giving an academic explanation of how Aldridge could be correct. The article reports Kadish as saying that the initial system would be 90 percent effective if more than one interceptor were launched at an enemy missile:

> If you assume a certain level of success for each [interceptor] missile, which doesn't have to be very high, not greater than 50 percent . . . [and] if you did a math probability calculation and if you use six of those [interceptor] missiles to attack a single incoming warhead. . . . Secretary Aldridge was very correct. On a pure math basis, [Aldridge] was correct (Ratnam 2003).

Kadish's argument gives the impression that a 50 percent level of success for each interceptor is not "very high" and should therefore be easily manageable for the missile defense system. However, the test program has been inadequate to assess—even roughly—the probability of success for an interceptor. And, as shown in chapter 3, there is no technical basis to believe the kill probability will be much greater than zero.

- ***"The first interceptor placed in its silo will provide a defense of the United States."***

Testimony about President Bush's deployment decision furnishes another example of administration officials overstating the capability of the initial defense deployment. Kadish asserted: "As soon as we have our first missile, it will be capable of defending the entire United States . . . [against a missile coming from] . . . Northeast Asia in '04" (Kadish and Crouch 2002). This statement implies that a single interceptor will provide a meaningful capability to defend the United States. The unstated assumption here is that the kill probability of the interceptors—the probability that an interceptor will hit its target—will be very high.

- ***"The system capability is limited only by the number of interceptors."***

In keeping with his assertions that the kill probability of the interceptors will be high, Kadish testified to Congress in March 2004 that

> The system we initially will put on alert is modest. It is modest not because the inherent capabilities of the sensors and interceptors themselves are somehow deficient, but rather because we will have a small quantity of weapons [i.e., interceptors] (Kadish 2004, p. 12).

This statement is not true. As chapter 3 shows, for a missile defense system to be effective, the primary issue is not the number of interceptors, but their kill probability.

As part of its ongoing efforts to imply publicly that the kill probability of the interceptors will be very high, the MDA recently invited seven reporters to a demonstration of its missile defense simulation software (Glanz 2004;

Graham 2004b). In the simulation, the United States had six GMD interceptors to defend against four incoming missiles launched from Northeast Asia. The defense fired four interceptors, one at each warhead (there were no decoys), and hit three of the warheads. It then fired a second interceptor at the warhead it first missed, and intercepted it. Incredibly, the simulation assumed the extremely high kill probability of 91 percent (Bradley Graham, private communication*,* March 17, 2004).

The outcome of any computer simulation depends on what parameter values are put into it. The Pentagon may, of course, put any numbers it wants into its simulation. But it is important to understand whether the numbers it uses are realistic enough for the simulation to be meaningful or whether it is simply playing a video game.

As chapter 3 shows, a more realistic assumption for the kill probability of the interceptors is a value closer to zero. If the kill probability is low, even large numbers of interceptors will not help in the simulation described above. For example, table 4 shows that for a kill probability of 10 percent, adding additional interceptors has little effect on the overall defense effectiveness. For an attack by five incoming missiles, the probability that one or more will get through the defense is almost 100 percent whether the defense has 5 or 20 interceptors. Only at high kill probabilities (for example, 50 percent and 91 percent, as shown in the table) does the number of interceptors have a significant effect on the probability of the defense intercepting all incoming warheads.

Table 4. Probabilities of Warhead Interception and Penetration

For an attack by five warheads, the probability that one or more warheads penetrates the defense is shown for 5. 10, and 20 interceptors, and for four different assumed probabilities that an interceptor will destroy its target.

Number of Attacking Missiles	Total Number of Interceptors	Probability That an Interceptor Will Intercept Its Target	Probability That One or More Warheads Gets Through the Penetrates Defense
5	5 (1-on-1 targeting)	5 %	99.999 %
5	10 (2-on-1 targeting)	5 %	99.999 %
5	20 (4-on-1 targeting)	5 %	99.98 %
5	5 (1-on-1 targeting)	10 %	99.99 %
5	10 (2-on-1 targeting)	10 %	99.98 %
5	20 (4-on-1 targeting)	10 %	99.5 %
5	5 (1-on-1 targeting)	50 %	97 %
5	10 (2-on-1 targeting)	50 %	76 %
5	20 (4-on-1 targeting)	50 %	28 %
5	5 (1-on-1 targeting)	91 %	38 %
5	10 (2-on-1 targeting)	91 %	4 %
5	20 (4-on-1 targeting)	91 %	0.03 %

Moreover, increasing the defense effectiveness by using multiple interceptors is only possible if the kill probabilities for the interceptors are independent of each other. This would be the case, for example, if interceptor failures were due to random failures of components. However, if the attack includes countermeasures, intercept failures are likely to be correlated. In this situation, firing multiple interceptors will produce little or no gain in the system effectiveness.

For Kadish or others to imply that the number of interceptors available to the defense is the key determinant of effectiveness is simply wrong. These claims appear to be part of an effort to convince Congress to fund its request for 20 additional interceptors to be deployed in the next few years—despite the fact that the interceptor boosters to be used for the deployed system have yet to be used in a flight intercept test.

- ***"The MDA's simulations allow the agency to predict the reliability of the initial BMD system."***

Kadish has also claimed that the MDA's simulation software will provide valuable information about the effectiveness of the defense system to be deployed later this year. In testimony before the Senate Armed Services Committee, he stated:

> Our modeling and simulation capabilities are very accurate and allow us to mirror the achieved outcome of a flight test. The graphic below provides an example of why we believe our simulation capabilities to be the most powerful tools for projecting the reliability of the initial BMD [ballistic missile defense] system (Kadish 2004, p. 17).

However, the graphic he showed was the speed of a missile interceptor during its boost phase in a recent test. The agreement between the computer model and flight data demonstrated that the MDA was able to model the missile trajectory with a high degree of accuracy. Such agreement is beside the point when it comes to missile defense under realistic conditions. It is one thing to calculate the trajectory of a U.S. rocket when the booster engine characteristics are known in detail, and Earth's atmosphere and gravity can be taken into account. It is quite another to model a real engagement in which most of the key factors are unknown: when and where an enemy might launch a missile; the propellant and flight characteristics of the enemy rocket; what trajectory the enemy has chosen; the nature and flight characteristics of the warhead; and the number and type of objects in the target cluster in addition to the warhead, such as decoys, countermeasures, and debris, along with their electromagnetic, infrared, and visible properties. Modeling a real engagement requires making assumptions about all these factors. These assumptions in turn affect other parameters key to accurate modeling, such as the probability that the sensors will accurately identify and track the target, and the probability that the interceptor will home on and destroy the target.

Yet the officials who ran the recent simulation for reporters echoed Kadish's assertions, stating that the model accurately depicted the real-world performance of the system because it was "based on years of study" and that "the models have accurately predicted flight performance in a number of previous tests" (Graham 2004b). But the ability to model a missile trajectory indicates nothing about the "reliability of the initial BMD system." This is not a trivial point: the MDA has conducted so few flight tests that it will rely on its computer models to assess the military utility of the deployed system. At the same time, because of the scarcity of flight tests, little operationally realistic data is available to help correct still-primitive and unrealistic simulations.

As the FY03 annual report of the Pentagon's director of operational testing and evaluation notes:

> It is important to understand that assessments of these [defense] capabilities are based primarily on modeling and simulation, developmental testing of components and subsystems, and analyses—not end-to-end operational testing of a mature integrated system. Due to the immature nature of the systems they emulate, models and simulations of the BMDS [ballistic missile defense system] cannot be adequately validated at this time (DOT&E 2004).

- ***"The demonstration of hit to kill provides confidence that the system will work."***

The United States demonstrated that it could perform hit to kill over 20 years ago in its Homing Overlay Experiments.[28] Many successful hit-to-kill intercept tests have been conducted since then—using Patriot missiles. Being able to destroy a target is not the issue; the issue is the ability to do so under unanticipated conditions in a real attack. For example, the Patriot system used in the 1991 Gulf War failed to intercept almost all of the incoming Iraqi short-range missiles, even though it had a perfect flight and intercept test record. The defense failed because the incoming missiles did not behave as expected: they broke up on reentry, creating numerous spiraling targets, which prevented the defense from intercepting them.

