APRIL 2017

Missile Defense 2020

Next Steps for Defending the Homeland

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A REPORT OF THE
CSIS MISSILE DEFENSE PROJECT

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Acronyms

ABIR	Airborne Infrared Radar
ABL	Airborne Laser
ABM	Antiballistic Missile
ABMDA	Army Advanced Ballistic Missile Defense Agency
AHD	Advanced Homeland Defense
ALPS	Accidental Launch Protection System
AMDR	Air and Missile Defense Radar
ARPA	Advanced Research Program Agency
ARPAT	Advanced Research Program Agency—Terminal
ASAT	Anti-satellite
BA	Budget Authority
BAMBI	Ballistic Missile Boost Intercept
BMDO	Ballistic Missile Defense Organization
BMDR	Ballistic Missile Defense Review
BMDS	Ballistic Missile Defense System
BP	Brilliant Pebbles
BSTS	Boost Surveillance Tracking System
BVT	Booster Verification Test
C2	Command and Control
C2BMC	Command and Control, Battle Management, and Communications
C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance
CE	Capability Enhancement
CKV	Common Kill Vehicle
CLE	Command Launch Equipment
CONUS	Continental United States
CTV	Controlled Test Vehicle

CY	Calendar Year
DACS	Divert and Attitude Control System
DDR	Deployment Decision Review
DLWS	Demonstrator Laser Weapon System
DOT&E	Director, Operational Test and Evaluation
DRR	Deployment Readiness Review
DSCS	Defense Satellite Communications System
DSP	Defense Support Program
E^2I	Exo-Endoatmospheric Interceptor
EHD	Enhanced Homeland Defense
EIS	Environmental Impact Statement
EKV	Exoatmospheric Kill Vehicle
EO/IR	Electro-optical/Infrared
EPAA	European Phased Adaptive Approach
ERIS	Exoatmospheric Reentry Interceptor Subsystem
EWR	Early Warning Radar
FGA	Fort Greely, Alaska
FTG	Flight Test Ground-based Midcourse Defense
FTX	Flight Test Other
FY	Fiscal Year
FYDP	Future Years Defense Program
GAO	Government Accountability Office
GBI	Ground-based Interceptor
GFC	GMD Fire Control
GLIPAR	Guide Line Identification Program for Antimissile Research
GMD	Ground-based Midcourse Defense
GPALS	Global Protection Against Limited Strikes
GSTS	Ground-based Surveillance and Tracking System
HALO	High Altitude Learjet Observatory
HEDI	High Endoatmospheric Defense Interceptor
HEL-MD	High Energy Laser-Mobile Demonstrator
HOE	Homing Overlay Experiment
ICBM	Intercontinental Ballistic Missile
IDT	In-Flight Interceptor Communications System Data Terminal
IFICS	In-Flight Interceptor Communications System
IFT	Integrated Flight Test
IMU	Inertial Measurement Unit
IOC	Initial Operating Capability
IRBM	Intermediate-range Ballistic Missile
ISR	Intelligence, Surveillance, and Reconnaissance
JCPOA	Joint Comprehensive Plan of Action
JIAMDO	Joint Integrated Air and Missile Defense Organization
KEI	Kinetic Energy Interceptor

LaWS	Laser Weapon System
LEAP	Lightweight Exoatmospheric Projectile
LoAD	Low Altitude Defense
LRDR	Long Range Discrimination Radar
MaRV	Maneuvering Reentry Vehicle
MDA	Missile Defense Agency
MEADS	Medium Extended Area Defense System
MF	Missile Field
MIRV	Multiple Independently-Targetable Reentry Vehicle
MKV	Multiple Kill Vehicle
MOKV	Multi-Object Kill Vehicle
MRBM	Medium-range Ballistic Missile
MRDR	Medium-range Discrimination Radar
MSX	Midcourse Space Experiment
NAS	National Academy of Sciences
NATO	North Atlantic Treaty Organization
NDAA	National Defense Authorization Act
NFIRE	Near Field Infrared Experiment
NIE	National Intelligence Estimate
NMD	National Missile Defense
NORTHCOM	Northern Command
NPR	Nuclear Posture Review
NSPD	National Security Presidential Directive
O&M	Operations and Maintenance
OPIR	Overhead Persistent Infrared
PACOM	Pacific Command
PATRIOT	Phased Array Tracking Radar to Intercept on Target
PTSS	Precision Tracking Space System
R&D	Research and Development
RDT&E	Research, Development, Test, and Evaluation
RHD	Robust Homeland Defense
RKV	Redesigned Kill Vehicle
SAC	Strategic Air Command
SBI	Space-based Interceptor
SBIRS	Space-based Infrared System
SBX	Sea-based X-band Radar
SDI	Strategic Defense Initiative
SDIO	Strategic Defense Initiative Organization
SKA	Space-based Kill Assessment
SLBM	Submarine-launched Ballistic Missile
SLV	Satellite Launch Vehicle
SM	Standard Missile
SM-3 IIB	Standard Missile-3 Block IIB

SRBM	Short-range Ballistic Missile
SSTS	Space-based Surveillance and Tracking System
STRATCOM	Strategic Command
STSS	Space Tracking and Surveillance System
THAAD	Terminal High Altitude Area Defense
TOA	Total Obligational Authority
UAV	Unmanned Aerial Vehicle
UEWR	Upgraded Early Warning Radar
UHF	Ultra-High Frequency
VAFB	Vandenberg Air Force Base
VLS	Vertical Launching System

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Study Methodology

Information for this study was compiled using a wide review of publicly available material on homeland missile defense issues. In particular, presentations from Department of Defense and Missile Defense Agency officials, and annual reports of the Director of Operational Test and Evaluation, were preferred when discrepancies emerged between sources. The study team also conducted extensive interviews and visited Fort Greely, Alaska.

Budgetary data for this study was compiled using budget materials on the Department of Defense Comptroller website. Each President's Budget includes an actual spent total from two prior fiscal years, a final congressional appropriated amount for the prior fiscal year, and a request along with the Future Years Defense Program (FYDP). For all years the data is available, the actual spending total (total obligational authority) was used rather than appropriated or requested amounts. For inflation adjustments, the Fiscal Year (FY) 2017 Green Book was used to calculate figures in FY 2017 dollars, using the overall GDP deflator.

Executive Summary

INTRODUCTION

In policy pronouncements over the last two administrations, the protection of the American homeland was regularly identified as the first priority of U.S. missile defense efforts. This prioritization was found, for instance, in the 2010 *Ballistic Missile Defense Review*, National Security Presidential Directive-23 of 2002, and numerous statements by senior officials. Defending U.S. forces, allies, and other partners has also long been recognized as important, but the formal prioritization of homeland missile defense and particular programmatic efforts both represent points of relative continuity.

Significant effort has been devoted to the development and deployment of the defenses now protecting the United States, stretching back to the beginnings of the National Missile Defense (NMD) program in 1996 and well before. Variations in programmatic emphasis and budgets, however, have not always supported the prioritization suggested in expressions of policy. At times, long-range missile threats to the homeland have been assessed as more urgent; at other times, regional missile defenses have received more emphasis (Figure ES.1). There is no doubt, however, that missile defenses of various kinds now represent an established part of U.S. national security.

Missile defense has been described as an evolving effort, with no final architecture. Each of the past five administrations has characterized a national missile defense program in terms of ongoing, phased, or block development. Since the U.S. withdrawal from the Anti-Ballistic Missile (ABM) Treaty in 2002, both the George W. Bush and Barack Obama administrations have opposed any legally binding restrictions on the numbers, locations, and capabilities of such defenses. Today's capabilities have now matured from a kind of infancy, to initial defensive capabilities, to a kind of adolescence—but have far to go before they might be described as mature or robust.

Homeland missile defense today is provided by the Ground-based Midcourse Defense (GMD) program. GMD and its associated systems span 15 time zones, including interceptors at two locations, seven types of sensors on land, sea, and space, and multiple distributed fire control systems. At the end of 2016, some 36 Ground-based Interceptors (GBIs) were deployed to silos at military bases in

Figure ES.1. Homeland and Regional Modernization, 1996–2021

*Based on FY 2016 enactment.
**Based on FY 2017 presidential budget request.

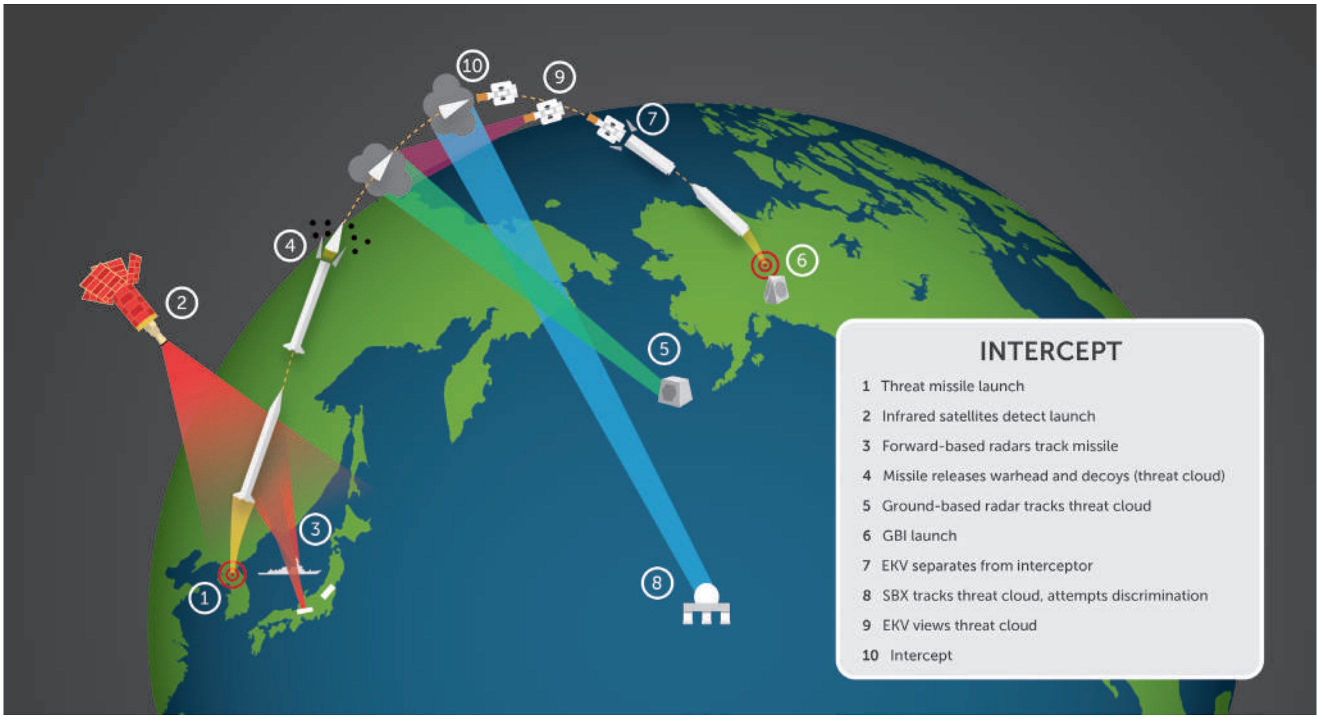
Alaska and California, providing a limited defense against long-range missiles from North Korea and potentially Iran. An additional eight interceptors will be added by the end of 2017, for a total of 44.

The challenge of deploying this global architecture in short order involved stitching together preexisting sensors and shooters from a wide array of Cold War–era systems that had not originally been designed for the mission. Over the past 12 years, the United States has since made considerable progress in addressing some inherent limitations. Newly developed or integrated systems now include the Sea-based X-band radar (SBX), upgraded Early Warning Radars, the SPY-1 radar on Aegis missile defense ships, and forward-based TPY-2 radars (Figures ES.2, ES.3, and ES.4).

GMD has seen some notable successes, including four consecutive successful intercept tests leading up to President Bush's 2002 deployment decision, and five more since. It has also suffered setbacks, reflecting the complexity of the missile defense challenge, short deployment time frames, a limited testing program, and uneven investments over time. The current system remains burdened with numerous interceptor configurations, older ground system hardware and software, and lower reliability. Many of the qualitative improvements that were planned and expected to follow the initial defensive capability have not yet, in fact, come to pass.

These challenges have been manifest in numerous test failures. Failures are to be expected in any technology development program and much can be learned from them. After three successive

Figure ES.2. GMD Intercept Sequence



intercept failures in 2010 and 2013, GBI deployments were paused while the Missile Defense Agency (MDA) identified the root causes of the failures, fixed them, and prioritized kill vehicle reliability.

These efforts paid off with the "return to intercept" over the Pacific Ocean on June 22, 2014. Facing a complex target with countermeasures, the test represented the most challenging missile defense intercept yet attempted. Had it been unsuccessful, there might have been political pressure to scrap the program and start anew. Instead, GMD has been reinvigorated. Besides improved confidence in the fielded GBI fleet, work is now under way on a Redesigned Kill Vehicle (RKV) to capitalize on what has been learned, as well as making gradual additions to the global sensor architecture.

The program's positive direction comes none too soon given increased missile activity by North Korea and others. Significant improvements remain under way, most notably with regards to discrimination, kill vehicle reliability, and additional sensors. Defenses fielded thus far may put the United States in an advantageous position relative to previous North Korean threats, but this advantage is unlikely to last. Foreign missile threats have continued to evolve in number, range, sophistication, and survivability.

POLICY AND STRATEGY

Unlike some past architectures, recent U.S. policy does not seek missile defenses to safeguard the American homeland against even small-scale missile attacks by Russia or China, instead relying on offensive-based deterrence. Rather, the focus of U.S. missile defense has been to counter the

Figure ES.3. Homeland Missile Defense Assets

limited and emerging Intercontinental Ballistic Missile (ICBM) threats from states such as North Korea and Iran.

Increased Modesty

The long policy, programmatic, and budgetary story of national and homeland missile defense is also one of increasing modesty. President Ronald Reagan's initial aspiration for the Strategic Defense Initiative (SDI) was to make nuclear weapons and their delivery vehicles "impotent and obsolete." At times, the goal of SDI was depicted as a defense against everything the USSR could throw. Later, SDI's Phase 1 was tailored to complicating a Soviet first strike and thereby strengthening deterrence.

Today's homeland missile defenses remain too limited, too modest, in light of current and emerging threats.

After the fall of the Soviet Union, the Global Protection Against Limited Strikes (GPALS) construct of President George H. W. Bush aimed at a narrower goal of protecting the United States against smaller, more limited attacks of 10 to 200 or so reentry vehicles, including accidental or unauthorized launches from a major nuclear power. President Bill Clinton's NMD architecture was comparatively more modest, and that which has since been fielded under the George W. Bush and Obama administrations is more limited yet. Much of the contraction relative to more ambitious past goals is understandable in terms of geopolitical, technological, and fiscal realities. Nevertheless, today's homeland missile defenses remain too limited, too modest, in light of current and emerging threats.

By several metrics, the capability and capacity of the defenses fielded today remain less than that outlined for the Clinton-era NMD program, which on paper at least included 100 to 250 interceptors at multiple sites, a space-based sensor layer, and numerous high-frequency radars dedicated to the missile defense mission. The number of targets that today's interceptors can defeat also remains quite limited and may not be far removed from the initial architecture proposed in the mid-1990s.

Widening the Scope

Today's missile defense capabilities and posture emerged in support of the 1999 National Missile Defense Act, which declared it U.S. policy to "deploy as soon as is technologically possible an effective National Missile Defense system capable of defending the territory of the United States against limited ballistic missile attack (whether accidental, unauthorized, or deliberate)."

Much has transpired in the 17 years since that act was passed. In December 2016, Congress passed a national defense authorization act updating this policy statement. This new language reflects the fielded status of homeland defense, identifies recent threat trends, expresses interest in more robust and layered capabilities, and broadens the mission to include allies and deployed forces.

As amended, the relevant section of the U.S. Code now reads, "It is the policy of the United States to maintain and improve an effective, robust layered missile defense system capable of defending the territory of the United States, allies, deployed forces, and capabilities against the developing and increasingly complex ballistic missile threat."

Whether it be relatively more "limited" or more "robust," an effective homeland missile defense serves several strategic purposes. These include providing a hedge against unpredictable regimes with which the nation is unwilling to accept vulnerability, preventing blackmail or attempts to divide the United States from its allies, creating uncertainty in the mind of an adversary, and raising the threshold for escalation by making "cheap shots" more difficult.

In the future, the purposes of homeland missile defense might be revised further to include protection against not only less limited attacks from countries like North Korea or Iran, but also to provide a thin defense against certain kinds of limited missile attack from Russia or China. A limited defense of population centers or strategic forces from any source could improve survivability, minimize coercion, and enhance strategic stability. For the time being, however, much remains to be done simply to keep pace with the existing threat set.

THREATS TO THE U.S. HOMELAND

Today, nearly 30 countries maintain ballistic missile capabilities, with approximately 50 ballistic missile variants. The missile defense mission has grown more challenging with threat missiles that are longer in range, more accurate, and diverse. The United States and its allies and partners may expect to encounter more multifaceted threats that could overcome current defense systems, including advanced cyber intrusions, electronic warfare, and hypersonic boost glide vehicles.

North Korea and Iran

As of today, Iran and North Korea have not yet, strictly speaking, demonstrated an ICBM with a flight test. Both nevertheless have extensive missile development programs, have deployed a significant number of medium- and intermediate-range missiles, and put satellites into orbit, all major steps critical to development of an ICBM development.

North Korea continues an unprecedented rate of testing in its missile and space launch vehicle programs. Test launches of the Musudan intermediate-range missile, as well as other ground tests, have further demonstrated advances with the missile engines that might be used as the lower stages of a KN-08 or KN-14 ICBM. Progress on warhead miniaturization also continues. Iran also maintains the most active and diverse ballistic missile program in the Middle East. Tehran similarly has a continuing space launch vehicle program that could be used to advance toward an ICBM capability.

In the coming years, North Korea could potentially begin serial production of intercontinental ballistic missiles. It would be quite difficult and costly to face a situation of significantly greater threats in, say, 2025, and attempt to catch up. Outpacing rather than chasing these threats will require increased effort.

Russia and China

Russia possesses over 300 ICBMs equipped with multiple independent reentry vehicles (MIRVs) and over 175 submarine-launched ballistic missiles (SLBMs) deployed across 11 submarines, all capable of delivering nuclear payloads to the United States. China deploys more than 60 ICBMs and is currently developing a nuclear ballistic missile submarine fleet equipped with nuclear-tipped SLBMs with a reported range of over 8,000 kilometers.

U.S. military officials have also highlighted the emerging threat posed by long-range land attack cruise missiles. One such missile is the Klub-K, a Russian export designed for launch from a cargo container, making it easy to transport and potentially launch from a ship or undersea platform. To date, the threat from land attack cruise missiles has not been a part of U.S. homeland missile defense efforts, but this exclusion may need to be revisited.

The magnitude of threats from Russia and China makes building a robust missile defense against them a significant challenge. It seems unlikely that the United States will attempt in the near term to adopt a defense-dominant posture with respect to these countries, but homeland missile defense need not forswear attention to these threats entirely. Differentiation between the two is also in order. A defense capable enough to complicate or protect against an attack from China, for instance, might still be far too limited to affect strategic vulnerability with Russia. In the past, the United States has pursued thin defenses and point defenses to support deterrence and enhance strategic stability. The relationship between strategic forces and missile defenses could well figure again in a future U.S. nuclear posture review.

THE STATE OF HOMELAND DEFENSE TODAY

Despite much progress, GMD remains in a form that might be described as an advanced prototype, still owing much to a basic design and technologies from the 1990s. The 2002 decision to field a limited defense capability by late 2004 left little choice but to embrace a kill vehicle still under development and to adapt legacy systems not designed for the mission. Virtually every element of the architecture and capabilities of today's GMD system has been conditioned and shaped by decades of history and the legacies of previous programmatic and strategic goals.

The requirements of simultaneously developing, fielding, maintaining, and upgrading a complex, operational system have resulted in a patchwork of kill vehicle types with a high number of possible failure points. Reliability issues require a higher shot doctrine, which directly reduces effective magazine capacity.

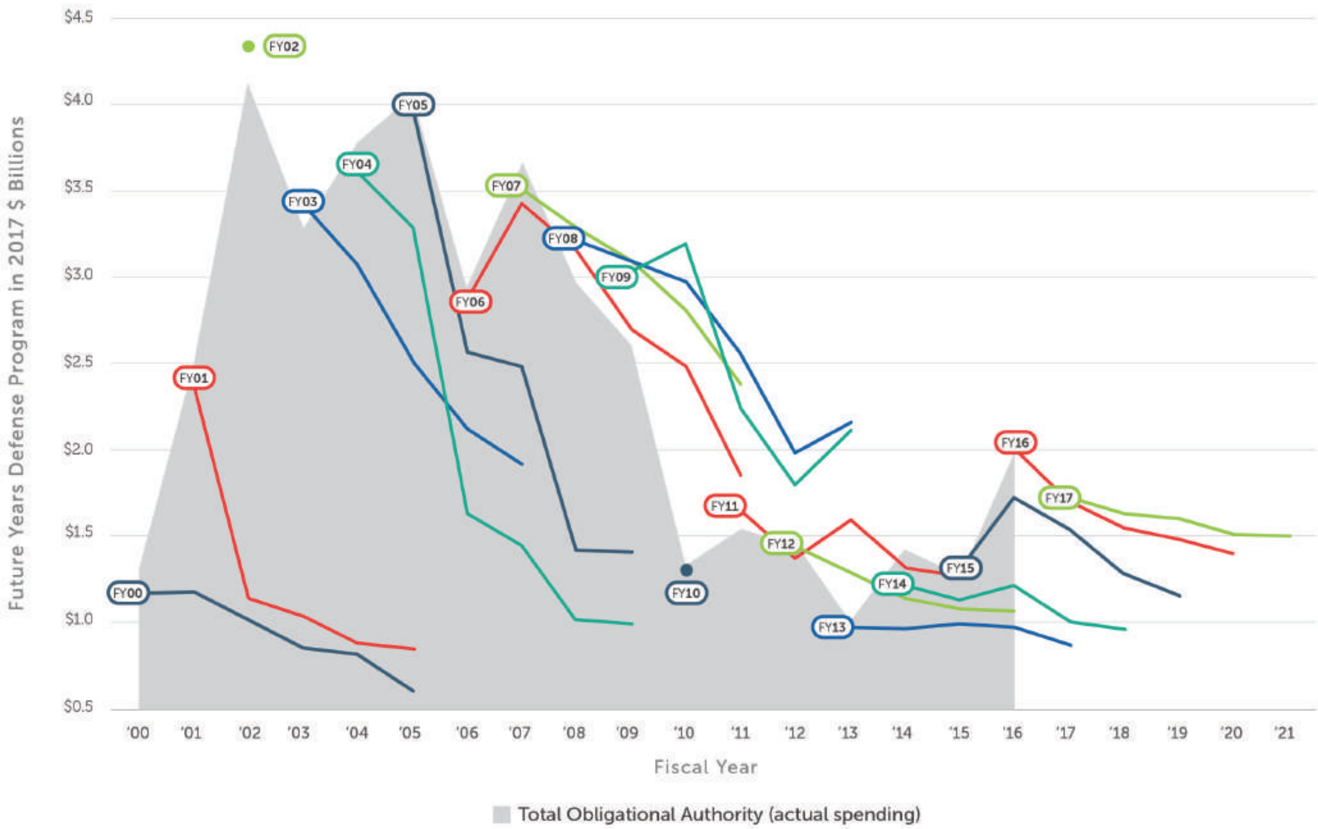
From a budgetary standpoint, homeland missile defense has been subject to decline relative to regional defenses as well as to the downward budgetary pressures that exist throughout MDA and DoD more broadly. At its height in 2002, homeland-related spending approached $4.5 billion, but was $2 billion by 2016 (all figures in adjusted 2017 dollars). This downward trend has adversely affected nearly every category of homeland missile defense.