Nevertheless, many missile defense proponents argue that successful hit to kill in five of the eight intercept tests that have occurred—despite the limitations of those tests—demonstrates the technical feasibility of the interceptors and therefore proves the concept of midcourse defense. Kadish has stated, "Our testing and analysis give us confidence that hit-to-kill technology works and that we can take the initial steps we are proposing . . . [to] introduce a modest defensive capability to defeat a limited long-range threat" (U.S. Senate 2003a).

The ability of a kill vehicle to maneuver to directly hit an object in space that is traveling at high speed is clearly an essential part of intercepting an incoming warhead. However, having a hit-to-kill capability is not nearly sufficient to intercept a warhead, and demonstrating hit to kill does not prove the concept of midcourse defense. Many other technical capabilities are

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[28] See, for example, Homing Overlay Experiment at *http://bobhampton.kwajonline.com/hoe.html.*

required for a successful defense, such as the ability to track and identify incoming objects. Demonstrating hit to kill is not the primary, or the most difficult, technical challenge in getting a missile defense to work reliably against real-world attacks.

Box 8. The MDA's Assessment of System Effectiveness: Pulling Numbers Out of Thin Air

As we discussed in chapter 2, there is essentially no information from the flight-test program on which to base an estimate of the system's defensive capability. This is clearly understood by the same Pentagon officials who have made highly optimistic claims about the system effectiveness, as indicated by a discussion between Senator Levin and then Under Secretary of Defense for Acquisition Aldridge at a March 2003 hearing (U.S. Senate 2003a). After Aldridge stated that the initial Block 2004 system would be 90 percent effective against a North Korean missile, Levin countered that the classified numbers did not support his claim. Aldridge then expressed surprise that there even was a classified number "because we don't know yet, until we get into the testing process . . ."

Aldridge then added that the classified estimate of system effectiveness "probably depends on whether it's one missile or two missiles or . . . a lot of other assumptions."

Aldridge is correct that the system effectiveness would depend on a lot of factors, as we discuss in chapter 3. For this reason, any estimate of the defensive capability would be meaningful only if the assumptions about those factors were specified.

However, according to an April 2004 GAO report, the MDA's assumptions about the GMD performance are "not explicitly defined." The MDA measures the defensive capability of the Block 2004 system by determining the "probability of engagement success." For the GMD system, this is defined as the probability that the system kills a warhead in an attack. While the MDA has assigned numerical values to "the probability of engagement success," the assumptions about the attack characteristics are not provided in the Block 2004 Statement of Goals, its top-level document about the system's performance capabilities (GAO 2004b, p.11).*

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* This document includes the composition of Block 2004; the costs and schedules for development, testing, and fielding; and the system's performance capabilities.

Why Overstating the Capability of National Missile Defenses Matters

Unjustified assessments of the effectiveness of defensive systems, such as the 90 percent figure given by Aldridge, are problematic because they can create misperceptions that affect the way policy makers make decisions. As aptly put by Senator Bayh in response to Aldridge's statement during the congressional hearing (U.S. Senate 2003a):

> The reason I asked this is, as you know, there is a great deal of tension between our country and North Korea today. The effectiveness of the system is going to affect our diplomacy, other possible military actions and so forth. And if you're advising the Congress or the president of the United States about possible North Korean reactions to our different actions, it's going to have a pretty profound impact. And you perhaps take one course of action if you think there is a minimal chance of them hitting one of our cities with a missile. And you take a different course of action if you think it's somewhat more significant.

Aldridge concurred, saying that this was exactly the reason they were deploying the defense:

> Exactly. Of course that's the rationale that went into the decision by the president to proceed. I think he clearly has many more options available if he has a limited operational defense—is the way he described it.

But leading military and political leaders to believe they have options that are not in fact realistic can be dangerous and, at the least, contribute to bad decision making.

For example, a country might threaten to launch one or more missiles at the United States to deter it from taking a specific military action. In deciding whether to take this action and thus risk a missile launch at a U.S. city, the president or military commanders would take into account the capability of U.S. defenses to defend against such an attack. Their perception of the defense effectiveness could play an important role, and this perception would depend on what their advisors were telling them. Senior policy makers might be much more willing to accept the risk of attack if they were told the system was 90 percent effective than if they were told it was 10 percent effective or that there is no way to accurately estimate how effective the system would be.

If a country were preparing to launch missiles at the United States, beliefs about the effectiveness of the U.S. missile defense system could also affect a decision about whether to use precision-guided weapons to try to destroy the missiles on the ground in advance of their potential launch.

Similarly, if administration officials believed that the GMD system could reliably intercept ballistic missiles launched by North Korea, they might be less motivated to pursue diplomatic means to address the North Korean missile program.

It is not difficult to find examples in which the perceptions of high-level policy makers differed starkly from the technical assessment of experts who were more familiar with the details of a situation. A striking example is the explosion of the space shuttle Challenger in 1986. It is clear in retrospect that the technical experts who understood the space shuttle in detail knew that the unusually cold temperatures on the night of the launch represented a significant risk if the launch proceeded. But this was not understood by the high-level officials who made the decision to launch, and the result was disastrous. Some of these officials were certainly influenced by overstated claims of the shuttle's reliability.[29]

Exaggerating the capabilities of U.S. missile defenses can also undermine U.S. relations with Russia or China, spurring them to develop new military capabilities to counter those defenses. For example, while the large Russian nuclear arsenal can clearly overwhelm any foreseeable U.S. missile defense, Russian President Vladimir Putin has nonetheless announced that Russia is developing new missile technologies intended to counter U.S. defenses.

China is considerably more wary of U.S. missile defense plans than Russia since it has only about two dozen long-range missiles. As a result, Chinese military leaders may be concerned that even a thin defense could stop the few missiles that might survive a U.S. first strike against Chinese silos. China is currently in the process of modernizing its nuclear forces, and U.S. missile defense claims could lead Chinese political and military leaders to increase the scope and pace of that modernization. Such decisions could result in a larger nuclear arsenal than China would otherwise build.

Missile defense proponents sometimes argue that it is contradictory to argue that the U.S. defense system will not be effective, but that other countries will act as though it is and react in ways that reduce U.S. security. However, in the same way that many senior U.S. officials apparently do not understand the technical limitations of this system and overestimate its effectiveness, so too will officials in other countries.

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[29] For an insider's discussion of the investigation into the Challenger explosion and the flawed risk assessments that had been done of the space shuttle, see Feynman 1988.

CHAPTER 5

INITIAL DEFENSIVE OPERATIONS: EVENT OR SCHEDULE DRIVEN?

On December 17, 2002, President Bush announced that the United States would begin fielding the ground-based midcourse defense (GMD) system in 2004 (White House 2002). Early in 2003, Defense Department and Missile Defense Agency (MDA) officials stated that interceptors would be deployed in Alaska and California and that the system would begin initial defensive operations (IDO) by the end of FY04, which is September 30, 2004.

Defense Department officials argue that the deployment date is "event driven" rather than "schedule driven." This means that the date for deploying the system and making it operational depends on events in the development and test program demonstrating that the system has achieved specific capabilities.

Testifying to the Senate Armed Services Committee in March 2004 about the date the system would become operational, Acting Under Secretary of Defense for Acquisition, Technology, and Logistics Michael Wynne stated:

> The position of the Secretary [of Defense] is [that] this is an event-driven program, and that we will follow the disciplines and the quality procedures and make sure we have the military utility assessment and the test reports (U.S. Senate 2004).

Similarly, in a recent interview, MDA Director Kadish argued that the date at which the system will be made operational is driven by events in the development program and not by politics, stating:

> We don't pick the time. We don't do these things for anything other than technical reasons (Hess 2004).

This section examines how the schedule for flight intercept tests leading up to initial defensive operations and the date proposed for those operations have changed over time, especially following the December 2002 deployment announcement. We also consider whether initiating defensive operations later this year can be considered to be driven by events in the development and testing program.

Schedule Slippage

Figure 4 shows the schedule of intercept tests for the GMD system at three different times in the last four years: May 2000, December 2002, and May 2004. As it indicates, the dates for testing have slipped significantly, while the date for activating the system has been advanced.

The top row of the figure shows the test schedule as of May 2000, late in the Clinton administration, beginning with Integrated Flight Test 5 (IFT-5), which failed. Prior to May, four flight tests had been conducted, two of which—IFT-3 and IFT-4—were intercept tests. IFT-3 resulted in an intercept, but IFT-4 missed. (The May 2000 test schedule is taken from Broad 2000.)