If not improved and expanded, today's system could become inadequate to its task. A 2012 National Academy of Sciences report predicted that without substantial improvement, the then-current GMD system would only be able to outpace the threat "for the next decade or so." That report recommended an evolved kill vehicle, a faster burning booster, additional X-band radar deployments to improve discrimination, and a third site in the northeast United States. Many of these and related issues are currently being addressed, but not all.

INTERCEPTOR DEVELOPMENT

Perhaps the most recognizable component of homeland missile defense is the GBI itself, which represents the product of a long line of hit-to-kill interceptors dating back to the 1980s. A gradual

Figure ES.4. Homeland Actual Spending and Future Years Defense Plans, 2000–2021



$ in Millions	FY00	FY01	FY02	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14	FY15	FY16
Then-Year	945	1,824	3,074	2,491	2,944	3,253	2,440	3,119	2,577	2,291	1,180	1,397	1,327	947	1,356	1,227	1,956
Inflation Adjusted	1,318	2,484	4,121	3,277	3,780	4,048	2,941	3,660	2,962	2,603	1,329	1,542	1,439	1,010	1,421	1,269	1,991

Programs include: GMD base, MKV/MOKV, SBX, Improved Homeland Defense Interceptors, LRDR, and GMD Test.

modernization and capacity increases over time have resulted in a diversity among the interceptors. Five main variants of GBIs are currently operational, in the process of being deployed, or under development.

One limitation of the current GBI fleet is the lack of on-demand communication between the Exoatmospheric Kill Vehicle (EKV) and ground systems and regular updates to the EKV. Today's in-flight communications are inferior in this respect to other more recently developed systems like the Standard Missile-3 (SM-3).

Today's current three-stage booster also limits flexibility to perform shorter-range shots at incoming missiles later in flight, since all three stages of the booster must burn out before the kill vehicle can be deployed. A shorter-range shot later in the threat missile's trajectory may be necessary if an initial GBI salvo fails to intercept, or if there is insufficient warning time. A fleet composed of only three-stage boosters compresses the battlespace that operators have to engage a set of incoming targets and reduces the ability to reengage if initial intercept fails.

A Redesigned Kill Vehicle (RKV) will not only decrease both the diversity and complexity across the fleet, but also ease production and improve reliability. Even after RKV is fully deployed in 2027, however, the fleet of 44 will still include nine comparatively older GBIs equipped with CE-II Block 1 kill vehicles. The significance of this "mixed fleet" includes potentially different capabilities and degrees of reliability, and thus some decreased flexibility.

TESTING

One of the most important parts of GMD development has been the regime of flight and intercept testing. Intercept tests typically involve the launch of an IRBM or ICBM representative target, followed by the launch of a single GBI to engage it. Flight tests may involve the launch of only an interceptor to prove out the kill vehicle or other sensor systems.

Since 1997, there have been 31 GBI flight and intercept tests, of which 17 have been intercept tests involving both the launch of GBI and a target missile. In nine intercept attempts, the interceptor successfully destroyed the target. Testing has uncovered several shortcomings and design flaws in the GMD system, some as simple as an error in a line of software code. Others, such as the "track gate anomaly," required more extensive efforts to investigate and correct. None of the test failures, however, indicated a fundamental flaw with the basic long-range concept or hit-to-kill technology, but rather represented fixable problems with individual components. In 2014, the director of the MDA, Vice Admiral James Syring, described the totality of GMD testing as "nothing unexpected in a prototype for a test bed." What makes GMD different, however, is its declared status for initial defensive operations even while design flaws are worked out and enhancements are implemented.

SENSORS AND COMMAND AND CONTROL

No missile defense system is better than the sensors and command and control systems that determine where the threat is and how to kill it.

While interceptors tend to capture the imagination, sensors are the underappreciated backbone of missile defense operations. Sensors are required across the entire intercept cycle: early warning, tracking, fire control, discrimination, and kill assessment. Homeland missile defense depends on sensor information from a wide array of ground- and sea-based radars as well as satellites. These individual sensors feed information about the target velocity, projected location, and discrimination data to the GMD Fire Control (GFC) component at Schriever AFB in Colorado Springs.

While interceptors tend to capture the imagination, sensors are the underappreciated backbone of missile defense operations.

Improvements in sensors may, at the margin, be one of the best ways to improve lethality, raise effective magazine capacity, and contribute to a more robust defense. The basic desire with sensors is to have as many as possible,

Table ES.1. Current and Future Phases of GMD Evolution

Phase	Time Frame	Capability Goals
Enhanced Homeland Defense (EHD)	FY16–18	• 44 Ground-based Interceptors by end of CY17 • Reliability Enhancements to EKV (8 upgraded CE-II and 8 CE-II Block 1)
Robust Homeland Defense (RHD)	FY18–21	• Complete development of RKV and begin production/deployment • Integration of KV to KV communications, on-demand communications for RKV • Complete development of 2/3 stage selectable booster upgrade for C1, C2, and C3 boosters. • Integration of Long Range Discrimination Radar in BMDS
Advanced Homeland Defense (AHD)	FY21+	• Development of Multi-Object Kill Vehicle (MOKV) • Advanced-air or space-based electro-optical/infrared (EO/IR) sensors • Improved track and discrimination software for BMDS radars

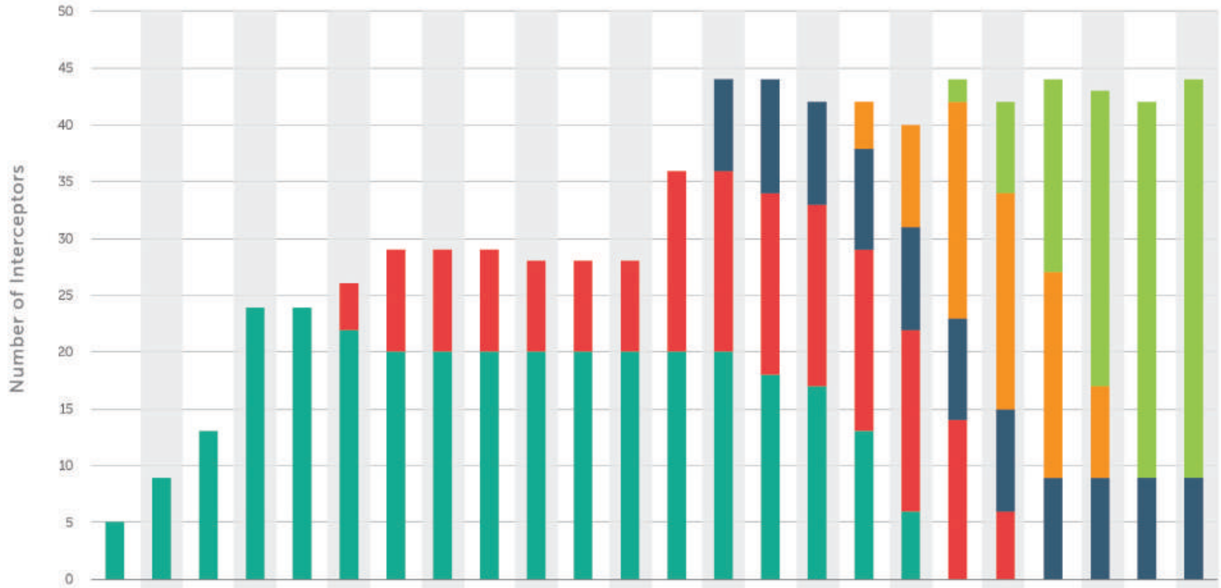
from as many different vantage points and technologies as possible, and then to effectively integrate them through a centralized command and control network. The depth of GMD sensor coverage has improved dramatically since initial defensive operations, but significant work still remains for persistent birth-to-death tracking and discrimination.

THE CURRENT ROADMAP

MDA's current path forward to improve GMD may roughly be divided into three phases: Enhanced, Robust, and Advanced. Although the phases overlap a bit, they reflect fairly discrete sets of development and deployment goals (Table ES.1). The cornerstone of the plan is the RKV, which will build on the lessons from nearly two decades of EKV testing to produce a more reliable kill vehicle. Although not a dramatic departure from EKV in terms of technology or capability, RKV will have greater modularity, simplify maintenance and upgrades, and reduce both cost and points of failure.

MDA currently estimates that flight tests of RKV might begin by 2018, with initial RKV deployments in 2020, and the goal of recapping 35 GBIs with RKVs by 2027. This estimate is probably overly ambitious. Budget pressure and other developmental work is likely to delay this schedule a bit, but an RKV flight test might take place before 2020.

Figure ES.5. GBI Fleet Evolution: Past and Projected Deployments, 2004–2027



Fiscal Year	'04	'05	'06	'07	'08	'09	'10	'11	'12	'13	'14	'15	'16	'17	'18	'19	'20	'21	'22	'23	'24	'25	'26	'27
RKV (C3 Booster)																			2	8	17	26	33	35
RKV (C1 Booster)																	4	9	19	19	18	8		
CE-II Block 1														8	10	9	9	9	9	9	9	9	9	9
CE-II						4	9	9	9	8	8	8	16	16	16	16	16	16	14	6				
CE-I	5	9	13	24	24	22	20	20	20	20	20	20	20	20	18	17	13	6						

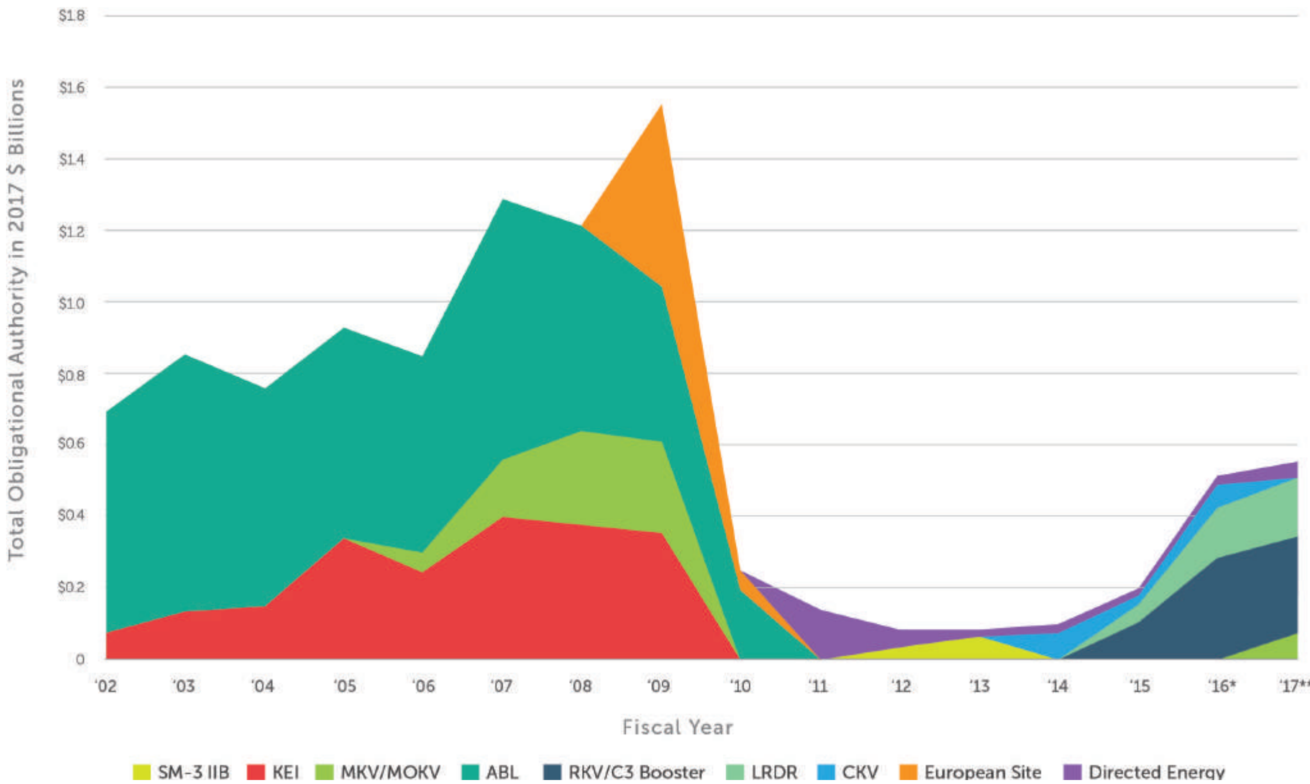
Although a cogent path forward, MDA's roadmap appears to contain several potential shortfalls.

The first potential obstacle is the multiyear production gap between the batch of GBIs currently being emplaced and future ones. After the final interceptors are produced for the goal of emplacing 44 by 2017, there is no planned procurement of additional interceptors until RKV goes into production, which could be 2020—and more likely later. Such a gap will present challenges for maintaining maintenance capability, and restarting production after several years of inactivity could be difficult and costly. A decision now to accept this gap would also mean accepting delays later in producing additional interceptors should threats grow and greater capacity be required before RKV is ready to field.

Connected to the first, another limitation in MDA's current plan is the reduction in near-term capacity. The planned production gap will coincide with a 10 percent dip in the number of operationally deployed interceptors, resulting in only 40 GBIs by 2021 (Figure ES.5). This reduction is a result of expending GBIs in tests without replacing them, in addition to further potential reductions in effective capacity for maintenance and other upgrades. This reduction appears to be in part the result of failing to acquire additional testing and operational GBI spares, as had been recommended in a 2013 Department of Defense report to Congress on homeland hedging strategies.

The third limitation is that the first RKVs produced in the 2020 time frame will go onto older C1 boosters. C1 boosters have known reliability issues, most notably that certain components have reached obsolescence and replacement parts can no longer be procured. Putting the newest kill

Figure ES.6. Homeland Missile Defense Advanced Technology: Select Programs, 2002–2017



*Based on FY 2016 enactment.
**Based on FY 2017 presidential budget request.

vehicles atop the oldest boosters has the potential to diminish for several years some of the reliability gains promised by RKV.

A final limitation concerns the sensor architecture, especially the continued lack of a space-based sensor layer. On paper at least, every homeland missile defense design across five administrations has included persistent orbiting sensors for tracking and discrimination. Additional shortfalls include the early midcourse gap over the Pacific, which the Long Range Discrimination Radar (LRDR) will narrow but not close; greater dependence on a fewer number of X-band radars; and the lack of an LRDR-like radar for the Atlantic for threats from the Middle East.

FUTURE OPTIONS

To protect the homeland, the United States currently relies almost exclusively on GMD and its associated assets for midcourse intercept of a limited set of long-range ballistic missile threats. In the future, the U.S. homeland missile defense posture will need to further improve GMD, but

The future of homeland missile defense may not remain GMD-centric.

may also need to broaden or change. Indeed, the future of homeland missile defense may not remain GMD-centric.

More advanced homeland missile defense efforts have more recently suffered from a downward trend in investment (Figure ES.6), moderated by an uptick since 2014 for RKV and LRDR. To expand further, MDA's research and development efforts will require both increased funding levels and more stability over time.

A variety of options present themselves to improve reliability, capability, and capacity of GMD, as well as supplement today's systems in new ways. These include increasing the number of interceptors, improved capabilities for boost-phase intercept and other forward-deployed interceptors, and improvements to the quality and number of sensors.

Expanded Capacity

The most cost-effective, near-term option for increasing homeland interceptor capacity would probably be to expand GBI deployments at Fort Greely beyond the 44 intended for the end of 2017.

Although interceptors in Alaska could in principle defend the entire United States, an additional site within the northeast United States would add significant battlespace and engagement time, support a shoot-look-shoot shot doctrine, and better defend the East Coast of the United States. Transportable GBIs or an alternative interceptor underlay for the U.S. homeland could, however, be a more cost-effective or temporary alternative to an additional East Coast site, or add further flexibility and depth to a defense with deployment elsewhere. The selectable-stage booster currently under development will add flexibility, as might a more energetic booster.

Improved Capabilities

Boost-phase directed energy has begun to again appear regularly in recent MDA presentations, which note both technological advances and new concepts of operation. Boost-phase intercept, nonetheless, remains an area of considerable inattention, despite MDA's charter to intercept missiles in "all phases of flight." Additional work on directed energy weapons, including Unmanned Aerial Vehicles (UAVs), could provide one path to ascent-phase intercept. Another option might be a return to kinetic boost phase, the current prospects for which could be examined with a renewed space test bed. The prospect of forward-deployed homeland interceptors might also be revisited, perhaps with continued block evolution of the SM-3.

Sensor Improvements

Significant sensor shortfalls remain for the entire BMDS. Today, missile tracking and discrimination remains almost entirely dependent on assets using one phenomenology (radio frequency, or radar) from two domains (land and sea). The number of terrestrial radars integrated into the BMDS has expanded considerably since 2004, and LRDR will improve coverage. Gaps will still remain in the early midcourse phase over the northern Pacific Ocean and over Hawaii, which additional high-frequency radars could help fill.

Overcoming the discrimination challenge will require greater variation in sensor type and location. Space-based satellites still offer the best vantage point for persistent, birth-to-death tracking of a target missile and its accompanying threat cloud. An alternative or supplement to space sensors is to have UAVs or other persistent aircraft perform this function at high, near-space altitudes.

Left of Launch Integration

Another closely related set of concepts for countering missile threats are measures to disable a missile prior to its launch, also called "left of launch." Attacking the "archers" or otherwise disrupting them means fewer "arrows" with which missile defenses must contend. This concept has achieved new salience of late with increased budget pressures and the inability of the DoD to supply the quantity of missile defenses demanded by combatant commanders. Left of launch efforts are nothing new, but U.S. defense planners have begun to consider new concepts for those operations. As the U.S. military discovered in Operation Desert Storm, however, Scud hunting is hard even with air superiority in an open desert. A broader perspective will include more than just preemption or kinetic strike, but also jamming and other means to reduce or degrade an adversary's command and control.

If it can be done reliably, defeating a North Korean missile on its mobile launcher or during its manufacturing would lessen the burden on GBIs or other active defenses. One difficulty, of course, is the challenge of reliably knowing in advance whether the efforts were successful. Active missile defenses have always existed within the larger context of other means to quiet a missile launcher, but represent an insurance policy should those efforts fail.

MISSILE DEFENSE 2020

A new focal point for homeland missile defense efforts appears to be emerging around the 2020 time frame. For various historical reasons, the intelligence community had long pegged the year 2015 as a marker for emerging Iranian or North Korean ICBM development. Now that 2015 has come and gone, threat estimates appear to have been revised outward.

When MDA director Syring was asked in March 2014 about the 2020 deployment deadline for a redesigned kill vehicle, he replied that it was threat-based. Likewise, in March 2013, when Secretary of Defense Chuck Hagel announced the cancellation of the SM-3 IIB and the expansion of GBIs back to 44, Hagel indicated that the SM-3 IIB would not be ready before 2022 and that "meanwhile, the threat matures." During an April 2016 congressional hearing, the commander of NORTHCOM, Admiral William Gortney, described Iran's progress with space launch vehicles, remarking that "in light of these advances, we assess Iran may be able to deploy an operational ICBM by 2020 if the regime chooses to do so." In terms of these recent assessments, one might say that 2020 is "the new 2015."

One might say that 2020 is "the new 2015."

Both the currently planned steps and others will likely be necessary to prepare for the threats of 2020 and beyond—if, that is, the United States intends to stay ahead of the emerging long-range ballistic missile threat.

Findings and Recommendations

FINDINGS

Policy and Strategy

- The goals of U.S. homeland missile defense have declined in ambition over the last five administrations, from complicating a large-scale ICBM attack by a great power, to global protection against limited attacks from whatever source, to today's defense against a (quite) limited attack from smaller nations like North Korea and Iran.
- Ambitions for regional missile defenses have expanded considerably over the same period.
- Despite programmatic change, the basic strategy of U.S. homeland missile defense has been fairly constant since the time frame of the 1999 National Missile Defense Act and the withdrawal from the ABM Treaty.

Budget

- The budget for homeland missile defense has experienced a steady downward trend, which may be quantified in a variety of ways. Over the last 10 years, from fiscal years 2007 to 2016, MDA's budget has included the following movements, expressed in adjusted 2017 dollars:
    - Total MDA topline: 23.4 percent decline, from $11 billion to $8.4 billion
    - Total homeland missile defense: 46.5 percent decline, from $3.7 billion to $2 billion
    - GMD base budget RDT&E: 53.6 percent decline, from $2.8 billion to 1.3 billion
    - GMD testing: 83.5 percent decline, from $400.6 million to $65.8 million
    - GBI development: 35 percent decline, from $1.2 billion to $794.2 million
    - Homeland-related advanced technology: 60 percent decline, from $1.3 billion to $513.3 million

- Sensor modernization: 47.3 percent decline, from $1.4 billion to $731 million
- Space and near-space activities: 86 percent decline, from $365.4 million to $51 million

Interceptor Capacity and Capabilities

- The capability and capacity of the homeland missile defenses currently fielded remain modest, with interceptor deployments below what past missile defense architectures envisioned and too limited relative to emerging missile threats.
- Current GBI deployments can likely handle the long-range ballistic missile threat to the United States presently posed by North Korea. Should North Korea establish and begin serial production of ICBMs, today's capabilities could soon become overmatched.
- The deployment of 44 GBIs appears to be on track for the end of 2017, but the number of operationally available interceptors will likely fall to 40 or fewer by 2022 due to the lack of testing and operational spares.
- U.S. homeland missile defense is largely structured and oriented toward limited long-range missile attacks from North Korea. It is relatively less capable against missile threats from the Middle East and is not at all oriented to defend against cruise or ballistic missiles fired from seaborne vessels or aircraft.
- GBI reliability has been depressed by a variety of policy, programmatic, and budgetary vacillations, as well as technical challenges.
- MDA has laid out a plan for the gradual evolution of homeland defense capabilities, but its pace and extent are limited by the current budget environment and past programmatic vacillation.
- The current plan to mount the first 19 RKVs atop the fleet's oldest boosters could potentially reduce capability or reliability gains relative to pairing them with newer boosters.
- Under current plans, there will be a several year gap in GBI production between the last-produced CE-II Block 1 and the RKV. The resulting need to restart GBI production after years of inactivity would likely increase the cost of RKV production and delay any potential expansion of CE-II or RKV capacity.
- Given the relative lack of attention to boost-phase intercept, current homeland programs fall short of the mission assigned in MDA's charter to develop and field defenses against missiles in "all phases of flight."
- The increasing roles and budgetary demands on MDA and a declining topline budget have limited its ability to pursue advanced missile defense technologies.
- Directed energy may one day make kinetic interceptors obsolete, but that day is likely still far away. For the near and potentially foreseeable future, missile defenses are likely to rely on chemically powered rockets carrying kinetic kill vehicles to defeat other chemically powered rockets.

Testing

- Since 2009, GMD flight and intercept testing has declined by half compared to the 2002–2008 time frame.
- The foundations of the hit-to-kill exoatmospheric missile defense mission remain sound.
- Nearly all GMD test failures have been the result of test anomalies and correctable malfunctions in peripheral systems.
- GMD testing has been one of the best ways to discover system flaws not otherwise revealed through ground testing and to validate the fixes to resolve them.
- GMD's flight and intercept testing cadence has been irregular since it became operational in 2004. This is partly explained by the need to investigate following several failures and by a decline in the testing budget.
- The historical progression of GMD tests reflects significant growth in the number of operational components, particularly sensors.
- MDA has made efforts to improve the operational realism of its intercept tests, including with the employment of countermeasures. It is difficult to assess whether these measures have made these tests as realistic as they could be.

Sensors

- The overall sensor architecture for homeland missile defense is improving, but falls short of persistent, birth-to-death tracking and discrimination. The new Long Range Discrimination Radar in Alaska will narrow but not close the current gap for North Korean ballistic missiles during their early midcourse phase.
- Both current capabilities and plans to improve tracking and discrimination capabilities for potential long-range Iranian ballistic missiles remain quite limited.
- The absence of any current program or plan to field a space-based sensor layer will hamper future homeland and regional missile defense efforts.

RECOMMENDATIONS

Policy

- Pursue a more robust and adaptable homeland missile defense architecture designed to outpace the various and increasingly less limited ballistic and cruise missile threats.
- Maintain MDA's special acquisition authorities to maximize flexibility and responsiveness to changing and emerging threats.
- Review the cruise missile threat to the homeland, including the National Capital Region and other strategic assets, and a range of possible responses. Such a study could be connected to and leverage two congressionally mandated studies in the defense authorization bill for

fiscal year 2017, one on anti-air war capabilities for Aegis Ashore sites and one requiring a review of missile defeat strategy, policy, and posture.

- Review the potential for increased integration of missile defenses with conventional and strategic assets to enhance deterrence and strategic stability.
- Review and update the MDA charter (DoD directive 5134.09), and that of any other appropriate entities, to ensure adequate whole-of-government attention to cruise missile and hypersonic threats, integrated air and missile defense efforts, the integration of missile defenses with conventional strike and other means to defeat missile threats prior to launch, and MDA's role and ongoing budget responsibility for foreign assistance and the procurement and operations of fielded systems.

Budget

- Increase funding for homeland missile defense to a level appropriate to its status as the top priority of U.S. missile defense efforts.
- Within homeland missile defense spending, prioritize funding for kill vehicle reliability and capability, including RKV.
- Increase and stabilize funding for advanced technology, including MOKV and directed energy.

Interceptor Capabilities

- Continue the current course toward the sets of goals known as Enhanced, Robust, and Advanced Homeland Defense, including with RKV, selectable-stage boosters, the C3 booster, and MOKV.
- Evaluate the benefits and costs of synchronizing booster development and RKV production, to put the latest and best kill vehicle atop the latest and best booster.
- Conduct an analysis of alternatives for more energetic homeland defense boosters, drawing on concepts and work from Standard Missile-3 Block IIB (SM-3 IIB), Kinetic Energy Interceptor (KEI), and other past programs, and revisit past concepts for forward-based interceptors.
- Improve the survivability and graceful degradation of kill vehicles, interceptor sites, sensors, and the broad GMD enterprise to hostile environments and direct attack.
- Evaluate the potential for accelerating MOKV development sooner than the current projection of 2025 or later.
- Evaluate novel payloads for coplacement alongside RKV and MOKV. Such payloads could include various dedicated sensors, directed energy, or other means to improve discrimination.
- Accelerate research and development efforts for compact lasers and other directed energy weapons for potential mounting aboard high-altitude UAVs flying within range of boosting ballistic missiles, for both tracking and boost-phase intercept missions.

Interceptor Capacity

- Initiate steps to continue production and fielding of GBIs at Fort Greely beyond the 44 expected at the end of 2017. Conduct an analysis of alternatives between completing existing Missile Fields and building Missile Fields 4 and 5.
- Procure operational and testing GBI spares to avoid the reduction in fielded GBIs between 2019 and 2022, create additional flexibility for increased testing requirements, and support increased capacity if the decision for such deployments is made. This expansion could be especially important if the RKV development and fielding is delayed or if new threats emerge.
- Evaluate continuing the current production and emplacement rate of one interceptor per month beyond the current goal of 44 interceptors. Continuing such a pace beyond 2017 could bring the total number of GBIs to around 68 by 2019 or 80 by 2020.
- Decisions about further expansion of the GBI fleet prior to RKV should take into account continued confidence in the CE-II Block 1 kill vehicles, which will be informed by upcoming flight and intercept tests.
- Complete readiness efforts for an East Coast site, and explore alternative and less costly fielding concepts such as transportable GBIs and alternative interceptors.
- Evaluate alternatives for a non-GBI interceptor underlay to enhance protection of selected areas.
- Improve integration of left of launch missile defeat efforts with active missile defenses.

Testing

- Accelerate the pace and complexity of GMD tests as much as possible.
- Restore a space test bed to evaluate concepts and viability for space-based sensors and interceptors.

Sensors

- Create and field a space sensor layer for persistent birth-to-death missile tracking and discrimination.
- Improve redundancy and quality for ground-based radar sensors, and close the midcourse gap over the Pacific.
- Evaluate additional sensor options to improve tracking of missile threats from the Middle East, such as with an additional LRDR-like system or the temporary relocation of SBX to the Atlantic.
- Evaluate the cost and benefits of deployment of additional discriminating radars colocated with UEWRs and the LRDR or at other sites, potentially by stacking TPY-2 X-band radars.
- Evaluate the risks and the possible means to address gaps in tracking and discrimination for missiles traveling to the United States from southern trajectories and from sea-launched cruise or ballistic missiles.

01

Homeland Missile Defense in U.S. Strategy

Missile defenses for the homeland now represent an established part of U.S. national security strategy and policy, and the first priority of U.S. missile defense efforts, even while the particular programs, budget levels, and metrics of sufficiency have varied over time. Sometimes long-range missile threats to the homeland have been assessed as more urgent; at other times, regional missile defenses have received more emphasis.

Global proliferation trends reflect a range of threats increasing in complexity, number, and capabilities, with missiles becoming more accurate, mobile, prompt, and survivable. Besides purely ballistic threats, new adversary capabilities now include a range of cruise missiles and maneuvering boost-glide vehicles. Should these missile trends continue, the demand for ways to defend against and defeat them will also continue to rise.

POLICY AND STRATEGY

Throughout the long history of efforts to protect against missile attack, active missile defense has never truly been a substitute or replacement for offensive retaliatory capabilities within the overall U.S. strategic posture. Some forms of passive defense against missiles have also never been controversial, such as hardening ICBM silos and putting missiles undersea and aircraft on alert. In terms of active defenses, there has been considerable variation between the objects of defense, the identity of the adversaries against whom defenses were directed, and the thickness or thinness of the defense pursued.

President Reagan's aspirations for the Strategic Defense Initiative (SDI) were perhaps too optimistic in the hope to make nuclear weapons and their delivery vehicles "impotent and obsolete." At times, the goal of SDI has been depicted as a perfect defense against everything the USSR could throw. Later, its Phase 1 architecture would focus on complicating Soviet nuclear strike and thereby strengthening deterrence. Reagan's 1983 SDI speech also contained caveats. While taking note of recent technological advancement, he described the challenge as "a formidable, technical task, one that may not be accomplished before the end of the century," predicting "failures and setbacks, just as there will be successes and breakthroughs."[1]

Recent U.S. policy does not seek missile defenses to safeguard the American homeland against either large- or small-scale missile attacks by Russia or China, preferring to rely on offensive-based deterrence to address these threats. The focus of U.S. missile defense has instead been to counter the limited and emerging ICBM threats from rogue states such as North Korea and Iran. This policy reflects two factors: the desire to not disrupt "strategic stability" with Russia or China, and the costs and technical limitations of such a system. This basic posture is evidenced in the characteristics, capacity, and capabilities of GMD.

These general expectations for homeland missile defense reflect significant continuity across at least the past two administrations, as indicated by high-level expressions of U.S. policy and strategy.[2] In 2008, Secretary of State Condoleezza Rice remarked, "It is true that the United States once had a Strategic Defense Initiative, a program that was intended to deal with the question of the Russian strategic nuclear threat. This is not that program. This is not the son of that program. This is not the grandson of that program."[3] Undersecretary of State Rose Gottemoeller made a similar point in a November 2014 speech in Bucharest. Addressing the perennial Russian and Chinese complaints about U.S. missile defenses as destabilizing, Gottemoeller noted that "our limited numbers of defensive systems cannot even come close to upsetting the strategic balance."[4] As she pointed out, even the plan for 44 homeland defense interceptors is 24 fewer than the 68 interceptors deployed around Moscow, but of course the United States is not concerned about the impact of those 68 on strategic stability.

Former vice chairman of the Joints Chief of Staff, Admiral James Winnefeld, addressed the issue in 2015, noting that "we prefer to use the deterrent of missile defense in situations where it has the highest probability of being most effective; we've stated missile defense against these high-end threats is too hard and too expensive and too strategically destabilizing to even try."[5] Rejecting the

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1. Ronald Reagan, "Address to the Nation on Defense and National Security" (speech, Washington, DC, March 23, 1983).

2. See, for example, U.S. Department of Defense, *Nuclear Posture Review* (Washington, DC: Department of Defense, 2001); George Bush, *National Security Strategy of the United States* (Washington, DC: The White House, 2002); George Bush, *National Strategy to Combat Weapons of Mass Destruction* (Washington, DC: The White House, 2002); George Bush, *National Policy on Ballistic Missile Defense* (Washington, DC: The White House, National Security Presidential Directive-23, 2002); Department of Defense, *Ballistic Missile Defense Review Report* (Washington, DC: Department of Defense, 2010); Department of Defense, *Nuclear Posture Review Report* (Washington, DC: Department of Defense, 2010); Martin E. Dempsey, *Joint Integrated Air and Missile Defense: Vision 2020* (Washington, DC: Joint Chiefs of Staff, 2013); Department of Defense, *Quadrennial Defense Review* (Washington, DC: Department of Defense, 2014); Department of Defense, *Strategy for Countering Weapons of Mass Destruction* (Washington, DC: Department of Defense, 2014); Barack Obama, *National Security Strategy of the United States* (Washington, DC: The White House, 2015).

3. Condoleezza Rice, "Remarks with Polish Foreign Minister Radoslaw Sikorski after Their Meeting" (news briefing, Benjamin Franklin Room, U.S. Department of State, Washington, DC, February 1, 2008).

4. Rose Gottemoeller, "America's Commitment to Ballistic Missile Defense and the European Phased Adaptive Approach" (speech, Bucharest, Romania, November 18, 2014).

5. James A. Winnefeld Jr., "Missile Defense and U.S. National Security" (speech, Center for Strategic and International Studies, Washington, DC, May 19, 2015).

attempt to degrade the Russian strategic deterrent is not the same, however, as saying that the United States would never use regional or homeland missile defenses against a Russian or Chinese missile. Indeed, even while disavowing the ambition to defeat large-scale Russian or Chinese missile attacks and "affect the strategic balance," the 2010 Ballistic Missile Defense Review (BMDR) explicitly says that the "GMD system would be employed to defend the United States against limited missile launches from *any source*."[6]

While this basic posture has been accepted toward Russia and perhaps China, U.S. policymakers have expressed an unwillingness to engage in a "balance of terror" type strategic relationship with rogue nations such as North Korea. The George W. Bush administration, for instance, noted that "the strategic logic of the past may not apply to these new threats, and we cannot be wholly dependent on our capability to deter them."[7] Speaking of North Korean leader Kim Jong-un, the commander of U.S. Northern Command (NORTHCOM), Admiral William Gortney, has likewise more recently commented, "We can live with some pretty ugly opponents as long as they are predictable. This guy we just can't . . . predict."[8]

"You can't be an internationalist if you allow yourself to be blackmailed."

Of course, this general posture of pursuing "limited" national missile defense could well change. A future administration could conceivably decide that long-range missile defense was too difficult or costly at the margin and choose to accept vulnerability, even with states like North Korea, and rely exclusively on offensive means of deterrence.[9] Such a choice would represent a significant discontinuity from the past. The Clinton administration began the NMD program in part based on the increasing realization that relying on purely offensive deterrence with North Korea simply did not seem to make sense. As President Clinton himself later put it, "You can't be an internationalist if you allow yourself to be blackmailed."[10] Such an offensive deterrence-only relationship with North Korea seems unlikely.

U.S. missile defense policy and posture are predicated on the principle that the United States homeland cannot be held hostage by a country such as North Korea. As Admiral Gortney remarked in April 2016, "We are concerned the possession of a nuclear ICBM could embolden the [North Korean] regime's intransigence below the nuclear threshold and complicate our response to a crisis on the peninsula."[11] As such, a limited long-range missile defense serves the strategic purpose of giving "the United States . . . the freedom to employ whatever means it chooses to

6. Department of Defense, *Ballistic Missile Defense Review Report*, 13. Emphasis added.

7. Bush, *National Policy on Ballistic Missile Defense*, 2.

8. William E. Gortney, "USNORTHCOM and NORAD Posture Statement" (statement before the House of Representatives Armed Services Committee, Strategic Forces Subcommittee, April 14, 2016).

9. Brad Roberts, "Nowhere to Go but Up? U.S.-Russia Relations and the Threat of Nuclear War" (speech at Middlebury Institute of International Studies at Monterey, CA, May 3, 2016); Brad Roberts, "Anticipating the 2017 U.S. Ballistic Missile Defense Review" (remarks at the Royal United Services Institute's Missile Defense Conference, London, UK, April 13, 2016).

10. Bradley Graham, *Hit to Kill: The New Battle over Shielding America from Missile Attack* (New York: Public Affairs, 2003): 96–99, 379.

11. Gortney, "USNORTHCOM and NORAD Posture Statement."

Table 1.1. Comparison of 1999 NMD Act and FY 2017 NDAA

1999 NMD Act	FY 2017 NDAA
It is the policy of the United States to **deploy as soon as is technologically possible**	It is the policy of the United States to **maintain and improve**
an **effective** National Missile Defense system	an **effective, robust layered** missile defense system
capable of defending the **territory** of the United States	capable of defending the territory of the United States, **allies, deployed forces, and capabilities**
against **limited** ballistic missile **attack** (whether accidental, unauthorized, or deliberate)	against the **developing and increasingly complex** ballistic missile **threat**
with funding subject to the annual authorization of appropriations and the annual appropriation of funds for National Missile Defense.	with funding subject to the annual authorization of appropriations and the annual appropriation of funds for National Missile Defense.

respond to aggression without risk of enemy escalation to homeland strikes."[12] This freedom of action supports allied confidence that the United States will live up to its alliance commitments, lowering the risk of alliance decoupling. Assurance of allies in turn strengthens extended deterrence, helps promote regional stability, and fosters an environment more favorable to nonproliferation.

The goals of homeland missile defense might alternatively be revised upward, to include protection against not only attacks from North Korea and Iran, but to provide a thin defense against certain kinds of limited missile attack from Russia or China. Such a defense could include either protection for U.S. population centers or for nuclear and other strategic forces so as to enhance rather than undermine strategic stability. The objectives of homeland defense might also be expanded to include nonballistic missiles. Hypersonic boost-glide vehicles have recently begun to get more research and development attention, but there remains virtually no significant capability to defend against cruise missile attack on the National Capital Region.

The National Defense Authorization Act passed in late 2016 revises the 1999 formulation (Table 1.1), declaring that U.S. policy is to "maintain and improve an effective, robust layered missile defense system capable of defending the territory of the United States, allies, deployed forces, and capabilities against the developing and increasingly complex ballistic missile threat."[13] The conference report further added that "nothing in this legislative provision requires or directs the

12. Brad Roberts, "On the Strategic Value of Ballistic Missile Defense," *Institut Français des Relations Internationales Proliferation Papers* 50 (June 2014): 24.

13. National Missile Defense Act of 1999, Pub. L. No. 106-38, 113 Stat. 205 (1999). National Defense Authorization Act for Fiscal Year 2017, *Conference Report to Accompany S.2943*, Sec.1694, 114th Congress (2016): 1598.

development of missile defenses against any country or its strategic nuclear forces."[14] For the time being, much more remains to be done simply to keep pace with the existing threat set.

Homeland missile defense can also improve crisis stability by offering the United States an option other than preemption or retaliation. This is especially true when dealing with smaller "rogue" states against which the United States might take preemptive military action during a crisis. In the lead-up to North Korea's Taepodong-2 launch in 2006, GMD may have lessened the pressure on President Bush to preemptively strike North Korea's launch facilities, a course of action advocated at the time by former secretary of defense William Perry and then former assistant secretary of defense Ashton Carter.[15] Such a posture buys time and creates options for decisionmakers, which in turn supports stability.

Another example of a stabilizing dynamic is found in the October 2016 attacks on the USS *Mason* (DDG-87), in which antiship cruise missiles were reportedly fired at the vessel as it sailed off the coast of Yemen. Instead of being hit (as was a United Arab Emirates navy ship just days prior), the ship fired SM-2 Block IV and Evolved Sea Sparrow Missile (ESSM) interceptors, as well as apparently employing other electronic countermeasures. The missiles did not hit the ship. Had the ship been damaged or sunk, there might have been substantial pressure to widen U.S. presence and engagement with Houthi forces in Yemen. Instead, the United States had the time to assess the situation and decide how to respond, choosing to limit its response to Tomahawk cruise missile strikes against coastal radar facilities that purportedly directed the attack.[16]

Homeland missile defense also serves the purpose of raising the threshold for aggression for an adversary wishing to undertake military action against the United States. Having the ability to defend against a certain number of long-range missiles requires an adversary to employ a greater number of missiles to achieve the same objective, thus making a "cheap shot" against the American homeland or military forces more difficult. Forcing an adversary to thus increase the size of an attack increases the likelihood that preparations for such an attack will be detected in advance, creating opportunities for the United States to either de-escalate the crisis or take preemptive strikes.

The fielding of a limited yet effective long-range missile defense system could contribute to a secondary deterrence-by-denial effect, whereby emerging regional challengers are dissuaded from investing in long-range ballistic missile technology. Without insight on the inner working of Iranian or North Korean strategy and U.S. resource allocation deliberations, however, this potential effect remains difficult to assess. Missile defenses have come a long way, but have thus far not dissuaded proliferators that missiles are impotent or obsolete.

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14. National Defense Authorization Act for Fiscal Year 2017, *Conference Report to Accompany S.2943*, Sec.1694, 114th Congress (2016): 2687.

15. Ashton B. Carter and William J. Perry, "If Necessary, Strike and Destroy," *Washington Post*, June 22, 2006, http://www.washingtonpost.com/wp-dyn/content/article/2006/06/21/AR2006062101518.html.

16. "USS Mason Launches Three Interceptors to Defend against Yemen Cruise Missile Attack," *Missile Threat*, Center for Strategic and International Studies, October 13, 2016, http://missilethreat.csis.org/uss-mason-launches-three-interceptors-defend-yemen-cruise-.

MISSILE THREATS TO THE U.S. HOMELAND

Today, nearly 30 countries maintain ballistic missile capabilities, with approximately 50 ballistic missile variants.[17] The missile defense mission has grown more challenging as antagonists now possess capabilities that are more robust, accurate, and diverse, threatening U.S. and allied forces both at sea and on land. In a November 2014 memo to the secretary of defense, Chief of Naval Operations Admiral Jonathan Greenert and Chief of Staff of the Army General Raymond Odierno jointly wrote of "growing challenges associated with ballistic missile threats that are increasingly capable, continue to outpace our active defense systems, and exceed our Services' capacity to meet Combatant Commanders' demand."[18]

Looking ahead, the United States and its allies and partners may expect to encounter more multifaceted threats that could overcome current defense systems, including advanced cyber intrusions, electronic warfare, directed energy, and hypersonics. MDA has been assigned responsibility for the hypersonic mission, but not the funds to do much about it. Future decisionmakers will have to consider whether MDA should retain its near-exclusive focus on material development for the *ballistic* missile defense mission or expand its mandate to address the broader suite of cruise missile, air defense, and hypersonic threats.

Research and development has always been at the institutional and conceptual center of ballistic missile defense efforts. In particular, the steady advance of missile technology creates an imperative for missile defense technology to "outpace the threat." Unfortunately, MDA's research and development efforts have been steadily declining, in both real dollars and in relative terms to MDA's overall (but also declining) topline budget.[19] The strain on MDA's investment in advanced technology is one of several concerning manifestations of what Secretary of Defense Ashton Carter and others have called the temptation to "eat our seed corn."[20] Undersecretary Frank Kendall has likewise stressed the importance of research and development: "Just patching the things we've got is probably not going to be adequate . . . we're going to have to go beyond that."[21] MDA and congressional leadership have also echoed these warnings.[22]

17. Lieutenant General David L. Mann, "Ballistic Missile Defense Policies and Programs" (statement before the Senate Armed Services Committee, Strategic Forces Subcommittee, April 13, 2016).

18. Jonathan W. Greenert and Raymond T. Odierno, "Adjusting the Ballistic Missile Defense Strategy," DoD Memorandum, November 5, 2014.

19. Thomas Karako, Wes Rumbaugh, and Ian Williams, *The Missile Defense Agency and the Color of Money: Fewer Resources, More Responsibility, and a Growing Budget Squeeze* (Washington, DC: Center for Strategic and International Studies, 2016), 4, https://www.csis.org/analysis/missile-defense-agency-and-color-money.

20. Ashton Carter, "Remarks at National Press Club" (speech, National Press Club, Washington, DC, May 7, 2013).

21. Andrea Shalal, "Pentagon Plans Work on New Missile Defense Interceptor," Reuters, February 25, 2014, http://www.reuters.com/article/us-usa-budget-missile-idUSBREA1P03F20140226.