As a result of these failures, President Clinton decided in September 2000 not to deploy the "Capability 1" (C-1) system. Had he decided in favor of deployment, the schedule called for initial operational capability in the fourth quarter of FY05 (summer 2005) after at least 21 tests, assuming all were successful and none needed to be repeated. The three flight tests scheduled just prior to deployment (IFT-19, IFT-20, and IFT-21) were to be operational tests. This schedule was criticized at the time for including too few tests to justify a deployment—especially since it included only three operational tests (see, for example, Sessler et al. 2000, p. 97).

In mid-2002, the Bush administration stated that it planned to increase the number of intercept tests to 24 through 2006, with operational tests beginning in 2007.

The middle row in figure 4 shows the test schedule as of December 2002, when the Bush administration announced it would deploy a system in 2004. While the initial White House announcement did not specify an exact date for the deployment, soon afterward Pentagon officials began talking about a date of September 30, 2004 (the end of FY04; see, for example, Kadish 2003). Thus, the planned initial deployment had been moved up by a year relative to the May 2000 timeline.

Intercept tests IFT-5 through IFT-10 were conducted between May 2000 and December 2002. By December 2000, these tests had slipped more than a year from their earlier planned dates. An additional 11 intercept tests were scheduled to take place by mid-2006.

The deployment decision might have been expected to include a decision to conduct as many tests as possible on the accelerated schedule. Kadish testified to Congress and told the press that he was going to pick up the pace of testing, as well as increasing the realism and complexity of the tests. But just the opposite occurred. Tests IFT-11, IFT-12, IFT-13, IFT-16, IFT-19, IFT-20, IFT-25, IFT-27, and IFT-28 were cancelled following the deployment decision, and the remaining tests were delayed.[30] One reason for these cancellations and delays is that development of the interceptor booster has itself been delayed (see box 9 on p. 52). Furthermore, the flight intercept tests conducted so far have been nearly identical, with little increase in complexity or realism.

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[30] As noted below, test IFT-13 will now take place, but as a nonintercept test.

The third line in figure 4 shows the test dates as of May 2004. Because of the cancellations and schedule slips, no flight intercept tests of the GMD system have occurred for nearly a year and a half, since IFT-10 on December 11, 2002. IFT-10 failed.

As the figure shows, the schedule slips that occurred between 2000 and 2002 have continued at roughly the same rate between 2002 and 2004, so that the next tests are now nearly a year behind their December 2002 schedule. The rate of slippage has been about a year every 18 months over the past four years. Such slips are not unusual for a complex system in the early stages of development, but they indicate that the pace of development is significantly slower than expected.

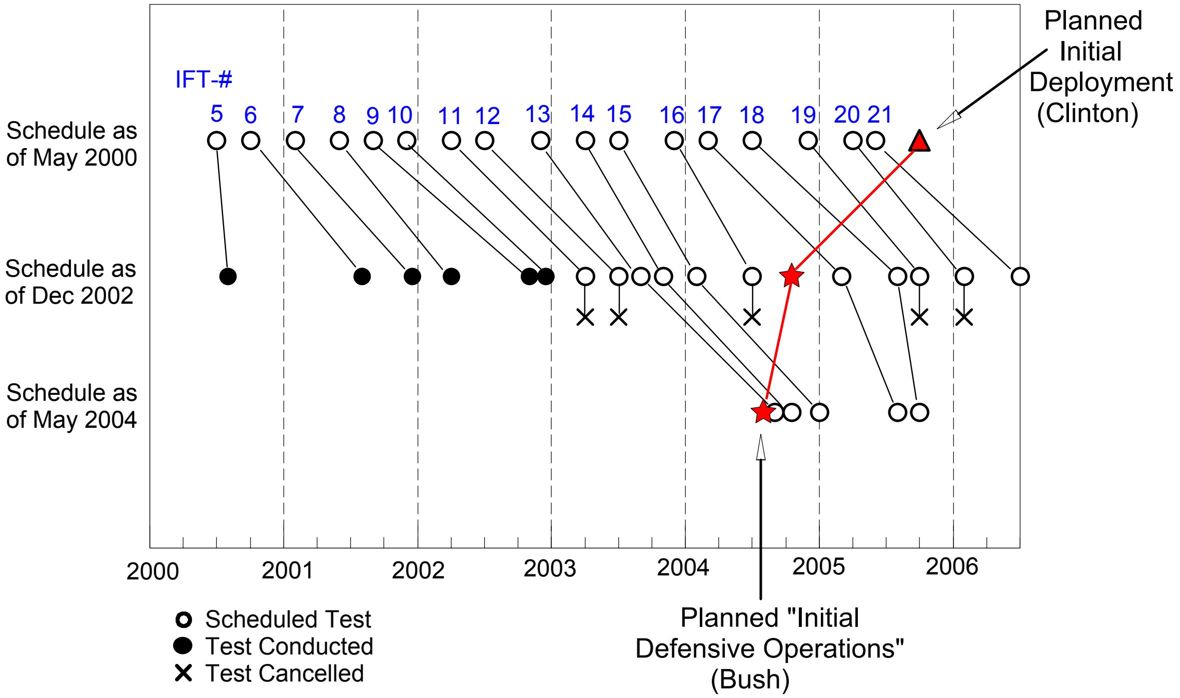

Figure 4. Change in Test Schedule from May 2000 to May 2004

This figure shows the test schedule for flight intercept tests of the GMD system at three dates: May 2000, December 2002, and May 2004. These integrated flight tests are marked by their IFT number. The open circles show the dates of scheduled tests, beginning with IFT-5. The dark circles in the middle line, which corresponds to the schedule as of December 2002, indicate the actual dates of tests that had been conducted by that time. The x's below the circles for IFT-11, IFT-12, IFT-16, IFT-19, and IFT-20 indicate which tests were cancelled following the deployment decision in December 2002. IFT-13 was also cancelled as a flight intercept test. We have included it in the schedule since IFT-13C may attempt an intercept even though it is not a goal of the test. The triangle in the top line (May 2000) shows the date discussed by the Clinton administration for a possible initial deployment. The stars on the lower two lines (the December 2002 and May 2004 schedules) show the dates for initial defensive operations discussed under the Bush administration's plan.

Box 9. Schedule of Interceptor Booster

The interceptor booster is a three-stage missile that carries the kill vehicle of the GMD system into space.

Like the testing program, booster development is several years behind schedule. The MDA had expected this to stay on schedule since booster development was to be based on mature technology.

Because of the delays, the booster to be deployed later this year in the GMD system has not been used in any of the flight intercept tests. All the intercept tests conducted to date have used a two-stage surrogate booster, which is a modified Minuteman payload launch vehicle (PLV). Since this has only two stages, it reaches a burnout speed of only 2.2 km/s, considerably less than the 6 km/s to 7 km/s planned for the deployed interceptor.* As a result of using this booster, and because of the geometry used for the intercepts, the closing speed between the interceptor and mock warhead in the intercept tests has been little more than 7 km/s, roughly half of the potential closing speed of an actual engagement. Why the tests were not performed using a three-stage surrogate booster, such as the one used to launch the target in those same tests, remains a mystery. This is one of many ways in which the flight intercept tests conducted thus far have not been realistic.

The original plan was to have Boeing develop the interceptor booster using commercial off-the-shelf components. Initially, development was expected to be straightforward, so that booster development and testing were expected to be completed in 2000.

By December 2001, when the booster failed its second flight test, development was more than two years behind schedule. As a result, the Pentagon decided to pursue two competing designs. Development of the Boeing booster was taken over by Lockheed Martin, and Orbital Sciences was chosen to develop an alternative design. These boosters are still in development, nearly four years behind schedule.

Orbital Sciences' booster has now had two nonintercept flight tests, in August 2003 and January 2004. Both carried simulated kill vehicles. It will be used in IFT-13C, now scheduled for the end of July 2004.

The first test flight of the Lockheed Martin booster was in January 2004. While the booster's flight was successful, the mock kill vehicle it was carrying failed to separate from it. According to press reports, the next test is scheduled for early 2005, so this booster will not be part of the initial deployment (Capaccio 2004).

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* The design speeds for the two interceptors being developed are 6.0 km/s (Lockheed Martin) and 7.2 km/s (Orbital Sciences), which refer to the maximum speed for the booster if it is fired vertically. The burnout speeds can be higher on nonvertical trajectories; for example, the maximum speed of the Orbital design is reportedly 8.3 km/s (private communication, March 2004).