22. Kenneth Todorov, "Consolidating Our Gains, Looking to the Future" (speech, Air Force Association, Reserve Officers Association and National Defense Industrial Association Capitol Hill Forum, Washington, DC, June 18, 2015); Senator Jeff Sessions, "Ballistic Missile Defense Policies and Programs" (statement during the hearing before the Senate Armed Services Committee, Strategic Forces Subcommittee, April 13, 2016).

As of today, Iran and North Korea have not yet, strictly speaking, demonstrated an ICBM with a flight test. Nevertheless, both have extensive missile development programs, have deployed a significant number of medium- and intermediate-range missiles, and put satellites into orbit, all major steps critical to ICBM development.

Much attention has been given to whether Iran or North Korea could acquire an ICBM by the year 2015. For at least 15 years, intelligence reports and testimony continued to peg threat assessments to the 2015 time frame. Now that 2015 has come and gone, some observers have questioned the validity of previous U.S. assessments on rogue state ICBM development.[23] It could well be, however, that actions taken on the basis of those intelligence assessments may have had some effect on preventing the past potentialities from being actualized. The United States and others have not stood idly by with missile developments by Iran, North Korea, and others. They have rather engaged in a systematic range of counterproliferation and nonproliferation efforts, ranging from diplomacy and sanctions to interdiction and, reportedly, various forms of sabotage. Relying on indefinite counterproliferation success in the absence of active defenses, however, also carries considerable risk.

"It is difficult to predict precisely how the threat to the U.S. homeland will evolve," the BMDR noted in 2010, "but it is certain that it will do so."[24] The overall trend line is that both ballistic and nonballistic missile threats to the United States homeland are growing, with little indication of relief. In the words of one observer, "There are no projections within the U.S. intelligence community showing a decline in the number of ballistic missiles in the world and no evidence at all that we will ever be without nuclear weapons."[25] The United States has been surprised before with foreign missile developments and may be again. The former deputy assistant secretary of defense for nuclear and missile defense policy, Elaine Bunn, has remarked on the importance of being "humble" about making threat predictions.[26]

North Korea

North Korea has invested much of its military resources to improve its ballistic missile and nuclear weapon capabilities, which together provide an ability to hold at risk military and civilian targets. A fourth North Korean nuclear test was conducted in January 2016, followed by a fifth in September that year. Their short- and medium-range systems include a host of artillery and short-range rockets, a newer mobile solid-fueled SS-21 variant called KN-02, legacy Scud missiles, and a No-Dong MRBM.[27]

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23. Greg Thielmann, "Updated: Iran's Overdue ICBM," *Arms Control Now* (blog), Arms Control Association, February 2, 2015, https://www.armscontrol.org/blog/ArmsControlNow/2015-01-26/Irans-Overdue-ICBM.

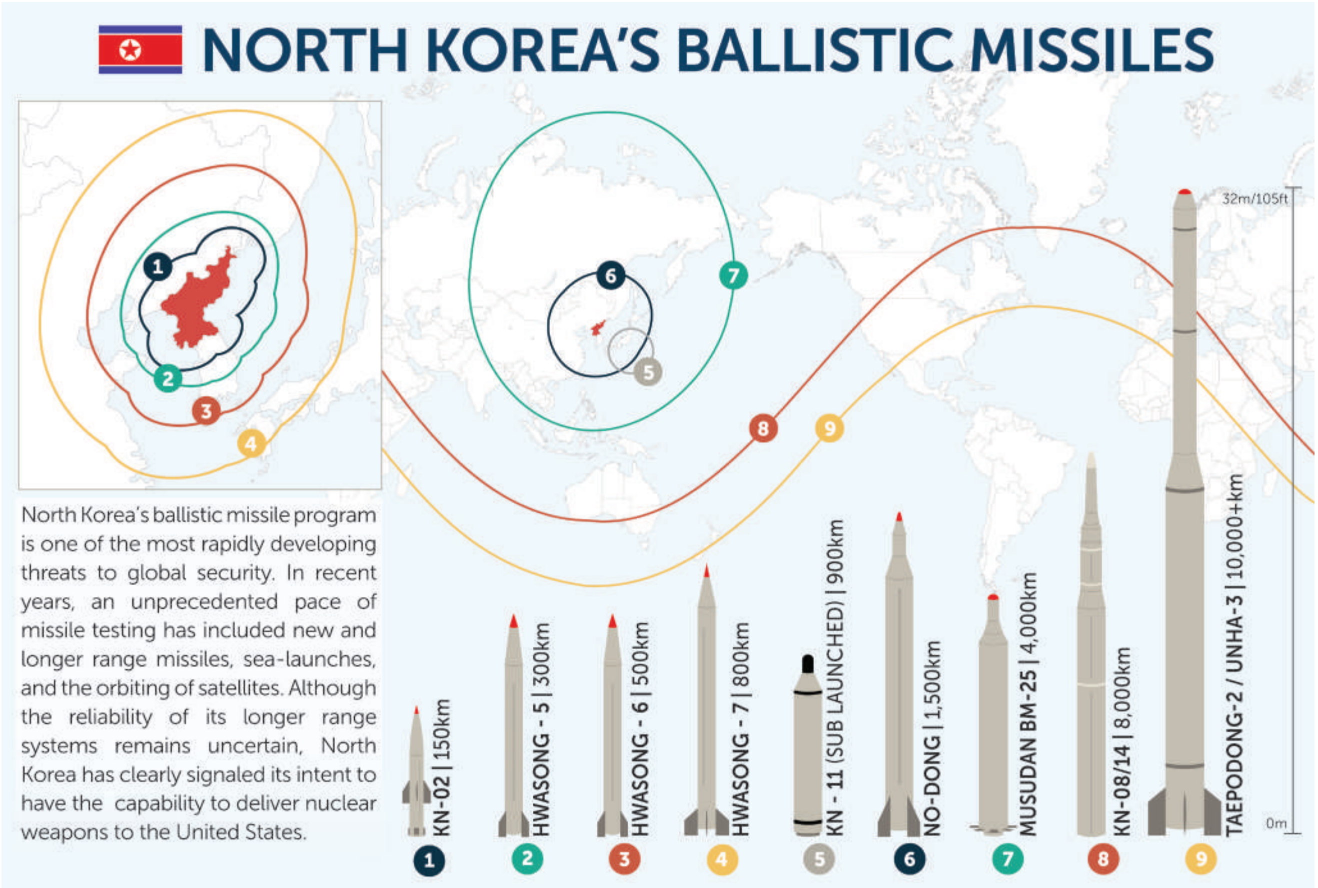
24. DoD, *Ballistic Missile Defense Review Report*, 11.

25. Steven Lambakis, *The Future of Homeland Missile Defenses* (Fairfax, VA: National Institute Press, 2014), 2.

26. Elaine Bunn, "U.S. Missile Defense Policy" (speech, 2014 Space and Missile Defense Symposium, Huntsville, AL, August 13, 2014).

27. "Ballistic Missiles of North Korea," *Missile Threat*, Center for Strategic and International Studies, accessed November 13, 2016, http://missilethreat.csis.org/north-korea/.

Figure 1.1. North Korea's Ballistic Missiles



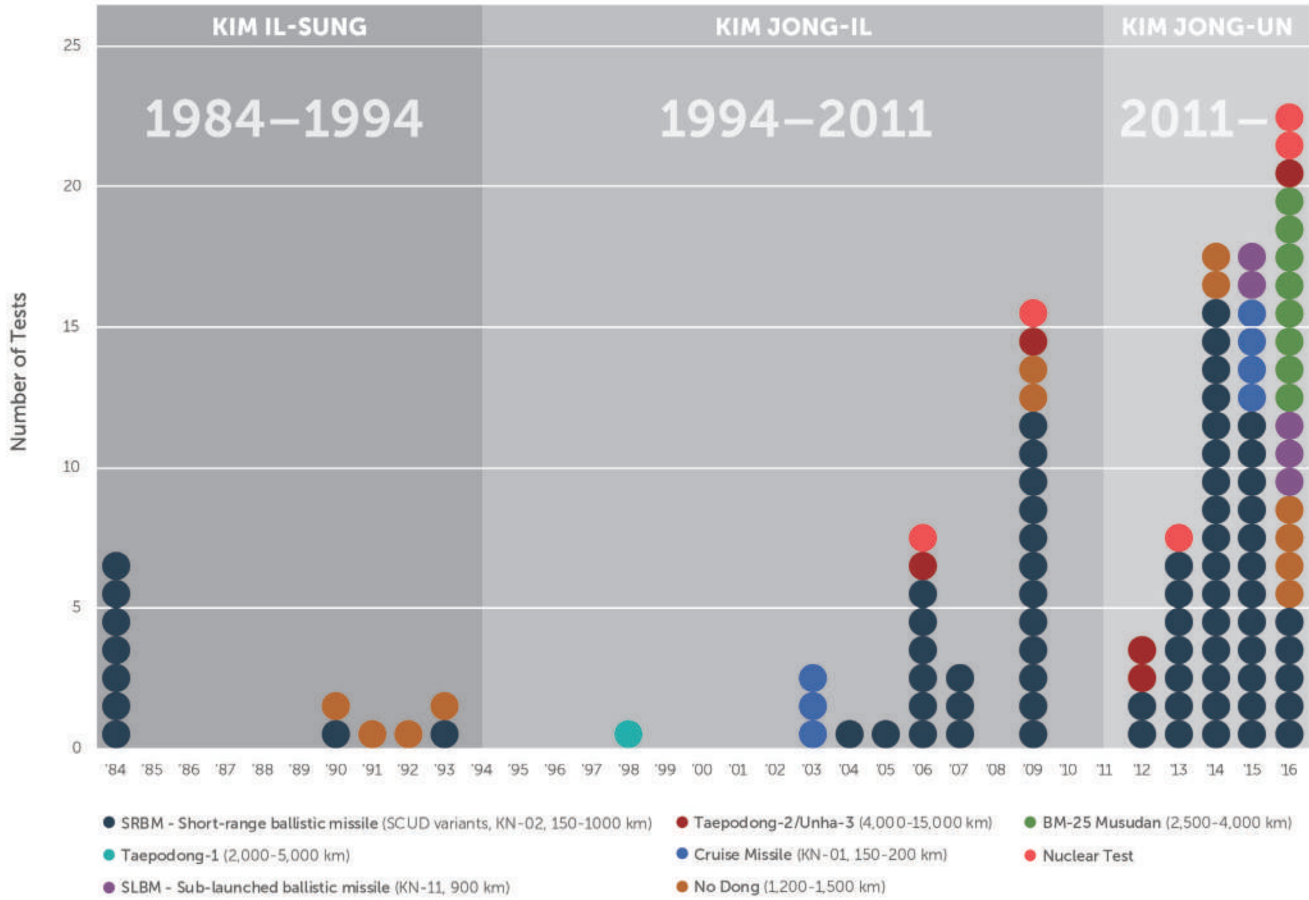
North Korea conducted eight Musudan IRBM tests in 2016, with its sixth test in June 2016 achieving "partial success" (see Figure 1.2). Although the missile had a lofted trajectory, it did appear to complete a full ballistic flight. Another Musudan launched just hours before appeared to have disintegrated shortly after launch. North Korea tested the same missile twice more in October 2016, but apparently without success. Despite these mixed results, the earnestness of North Korea's testing regime demonstrates a commitment to the Musudan's development. The missile is estimated to have a range of around 3,500 to 4,000 kilometers (km), putting it within striking distance of U.S. military bases in Japan and possibly Guam.[28]

North Korea also possesses a Satellite Launch Vehicle (SLV), the Unha-3, which was used to successfully orbit a small satellite in December 2012 and January 2016, thus indicating North Korea's capabilities for a number of long-range missile technologies.

North Korea's SLV experiments may be informing the development of a new class of North Korean ICBMs. In 2012, North Korea began to display a road-mobile ICBM designated KN-08, also known as Hwasong-13. In October 2015, another variant dubbed the KN-14 made its appearance at the

28. John Schilling, "A Partial Success for the Musudan," *38 North*, June 23, 2016, http://38north.org/2016/06/jschilling062316/.

Figure 1.2. North Korean Ballistic Missile Testing, 1984–2016



Worker's Party of Korea annual parade. Neither variant has been flight-tested, but the missile's estimated range is between 5,000 and 9,000 km, giving it the potential to strike the U.S. West Coast and parts of the northern Midwest.[29] Pyongyang has also made surprisingly rapid progress toward a submarine-launched ballistic missile capability, with an apparently successful test launch of its KN-11 SLBM in August 2016.[30]

The heads of U.S. Forces Korea (USFK) and of NORTHCOM have both suggested that North Korea has the capability to miniaturize a nuclear weapon for the KN-08.[31] In March 2016, images released by the Korean Central News Agency (KCNA) featured North Korean leader Kim Jong-un

29. John Schilling, "Where's That North Korean ICBM Everyone Was Talking About?," *38 North*, March 12, 2015, http://38north.org/2015/03/jschilling031215/; Richard D. Fisher Jr., "North Korea Unveils New Version of KN-08 ICBM," *IHS Jane's 360*, October 13, 2015, http://www.janes.com/article/55190/north-korea-unveils-new-version-of-kn 08-icbm.

30. "North Korea Submarine Fires Ballistic Missile," BBC, August 24, 2016, http://www.bbc.com/news/world-asia -37171608.

31. Richard Sisk, "U.S. General Tells Senate North Korea Can Hit U.S. with Nuclear ICBM," *Military.com*, April 16, 2015, http://www.military.com/daily-news/2015/04/16/us-general-tells-senate-north-korea-can-hit-us-with-nuclear-icbm .html; William E. Gortney, "Department of Defense Press Briefing by Admiral Gortney in the Pentagon Briefing Room" (news briefing, Washington, DC, April 7, 2015).

inspecting what appears to be a miniaturized nuclear device.[32] The validity of these photographs has not been verified, however, and North Korea has been known to use mock-ups in state propaganda in the past. Images released of ground tests on the reentry vehicle heat shield, and of more advanced missile engine tests, are made to leave the impression that North Korea is progressing in its long-range ballistic missile capabilities and is not deterred or slowed by international sanctions.

Iran

Iran maintains the most active and diverse ballistic missile program in the Middle East, amassing more than 800 short- and medium-range missiles capable of striking targets within its region and southeastern Europe. While engaging in significant transnational cooperation with North Korea and likely Pakistan, Iran has made major progress in the overall reliability of its missiles. These include the Shahab-3 series (which includes the Ghadr and Emad variants), the solid-fueled Sejjil and Fateh-110, along with the recently revealed Fateh 313, Qiam, and the Fajr-3.[33] It is likely, however, that Iran's ballistic missiles currently lack the accuracy to effectively destroy critical military and infrastructure targets with conventional warheads, at least without large salvo attacks.[34] Iran has yet to display or flight-test an ICBM. Most of Iran's longer-range missiles have demonstrated a range of around 2,000 km. To reach the United States from Iran, an ICBM would need a range of over 9,000 km.[35]

Iran has also used its long-range rockets to put satellites into orbit, with its fourth launch occurring in February 2015. Over the past decade, Iran has conducted numerous tests of the two-stage Safir SLV and has been developing a larger two-stage SLV dubbed the Simorgh, which Iran reportedly tested in April 2016 with unclear results.[36] Many of the technologies developed for these SLV programs could be applied to creating an ICBM.[37] Where SLV and ICBM technologies differ, however, is the ICBM's need for a reentry vehicle capable of reentering the atmosphere and detonating a nuclear device.[38] Iran has not yet demonstrated these capabilities.

Iran nonetheless appears intent on maintaining and continuing development of its missile programs. Since the signing of the 2015 Joint Comprehensive Plan of Action (JCPOA) and despite restrictions by United Nations Security Council Resolution 2231, Iran's missile testing has

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32. "North Korea 'Has Miniature Nuclear Warhead,' Says Kim Jong-un," BBC, March 9, 2016, http://www.bbc.com/news/world-asia-35760797.

33. National Air and Space Intelligence Center (NASIC), *Ballistic and Cruise Missile Threat* (Wright-Patterson Air Force Base, OH: NASIC Public Affairs Office, 2013), 10–28; "Ballistic Missiles of Iran," *Missile Threat*, Center for Strategic and International Studies, accessed November 29, http://missilethreat.csis.org/iran/.

34. John Chipman et al., *Missile-Defence Cooperation in the Gulf* (London: International Institute for Strategic Studies, 2016), 30–31.

35. Kelsey Davenport, Daryl G. Kimball, and Greg Thielmann, *Solving the Iranian Nuclear Puzzle: The Joint Comprehensive Plan of Action* (Washington, DC: Arms Control Association, 2015), 27.

36. Tamir Eshel, "Simorgh First Launch—An Iranian Success or Failure?," *Defense Update*, April 24, 2016, http://defense-update.com/20160424_simorgh.html.

37. NASIC, *Ballistic and Cruise Missile Threat,* 19.

38. Bob Walpole, "Foreign Missile Developments and the Ballistic Missile Threat to the United States through 2015," National Intelligence Council, September 1999.

Figure 1.3. Iran's Ballistic Missiles

continued and even accelerated. This has included recent launches of Emad, reportedly a Shahab-3 variant with a maneuvering reentry vehicle (MaRV) to improve accuracy.[39] The regime's use of mobile launchers and underground tunnels below silo-like launch hatches will make it more challenging for the United States or others to target the missiles prior to launch.[40]

39. Emad has a reported accuracy of within 500 meters, in contrast to the Shahab-3, reportedly only accurate to within 2,500 meters. James C. O'Halloran, ed., *IHS Jane's Weapons: Strategic 2015–2016* (United Kingdom: IHS, 2015), 48.

40. Lieutenant General Michael T. Flynn, "Current and Future Worldwide Threats" (statement before the Senate Armed Services Committee, February 11, 2013).

China and Russia

Both Russia and China have formidable strategic assets. Russia possesses over 300 ICBMs equipped with multiple independent reentry vehicles (MIRVs), as well as over 175 SLBMs deployed across 11 submarines, all capable of delivering nuclear payloads to the United States.[41] Russian missiles are furthermore described as having been designed to defeat U.S. missile defenses, including with decoys and other sophisticated countermeasures and penetration aids. China, for its part, deploys more than 60 ICBMs holding the continental United States at risk, and it is currently developing a modern fleet of nuclear ballistic missile submarines equipped with nuclear-tipped SLBMs with a reported range of over 7,000 km.

The magnitude of the threat from these near-peer actors makes building a robust missile defense against them a significant challenge. It seems unlikely that the United States would attempt in the near term to shift toward a defense dominant posture with respect to Russian and Chinese long-range missile forces, but homeland missile defense need not forswear attention to these threats entirely. In the past, the United States has pursued thin or point defenses to support deterrence and enhance strategic stability with Russia or China, such as with Sentinel, Safeguard, and LoAD (see Chapter 2). Given the past decade's developments in the demonstrated hypersonic and cruise missile capabilities of Russia and China, missile defenses of various kinds could support the survivability of U.S. nuclear forces. The dynamic between strategic forces and active missile defense could perhaps figure in the next U.S. nuclear posture review.

The dynamic between strategic forces and active missile defense could perhaps figure in the next U.S. nuclear posture review.

Cruise Missiles

Another threat to the U.S homeland increasingly highlighted by senior U.S. military officials is the threat posed by long-range cruise missiles possessed by Russia, and their proliferation around the globe. Once advanced technology possessed only by the superpowers, cruise missiles are now widely acquired, including by such countries as Pakistan (Hatf 7,8), North Korea (KN-01), Iran (Soumar), and others.[42]

Vice Admiral James Winnefeld, then vice chairman of the Joint Chiefs of Staff, remarked in 2015 that "homeland cruise missile defense is shifting above regional ballistic missile defense, in my mind, as far as importance goes."[43] More recently, NORTHCOM Commander William Gortney, commenting on Russia's conspicuous employment of long-range SS-N-30 cruise missiles to hit targets in Syria, told Congress that "there's no operational or tactical requirement to do it. They're messaging us that they have this capability."[44]

41. Hans M. Kristensen and Robert S. Norris, "Russian Nuclear Forces, 2016," *Bulletin of the Atomic Scientists* 72, no. 3 (2016): 125–134.

42. NASIC, *Ballistic and Cruise Missile Threat,* 26.

43. Winnefeld, "Missile Defense and U.S. National Security."

44. Gortney, "USNORTHCOM and NORAD Posture Statement," April 14, 2016.

Russia moreover openly markets for export highly portable cruise missiles that could be used to threaten the United States homeland. The Klub-K missile is derived from the SS-N-27 Sizzler, whose shorter range falls within arms control export regimes. It can also fit inside a cargo container, making it easy to transport and potentially launch from a ship or undersea platform of some kind.[45] In addition to the element of surprise these systems could bring, they also provide mobility and could be fired from locations such as the Gulf of Mexico or elsewhere to evade some U.S. early warning sensors.

The ballistic and cruise missile threats to the United States and its allies are not diminishing. In the coming years, North Korea could well enter into serial production of intercontinental ballistic missiles. Iran has also shown no sign of abandoning its long-range efforts. It would be quite difficult and costly to face a situation of significantly greater threats in, say, 2025, and attempt to catch-up. Outpacing rather than chasing these threats will require increased effort.

45. Igor Sutyagin, "Advances in Missile Delivery Systems" (remarks at the EU Non-Proliferation and Disarmament Conference 2015, Special Session 8, Brussels, Belgium, November 11, 2015).

02

The Evolution of Homeland Missile Defense

The homeland missile defenses fielded today and those under consideration for the future are shaped by two basic factors: the fundamentals of how missile defense works and past policy and programmatic history.

The fundamentals of ballistic missile defense have changed little over the last 70 years. Concepts for hit-to-kill kinetic intercept (Table 2.1) have been present since the beginning, but early efforts failed in part due to a lack of precision guidance, insufficient or inadequate sensors and computing power, and the problem of discrimination.[1] Nuclear kill devices compensated for these early shortcomings in some respects, but challenges remained. Besides numerous adverse effects and limitations, a nuclear weapon–based interceptor still required significant advances in discrimination.

The history of missile defense also reveals the remarkable degree to which historical programs made possible the system in place today. Virtually every element of the architecture and capabilities of today's Ground-based Midcourse Defense (GMD) system has been conditioned and shaped by decades of history and the legacies of previous programmatic and strategic goals (Table 2.4). The Exoatmospheric Kill Vehicle (EKV) deployed today, for example, in many ways reflects 1990s-era technology dating to the National Missile Defense (NMD) effort of the Clinton administration. The EKV in turn represents the product of decades of prior research and development, including the Homing Overlay Experiment (HOE), the Exoatmospheric Reentry-vehicle Interceptor System (ERIS), the High Endoatmospheric Defense Interceptor (HEDI), the Lightweight Exoatmospheric Projectile (LEAP), and Brilliant Pebbles.

While these past efforts made the fielding of GMD possible, they also shaped and constrained it. Today's system relies not only on technologies but also installations that were not specifically designed for the missile defense mission. In some cases, they are the same facilities. A launch

1. James Walker, Lewis Bernstein, and Sharon Lang, *Seize the High Ground: The U.S. Army in Space and Missile Defense* (Huntsville: U.S. Army Space and Missile Defense Command, 2003), 47; Security Resources Panel, President's Science Advisory Committee, "Deterrence and Survival in the Nuclear Age," November 7, 1957, appendix F.

Table 2.1. Missile Defense Tasks

Detection	Initial indication by any one of a variety of sensors that a booster has been launched from some point on the surface of the earth, with initial characterization of the booster type.
Classification	Identification of the estimated target category based on surveillance, discrimination, and intelligence data.
Tracking	The act of generating and maintaining a time history of an object's position and any other features of interest.
Discrimination	The use of surveillance systems to identify lethal reentry vehicles amidst the cloud of debris created by a missile after burnout.
Fire Control	Systems to integrate launch warning, track and discriminate data, manage interceptor launch, provide interceptors with targeting information, and process kill assessment data.
Divert	The ability of the kill vehicle once in space to adjust course based on new information provided by external and onboard sensors.
Intercept	The successful destruction of an incoming missile or reentry vehicle.
Kill Assessment	An evaluation of information to determine the result of an attempted intercept, for the purpose of providing information for defense effectiveness and reengagements.

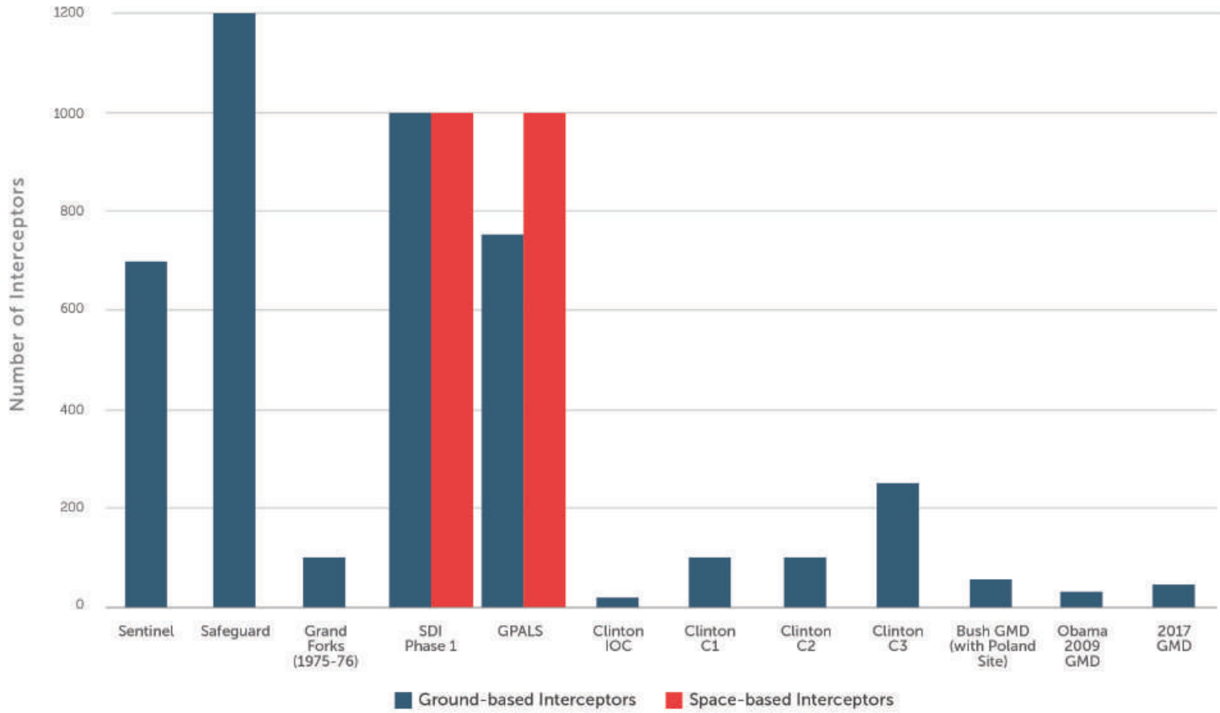
control room used for some early tests of GBIs in the 1990s, for instance, was a holdover from Safeguard days in the 1970s.[2] Early Warning Radars designed and built in the 1980s to support nuclear deterrence and the possibility of "launch under attack" have now been pressed into service for missile defense tracking, in addition to serving their traditional role. While necessary to do so, such reliance also brings limitations.

FROM AMBITION TO MODESTY

Efforts to defend the U.S. homeland against ballistic missile attack did not begin with the 2002 U.S. withdrawal from the ABM Treaty, nor even in 1983 with President Reagan's concept of a Strategic Defense Initiative. The first military programs aimed at protecting the United States from ballistic missiles can be traced back to 1946, nine years before the Soviet Union tested the first

2. Bradley Graham, *Hit to Kill: The New Battle over Shielding America from Missile Attack* (New York: Public Affairs, 2003), 291.

Figure 2.1. Planned Interceptor Levels



	Sentinel	Safeguard	Grand Forks (1975-76)	SDI Phase 1	GPALS	Clinton IOC	Clinton C1	Clinton C2	Clinton C3	Bush GMD	Obama 2009	2017 GMD
Number of Sites	15	12	1	N/A	N/A	1	1	1	2	3	2	2

intercontinental-ranged ballistic missile, the R-7, a version of which also orbited the Sputnik satellite.

Indeed, U.S. planners and officials have looked at ways to counter missile threats since they first came into existence. During World War II, allied forces used manned aircraft to tip over V-1s mid-flight, but also destroyed them on their launchers in Belgium and degraded production facilities within Germany.[3] Both left and right of launch attempts to counter missile threats have thus been present from the beginning. As revealed by the Scud hunts during Operation Desert Storm, however, finding and defeating missiles on the ground can be quite challenging.[4]

The history of homeland missile defense also reveals the trend of high ambition followed by increasing modesty (Table 2.2). This is true for both the scope and nominally planned deployments of homeland missile defense. Early missile defense programs under the auspices of the Nike program were once on course for wide coverage of the United States against a Soviet nuclear attack. This was eventually reduced to merely providing force protection of the U.S. ICBM fields under the Safeguard system. The ABM Treaty of 1972 permitted both the United States and the Soviet Union two missile defense sites each, one for the National Capital Region and one for an ICBM field, but in 1974 was amended to permit only a single site.

3. James D. Crabtree, *On Air Defense* (Westport, CT: Praeger, 1994), 62–66.

4. U.S. Department of Defense, "Conduct of the Persian Gulf War" (Final Report to Congress, April 1992), 219.

Table 2.2. Homeland Defense Architectures at a Glance

Architecture	Mission
Sentinel	Protect cities from a small Chinese arsenal or Nth country
Safeguard	Defend ICBMs from USSR attack
SDI Phase 1	Counterforce mission to interfere with timing and offensive operations of Soviet ICBM force
Later SDI	Prevention of military attack by the Soviet Union
GPALS	Defend against third world powers or accidental launches from a major nuclear power, 10 to 200 reentry vehicles
Clinton IOC	Intercept five ballistic missiles
Clinton C1	Intercept 10 ballistic missiles
Clinton C2	Intercept 10 ballistic missiles with limited countermeasures
Clinton C3	Intercept up to 20 ballistic missiles with more advanced countermeasures
Bush-Obama GMD	Intercept undefined number of ballistic missiles from both North Korea and Iran

The pattern of increased modesty is again repeated with the planned deployments of ground-based kinetic interceptors. During Phase 1 of the Strategic Defense Initiative, for instance, some 1,000 GBIs were identified as a supplement to an additional architecture of one (or several) thousand space-based interceptors. This number was revised down to 750 GBIs with the Global Protection Against Limited Strikes (GPALS) program under the George H. W. Bush administration.

The Clinton administration developed a three-phase NMD architecture that envisioned first 20, then 100, and then 250 GBIs deployed at several sites. The Clinton Capability-3 architecture included a robust satellite architecture and numerous X-band radars colocated at the sites for the Cold War–era early warning radars.[5] In terms of size and scope, even the Clinton C2 was more ambitious than both the GMD architecture deployed today and that now envisioned for the 2020 time frame (Figure 2.1).

5. James M. Lindsay and Michael E. O'Hanlon, *Defending America: The Case for Limited National Missile Defense* (Washington, DC: Brookings Institution, 2004), 99.

EARLY EFFORTS

With the damage inflicted by Germany's V-2 ballistic missiles during World War II, efforts to defend the U.S. homeland against missile attack became a high postwar priority for U.S. defense planners. In May 1946, the U.S. Army Equipment Board, under the leadership of Army General Richard Stillwell, issued a report identifying postwar requirements for U.S. ground forces. The report predicted the appearance of guided intercontinental missiles carrying nuclear weapons, as well as the inability of existing fighter aircraft or anti-aircraft defenses to defeat them. It also envisaged the need for "guided interceptor missiles, dispatched in accordance with electronically computed data obtained from radar detection stations."[6] The Stillwell report recommended that "defensive measures against atomic weapons should be accorded priority over all other National Defense projects."[7]

The report led to the U.S. Army Air Force's Project Wizard and Project Thumper programs to develop missile intercept capability. The nascent state of radar technology, however, presented serious hurdles for early warning and tracking of incoming threats. Both programs were later abandoned, but research conducted for Project Thumper contributed to the U.S. Air Force CIM-10 BOMARC surface-to-air missile, in service from 1959 to 1972 to defend North America against bomber attack.

In 1957, the maiden launch of the Soviet Union's R-7 *Semyorka* ICBM and the orbiting of Sputnik both reinvigorated America's sense of urgency for ballistic missile defense. That same year, the President's Science Advisory Committee issued the influential Gaither report, one of the earliest articulations of the strategic purpose of active defense for both military retaliatory assets and population centers:

> The main protection of our civil population against a Soviet nuclear attack has been and will continue to be the deterrent power of our armed forces, to whose strengthening and securing we have accorded the highest relative value. But this is not sufficient unless it is coupled with measures to reduce the extreme vulnerability of our people and our cities. As long as the U.S. population is wide open to Soviet attack, both the Russians and our allies may believe that we shall feel increasing reluctance to employ [Strategic Air Command] in any circumstance other than when the United States is directly attacked.[8]

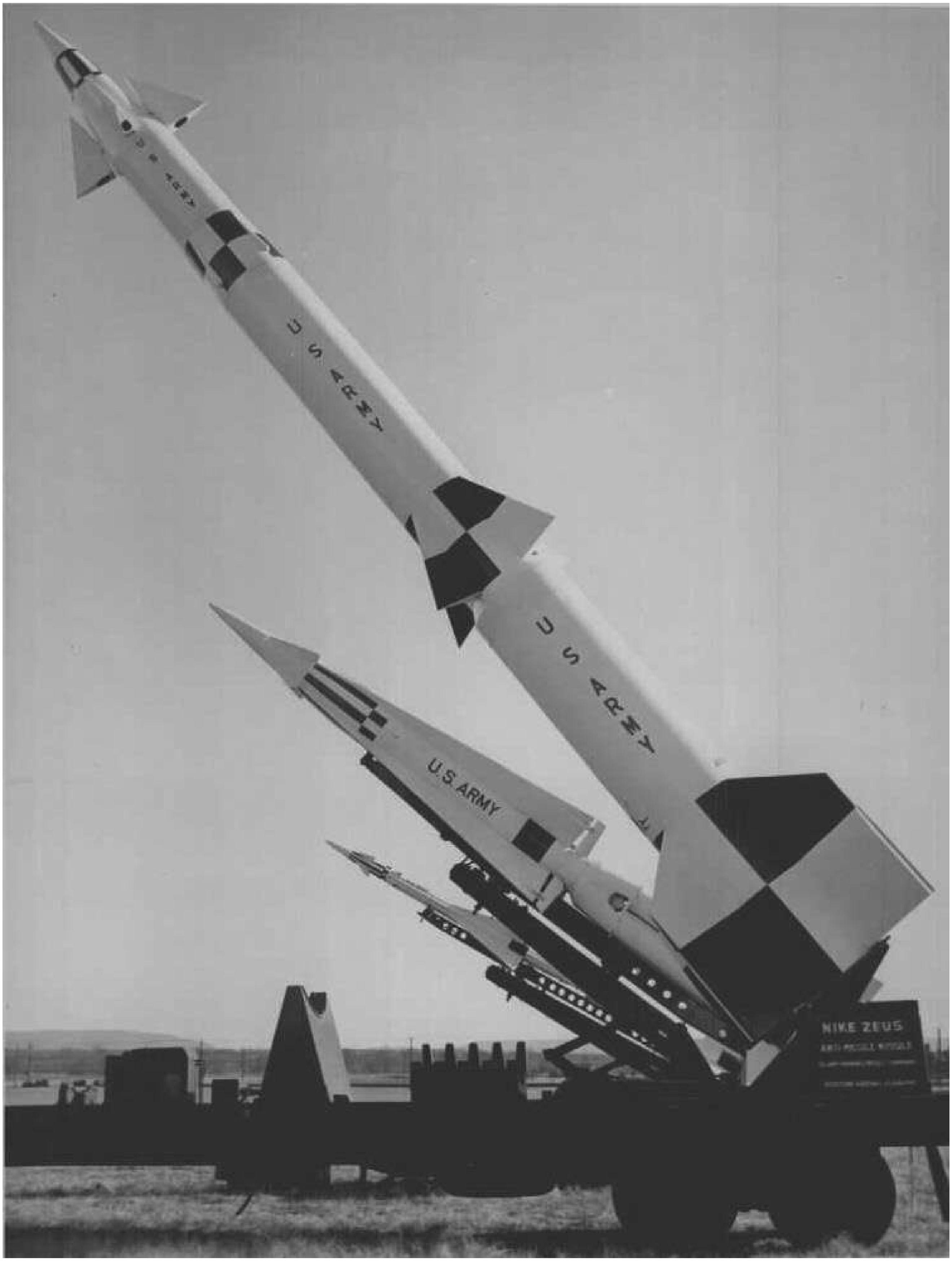
In addition to recommending the active defense of Strategic Air Command (SAC) bases against ballistic missile attack, the commission also concluded that "an effective air defense is so important to ensure continuity of government, and to protect our civil population, our enormously

6. Ruth Jarrell and Mary T. Cagle, *History of the Plato Anti-Missile System: 1952–1960* (Redstone Arsenal, AL: U.S. Army Ordinance Missile Command, 1961), appendix.

7. Ibid., 6.

8. Security Resources Panel, President's Science Advisory Committee, "Deterrence and Survival in the Nuclear Age," 7.

Figure 2.2. Nike Ajax, Hercules, and Zeus Interceptors



From front to back: Nike Zeus, Nike Hercules, Nike Ajax interceptors.
Source: U.S. Space and Missile Defense Command.

valuable civil property and military installations, that these development programs we suggest should be pushed with all possible speed."[9]

The committee identified two categories of systems that could provide some defense against ballistic missile attack. These included adaptations of existing "off the shelf" weapons such as the nuclear-tipped Nike Hercules anti-aircraft missile. With some modifications, the Gaither report surmised, these systems could provide a preliminary, lower tier defense of SAC installations and the basis for later evolution. The committee warned against the use of nuclear-tipped interceptors at lower altitudes for defense of population centers and recommended research into higher altitude interceptors that would reach into midcourse, while acknowledging that "to do this in the face of decoys poses a number of technical questions, the answers for which require a high priority research and test program."[10]

NIKE AND THE LIMITATIONS OF NUCLEAR INTERCEPT

Early inter-service rivalries in the new missile age of the Cold War soon led to a basic division of labor for the missile defense problem. With the Navy preoccupied with SLBMs and the Air Force with ICBMs and bombers, the U.S. Army took the lead on ABM or missile defense efforts. By 1955, two years prior to the release of the Gaither report, the Army had commissioned the Nike-II study to examine the feasibility and requirements for a higher altitude homeland missile defense. Many of the key findings would still be recognized by today's missile defense engineers, such as the need for "local radars in the vicinity of the target and forward radars for initial detection."[11]

The Nike-II study also identified discrimination between warheads and decoys as a particularly difficult challenge, recommending a point-defense system capable of intercepting warheads in their terminal phase after decoys and other debris had been dispersed. Another important finding was the need for consistent tracking and accurately guided interceptors. Even with a nuclear warhead, the acceptable miss-distances were small, and increasing the yield of the warhead did not significantly enlarge the interceptor's kill radius.[12]

Throughout Nike's development, numerous other studies were conducted, largely under the auspices of the Advanced Research Program Agency (ARPA) formed in 1958. Noteworthy projects included Project BAMBI (an acronym for Ballistic Missile Boost Intercept) and an Air Force program funded by ARPA examining the potential for satellite-based defenses. The BAMBI concept involved interceptors launched over Soviet territory from 30-ton, low-earth orbit satellites to

9. Ibid., 8.

10. Ibid., 28–29.

11. Bell Laboratories, *ABM Research and Development at Bell Laboratories: Project History* (Whippany, NJ: Bell Labs for U.S. Army Ballistic Missile Defense Systems Command, 1975), I-4.

12. Ibid., I-3.

interrupt a Soviet ICBM's propulsion during boost phase.[13] The ARPAT (ARPA-terminal) program considered the next generation of terminal phase interceptors beyond Nike. Project GLIPAR (Guide Line Identification Program for Antimissile Research) explored the viability of more exotic technologies, including various forms of directed energy. GLIPAR concluded, however, that such efforts were not "within the bounds of existing scientific knowledge."[14]

The first test "intercept" of an ICBM by the Army-led Nike-Zeus missile program took place in 1962. Although the test did not involve a nuclear detonation, developers deemed it to have flown close enough to the target that a nuclear detonation would have destroyed the reentry vehicle. Despite the system's initial success, it was not deployed due to cost, concerns with detonating a nuclear weapon in the atmosphere, and its limited operational capability.[15] Particular technical concerns included the slow speed of the Nike-Zeus booster and the limited capabilities of the system's manually swiveled radars.

Using a nuclear warhead to destroy incoming missiles in space helped overcome the lack of precision guidance, thanks to neutron heating. As President John F. Kennedy's science adviser, Jerome Wiesner, explained, "When one explodes a nuclear weapon near another, a flux of neutrons is released; these penetrate into the guts of the second nuclear weapon and heat it enough to melt it." This destruction of adversary nuclear weapons from the inside was critical to success in space intercepts, as an ABM nuclear explosion would not create destructive shockwaves in the vacuum of space. "However," Wiesner noted, "this effect does not work over very great distances . . . so the Nike nuclear explosion could be effective against only a limited number of incoming targets."[16]

Another complication facing Nike-Zeus was the phenomenon known as "blackout," in which a nuclear explosion in the upper atmosphere would cause air molecules to ionize. Wiesner again explained: "For a while the gas acts like a metal . . . so that radar waves cannot go through it and you cannot see what is behind it."[17] This limited the utility of the ground radars and made them susceptible to deliberate blinding. Both redundancy and hardening were important for sensors as well as other components. The "blackout" effect was observed during the 1962 "Starfish Prime" high-altitude nuclear tests.[18]

The Kennedy administration expressed concern over these limitations, as well as with concerns over cost. Secretary of Defense Robert S. McNamara's "whiz kids" concluded in 1963 that the cost of missile defense was greater than the cost to the Soviets to build more missiles. McNamara

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13. Donald R. Baucom, "Space and Missile Defense," *Joint Forces Quarterly* (Winter 2002/03): 50–55.

14. Ernest Yanarella, *The Missile Defense Controversy: Technology in Search of a* Mission (Lexington: University Press of Kentucky, 2002), 74.

15. Jacques S. Gansler, *Ballistic Missile Defense: Past and Future* (Washington, DC: Center for Technology and National Security Policy, 2010), 39.

16. Missile Defense Agency, "Nike Zeus: The U.S Army's First Antiballistic Missile," October 20, 2009, 12.

17. Ibid., 11.

18. Defense Special Weapons Agency, "Defense Special Weapons Agency 1947–1997: The First 50 Years of National Service," 1997, 13.

Figure 2.3. Starfish Prime High Atmospheric Nuclear Test, 1962

A belt of ionized gas caused by the 1962 Starfish Prime nuclear test (1.45 megaton).
Source: Wikimedia.

asserted that the Soviets would respond to an ABM system by increasing the size of their nuclear arsenal, accomplishing only an increase in both sides' defense spending.[19]

In the wake of the Cuban Missile Crisis, however, President Kennedy placed a higher priority on Project Defender and Nike. In January 1963, the Nike-X was created to shore up the weaknesses

19. U.S. Congress, Office of Technology Assessment, *Ballistic Missile Defense Technologies*, OTA-ITC-254 (Washington, DC: U.S. Government Printing Office, 1985), 45–46.

of Zeus. Nike-X relied on faster Sprint interceptors located around areas likely to be targeted by ICBMs to intercept warheads reentering the atmosphere. Nike-X also employed improved radar elements, including integration of a forward-based acquisition radars, together with separate radars for tracking and discrimination.

SENTINEL, SAFEGUARD, AND THE ABM TREATY

Secretary McNamara, now with the Lyndon Johnson administration, continued his push to limit ABM deployments. Toward the end of 1966, however, the administration faced increasing pressure from Congress to deploy an ABM system amid widespread reports of Soviet ABM deployments. In response, President Johnson requested money for fiscal year 1968 to deploy Nike-X. The administration, however, decided to delay Nike-X pending attempts to spark Soviet interest in a treaty limiting ABM deployments.

The proposed Nike-X interceptor, now dubbed Sentinel, would minimize congressional pressure on the administration to develop a large-scale system. McNamara settled on a limited ABM system that could protect the United States from the much smaller Chinese nuclear threat or an accidental Soviet launch. The proposed deployments instead garnered opposition, however, from people living in protected areas, from scientists who thought the system was too dangerous to station them near populated areas, and from members of Congress that preferred to tailor the system for the Soviet threat.[20] Further concern came from those worried that defenses would undermine arms control negotiations or contribute to an arms race.[21]

In 1969, the administration of President Richard Nixon suspended Sentinel and announced plans to restructure it as a new program called Safeguard, a more limited deployment of the Nike-X system to protect only ICBM fields against a counterforce strike. In addition to concern over new Soviet missile technologies, Nixon may have also viewed the retention of some ABM capabilities as a useful bargaining chip in future arms control negotiations.[22]

Besides Sprint, Safeguard also deployed an updated Nike-Zeus interceptor renamed Spartan, capable of intercept outside the atmosphere. The combination of the two represented an early iteration of a "layered" defense. Despite improvements, the basic shortcomings of nuclear-based intercept continued to haunt the program. Kinetic intercept seemed far off, but the way appeared to be paved. Simulations run by the Army Advanced Ballistic Missile Defense Agency (ABMDA) in 1969, for instance, seemed to indicate that the combination of optical homing with ground-based radars might make hit-to-kill possible.[23]

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20. U.S. Army Center of Military History, *History of Strategic Air and Ballistic Missile Defense: Volume II 1956–1972* (U.S. Army, 2009), 212–213.