At the same time, MDA officials have told the press that the system might be activated (i.e., that "initial defensive operations" might occur) as early as July 2004—several months earlier than the previous goal of September 31 (Graham 2004; Bush National 2004).

Until recently, only one nonintercept test (IFT-13C)[31] was scheduled to occur prior to July, but this test has now slipped to July 31, 2004.

In late April 2004, Kadish stated that no decision had been made about when the system would be activated, but the first five interceptors would be in silos in Alaska by September. "From a common sense standpoint," he continued, "the earliest [date for initial defensive operations] would come when we have at least one bullet in the chamber, one missile," suggesting that it might occur when the first interceptor was placed in a silo, which would presumably be earlier than September (Mannion 2004). In the same interview, he also stated that the Pentagon might decide to activate the system even if all of the remaining flight tests prior to deployment failed (Graham 2004).

In summary, figure 4 makes several important points:

- The test schedule has continued to slip significantly since the deployment decision was made, with tests slipping roughly one year every 18 months.

- The last flight intercept test of the system (IFT-10) was held a year and a half ago, in December 2002, prior to the deployment decision. That test failed.

- A large number of tests, about half of the remaining flight intercept tests, have been cancelled since the deployment decision has been made.

- As a result of schedule slippage and cancellations, no flight intercept tests are planned prior to a July 2004 activation date, and only one is currently scheduled before the end of September.[32]

- Despite all of these facts, the date for initial operation of the system has been advanced since early 2003.

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[31] The original IFT-13 test was changed into three flight tests of the two interceptor boosters that are being developed for the deployed system. IFT-13A, which was intended to be a nonintercept flight test of the booster being developed by Lockheed Martin, has apparently been cancelled. IFT-13B was a nonintercept flight test of the booster developed by Orbital Sciences, which took place January 27, 2004. IFT-13C, scheduled for July 2004, is described as a fly-by test in which the kill vehicle will collect data on a target warhead. While the kill vehicle will attempt to intercept the target, intercept is not considered an official goal of the test.

[32] In early May 2004, the MDA announced that the IFT-13C had slipped to July 31, 2004, and the IFT-14 had slipped to September 15, 2004.

Thus, despite claims that deployment of the system is "event driven"—that is, determined by progress in the development and testing program—the fact that the deployment date has not slipped along with the development and test schedule indicates it is instead being driven by events other than development.

Driven by What Events?

One event that could be setting the deployment date is simply the earliest possible date that MDA could place an interceptor in a silo. This may be what Kadish was referring to by "one bullet in the chamber." However, it makes no sense to declare a system operational when it will not be effective. If missile defense is important, the goal should be the earliest deployment of a defensive capability, not simply the earliest possible deployment of placeholder hardware.

Moreover, the long hiatus in flight intercept testing since the deployment decision appears to have resulted in part from the administration's desire to have interceptors available to meet an early deployment date. Conducting the tests would have consumed interceptors, and since their production is behind schedule, testing would have delayed deployment. The president's deployment decision shifted priority from developing the system to rushing deployment of incomplete and ineffective hardware during 2004.

This schedule suggests that the driving event may be the presidential election. In any case, this deployment schedule is not based on events in the development or testing program.

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APPENDIX A

MODEL FOR AEGIS SPY RADAR

Our calculations assume a SPY-1B/D radar with the following parameters (see appendix B):

Average power:	58 kW
Antenna gain:	14,000
Antenna effective area:	12 m^2
System noise temperature:	500 K
System losses:	10

For detection, a signal-to-noise ratio (S/N) of 13 dB = 20 is assumed.[33] For tracking, we assume only a lower signal-to-noise value of 10 is needed. This is probably unrealistically low, but the difference of a factor of two does not make a large difference in the range.

Atmospheric effects are not included. These will reduce the detection range when the target is close to the horizon.

The radar cross section (RCS) of the target cannot be known with certainty in advance. The APS Boost Phase Study (APS Study Group 2003) estimated the target RCS to be 0.48 m^2 for a two-stage liquid booster and 0.17 m^2 for only the second stage of the booster, and we use these values here (APS Study Group 2003). The RCS of the missile warhead is even more uncertain, since no one knows in detail what a North Korean nuclear reentry vehicle will look like, and the RCS will certainly depend on whether the attacker makes any efforts to control it. Very low RCS values can be produced, particularly when the warhead is viewed from the front, simply by shaping the warhead.

The RCS may be estimated by simply assuming the warhead to be a frustum. Published data shows that for a radar wavelength of 0.1 m, a frustum of length 2.43 m, with a base diameter of 1.33 m and a nose diameter of 0.47 m, will have an RCS that is always below 0.01 m^2, except for a small range of angles near nose-on, base-on and perpendicular to the conical surface (Knott 1990). Shaping the front and rear in an actual warhead would reduce reflections from those surfaces.

As a result, for this study we take the radar cross section of the warhead to be 0.01 m^2.

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[33] This is on the low end of standard figures for detection. For comparison, the APS Study Group's analysis of Aegis assumes a figure of 13.2 dB = 20.9 for detection (APS Study Group 2003). A value of 20 dB gives a probability of detection of 0.9 with a false alarm probability of about 10^{-6}.

APPENDIX B

RADARS IN THE CLINTON C-1 NMD SYSTEM AND BUSH'S BLOCK 2004 GMD SYSTEM

The radar capabilities of the Block 2004 ground-based midcourse defense (GMD) system are very different than the capabilities planned for the Clinton Capability 1 (C-1) national missile defense system. Of the five types of radars involved, only one type, the upgraded early warning radar (UEWR) is common to both systems, but the number to be deployed differs between systems.

The Clinton C-1 system would have deployed one X-band Radar (XBR) on Shemya Island at the western end of the Aleutian Islands chain. The X-band Radar was to be a large phased-array radar designed specifically for missile defense, and optimized in particular for precision tracking and discrimination. The location on Shemya was well suited for countering an attack from North Korea, but it could not be used against missiles fired from the Middle East toward the U.S. east coast, since such missiles would never rise above the radar's horizon. To provide coverage for such missiles, existing U.S. early warning radars in England, Greenland, and Massachusetts were to be upgraded to make them able to track ballistic missiles accurately enough to guide interceptors (two additional early warning radars, in California and Alaska, were also to be upgraded). However, the tracking and discrimination capabilities of these UEWRs are far inferior to those of the planned X-band radar.

The Block 2004 system will not have a radar with capabilities similar to the X-Band Radar. Such a capability is not planned until sometime in 2006, when the sea-based X-band radar (SBX) is scheduled for deployment. The SBX is a smaller version of the XBR mounted on a sea-going platform.

The Block 2004 system would instead initially rely primarily on the Cobra Dane radar, a large-phased array radar on Shemya Island that was built to gather intelligence on Soviet ballistic missile test flights. Cobra Dane played no role in the planned Clinton system. As with the UEWRs, its tracking and discrimination capabilities are not comparable to the XBR or SBX.

The Block 2004 system would also include the Beale UEWR in California, with the UEWR in England becoming available sometime in 2005. (Thus initially the GMD system could not provide coverage of missiles from the Middle East). At one time, plans called for the UEWR in Greenland to become operational in Block 2004, but the schedule for that to occur has now slipped.

Because of horizon restrictions, the Cobra Dane radar has marginal capability to detect missiles launched from North Korea toward Hawaii. Thus as part of the initial system, the MDA plans to deploy a single Aegis surveillance and tracking destroyer to the sea of Japan to provide track data on missiles launched from North Korea toward Japan. This destroyer is an Arleigh Burke class Aegis destroyer that has been modified to allow its SPY-1 radar to track ballistic missiles. Up to 10 of these destroyers may be deployed by the end of 2005. In addition, by the end of 2005, three Aegis ballistic missile defense cruisers are also to be deployed. These are Aegis cruisers with radar modifications similar to the destroyers, but also armed with a small number of interceptors intended to be able to intercept short- to medium-range missiles (but not the long-range missiles the GMD is intended to counter).

Below we discuss the characteristics and capabilities of each of these radars.

X-Band Radars

The Clinton administration's C-1 system called for one X-Band Radar (XBR) to be deployed in Alaska, with up to nine XBRs deployed around the globe by the time the full Capability 3 (C-3) system was complete.