21. McGeorge Bundy, "To Cap the Volcano," *Foreign Affairs* 48, no. 1 (October 1969): 1–20.

22. U.S. Army Center of Military History, *History of Strategic Air and Ballistic Missile Defense: Volume II*, 218.

23. Committee on an Assessment of Concepts and Systems for U.S. Boost-Phase Missile Defense in Comparison to Other Alternatives, Division on Engineering and Physical Science, National Research Council, *Making Sense of Ballistic Missile Defense: An Assessment of Concepts and Systems for U.S. Boost-Phase Missile Defense in Comparison to Other Alternatives* (Washington, DC: National Academies Press, 2012), 20.

Figure 2.4. Signing of the ABM Treaty, 1972

Source: U.S. State Department.

Efforts to limit ABM technology in favor of retaliation-based deterrence culminated with the 1972 signing and ratification of the ABM Treaty between the United States and Soviet Union. The treaty imposed legal limits on the development and deployment of missile defense systems, pursuant to the promise that "effective measures to limit antiballistic missile systems would be a substantial factor in curbing the race in strategic offensive arms and would lead to a decrease in the risk of outbreak of war involving nuclear weapons."[24]

The restrictions placed on ABM development were quite comprehensive and have had lasting implications for U.S. missile defense up to the present day. Specifically, the treaty limited the United States and USSR to two missile defense sites (later reduced to one), with no more than 150-kilometer radius separating the interceptors and radars.[25] Within this radius, deployment was

24. U.S. Department of State, "Treaty between the United States of America and the Union of Soviet Socialist Republics on the Limitation of Anti-Ballistic Missile Systems," May 26, 1972, Preamble, http://www.state.gov/t/isn/trty/16332.htm.

25. The original wording of the treaty allowed for two sites, one encompassing each party's national capital, the second encompassing protecting an area containing ICBM silos. A follow-on protocol, signed in 1974, limited this to one site, at the party's capital or an ICBM field. The protocol went into force May 1976. U.S. Department of State, "Protocol to the Treaty between the United States of America and the Union of Soviet Socialist Republics on the Limitation of Anti-Ballistic Missile Systems," July 3, 1974.

limited to 100 fixed, land-based interceptors. Supporting ABM radars had to be colocated within the designated ABM site and were also limited in number. The testing and development of interceptors was also limited to fixed, silo-based launchers, precluding mobile defenses or basing at sea, in the air, or in space.[26]

Although technically permitted by the ABM Treaty and deployed for a short time, the Safeguard system was soon scuttled. The deployment was confined to the Michelson Safeguard Complex at Grand Forks, North Dakota. Congress subsequently voted to deactivate the site in 1975, however, and the site was closed in February 1976, just 315 days after achieving its initial operational capability.[27]

Research into missile defense technologies continued under the treaty, but at a much scaled-down level. In part, such efforts hedged against Soviet breakout and the increase in the number of warheads required to carry out a counterforce strike against U.S. ICBM fields.[28] As a defensive accompaniment to the MX missile program in 1979, for instance, the Army proposed the development of the Low Altitude Defense (LoAD) missile defense system. Approximately half the size of a Sprint, LoAD would use a nuclear payload to destroy incoming warheads lower in the atmosphere—below 50,000 feet. As such, it would have been only suitable to defend already-hardened targets, such as ICBM silos.[29] LoAD was canceled in 1983, five months prior to the first flight test of the MX Peacekeeper ICBM.

SDI AND EARLY HIT-TO-KILL

When President Reagan announced the Strategic Defense Initiative in 1983, it came with the hope of rendering nuclear weapons "impotent and obsolete." The initiative was heralded by many as "an unprecedented development in recent U.S. strategic policy."[30] Others, including ABM Treaty architects, mobilized to again prosecute their case against defenses and in favor of mutual vulnerability.[31] The context of the SDI announcement, however, was growing concern about increasing Soviet SS-18 ICBM deployments as a "direct challenge to our policy of deterrence based

26. U.S. Department of State, "Treaty between the United States of America and the Union of Soviet Socialist Republics on the Limitation of Anti-Ballistic Missile Systems," Article III.

27. John W. Finney, "Safeguard ABM System to Shut Down; $5 Billion Spent in 6 Years since Debate," *New York Times*, November 25, 1975, http://www.nytimes.com/1975/11/25/archives/safeguard-abm-system-to-shut-down-5-billion-spent-in-6-years-since.html.

28. William A. Davis Jr., "Reactions and Perspectives," in *Ballistic Missile Defense*, ed. Ashton B. Carter and David N. Schwartz (Washington, DC: Brookings Institution, 1984), 381.

29. U.S. Army SMDC/ARSTRAT Historical Office, "From LoAD to Sentry: Defense of the MX," *Eagle* 14, no. 6 (June/July 2007): 14.

30. Keith B. Payne and Colin S. Gray, "The Star Wars Debate: Nuclear Policy and the Defensive Transition," *Foreign Affairs* 62, no. 4 (Spring 1984): 820–842.

31. McGeorge Bundy, George F. Kennan, Robert S. McNamara, and Gerard Smith, "Arms Control: The President's Choice: Star Wars or Arms Control," *Foreign Affairs* 63, no. 2 (Winter 1984/85): 264–278.

Figure 2.5. President Reagan Delivers Speech on SDI, March 23, 1983

on assured retaliation"—namely, what appeared to be the growing vulnerability of U.S. ICBMs and bombers to a Soviet first strike.[32] Most of the speech that announced SDI was in fact devoted to the Soviet ICBM advances.

The SDI Phase I architecture had the express purpose of complicating Soviet offensive options and thereby closing the perceived "window of vulnerability" to a counterforce attack. Richard Cheney, then secretary of defense, described its purpose to be intercepting 40 percent of the first wave of Soviet missiles and 50 percent of all SS-18s.[33] The concept for a Phase II was to enhance deterrence by denying the USSR the ability to destroy "militarily significant portions of important sets of targets (such as missile silos or command and control nodes) in the United States." The stated goal of Phase III was to maintain Phase II's level of protection in the face of advancing Soviet countermeasures while aspiring to "even higher levels of protection," perhaps assured survival of the U.S. population despite full-scale nuclear war. Directed energy would be key to achieve this

32. Strategic Defense Initiative Organization, "The Strategic Defense System Architecture" (Final Report to Congress, January 1988), 2, http://www.dtic.mil/dtic/tr/fulltext/u2/a195476.pdf.

33. David Denoon, *Ballistic Missile Defense in the Post–Cold War Era* (Boulder, CO: Westview Press, 1995), 125.

goal, but it was recognized that "it is unlikely that confidence in [directed energy] feasibility could be established by the early 1990s."[34]

Between the Safeguard era and the early 1980s, several technological advances had emerged that would play a significant role in making hit-to-kill more technologically feasible. These included increases in computing speed, signal processing and imaging, miniaturization of electronic circuitry, and investments in the precision guidance revolution during the 1970s.

SDI's notional architecture included a wide range of terrestrial and space-based systems.[35] Although directed energy weapon research was a featured component of SDI research, its lack of technological maturity excluded it from the proposed components for what became three periods for SDI: Phase 1, a somewhat more modest "Phase 1 Modified," and finally Brilliant Pebbles. A look at its architecture reveals a network of sensors, interceptors, and command and control that in some ways was the precursor of the missile defense architecture of today.

Phase 1 included hundreds of space-based interceptor carrier satellites (SBIs), along with 1,000 ground-based interceptors and a layered system of sensors.[36] The space-based sensor layer consisted of the Boost Surveillance and Tracking System (BSTS), which would have detected missiles at launch, and the Space-based Surveillance and Tracking System (SSTS), low-earth orbit satellites for tracking and discrimination.[37] Additional discrimination capability was to be provided by the Ground-based Surveillance and Tracking System (GSTS), a nonorbital pop-up type sensor based on a ground-based rocket. In the event of a major attack, a GSTS could be fired aloft (remaining on station for 600 to 1,200 seconds) and help with midcourse tracking, thereby supplementing space-based sensors that might be blinded or disabled. GSTS pop-up sensors were envisioned at each of three sites within the United States, with 12 per site.[38] Yet another layer of sensors included ground-based radars.[39]

Approved by the Defense Acquisition Board on July 30, 1987, Phase 1 included both SBIs and ground-based interceptors to defeat missiles both in and outside of the atmosphere. A subsequent and more modest Phase 1 Modified plan reduced the number of ground-based HEDI and ERIS interceptors and switched from garages of 10 SBIs to more distributed singlets.

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34. Office of Technology Assessment, *SDI: Technology, Survivability, and Software*, OTA-ISC-353 (Washington, DC: U.S. Government Printing Office, 1988), 9, 17, 125.

35. Ronald Reagan, "Address to the Nation on Defense and National Security" (speech, Washington, DC, March 23, 1983), https://reaganlibrary.archives.gov/archives/speeches/1983/32383d.htm.

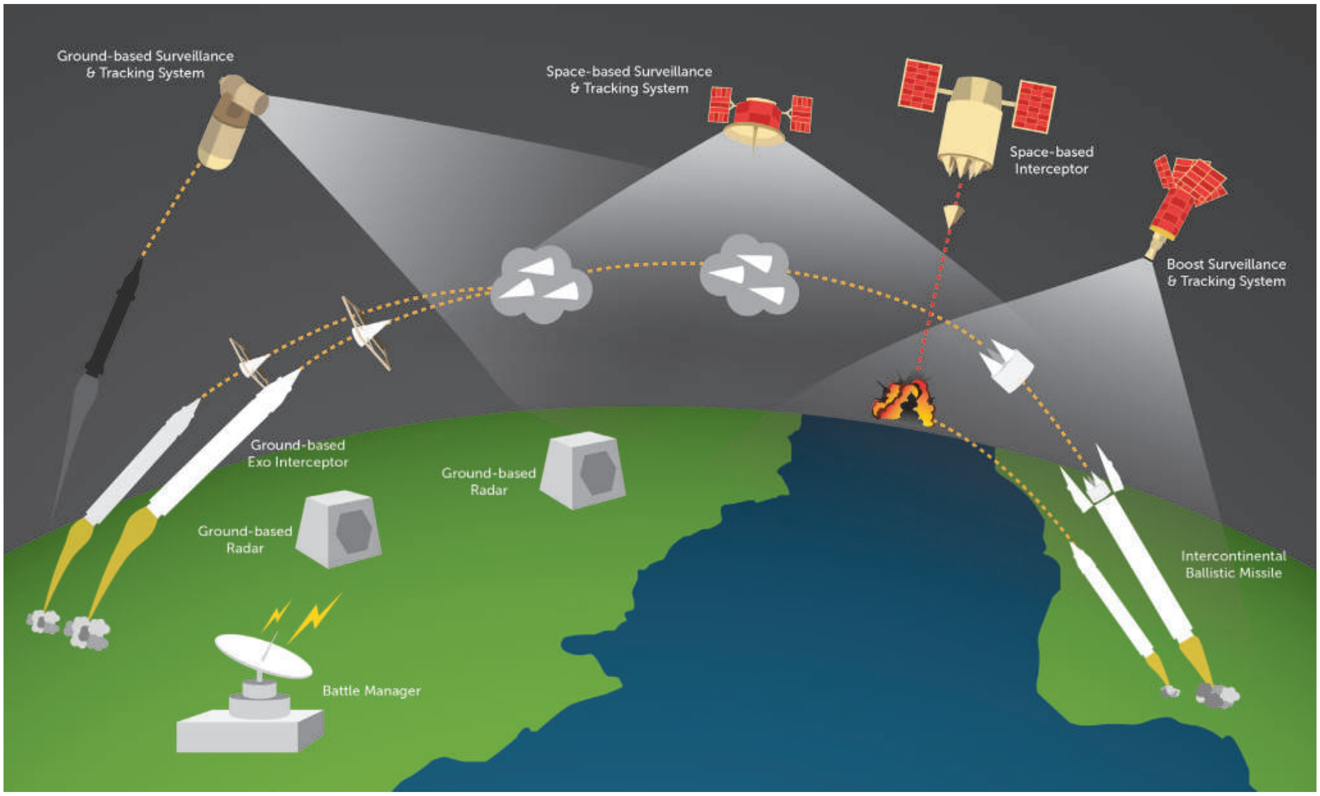
36. Office of Technology Assessment, *SDI*, 8.

37. J. W. Schomisch, ed., *1989 Guide to the Strategic Defense Initiative* (Arlington, VA: Pasha Publications, 1989), 34–35.

38. Henry Cooper and Stephen J. Hadley, "Global Protection against Limited Strikes (GPALS): Briefing on the Refocused Strategic Defense Initiative, Edited Transcript" (presentation, Department of Defense, Pentagon Press Center, Washington DC, February 12, 1991), 81, http://highfrontier.org/wp-content/uploads/2012/09/GPALS-Briefing-to-Press-12-February-1991.pdf.

39. Schomisch, *1989 Guide to the Strategic Defense Initiative*, 31–32.

Figure 2.6. Strategic Defense Initiative Phase 1 Concepts



Many of the ideas for current and future improvements to today's BMDS find at least an analogue to some element of SDI concepts.

While the SDI architecture was of course never realized, its components were tailored to perennial missile defense problems of detection, tracking, and discrimination and, at the conceptual level, may provide lessons for future efforts. Many of the ideas for current and future improvements to today's BMDS find at least an analogue to some element of SDI concepts.

Homing Overlay Experiment

During the 1970s, interest in overcoming the problems associated with nuclear interceptors led to early experiments into kinetic kill technologies—interceptors that would physically collide with an incoming warhead and destroy it with the force of impact. In prior decades, hit-to-kill had been viewed as beyond state-of-the-art, but progress made in the fields of infrared sensing and computers began moving it into the realm of the possible.[40] The U.S. Army undertook these early efforts, which led to the Homing Overlay Experiment (HOE) Task Force in 1977. These efforts ran in parallel to the precision strike revolution begun in the 1970s as part of the Carter administration's "offset" strategy.

40. U.S. Army SMDC/ARSTRAT Historical Office, "The Homing Overlay Experiment: The First 'Hit-to-Kill' Kinetic Energy Interceptor Missile," *Eagle* 14, no. 6 (June/July 2007): 11.

Figure 2.7. Homing Overlay Experiment Interceptor

Source: Wikimedia.

The HOE used a modified Minuteman booster to deliver a kill vehicle in the path of an incoming reentry vehicle (RV). Once separated from the booster, the 247 kilogram (kg) kill vehicle (KV) extended a 13-foot "radial net" of metallic spokes resembling a bicycle wheel to increase the chances of striking the RV. Fueled, the HOE may have weighed around 1,200 kg.[41] Similar "kill enhancement" mechanisms would continue to return in future programs, including early kill vehicles for the GBIs launched on Minuteman ICBM boosters in the late 1990s.[42]

Guided primarily by onboard infrared sensors, the HOE collided head-on with its target. With revitalized interest in missile defense following President Reagan's announcement of the Strategic Defense Initiative in 1983, HOE pushed past the concept phase and entered testing.

HOE experienced three intercept failures in 1983 due to malfunctions in the KV's infrared and guidance systems. In June 1984, HOE scored a successful intercept of a dummy warhead 100 miles above the earth's surface, the first exoatmospheric hit-to-kill intercept of a ballistic missile. This success was somewhat mired in controversy, with reports citing allegations that the test had

41. Cooper and Hadley, "GPALS: Briefing," 26–27.

42. *Making Sense of Ballistic Missile Defense*, 252.

been rigged by placing a beacon in the dummy warhead.[43] In 1994, a congressional investigation debunked these allegations, but nevertheless stated that "steps were taken to make it easier for the interceptor's [infrared] sensor to find the target" by having it heated prior to launch.[44] The General Accounting Office (GAO; later renamed the Government Accountability Office), described these steps as a "reasonable decision for this early technology demonstration."[45]

In 1993, DoD acknowledged there had been an ongoing "deception plan" associated with HOE to influence arms control negotiations and Soviet military spending. The GAO concluded that the deception program had been discontinued prior to the fourth HOE test and that it did not affect the results of the intercept. As an operational system, however, the Army determined HOE itself to be too heavy and too expensive to deploy.[46]

ERIS and HEDI

Following the HOE intercept, in 1984 the BMD Systems Command (BMDSCOM) allocated funds for its further development under a program called the High Endoatmospheric Defense Interceptor (HEDI), as well as allocating $2 million to prove the concept for the Exoatmospheric Reentry Interceptor Subsystem (ERIS).[47]

The purpose of ERIS was to further develop the technology to engage reentry vehicles outside the earth's atmosphere and, more specifically, to increase hit-to-kill probability, reduce cost, and develop a seeker that could lie dormant for long periods of time and require little maintenance.[48] The kill vehicle weighed about 200 kg.[49]

On January 28, 1991, the first ERIS test was conducted from the Kwajalein Missile Test Range to intercept a Minuteman missile from Vandenberg AFB.[50] The goals for the test were to communicate target information to the ERIS interceptor during flight, acquire the proper target, and maneuver toward the target and destroy it. The test achieved all of its major goals and resulted in an intercept, representing another important hit-to-kill milestone. It did not involve discrimination, but that was not a goal of the test.[51] Whereas the 1984 HOE experiment "exploited 1978 technologies,"

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43. Tim Weiner, "Inquiry Finds 'Star Wars' Tried Plan to Exaggerate Test Results," *New York Times*, July 23, 1994.

44. U.S. General Accounting Office, *Ballistic Missile Defense: Records Indicate Deception Did Not Affect 1984 Test Results*, GAO/NSIAD-94-219 (Washington, DC: U.S. General Accounting Office, 1994), 3.

45. Ibid., 4.

46. Graham, *Hit to Kill*, 13.

47. Dwight D. Oland and Cheryl Morai-Young, *Department of the Army Historical Summary: Fiscal Year 1984* (Washington, DC: Center of Military History, U.S. Army, 1995), 127.

48. Schomisch, *1989 Guide to the Strategic Defense Initiative*, 130.

49. Cooper and Hadley, "GPALS: Briefing," 26–27.

50. U.S. Government Accountability Office (GAO), *Strategic Defense Initiative: Some Claims Overstated for Early Flight Tests of Interceptors*, NSIAD-92-282 (Washington, DC: U.S. Government Accountability Office, 1992), 21.

51. Ibid., 23. There was controversy after the test when program officials mistakenly stated that the ERIS kill vehicle had "discriminated" the target from the decoys. This in fact was not the case. The ERIS EKV engaged a preprogrammed target and did not have the ability to discriminate between decoys and actual targets because the system was designed to rely on Brilliant Eyes satellites that were not deployed. Discrimination was not, however, a stated goal of the test.

the 1991 ERIS kill vehicle was "based on 1986 technology," in both cases a development lag of about five years.[52]

The second ERIS test was less successful. On March 13, 1992, an ERIS was launched from the same test range to accomplish the same goals as the previous test, with the addition of using its infrared sensor to properly discriminate between two objects based on their respective temperatures.[53] While the additional sensing goal was achieved, the ERIS kill vehicle failed to intercept the target.[54]

Funded concurrently with the ERIS, the HEDI program looked to develop technology for a ground-launched endoatmospheric component of a layered defense architecture.[55] HEDI interceptors were to defeat missiles at the end of their midcourse and into the terminal phase of flight. While no intercepts were attempted, HEDI technology contributed to what is now known as the Terminal High Altitude Area Defense (THAAD) system.

LEAP

The Lightweight Exoatmospheric Projectile (LEAP) was initially conceived in the 1980s by the Army's Strategic Defense Command to be a hit-to-kill projectile small enough to be launched from a rail gun.[56] The rail gun effort was discontinued, but the program migrated to BMDO and the U.S. Navy, evolving into an effort to further miniaturize kinetic kill vehicle technology. The prototype LEAP kill vehicle was fitted with an infrared sensor system, a dense electronics package, and a more compact set of divert thrusters.

In June 1991, LEAP successfully completed a free flight hover test at Edwards Air Force Base, highlighting its initial capacity to be integrated onto missile systems. In 1993, the program was transferred to the Navy. Through 1995, four test flights took place under Navy command, in which LEAP completed 42 of the 43 objectives.[57]

This success allowed for LEAP to be deemed operationally fit to be adapted for the Navy's Theater Ballistic Missile Defense Program for exoatmospheric missile defense.[58] As such, LEAP is the technological forbearer of the Aegis Standard Missile-3, but also laid the groundwork, particularly in miniaturization, for today's EKV.[59]

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52. Cooper and Hadley, "GPALS: Briefing," 26–27.

53. U.S. GAO, *Strategic Defense Initiatives*, 16.

54. Ibid., 3–23. ERIS program officers noted that the interceptor was required to collect extra testing data pre-intercept and that this additional requirement interfered with the missile making a successful intercept in time.

55. Schomisch, *1989 Guide to the Strategic Defense Initiative,* 132.

56. Rodney P. Rempt and Marvin J. Langston, "Theater Missile Defense: Technologies to Support a New Naval Mission," *Johns Hopkins APL Technical Digest* 14, no. 2 (1993): 145.

57. Hughes Missile Systems Company, "Navy LEAP: 42 of 43 Objectives Achieved," 1995.

58. Walker, Bernstein, and Lang, *Seize the High Ground*, 66.

59. James D. Syring, "Homeland Defense" (speech, 2014 Space and Missile Defense Symposium, Huntsville, AL, August 13, 2014).

Space-based Interceptors

The Strategic Defense Initiative was perhaps best known, however, for its layer of orbiting kill vehicles. SDI's Phase 1 concept included a number of satellites serving as SBI "garages," housing 10 hit-to-kill interceptors apiece.[60] Concerns about the relative vulnerability of these garages to anti-satellite (ASAT) weapons, however, led to a more distributed design known as Brilliant Pebbles, a constellation of smaller, independent kill vehicles in space that would have presented a more dispersed target set for ASATs to defeat.[61]

Alternative Proposals

One alternative proposal to SDI from Congress was the Accidental Launch Protection System (ALPS), forwarded by Senator Sam Nunn in 1988. The ALPS concept challenged Phase 1 by proposing a combination of nearer-term deployments and longer-term research in directed energy. To remain ABM Treaty compliant, ALPS would have employed only 70 ERIS and 30 HEDI interceptors at Grand Forks—the same number and location of Safeguard, but with two kinetic kill interceptors rather than the nuclear-armed Spartan and Sprint. This capacity might have provided protection against only one or two MIRV-equipped Soviet ICBMs, however, and would have been of little use against an SLBM launch. In 1990, the Senate voted down an amendment to fund ALPS from SDI funds.[62]

Another alternative came after the Soviet coup attempt in August 1991, when three senators, including William Cohen, introduced a bill for the deployment of 700 to 1,200 ground-based interceptors at five to seven sites across the continental United States—a sort of nonnuclear version of Sentinel.[63]

POST-SOVIET ERA AND GPALS

The fall of the Soviet Union and relaxation of the strategic threat environment led the George H. W. Bush administration and some members of Congress to scale back, but not cancel, the Strategic Defense Initiative and focus on more limited threats.

In 1990, soon to be director of the Strategic Defense Initiative Organization (SDIO), Ambassador Henry Cooper, wrote a report suggesting the redirection of SDI Phase 1 into something more modest, in light of the reduced threats from formerly Soviet missiles. Cooper recommended that SDI be scaled back to deal with limited attacks of up to 200 warheads, the number that might be

60. Office of Technology Assessment, *SDI*, 12.

61. Donald R. Baucom, "The Rise and Fall of Brilliant Pebbles," *Journal of Social, Political, and Economic Studies* 29, no. 2 (Summer 2004): 143–190.

62. Ivo H. Daalder, *Strategic Defences in the 1990s: Criteria for Deployment* (London: International Institute for Strategic Studies, 1991), 24–31.

63. Eric Schmitt, "3 Republicans Break with Bush over 'Star Wars,'" *New York Times*, June 16, 1991, http://www.nytimes.com/1991/06/16/us/3-republicans-break-with-bush-over-star-wars.html.

expected from a rogue submarine, and to rely primarily on presently available technologies.[64] In emphasizing accidental or rogue launches it resembled ALPS, but was expanded or redirected to include missile threats from additional countries.

Over the next year, this concept evolved again and became known as Global Protection Against Limited Strikes (GPALS). In his 1991 State of the Union address, President Bush called for SDI to be "refocused" to provide protection from limited ballistic missile strikes, "whatever their source."[65] Instead of enhancing deterrence by complicating a Soviet first strike, however, it was expressly "protection" focused, in the event deterrence failed: "With GPALS, we are talking about protection against limited strikes, rather than deterrence of a massive attack." Whereas some previous concepts focused on the continental United States, GPALS was billed as a 50-state solution, including Alaska and Hawaii.[66]

GPALS included a mix of space- and surface-based sensors, and interceptors based in space and on land or at sea. The 1,000 space-based interceptors were devoted to intercepting any missile with a range in excess of 600 to 800 kilometers, and the ground-based interceptors and other defenses in the United States or deployed abroad were to intercept missiles of almost any range.[67]

The new feature came with the space layer—namely, Brilliant Pebbles (BP). The BP concept (Figure 2.8) consisted of kinetic kill vehicles housed individually in a carrier vehicle called a "life jacket," to provide each pebble with communications, power, and protection from particulate space debris. BPs were designed to engage incoming missiles in the boost or early midcourse phase, reducing the burden on but not replacing ground-based interceptors.

Each pebble would also have had an onboard seeker, computing capability, and communication, allowing it to be less reliant on external sensors as well as communicate to other BPs and the ground.[68] The kill vehicles themselves were not so dissimilar from ground-based kill vehicles, such as those designed for ERIS or today's EKV, except that they were pre-accelerated and parked in orbit.

In 1989, BP underwent a series of major reviews for technological feasibility, which ultimately found the concept to be within the bounds of available technology, although additional steps were recommended to make BPs less vulnerable to attack. By 1990, BP was cleared for demonstration and validation.[69]

The ground-based layer remained necessary for both shorter-range missile attacks abroad and as an underlay for the United States. For the newly "increased priority on theater missile defense programs," PATRIOT evolution, the new THAAD program, the jointly developed Arrow, and ship-based interceptors were under consideration. For homeland defense, the plan was to have a

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64. The metric was identified both as "tens to a hundred or so" warheads, and elsewhere "ten to 100 or 200." Cooper and Hadley, "GPALS: Briefing," 14.

65. George H. W. Bush, "State of the Union Address" (speech, Washington DC, January 29, 1991).

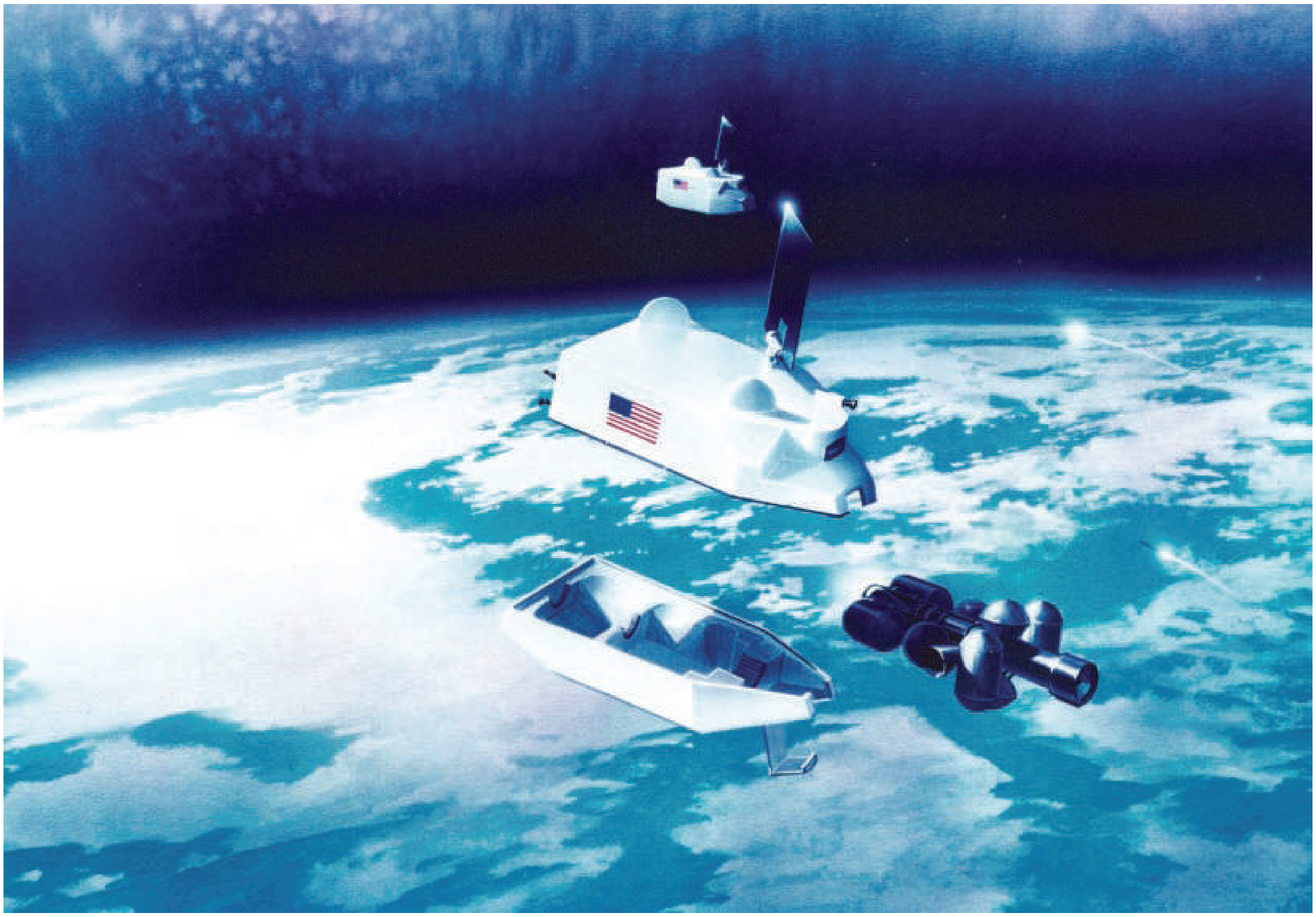
66. Cooper and Hadley, "GPALS: Briefing," 14.

67. Office of the Assistant Secretary of Defense (Public Affairs), "Fact Sheet: New Strategic Defense Initiative Program Focus: Global Protection against Limited Strikes (GPALS)," January 30, 1991.

68. Ibid., 151.

69. Baucom, "The Rise and Fall of Brilliant Pebbles," 150, 166.

Figure 2.8. Brilliant Pebbles Concept



Source: Missile Defense Agency.

competition between the Exo-Endoatmospheric Interceptor (E^2I) and the (strictly exoatmospheric) Ground-based Interceptor (GBI). Between these two, and therefore between the midcourse and terminal missions, SDIO director Ambassador Cooper noted, "Which interceptor we would lead with would depend on whether we're better at working the discrimination problem or the atmospheric heating problem."[70]

The GPALS rollout emphasized the commonality between space-based and ground-based kill vehicles development. Both did a similar job, regardless of where they began from or whether their acceleration is done on warning or in advance. Cooper emphasized that:

> the technology that they are now exploiting in the ground-based interceptor is a direct derivative of the space-based interceptor work that was going on previous to Brilliant Pebbles. So what we are seeing is a convergence of the technology to be exploited by interceptors, based on the ground or based in space, to conduct intercepts in space. The ground-based interceptor does its thing in space. So the issue is, where do you put it when it's not actually being

70. Cooper and Hadley, "GPALS: Briefing," 8, 17.

> energized. Is it to be based on the ground or is it to be based in orbit? In my mind, there are technical issues as to which costs less, what's more effective, which is more intrusive on the environment in terms of basing issues—and there are questions, political issues, raised by those who have concerns about so-called weapons in space, and so on.[71]

GPALS also deemphasized directed energy weapons for being beyond the state-of-the-art and expanded the mission of Brilliant Pebbles to include not only boost-phase but also early midcourse intercept. To address midcourse discrimination, GPALS coupled Brilliant Pebbles with a satellite constellation known as Brilliant Eyes, composed of small infrared sensors in low-earth orbit.[72] As with subsequent National Missile Defense proposals, its deployment would have violated the ABM Treaty without renegotiation. Cooper predicted that if development efforts went well and the decision was made to deploy, treaty issues would come to a head by the end of the 1990s.[73]

The 1991 National Missile Defense Act

The Gulf War further enhanced interest in missile defense. An Army program, the PATRIOT anti-aircraft missile (originally begun under Secretary Robert S. McNamara in 1965), was pressed into missile defense duty. Reports suggest that the Iraqis fired 42 Scuds at Israel and another 46 at Saudi Arabia and other Gulf states.[74] In one such attack, in February 1991, an Iraqi Scud missile struck a U.S. Army barracks in Saudi Arabia, killing 27 U.S. military personnel and wounding 98 others.[75] Although the U.S. military initially believed that PATRIOTs had intercepted many Iraqi Scuds, they may instead have merely broken up on reentry, perhaps due to faulty modifications to extend their range.[76]

Following the conflict, Congress passed the Missile Defense Act of 1991, which called for the deployment of "an anti-ballistic missile system, including one or an adequate additional number of anti-ballistic missile sites and space-based sensors, capable of providing a highly effective defense of the United States against limited attacks of ballistic missiles."[77] It also called for "highly effective theater missile defenses" to protect forward-deployed forces and allies.

The act called for an initial deployment by 1996 of 100 fixed interceptors at a single site, designed to protect the United States against "limited ballistic missile threats, including accidental or unauthorized launches or Third World attacks." The window would have required, then, about five years from enactment to deployment. This first deployment was also to include ground-based battle

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71. Ibid., 64 (Cooper, response to press question).

72. The sensors might have expanded for multiple sensor technologies, such as LADAR. Cooper and Hadley, "GPALS: Briefing," 76.

73. Ibid., 70 (Cooper, response to press question).

74. Department of Defense, "Conduct of the Persian Gulf War," 168.

75. R. W. Apple Jr., "War in the Gulf: Scud Attack; Scud Missile Hits a U.S. Barracks, Killing 27," *New York Times*, February 26, 1991, http://www.nytimes.com/1991/02/26/world/war-in-the-gulf-scud-attack-scud-missile-hits-a-us-barracks-killing-27.html.

76. U.S. Department of Defense, "Iraq's Scud Ballistic Missiles," *Information Paper,* July 25, 2000, I.

77. National Defense Authorization Act for Fiscal Years 1992 and 1993, Pub. L. No. 102-190, Division A, Title I, Part C (1991).

management radars and optimized use of space sensors for launch detection and interceptor cueing.

This scale of 100 interceptors was intended to be ABM Treaty–compliant, but the 1991 act encouraged negotiations to amend the ABM Treaty to permit the construction of additional interceptor sites, greater use of space assets for battle management, and clarifications to permit greater flexibility in missile defense research and testing.[78] The act also called for continued research into Brilliant Pebbles, but excluded it, by name, from the prescribed architecture.

CLINTON ADMINISTRATION: DEVELOPMENT

The Clinton administration initially pivoted away from homeland defense. The homeland defense budget was slashed by more than half, from over $2 billion to under $1 billion.[79] The Strategic Defense Initiative Organization (SDIO) was restructured and renamed the Ballistic Missile Defense Organization (BMDO), with a new programmatic and budgetary focus on theater or short-range defenses.[80] This shift included the cancellation of Brilliant Pebbles, marked by Secretary of Defense Les Aspin's declaration that he was "taking the stars out of Star Wars."[81] The emphasis on national efforts would remain on "developing" but not "deploying."[82]

When Republicans took control of Congress in early 1995, national missile defense again became a point of contention. Later that year, President Clinton vetoed the initial submission of the FY 1996 defense authorization act, specifically because of its mandate to deploy by 2003 a national missile defense capable of defending all 50 states.[83] In his veto message, Clinton noted that such a mandate would "likely require a multiple-site architecture that cannot be accommodated within the terms of the existing ABM Treaty."[84] The veto also cited the conclusions of a National Intelligence Estimate (NIE) in 1995, which predicted that "no country, other than the major declared nuclear powers, will develop or otherwise acquire a ballistic missile in the next 15 years that could threaten the contiguous 48 states and Canada."[85] The apparent exclusion of Alaska and Hawaii would be the basis for much concern.

78. Ibid.

79. Lindsay and O'Hanlon, *Defending America*, 87.

80. Department of Defense, "Ballistic Missile Defense Organizational Charter," Directive, August 18, 1994.

81. Taylor Dinerman, "The Bush Administration and Space Weapons," *Space Review*, May 9, 2005, http://www.thespacereview.com/article/368/1.

82. Les Aspin, "The End of the Star Wars Era" (news briefing, Office of the Assistant Secretary of Defense, Washington, DC, May 13, 1993).

83. Eric Schmitt, "Missile Defense Divides G.O.P. on Part of Bill before House," *New York Times*, February 16, 1995, http://www.nytimes.com/1995/02/16/world/missile-defense-divides-gop-on-part-of-bill-before-house.html.

84. William J. Clinton, "Message to the House of Representatives Returning without Approval the National Defense Authorization Act for Fiscal Year 1996," in *Public Papers of the Presidents of the United States: William Clinton, 1995, Book 2—July 1 to December 31, 1995* (Washington, DC: Government Printing Office, 1995), 1929.

85. Director of Central Intelligence, "Emerging Missile Threats to North America during the Next 15 Years," National Intelligence Estimate, NIE 95-19, November 1995.

Congress rejected the conclusions and seized upon the caveats of the 1995 NIE and, in response, created the bipartisan Commission to Assess the Ballistic Missile Threat to the United States, more commonly known as the Rumsfeld Commission after its chair, Donald Rumsfeld. The commission's report concluded that the 1995 NIE had underestimated the future threat of ballistic missiles to the United States, most notably by underestimating the prospects for foreign assistance from Russia and China. The report concluded that both Iran and Iraq could deploy an ICBM within 10 years of a decision to begin a program and that North Korea was likely close to developing a missile capable of hitting western parts of the United States.[86] The report also cautioned that the United States might have little warning of foreign missile development and that new proliferators may be willing to operationally deploy missiles without significant flight testing.

Shortly after the report's release, North Korea tested a three-stage variant of its Taepodong-1 missile, overflying Japan in what appeared to be an attempt at satellite orbit.[87] The development further energized the national missile defense debate and helped spur passage of the National Missile Defense Act of 1999. The act declared it U.S. policy "to deploy as soon as is technologically possible an effective National Missile Defense system capable of defending the territory of the United States against limited ballistic missile attack."[88] A revised NIE was released in September 1999, stating that "during the next 15 years the United States most likely will face ICBM threats from Russia, China, and North Korea, probably from Iran, and possibly from Iraq . . ."[89]

In this context, the Clinton administration began to put together plans for a National Missile Defense (NMD). In some ways it resembled a scaled-down version of the GBI component from GPALS (minus the space-based layer) or perhaps ALPS. The details of NMD development are especially important for understanding the capabilities and limitations of GMD today (Table 2.3).

The details of NMD development are especially important for understanding the capabilities and limitations of GMD today.

By 1996, the Clinton administration elected to pursue a "3+3" strategy for development of a national missile defense, which would include a three-year period of testing and development followed by three years to deploy an initial system, if it was deemed technologically feasible.[90] The timing of the plan was intentionally "phased" to both ensure effectiveness of the system and to allow time to renegotiate the ABM Treaty. The first phase, tailored to a "threshold" threat, was called Capability-1 (C1). The C1 configuration included 20 interceptors at one site, in either Alaska

86. Commission to Assess the Ballistic Missile Threat to the United States, "Executive Summary of the Report of the Commission to Assess the Ballistic Missile Threat to the United States," July 15, 1998.

87. Sheryl WuDunn, "North Korea Fires Missile over Japanese Territory," *New York Times*, September 1, 1998, http://www.nytimes.com/1998/09/01/world/north-korea-fires-missile-over-japanese-territory.html.

88. National Missile Defense Act of 1999, Pub. L. No. 106-38, 113 Stat. 205 (1999).

89. Bob Walpole, "Foreign Missile Developments and the Ballistic Missile Threat to the United States through 2015," National Intelligence Council, September 1999.

90. Steven A. Hildreth and Amy F. Woolf, "National Missile Defense: Issues for Congress," Congressional Research Service, May 2, 2001, 3.

Table 2.3. Phases of Clinton National Missile Defense

Phase	C1	Expanded C1	C2	C3
Mission	Intercept 5 targets without countermeasures	Intercept 10 ICBMs with limited countermeasures	Intercept 10 ICBMs with less-limited countermeasures	Intercept up to 20 ICBMs
GBIs	20	100	100	250
GBI Sites	Alaska	Alaska	Alaska	Alaska, North Dakota
UEWRs		Beale, Clear, Cape Cod, Fylingdales, Thule	Beale, Clear, Cape Cod, Fylingdales, Thule	Beale, Clear, Cape Cod, Fylingdales, Thule, South Korea
X-band Radars		Shemya	Shemya, Clear, Fylingdales, Thule	Shemya, Clear, Fylingdales, Thule, Beale, Cape Code, Grand Forks, Hawaii, South Korea
In-Flight Comm. Systems		Central Alaska, Caribou, Shemya	Central Alaska, Caribou, Shemya, Munsing	Central Alaska, Caribou, Shemya, Munsing, Hawaii
SBIRS-High		4	5	5
SBIRS-Low		6	24	24

or North Dakota, capable of intercepting a few simple warheads with no countermeasures.[91] This site could be deployed by 2003 and then built up by 2005 to around 100 interceptors (the ABM Treaty–compliant number).[92]

President Clinton later emphasized to Russian president Vladimir Putin the seriousness of the American effort: "Don't make the mistake of thinking that this is just about current politics or me protecting Al Gore. This is a real strategic problem for the United States."[93]

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91. David C. Gompert and Jeffrey A. Isaacson, *Planning a Ballistic Missile Defense System of Systems: An Adaptive Strategy*, Issue Paper-181 (Santa Monica, CA: RAND, 1999), http://www.rand.org/pubs/issue_papers/IP181.html.

92. Lindsay and O'Hanlon, *Defending America*, 83.

93. Graham, *Hit to Kill*, 282.

Eventually a decision was made to deploy the first site in Alaska to provide limited coverage even to the far reaches of Alaska and Hawaii. North Dakota would have given better coverage of the continental United States, but it would have left certain parts of Hawaii and Alaska undefended, and amending the ABM Treaty requirement for radar colocation and radar direction may have seemed easier than amending it to permit more than one interceptor site.[94] The C1 configuration would also include building an X-band radar in Shemya, Alaska, and upgrading various existing early warning radars to provide sensor coverage. Alaska was not the optimal location for a robust defense of the continental United States, but it did satisfy the political criteria for 50-state coverage, even if the character of that coverage for much of the continental United States was weakened as a result, most notably for the East Coast. Then U.S. deputy secretary of defense John Hamre later remarked, "We have . . . done modeling that shows that there are very good reasons why you may want to put it [an X-band radar] in Alaska. . . . Now, if it goes to Alaska, that requires us to sit down and make a change in the treaty."[95]

The C2 configuration kept the number of interceptors at 100, but upgraded them. It also called for three more X-band radars, a space-based infrared sensor constellation (SBIRS-low) to improve initial tracking, and upgraded command, control, and communications, all with a 2010 goal of intercepting missiles with more advanced countermeasures. The final C3 deployment would expand the number of interceptors to 250 evenly distributed between Alaska and North Dakota sites and nine X-band radars deployed on U.S. and allied territory.[96]

During the Deployment Readiness Review (DRR) phase (1996–1998) and the Deployment Decision Review (DDR) phase (1998–2000), BMDO began some early tests of a prototype kill vehicle, derived in part from the LEAP and other early hit-to-kill experiments. Several competitors produced designs for what became known as the EKV, as well as for the booster underneath it. To facilitate early testing of the EKV, early tests of the NMD systems used surplus stages of Minuteman missiles as boost vehicles, as had earlier tests. These early steps allowed the first fly-out test of a prototype EKV in 1997. The first successful EKV intercept occurred in October 1999—just 15 years after HOE and eight years after ERIS.[97]

The first successful EKV intercept occurred in October 1999—just 15 years after HOE and eight years after ERIS.

Secretary of Defense William Cohen was a supporter of swiftly fielding a ballistic missile defense. Within the administration, however, some felt that the goal of 2003 was too ambitious, and a 1998 review of the testing program led by General Larry Welch warned against a "rush to failure."[98] Cohen agreed but was hesitant to push deployment back until 2007, as suggested by the

94. Lindsay and O'Hanlon, *Defending America,* 89.

95. Graham, *Hit to Kill*, 80. Article III of the ABM Treaty required that missile defense radars had to be colocated with interceptors.