The XBR was to be a large phased-array radar designed for long-range target tracking and discrimination. The XBRs were crucial to the operation of the Clinton NMD system. They would be powerful enough to detect incoming warheads at long ranges (if they were cued by other sensors). They would have the narrow beamwidth needed to track the warhead and other objects and thus could provide the interceptors an accurate estimate of their future location. Moreover, their very high range resolution would be key to discriminating the warhead from decoys.

The XBRs are part of a family of x-band radars for ballistic missile defense that also includes the radars for the THAAD theater missile defense (TMD) system and the forward-based radar scheduled for deployment sometime after 2005 in support of the GMD system.[34] A prototype XBR built on Kwajalein Atoll in the South Pacific has been used in some of the flight intercept tests of the missile defense program. This radar has an aperture of 123 m^2 (corresponding to a circular diameter of 12.5 m) and its antenna has 16,896 transmit/receive modules (MDA 2002).[35] Published reports indicate that this radar has a range of 2,000 km, but do not specify the target radar

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[34] The term "X-Band Radar" can be somewhat confusing since it refers both to the specific radar developed for the Clinton NMD system and more generally to any radar that operates in the x-band frequency range (8–12 GHz). Here we will use capitals (X-Band Radar) when referring to the NMD radar and lower case (x-band radar) when referring to any radar that operates in the x-band.

[35] At the time that the *Countermeasures* report (Sessler et al. 2000) was published (April 2000), publicly available data indicated that the prototype XBR antenna area was 123 m^2.

cross section (RCS) that this range assumes. This radar is not fully populated with transmit/receive modules, and its effective aperture is reported to be only 105 m^2 (Kandebo 1997).[36]

Publicly available information about the XBR that would have been deployed on Shemya under the Clinton plan differ in detail, which may reflect plans that were changing over time. In data available at the time the *Countermeasures* study was written, it was described as having an aperture identical to that of the prototype XBR on Kwajalein (123 m^2), except that, in contrast to the prototype XBR, it would be fully populated with about 81,000 transmit/receive modules, resulting in a detection range of 4,000 km (Kandebo 1997). More recent data indicates that the XBR planned for Shemya would have a considerably larger aperture, but fewer transmit/ receive modules: a 384 m^2 aperture with 69,632 transmit/receive modules, and a detection range of 6,700 km (again, against an unspecified RCS). Its total cost would be about $1.2 billion (MDA 2002, p. *v*). Assuming that the average power of the radar's transmit/receive modules is 2.9 watts, the XBR's average power would have been about 202,000 watts.[37] The bandwidth of the XBR is classified, but making a reasonable estimate of a bandwidth of 1 GHz (one-tenth the operating frequency), this radar would have a range resolution of about 15 cm, potentially allowing it to make detailed observations on the size and shape of targets and decoys. It will use linear frequency-modulated waveforms in narrow, medium, and wide bandwidths (Mahafza et al. 1998).

Each XBR would have a single face with an electronic field of view limited 50 degrees in both azimuth and elevation. However, the radar would be mounted on a platform that could be rotated ±178 degrees in azimuth, and the radar antenna could be tilted 0–90 degrees in elevation (Kandebo 1997).

Sea-Based X-Band Radar (SBX)

The Bush administration GMD plans announced to date do not include any large ground-based XBRs, although the possible future deployment of such radars has not been excluded. Instead, the MDA has announced that it will develop and deploy in late 2005 a sea-based version of the X-Band Radar. This sea-based X-band radar (SBX), whose home port will be Adak, Alaska, will not be part of the operational defense until Block 2006. Moreover, the MDA emphasizes that this radar is a test asset and "is not a substitute for the Shemya XBR" (MDA 2002, pp. *i* and 1).

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[36] The figures for 167,896 transmit/receivers modules, 105 m^2 aperture and 200 km detection range were subsequently confirmed in MDA 2002.

[37] The *Countermeasures* report assumed that the XBR had transmit/receive modules with an average power of 2.1 watts, based on a 1991 MITRE briefing on the TMD version of the XBR (Sessler et al. 2000; Davis et al. 1991). The transmit/receive modules on the planned sea-based X-band (SBX) radar will have an average power 40 percent greater than those on the prototype X-band radar on Kwajalein (MDA 2002, p. 9). Since the XBR would have been built on approximately the same time scale as the SBX, it is reasonable to assume that it would also have used these improved modules. Thus we take the average power of the modules to be 1.4 x 2.1 watts = 2.9 watts.

Why is the MDA building the SBX instead of the GBR on Shemya? The primary reason cited is that the mobile SBX will be able to support a much wider range of testing geometries than the fixed XBR.

A second factor is the amount of time required to build the XBR at Shemya. The SBX is to be built on an existing semi-submersible platform, thereby reducing the acquisition time "by the 18 to 24 months that is required to build a new platform" (MDA 2002). In addition, construction on the SBX could proceed year-round at a warm weather U.S. port, while the difficult weather conditions at Shemya would limit construction to only part of the year. Taken together, these factors meant that the SBX could be operational two years before the XBR (MDA 2002, p. 12). Given that as of mid-2003 there were still no plans to build the Shemya XBR, it now appears that such a radar could not be operational until at least mid-2007 or later.

The SBX is smaller than the previously planned Shemya XBR. According to an MDA report, the SBX will have only 50–65 percent as many transmit/receive modules as the planned Shemya XBR, and a correspondingly reduced aperture, reducing detection range to 4,800 km (for the 65 percent populated SBX) rather than the XBR's 6,700 km (MDA 2002, p. *v*). This reduction may not be significant, since a detection range of 4,500 km corresponds to a radar horizon altitude of about 1,500 km, which is roughly the maximum altitude of a long-range missile. However, the specified detection range is against a target with an RCS that is not publicly known. If the actual RCS is less than this value (for example, if stealth is used as a countermeasure), than the larger power and aperture of the XBR relative to the SBX might have been useful. In addition, the larger aperture and power of the XBR relative to the SBX will give it a higher signal/noise ratio against a specific target at any given range, and a narrower beam providing somewhat better tracking, resolution, and decoy discrimination capability. However, these differences are not large, and for the purposes of roughly estimating the capabilities of these systems, it appears reasonable to assume that the somewhat smaller size of the SBX relative to the XBR is not a significant issue. Other factors may be of more significance.

The planned 2005 SBX appears to have some advantages over the planned XBR on Shemya. As noted above, it can be built more quickly. It can be moved, although since its top speed is only about 6 km/hr (less than 4 m/hr), it will take time to relocate (Space News 2003). This mobility is useful if the GMD system is to be tested under a wide range of geometries, which is a primary MDA argument for the SBX versus the Shemya XBR. According to MDA figures, the SBX is also about $400 million less expensive than the Shemya XBR (about $800 million for the SBX as compared with $1,200 million for the Shemya XBR). Its mobility will also affect its vulnerability to attack, although whether this is a net gain or loss may depend on the protection the U.S. Navy plans to provide for it.

The SBX also has some apparent disadvantages when compared with the planned Shemya XBR. Because the MDA apparently views the SBX more as testing asset than a component of an operational system, in a fast-breaking crisis, it may not be in the right location to be effective as part of the GMD system. And, while mobile, it is not fast, only able to move about 100 miles per day.

More importantly, since the SBX is viewed as a test asset, it has a number of serious deficiencies when viewed from the perspective of an operational system (MDA 2002). Unlike the planned Shemya XBR it does not have dual redundant electronics, so it is less reliable. Unlike the planned Shemya XBR, it will not be hardened against the electromagnetic pulse from a high altitude nuclear explosion. And it does not have the fiber optic cable connection that was planned to give the XBR secure communications.

The Cobra Dane Radar

Cobra Dane is a large phased-array radar located on Shemya Island It became operational in July 1977, replacing several mechanically steered radars on the island. In 1976, the United States released a number of technical details about this radar. According to press reports, this information about Cobra Dane was released "to demonstrate that it is not intended as an antiballistic missile radar in violation of the ABM Treaty."[38] It is an L-band radar. For narrow-band functions it operates between 1.215 GHz and 1.25 GHz, and for wideband functions it operates between 1.175 GHz and 1.375 GHz.

Cobra Dane's original primary mission was "to acquire precise radar metric and signature data on developing [Russian] ballistic missile weapons system characteristics determination" (Richelson 1999, p. 24). It is also part of the U.S. early warning system (the integrated tactical warning and attack assessment system) and is used for tracking, characterizing and identifying satellites.

The radar sits on a 230-foot bluff on the northwestern part of Shemya overlooking the Bering Sea (Richelson 1999, p. 24). Its boresite is about 41 degrees west of due north and points toward the northern part of the Kamchatka peninsula. The original field of view of the radar was 259 to 19 degrees in azimuth (a line pointing due north from Shemya would be 0 degrees) and up to 80 degrees in elevation (where 90 degrees is looking straight up). There is also an "extended field of view" in which the radar can look 8 degrees farther on both sides (251 to 27 degrees), but it does that at the expense of not being able to look up as far, since in this mode the radar can only see up to 30 degrees in elevation (Englander 2001). However, wideband functions can be carried out only within 22.5 degrees of the boresight.

The fixed direction of Cobra Dane's field of view is not well placed to take in some missile trajectories from North Korea. In contrast, the previously planned X-Band Radar would have been able to rotate and thus could have tracked North Korean missiles over much larger portions of their trajectories. This orientation problem may be part of the reason that Department of Defense officials concluded that, even though Cobra Dane is larger and more powerful than other U.S. large phased-array early warning

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[38] The discussion here is based primarily on Klass 1976, pp. 41, 43, 46, and Brookner 1988. Unless otherwise cited, all figures stated here are from one or both of these sources.

radars, it would be unable to provide adequate early warning capabilities against a North Korean missile threat.[39]

The radar face is oriented at 20 degrees above the horizon and it can thus look up to angles 80 degrees above the horizon. It is apparently designed to operate down to angles within 0.6 degrees above the horizon. And it has a special millisecond-long waveform (25 MHz bandwidth) used to correct for ionospheric propagation errors.

The radar is a corporate-fed phased array (i.e., a series of power splitters is used to distribute power to elements), composed of 96 subarrays. Each of these is powered by a single traveling wave tube with a peak power of 160 kW (average power about 9.6 kW). Each subarray has 160 active elements (each with a peak power of 1 kW). Thus the radar has a total of 15,360 active elements, a peak power of 15.4 MW, and an average power of 0.92 MW. The radar uses time delay steering of the subarrays to improve range resolution for wideband operations.[40]

The antenna face is 30 m in diameter. Cobra Dane's wavelength and antenna diameter give a beamwidth of about 8 milliradians (mR) (about one-half degree). This is several times worse than the X-Band Radar (which is about 2.5 mR), but several times better than the PAVE PAWS or BMEWS radars (about 30 mR).

A standard measure of the search capability of a radar is its power-aperture product: the product of its antenna area (in square meters) and its average power (in watts). An antenna diameter of 30 m with an average power of 0.92 MW has a power-aperture product of about 6.5×10^8 W-m^2 for Cobra Dane. Because of the array tapering, the actual power-aperture product is probably somewhat more than a factor of two lower, so 3×10^8 W-m^2 is probably a good estimate of its effective power-aperture product. This is about twice that of the BMEWS early warning radars in Greenland and England (1.3×10^8 W-m^2 per face) and about five times that of the PAVE PAWS radars in Massachusetts, Alaska, and California (6×10^7 W-m^2 per face).

In search mode, the radar operates with a 1 MHz bandwidth and with pulselengths of 1.5 or 2 milliseconds. In the tracking mode, the radar uses a waveform with a 5 MHz bandwidth. This gives a range resolution of about 30 m. However, Cobra Dane also has a wide-band pulse-compression

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[39] Discussing plans for radars on Shemya island in 2000, when plans still called for putting an X-band radar on Shemya, General Kadish stated: "Well, there was— there are basically two reasons why we use an x-band in that point in time. We did not have early warning coverage adequate enough for the Korean threat in that area of the world. So, we took advantage of the fact that we could put an x-band radar with its much more refined capability for discrimination purposes and fill the early warning gap. So, we got kind of dual capability out of that radar, which we thought was very valuable" (U.S. House of Representatives 2000).

[40] To see why this is needed, consider the radar operating at the edge of its wide-band fan, 22.5 degrees off boresite. Since the radar has a 30 m aperture, signals from the opposite sides of the radar will be separated by 30 m x sin 22.5 degrees = 11.5 m, limiting the range resolution to roughly 6 m. By dividing the array into 96 subarrays, each of which can be given a required time delay relative to the other subarrays, this effect can be reduced by a factor of about 10, allowing it to achieve its claimed range resolution of 1.1 m.

tracking mode, which has a bandwidth of 200 MHz. While this is capable of supporting a range resolution of 0.75 m, the actual range resolution is only 1.1 m, due to the use of amplitude weighting on receive to reduce its time sidelobes (Skolnik 2002, p. 346). However, this high-resolution mode is only available over a limited range of angles: within 22.5 degrees of the boresight (and presumably within a similarly limited range of angles in elevation). This range resolution is much better than PAVE PAWS or BMEWS, but a factor of five or so less than that of the X-Band Radar.

Cobra Dane can probably use Doppler measurements to obtain small cross-range resolutions on objects that are rotating. (For an object with a fixed orientation relative to the earth, the rotation that occurs due to its orbital motion can be used.) This could give a cross-range resolution comparable to (or slightly larger than) that of the range resolution. This capability could be used to form two-dimensional maps of targets with a resolution of roughly 1 m (within the central part of the radar fan).

Cobra Dane is said to be able to track a basketball-sized object at a range of 2,000 miles (3,200 km).[41]

The Bush administration has stated that in any operational system, an X-Band Radar will be required, even if Cobra Dane is upgraded.[42]

Upgraded Early Warning Radars

The United States currently operates a network of ground-based early warning radars made up of three PAVE PAWS and two BMEWS radars. These two types of radars are similar in many respects. Both use the same receive/transmit modules and thus operate over the same frequency range, from 420 MHz to 450 MHz. Their primary mission was to provide early warning of attacks by ICBMs or SLBMs, although they also had secondary missions such as space surveillance.

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[41] According to one source, it has a range of 1,000 mi (1,850 km) against 0.01 m^2 RCS target with a S/N of 16.5 dB (45) using a 1 millisecond pulselength and a PRF of 60 Hz (Brookner 1977, p. 25).

[42] Hearing before Senate Armed Services Committee, July 17, 2001:

SEN. LEVIN: Okay. Will— I want to talk about the Cobra Dane radar for a few minutes. In your [Under Secretary of Defense Paul Wolfowitz] point paper that was provided to this committee, you said that an upgraded Cobra Dane radar, quote, “may have some ABM radar capability,” close quote, but in any operational system, we anticipate that a new X-Band Radar at Shemya would be required to provide needed discrimination, even with all possible upgrades to Cobra Dane**.** So are you then saying that Cobra Dane will provide that contingency capability as early as ’04?

GEN. KADISH: If I understand the question, I believe the answer would be yes, because it’s an early warning radar, and it only functions as an early warning radar. And one of the issues, as you know, is the countermeasure problem for any midcourse system that we need X-Band for. So the capability is very basic and, as we’ve been describing it, rudimentary.

The point paper accompanying prepared testimony of Paul Wolfowitz, deputy secretary of defense, to the Senate Armed Services Committee, July 17, 2001, stated:

“In any operational system, we anticipate that the X-Band Radar at Shemya would be required for to provide needed discrimination, even with all possible upgrades to Cobra Dane.”

The three PAVE PAWS sites are in Clear, Alaska; Cape Cod, Massachusetts; and Beale Air Force Base, California. PAVE PAWS radars have two antenna faces, each covering 120 degrees in azimuth, for a total coverage of 240 degrees. Elevation coverage is from 3 to 85 degrees above the horizon. The diameter of each face is 31.1 m, although only an area with a diameter of 22.1 m is actually populated with the 1,792 active transmit/receive modules. The average power per face is about 150 kW. They are said to be capable of detecting a target with a radar cross section of 10 m^2 at a range of 5,000 km.[43]

The PAVE PAWS radars reportedly have a beamwidth of about 2.2 degrees, corresponding to cross-range resolution of about 75 km at a range of 2,000 km. They have a bandwidth of 100 kHz in search mode and 1.0 MHz in track mode. This track-mode bandwidth corresponds to a very poor range resolution of 150 m, which severely limits their ability to discriminate actual warheads from decoys and other objects.

The two BMEWS (ballistic missile early warning system) radars are located in Thule, Greenland, and at Fylingdales in England. Unlike the PAVE PAWS and Thule radar, which have two faces, the BMEWS radar in England has three faces, providing 360-degree coverage in azimuth.

The BMEWS radars are larger and more powerful than the PAVE PAWS radars, with a face diameter of 25.6 m (compared with 22.1 m for PAVE PAWS) and an average power per face of 255 kW (compared with 150 kW for PAVE PAWS). Because of their larger aperture, the BMEWS radars have a slightly narrower beamwidth than the 2.2 degrees of the PAVE PAWS. Perhaps more importantly, they have a significantly higher maximum bandwidth, between 5 MHz and 10 MHz in the track mode, corresponding to range resolutions of 15–30 m. While this is far better than the range resolution of the PAVE PAWS radars, it is far inferior to that of planned x-band radars and too poor to discern the structural details of warhead-sized targets.

As part of the GMD system, the two BMEWS radars and the PAVE PAWS in California, would be upgraded. Thereafter, they would be known as UEWRs. At this time, there appear to be no plans to upgrade the PAVE PAWS in Massachusetts and Alaska (Early Warning 2003). These upgrades are said to involve hardware software changes to enable the UEWRs to track targets accurately enough to guide interceptors. According to the Pentagon, regarding the PAVE PAWS radars: “In their current configurations, these radars can detect and develop approximate impact-location data for objects associated with a missile launch, such as the last missile stage. This information is insufficient for use by a ballistic missile defense system, for two reasons: it does not track each missile long enough before returning to the search mode, and it does not permit the derivation of sufficiently accurate trajectory parameters to support intercepts. Upgrades to the system’s software, and modest changes to the hardware, are needed to address these

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[43] The power of the PAVE PAWS radars could be significantly increased by fully populating the 31.1 m diameter face with its full complement of 5,376 modules. This would give an increase in power-aperture product of about a factor of 10. However, no such upgrade is currently planned.

shortfalls and to make the data so obtained available to the national missile defense battle management, command, control, and communications system" (White 1995).

A draft environmental impact statement for PAVE PAWS spells out which equipment would be upgraded: "The hardware modifications would consist of replacing existing computers, graphic displays, communication equipment, and the radar receiver/exciter to perform the NMD mission (i.e., identification and precise tracking of a ballistic missile launched against the United States). The early warning radar software would be rewritten to incorporate the NMD function and allow the acquisition, tracking, and classification of small objects near the horizon. The UEWRs would be able to search for different types of missiles, distinguish hostile objects such as warheads from other objects, and provide this data to other NMD elements using improved communications systems" (USASMDC 2000, p. es-2). Despite these changes, "The radiated peak and average power, radar antenna patterns, and operating bands of the UEWRs would remain unchanged from current operations" (USASMDC 2000, p. es-2). However, the increased radar sensitivity and resolution achieved via these upgrades was expected to lead to increased detection ranges and target identification capability, in addition to the improved tracking capabilities.

One possible outcome of the modifications would be to increase the bandwidth of the radars, and doing so would not contradict any of the above statements about radar characteristics that would remain unchanged. One source indicates that the UEWRs would have their effective bandwidth increased up to about 30 MHz (Canavan 2003, p. 66). Thirty MHz is the upper limit for the bandwidth, since it is the full spectral range of the radars, corresponding to a range resolution of 5 m. While a significant improvement, this range resolution would still be too poor to make out details of warhead-sized targets, although it might be useful for distinguishing between a warhead and a final booster stage. Even if these radars are not upgraded to a 30 MHz bandwidth, it seems reasonable to expect that the upgraded PAVE PAWS would be upgraded from their current track bandwidths of 1 MHz to the 5–10 MHz of the BMEWS radars.

Aegis SPY Radar

The MDA has stated that it plans to use the SPY radars on U.S Navy Aegis cruisers and destroyers as part of a defense against long-range missiles. By the end of 2005, three Aegis missile defense cruisers are to be modified and deployed, carrying up to 10 SM-3 interceptors equipped with exoatmospheric LEAP kill vehicles. These interceptors were designed for use against short- and medium-range missiles and were not intended for use against the long-range missiles the GMD system is intended to counter. In addition, one Aegis surveillance and tracking destroyer is to be deployed in 2004, with the number of such destroyers rising to 10 by the end of 2005 and 15 by the end of 2006. The modifications planned for these ships appear to be primarily to their computers, software, and command, control, and communication systems.

The Aegis radar is a large, four-faced, phased-array system deployed on U.S. Aegis cruisers and Arleigh Burke destroyers. The first version of Aegis radar was the SPY-1. This test version was initially installed at a land test site and then on ship for at-sea testing. Following these tests, it was decided to deploy the radar on the Aegis cruisers the Navy was then planning to build. The first deployed version of the radar was the SPY-1A, which was installed on the first 12 Aegis cruisers. The next version, the SPY-1B, was installed on the next 15 Aegis cruisers. It had roughly double the average power of the SPY-1A and significantly reduced sidelobes. The MDA's missile defense test ship, the Lake Erie, is a SPY-1B cruiser. The SPY-1D, installed on Arleigh Burke destroyers, is similar to the SPY-1B, except that it uses one transmitter to drive all four radar faces, where in the SPY-1B, two transmitters each drove two faces.[44] Starting with the 41st destroyer (DDG-91, scheduled to be commissioned in late May 2004), an improved version, the SPY-1D(V) will be deployed. It has improved clutter-rejection capabilities, higher average power, and other improvements.

Each of the four radar faces is a 3.65 m × 3.85 m octagon, with an area of about 12 m^2. The antenna gain is reportedly 42 db (Friedman 1991, p. 357). Since the radar operates in S band from about 3.1 to 3.5 Ghz ($\lambda \approx 0.1$ m), the effective area of the antenna is about 12.6 m^2 (using $A = G\lambda/4\pi$). However, the APS Boost Phase Study indicates that, with weighting, the effective aperture area is 12 m^2 (APS Study Group 2003, p. 178).

Each SPY transmitter uses 32 cross-field amplifiers, and each transmitter drives either two (SPY-A, SPY-B) or four faces of the radar. The peak power of each amplifier is 132 kW, thus giving a total peak power of 4.2 MW (Friedman 1997, p. 374). Each transmitter produces only one beam at any given time, indicating that the full power of the radar can be put out of one face.[45] Thus for our purposes here, the fact that the SPY-1D transmitters drive more faces than those of the SPY-1B does not make a difference. The average power of the SPY-1A radar has been reported to be 32 kW (Adams, 1988). By increasing the duty cycle of the amplifiers, the average power for SPY-1B and SPY-1D was roughly doubled, to 58 kW (Friedman 1997, p. 357). The SPY-1D(V) uses improved amplifiers, with an increase in input power of 45 percent and an increase in duty cycle of over 33 percent. A 33 percent increase in average power for the SPY-1D(V) gives an average power of about 77 kW, giving a power-aperture product of about 925,000 W-m^2. The duty cycle of this radar would then be about 81kW/4.3MW = 0.02.

Versions of the SPY radar indicated by the letter B or D reportedly have a "sustained coherent bandwidth of 10 MHz, instantaneous 40 MHz," with pulse widths of 6.4, 12.7, 25, and 51 microseconds, and a pulse compression ratio of 128 (Friedman 1991, p. 374).[46] A sustained coherent bandwidth of 10 MHz corresponds to a compressed pulse length of 1×10^{-7} seconds. With a pulse compression ratio of 128, this gives a noncompressed pulse length of 12.8 microseconds.

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[44] The SPY-1C was a proposed version for aircraft carriers, but was never produced.

[45] The new SPY-1D(V) can put two beams at once through different faces.

[46] A maximum pulse length of about 51 microseconds is confirmed by a report on electromagnetic interference due to the Aegis radar that states that any radar pulse can only cause interference for 52 microseconds or less (Sanders, Ramsey, and Hinkle 1997).

The primary objective for the new SPY-1D(V) was to improve its capabilities in heavy clutter environments, such as might occur in littoral operations (Engle 1998). Improvements include a higher average power and increased waveform stability (both achieved by using a new amplifier with a higher duty cycle). Perhaps most significantly, the SPY-1D(V) incorporates a new signal processor that significantly increases its ability to operate against low RCS targets in a clutter environment. It has an improved moving target indicator (MTI) capability, with two to seven pulse waveforms. It also adds 12-pulse and 16-pulse Doppler acquisition and tracking waveforms.

While the Aegis SPY-1B radar is large and powerful from an air defense perspective, it is much smaller and less powerful than the other radars that would be involved in the Block 2004 GMD system. The SPY radars are too small to detect missile warheads at ranges of thousands of kilometers. Used as a terminal or midcourse radar, its detection range against an incoming intercontinental-range warhead will be too short to guide the GMD interceptors. This is not surprising since the SPY was designed to track relatively large objects—airplanes and entire missile bodies—that are fairly close to the radar, not small warheads at the long ranges needed for national missile defense.

This conclusion is echoed by official assessments of the radar's capabilities. In the unclassified summary of the classified report, "Utility of Sea-Based Assets to National Missile Defense (U)," dated May 15, 1998 and submitted to Congress by Lt. Gen. Lester Lyles, the Ballistic Missile Defense Organization (BMDO) notes, "The AEGIS AN/SPY-1B radar is not capable of supporting NMD type engagements due to limited detection and tracking ranges for strategic (long-range) ballistic missiles and their reentry vehicles." A nearly identical statement is in the FY2000 annual report of the office of the director, operational test and evaluation (DOT&E, 2001).

Nor, according to earlier official assessments, was the radar capable of intercepting long-range missiles with the interceptors planned for deployment on its ship. On April 12, 1995, an ABM Treaty compliance report on the Aegis theater missile defense system Navy Upper Tier, which used the SPY radar, was submitted to Congress. According to then Deputy Defense Secretary John Deutch, the compliance report found that the Upper Tier system is legal under the ABM Treaty (Gertz 1995).[47] Other U.S. officials stated that the compliance report said the Pentagon studied whether the Aegis SPY-1 radar could lock onto a target before launching its interceptor missile in a one-on-one engagement and found that "the system clearly has no capabilities to counter strategic ballistic missiles." "In essence, by the time the SPY-1 . . . radar has acquired and tracked the target for the time necessary for the system to generate the engagement data needed for the interceptor launch, there is insufficient time for the interceptor (even at 4.5 km/s) to fly out and engage the target before it is either too high or too low" (Gertz 1995).

It is also informative to compare the SPY radar with the THAAD missile defense radar. The APS Boost Phase Study estimated THAAD's power-aperture product to be 324,000 kW-m^2. If this figure is close to correct, then

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[47] Deutch made these comments in a speech to the Navy League on April 13, 1995.

the SPY-1B radar's single face power-aperture-product would be more than twice as large as THAAD's. However, the SPY radar is consistently described as not being as capable as THAAD for long-range target detection (Limits 1996; Canavan 2003). This difference in detection range is attributed to AEGIS not using coherent integration, to different system losses and different operating frequencies, and to the fact that the two systems "benefit from external cues differently." Note that the difference in operating frequencies could favor Aegis, although the difference is likely to be small. An inability to perform coherent integration could be a serious limit on Aegis's ability to detect targets at long ranges.

Nevertheless, the Bush administration apparently plans is to deploy such Aegis ships off the coast of North Korea or other missile threat country, with the intention of using their radars to observe missiles during their boost phase and perhaps during the early part of their midcourse trajectory. According to MDA Director Kadish, such an Aegis ship would "act as a surveillance platform for protecting Hawaii, as well as giving queues for the whole United States."[48] An Aegis cruiser was stationed off the coast of California to watch

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[48] Senate Armed Services Committee, March 18, 2003:

SENATOR AKAKA: General Kadish, I understand you plan to use the radars of Aegis ships floating off the coast of North Korea to augment the 2004 national missile defense deployment. I also understand those ships are required to defend Hawaii from a North Korean missile attack.

A senior Missile Defense Agency official was recently quoted as saying, and I quote, "These ships will carry two computer programs, both of which will use Aegis radar data. The programs will not run concurrently. Operators will have to choose to operate the standard air defense program or the ballistic missile defense program. While the ballistic missile defense program is installed, it won't also at the same time have a program that can do the other full air defense missions," unquote.

Does this mean that a crew of a ship off the coast of North Korea [a] choice between defending themselves for the type of anti-ship cruise missile launched by the North Koreans last month or defending Hawaii from a missile attack? And, if so, isn't this a terrible choice to have to make?

GEN. KADISH: Let me take that— the answer is no. Now, let me explain why I said no that they wouldn't have to make a choice. It gets a little bit complicated. And we still have some things to work out with how the United States Navy will actually have that as a concept of ops for those ships and what they are going to do. But let me start by saying that the Aegis ships in this configuration have two functions. One is to act as a surveillance platform for protecting Hawaii, as well as giving cues for the—for the whole United States. The second function they would have would be to actually defend against shorter-range missiles. Okay?

To the best of my knowledge, the surveillance function can occur while the ship is actually engaged in the full operation of its defensive capability. When we move to the missile defense against shorter range missiles, because those are— those ships may have dual tasks, defending against shorter range missiles, as well as surveillance for Hawaii and other purposes, they would have a choice between the full fleet defense missile air defense capability and operating the only missile defense— standard missile three capability. That's the choice they would have to make.

They have full self-defense capability on the ship for their own purposes, but they wouldn't have the fleet air and missile defense that is inherent in the Aegis platform.

the boost and early ascent phase of the target missiles for IFT-9 (October 2002) and IFT-10 (December 2002). Using Aegis ships and radars in this way during NMD tests was one of the reasons the Bush administration cited for pulling out of the ABM Treaty.

And we're working through some of the operational concepts that make sure that our sailors are protected to the maximum extent possible doing this mission and that's underway by the Navy senior leadership right now.

So the choices are very compatible and commensurate with the risks that we're running as they— is the best way I could put it. And if it's there to help us protect Hawaii and give cues to other radar systems, then that's what it will do.

Authors

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Dr. Gronlund is a fellow of the American Physical Society (APS), which is the professional association of 42,000 physicists. She received the 2001 Joseph A. Burton Forum Award of the APS "for creative and sustained leadership in building an international arms-control-physics community and for her excellence in arms control physics."

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Dr. Wright is an established expert on the technical aspects of arms control, particularly those related to missile defense systems and missile proliferation. He has authored numerous articles and reports on arms control and international security, has testified before Congress on arms control issues, and is a frequently quoted source in *The New York Times* and on National Public Radio. He has worked for a number of years on projects to help train technical arms control experts in other countries, especially Russia and China.

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Dr. Lewis's research has included studies of arms control and verification for sea-launched cruise missiles and other nonstrategic nuclear weapons; air surveillance and early warning systems; and the effectiveness of short-range missiles and short-range missile defenses, including the performance of the Patriot missile defense in the 1991 Gulf War. Dr. Lewis is now conducting research on issues relevant to ballistic missile defense and deep reductions in nuclear weapons. He is a co-author of the April 2000 *Countermeasures* report, published by UCS and the MIT Security Studies Program

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Hon. Philip E. Coyle III, Senior Advisor to the President of the Center for Defense Information. Mr. Coyle is a recognized expert on U.S. and worldwide military research, development and testing, operational military matters, nuclear weapons and nuclear weapons technology, and national security policy and defense spending.

From September 29, 1994, through January 20, 2001, Mr. Coyle was assistant secretary of defense and director, operational test and evaluation, in the Department of Defense. He was the longest-serving director in the 20-year history of the office. In this capacity, he was the principal advisor to the secretary of defense on test and evaluation in the DOD.

As assistant secretary, Mr. Coyle had responsibility for overseeing the test and evaluation of more than 200 major defense-acquisition systems. This included reporting to the secretary of defense, and to Congress, on the adequacy of the DOD testing programs, and on the results of those testing programs. Mr. Coyle was called upon regularly to testify before Congress and to brief congressional staff on the status of major defense acquisition programs. His work was followed closely by the four defense committees of Congress and was frequently praised in the press. His integrity and objectivity have been widely recognized.

Technical Realities

An Analysis of the 2004 Deployment of a U.S. National Missile Defense System

This year the United States will begin deploying a national missile defense system initially intended to counter attacks by long-range ballistic missiles that North Korea might deploy in the future.

Technical Realities finds that flight intercept tests have provided essentially no information on system or component performance under realistic conditions. The study analyzes the technical capabilities of the system and shows that the defensive capability of the so-called Block 2004 system will be very limited. In particular, the limitations of the Block 2004 radars will render the system vulnerable to many types of unsophisticated countermeasures.

Moreover, the additional 20 interceptors the Bush administration is planning to deploy over the next few years would not in any meaningful way enhance the defensive capability of the deployed system, as the administration claims. This study finds no justification for procuring and deploying these interceptors.

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