96. Lindsay and O'Hanlon, *Defending America*, 83, 99.

97. Syring, "Homeland Defense."

98. Lindsay and O'Hanlon, *Defending America*, 93.

Pentagon's Office of Program Analysis and Evaluation. Splitting the difference, he decided on the middle point of a 2005 deployment date.[99]

Yet another element of homeland missile defense present in the Clinton era plans is that of using ship-based radars and potentially also ship-based interceptors. In 2000, the chief of naval operations, Admiral Jay Johnson, proposed to the secretary of defense that ships could make the then-proposed NMD more effective, assisting with midcourse and potentially also boost-phase defense. A similar proposal had been made years before by SDIO Director Cooper.[100]

In addition, the Clinton administration sought to engage Russia in what became known as the "demarcation talks," intended to establish a clearer demarcation between national missile defense and theater missile defense systems that would clarify the ABM Treaty's restrictions on certain systems. An agreement to this effect was reached with Russia in 1997.[101]

At minimum, the Clinton administration's architecture would have required at least amendment and perhaps the radical redrafting of the ABM Treaty in order to permit more than one GBI site and the construction of the X-band radar at Shemya, Alaska. Indeed, by the late years of the Clinton administration, lawyers were consulted to determine whether some level of initial construction at Shemya would be permissible under the treaty, such as the pouring of concrete for the foundation.[102]

Consistent with the administration's previous "3+3" timeline, the schedule for a decision to deploy a national missile defense was set for late 2000. The results of the initial two tests were mixed, with a successful intercept in October 1999 and a failure in January 2000. The decision would not be made until after the third test, which would take place on July 8, 2000. The test was unsuccessful: the clamshell cover protecting the kill vehicle's eyes did not eject and never separated from the second stage. An avionics processor, hardly cutting-edge technology, was later deemed to have been the cause.[103]

In September 2000, President Clinton decided to defer the deployment decision to his successor.[104] The speech announcing the deferment decision also laid out the rationale for continued efforts, however, especially in light of the failure of applying Cold War deterrence to new threats:

> The question is, can deterrence protect us against all those who might wish us harm in the future? Can we make America even more secure? The effort to answer these questions is the impetus behind the search for NMD. The issue

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99. Graham, *Hit to Kill*, 92.

100. Ibid., 214.

101. Amy F. Woolf, "Anti-Ballistic Missile Treaty Demarcation and Succession Agreements: Background and Issues," Congressional Research Service, April 27, 2000.

102. Graham, *Hit to Kill*, 266.

103. Ibid., 289.

104. Eric Schmitt, "Clinton's Missile Decision: The Overview; President Decides to Put Off Work on Missile Shield," *New York Times*, September 2, 2000, http://www.nytimes.com/2000/09/02/world/clinton-s-missile-decision-overview-president-decides-put-off-work-missile.html.

> is whether we can do more, not to meet today's threat, but to meet tomorrow's threat to our security.
>
> For example, there is the possibility that a hostile state with nuclear weapons and long-range missiles may simply disintegrate, with command over missiles falling into unstable hands; or that in a moment of desperation, such a country might miscalculate, believing it could use nuclear weapons to intimidate us from defending our vital interests, or from coming to the aid of our allies, or others who are defenseless and clearly in need. . . .
>
> Now, no one suggests that NMD would ever substitute for diplomacy or for deterrence. But such a system, if it worked properly, could give us an extra dimension of insurance in a world where proliferation has complicated the task of preserving the peace. Therefore, I believe we have an obligation to determine the feasibility, the effectiveness, and the impact of a national missile defense on the overall security of the United States.[105]

While the Clinton administration did not deploy any components of national missile defense, it nevertheless began the development and laid out the basic elements for what would soon be renamed Ground-based Midcourse Defense (GMD).

BUSH ADMINISTRATION: DEPLOYMENT

The George W. Bush administration wasted little time in moving forward on national missile defense, largely along the lines laid out in the previous years. Rather than amend the ABM Treaty to accommodate national missile defense efforts, the president in December 2001 announced plans to withdraw from the treaty pursuant to its terms, citing its diminished relevance in a world where the threat of Soviet attack had been superseded by missile threats from multiple and less predictable actors. Due to the requirement for a six-month notice of withdrawal, the treaty would not officially terminate until June 13, 2002.

In announcing the U.S. intention to withdraw, the president emphasized the changing strategic environment and the relation of missile defense to deterrence:

> Today, I have given formal notice to Russia, in accordance with the treaty, that the United States of America is withdrawing from this almost 30-year-old treaty. I have concluded the ABM Treaty hinders our government's ability to develop ways to protect our people from future terrorist or rogue-state missile attacks.
>
> The 1972 ABM Treaty was signed by the United States and the Soviet Union at a much different time, in a vastly different world. One of the signatories, the Soviet Union, no longer exists. And neither does the hostility that once led

105. William Clinton, "Remarks by President Bill Clinton on National Missile Defense" (speech, Georgetown University, Washington, DC, September 1, 2000).

> both our countries to keep thousands of nuclear weapons on hair-trigger alert, pointed at each other. The grim theory was that neither side would launch a nuclear attack because it knew the other would respond, thereby destroying both.
>
> Today, as the events of September the 11th made all too clear, the greatest threats to both our countries come not from each other, or other big powers in the world, but from terrorists who strike without warning, or rogue states who seek weapons of mass destruction.
>
> We know that the terrorists, and some of those who support them, seek the ability to deliver death and destruction to our doorstep via missile. And we must have the freedom and the flexibility to develop effective defenses against those attacks. Defending the American people is my highest priority as Commander in Chief, and I cannot and will not allow the United States to remain in a treaty that prevents us from developing effective defenses.[106]

While waiting for withdrawal to take effect, Secretary of Defense Rumsfeld issued a January 2002 memo creating the Missile Defense Agency (MDA) and granting it special acquisition authorities in recognition of the "special nature of missile defense development, operations, and support."[107] The memo mandated streamlined executive oversight and reporting requirements for MDA to facilitate quick deployment of an initial operating capacity. In June 2002, the treaty withdrawal took effect and work began at Fort Greely, Alaska. After having reviewed a wide array of concepts, those left over from the Clinton administration were regarded as the most mature and formed the basis of the path forward. The Nuclear Posture Review of 2001 described the path forward as having two dimensions: first, the need to acquire rudimentary "near-term emergency capabilities" for 2003 to 2006, and "operational capabilities" from 2006 to 2008.[108]

On December 16, 2002, President Bush issued National Security Presidential Directive 23 (NSPD-23), which declared it the policy of the United States to "develop and deploy, at the earliest possible date, ballistic missile defenses drawing on the best technologies available," a slight reformulation of the NMD Act of 1999.[109] NSPD-23 also eliminated the distinction between national and theater missile defenses, a rejection of the previous treaty demarcation agreements

106. George W. Bush, "Remarks by the President on National Missile Defense" (speech, Rose Garden, Washington DC, December 13, 2001).

107. Donald Rumsfeld, "Missile Defense Program Direction," Office of the Secretary of Defense Memorandum, January 2, 2002.

108. The 2001 NPR list of near- and mid-term options included "a single Airborne Laser for boost-phase intercept, a rudimentary ground-based midcourse system, consisting of a small number of interceptors taking from the test program . . . and, a sea-based Aegis system [that] could be available to provide a rudimentary midcourse capability against short to medium-range threats." The list of "operational capabilities" for the 2006–2008 period included "2–3 Airborne Laser aircraft, additional ground-based midcourse sites, 4 sea-based midcourse ships, Terminal systems, able to defend against shorter-range threats: PAC-3 . . . and THAAD, which could be available by 2008." Department of Defense, *Nuclear Posture Review* (Washington, DC: Department of Defense, 2001), 26.

109. George Bush, *National Policy on Ballistic Missile Defense* (Washington, DC: The White House, National Security Presidential Directive-23, 2002).

Figure 2.9. George W. Bush ABM Withdrawal Announcement, December 13, 2001

Source: Getty Images / Alex Wong.

from 1997, since the distinction depended as much on context as on physics. One person's theater defense was another's national missile defense. European commentators praised the move. NATO Secretary General Lord Robertson praised the move for its reception abroad, saying that "taking the 'N' out of 'NMD' has changed perceptions on that and encouraged a more rational debate."[110]

NSPD-23 further directed the Department of Defense to deploy an initial capability to defend the homeland by the end of fiscal year 2004. This capability was envisioned as a first step toward the future deployment of more robust "evolutionary" missile defenses that could include space-based interceptors and other capabilities previously banned by treaty. NSPD-23 focused the U.S. missile defense effort on defending against missiles "of varying ranges in all phases of flight," an injunction that in time would make it into the charter of the Missile Defense Agency.[111]

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110. Graham, *Hit to Kill*, 361.

111. Bush, "National Policy on Ballistic Missile Defense."

In support of this policy, the Bush administration also initiated several rounds of diplomacy with U.S. allies to explain the withdrawal and to explore possible avenues of missile defense cooperation. The administration also reassured Russia that the treaty decision was not intended to threaten Russia's strategic nuclear capabilities, and despite initial objections, President Vladimir Putin acknowledged that the U.S. withdrawal "does not pose a threat to the national security of the Russian Federation."[112] The United States and Russia also engaged in a series of bilateral discussions on possible missile defense cooperation, in accordance with the Joint Declaration signed by Presidents Bush and Putin in May 2002, but did not conclude with any meaningful agreement.[113]

To facilitate the rapid deployment of an initial system, MDA was granted significant flexibility to construct facilities and procure and field assets. The development process was dubbed "capabilities-based" acquisition, the logic of which was explained by then MDA director Lieutenant General Ronald Kadish:

> Missile defense has perhaps more uncertainties in this regard than many other mission areas. We do not want to alter our baseline every time we recognize a change in the threat. Such changes could ripple through the program and likely cause significant delay and cost. So instead of a point threat, we are setting a wider range of boundaries for adversarial capabilities over time in defining our own needed capabilities. The baseline we set must be able to deal with surprises and changes in the threat. A capability-based approach allows us to adjust to those changes in ways that the traditional requirement-based approach does not.[114]

Such flexibility was arguably necessary, given NSPD-23's directive that there would be no "final, fixed missile defense architecture," that the initial deployments would evolve with the threat and technological change, and with "the number and location of systems" changing over time.[115]

In September 2004, then MDA director Lieutenant General Trey Obering declared "limited defensive operations" status for GMD. At the time, this capability was quite limited indeed, consisting of only five GBIs at Fort Greely, Alaska, and the upgraded Cobra Dane radar at Eareckson Air Station in

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112. About the ABM Treaty, Putin stated,

> As is known, Russia, like the United States and unlike other nuclear powers, has long possessed an effective system to overcome antimissile defense. So, I can say with full confidence that the decision made by the President of the United States does not pose a threat to the national security of the Russian Federation.

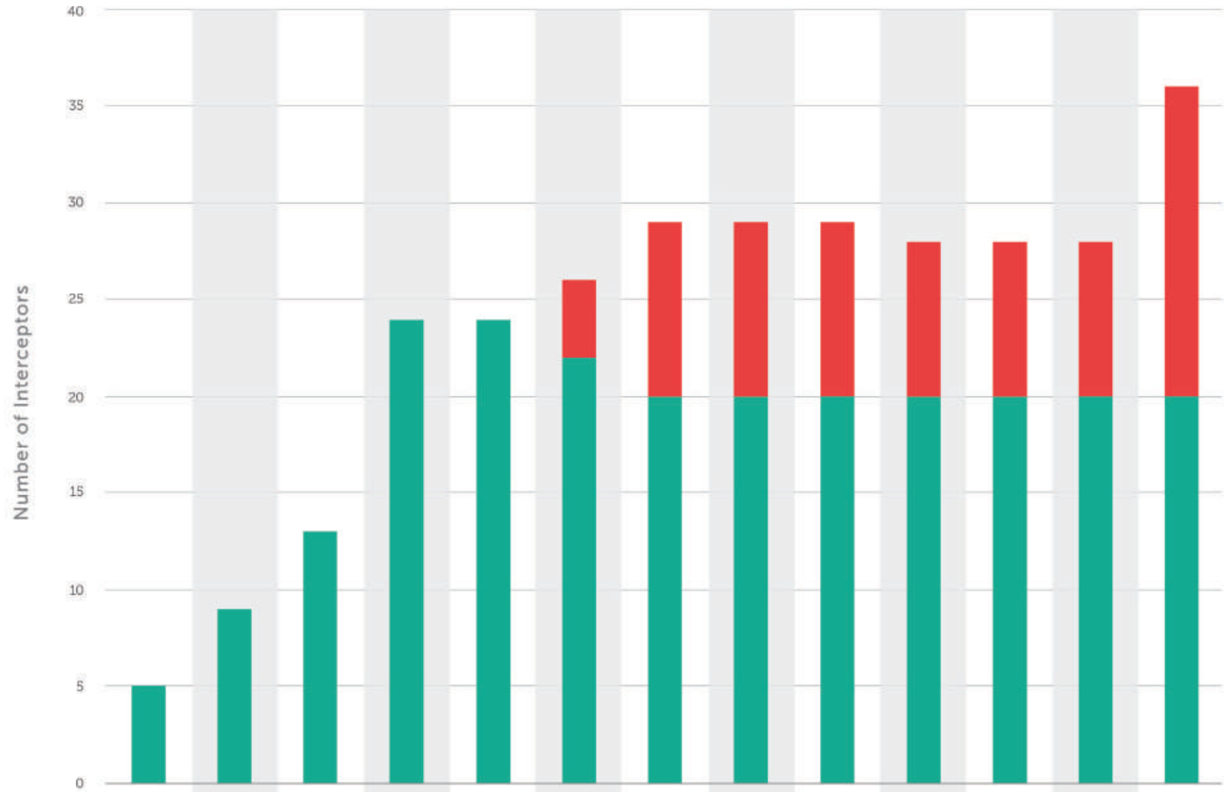
Ministry of Foreign Affairs of the Russian Federation, "Statement Made by Russian President Vladimir Putin on December 13, 2001, regarding the Decision of the Administration of the United States of America to Withdraw from the Antiballistic Missile Treaty of 1972," December 14, 2001.

113. "Joint Declaration by President George Bush and President Vladimir Putin on the New Strategic Relationship between the United States of America and the Russian Federation," White House, Office of the Press Secretary, May 24, 2002.

114. Lieutenant General Ronald T. Kadish, "Reorganization of the Missile Defense Program" (statement before the Senate Armed Services Committee, Strategic Forces Subcommittee, March 13, 2002).

115. Bush, "National Policy on Ballistic Missile Defense."

Figure 2.10. GBI Fleet Evolution, 2004–2016



Fiscal Year	'04	'05	'06	'07	'08	'09	'10	'11	'12	'13	'14	'15	'16
CE-II						4	9	9	9	8	8	8	16
CE-I	5	9	13	24	24	22	20	20	20	20	20	20	20

Shemya, Alaska.[116] Aegis BMD ships then in the Sea of Japan were tethered to the GMD system for testing, but were yet to be operationally integrated.

Other elements soon came online. Over the next four years, additional interceptors continued to be emplaced, rising to 24 by the end of 2008. In 2006, the newly constructed Sea-based X-band radar (SBX-1) arrived in the Pacific to enhance the GMD system's discrimination capabilities, participating in its first GMD intercept in September of that year. The TPY-2 and SPY-1D radars were operationally integrated through the Command and Control, Battle Management, and Communications (C2BMC) program, and the Early Warning Radar at Thule also received upgrades to contribute to the missile defense mission.

The Bush administration also continued or began longer-term technology development programs to lay the groundwork for subsequent generations of missile defense technology. These included the Multiple Kill Vehicle (MKV), the Kinetic Energy Interceptor (KEI), and the Airborne Laser (ABL), a

116. Steven Lambakis, *The Future of Homeland Missile Defenses* (Fairfax, VA: National Institute Press, 2014), 14.

technology demonstrator to validate the use of aerial directed energy platforms for boost-phase intercept.

As with NMD, GMD was largely but not exclusively oriented westward, weighted toward the North Korean threat. In 2007, President Bush proposed deploying additional GMD system elements in Europe designed to intercept a potential Iranian ICBM headed toward the United States. The location of 10 GBIs in Poland and an X-band radar in the Czech Republic would have also allowed this system to provide some limited protection for European NATO allies from the developing Iranian IRBM arsenal, but additional interceptors for NATO territorial defense would still have been needed.[117] Those 10 GBIs would have been in addition to the 44 intended for Fort Greely and Vandenberg and would thus have brought the total number of homeland defense interceptors to 54. The decision to put interceptors on European soil created significant Russian opposition, despite the limited nature of the deployment and its inability to affect Moscow's strategic arsenal.[118]

Because they were located closer to Iran than those in Alaska were to North Korea, the GBIs intended for Europe would have had to intercept an Iranian ICBM relatively earlier in its flight, during the ascent component of the midcourse phase. For this reason, the European third site was intended to host two-stage rather than three-stage boosters.[119] From the outside, the two-stage GBI configuration was virtually indistinguishable from the three-stage configuration in Alaska, but without the additional weight and required burn time of the third stage. This allowed for a quicker deployment of the kill vehicle. Agreements were signed with both Poland and the Czech Republic to accommodate these sites.[120] Deployments of GBIs in Poland were scheduled to begin in 2011, with completion scheduled for 2013.

OBAMA ADMINISTRATION: SUSTAINMENT

President Barack Obama made a number of significant decisions affecting the scope and nature of homeland missile defense, most notably to cancel plans to deploy the full number of 44 GBIs divided between Alaska and California, scale back (and ultimately cancel) the ABL, and terminate the MKV program, which would have developed multiple kill vehicles for each GBI, simplifying the discrimination problem and improving shot doctrine.[121] The KEI program was

117. "Fact Sheet: Defending America and Its Allies against Ballistic Missile Attack," White House, Office of the Press Secretary, October 23, 2007.

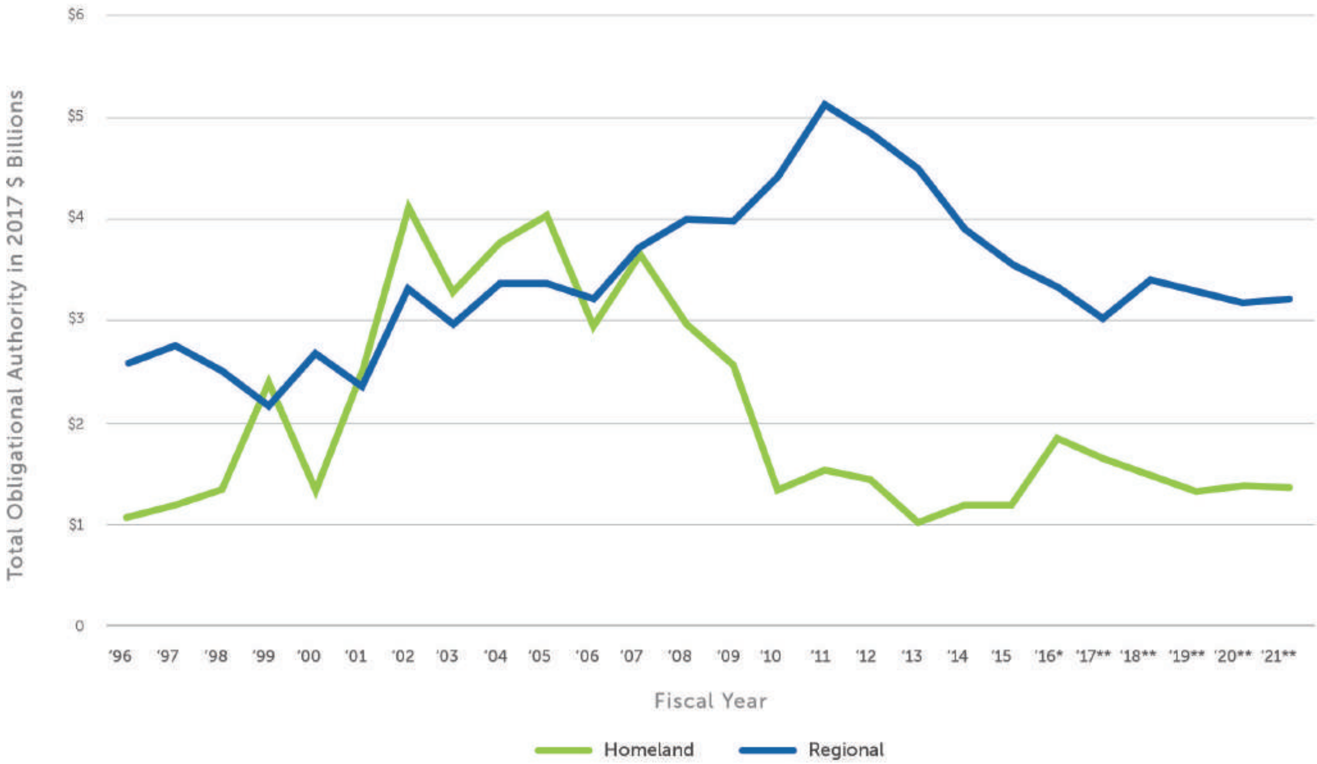
118. Bruce Konviser, "U.S. Missiles in E. Europe Opposed by Locals, Russia," *Washington Post*, January 28, 2007, http://www.washingtonpost.com/wp-dyn/content/article/2007/01/27/AR2007012701370.html.

119. Steven A. Hildreth and Carl Ek, "Long-Range Ballistic Missile Defense in Europe," Congressional Research Service, September 23, 2009, 7.

120. U.S. Department of State, "Agreement between the Government of the United States of America and the Government of the Republic of Poland concerning the Deployment of Ground-based Ballistic Missile Defense Interceptors in the Territory of the Republic of Poland," August 20, 2008; U.S. Department of State, "Agreement between the United States and the Czech Republic on Establishing a United States Ballistic Missile Defense Radar Site in the Czech Republic," July 8, 2008.

121. Robert Gates, "Defense Budget Recommendation Statement" (speech, Arlington, VA, April 6, 2009).

Figure 2.11. Homeland and Regional Modernization, 1996–2021



Note: Modernization herein includes appropriations for procurement and for RDT&E. The "homeland" category includes GMD/NMD and related programs: SBX, LRDR, MKV/MOKV, Improved Homeland Defense Interceptors, and Midcourse Defense Test. The "regional" category includes THAAD, Aegis, and PATRIOT/MEADS.

*Based on FY 2016 enactment.

**Based on FY 2017 presidential budget request.

also canceled, which would have used a highly energetic booster to intercept missiles in the ascent phase.[122]

In September 2009, President Obama also announced a major shift in European missile defense. The plans for a GBI site in Poland and X-band radar in Czech Republic were to be scrapped. In its place would go a new architecture, dubbed the European Phased Adaptive Approach (EPAA).[123] The Clinton administration had explicitly deemphasized strategic or national missile defense in favor of theater missile defense, and the Obama administration again put new emphasis on regional missile defenses, with corresponding budget movements (Figure 2.3).

The first three phases of the EPAA would include sea- and later land-based SM-3s, the latter concept having previously originated during talks to identify a midcourse intercept solution for

122. "U.S. Kills Northrop Grumman Missile-Defense Program," Reuters, June 11, 2009, http://www.reuters.com/article/us-missile-northrop-idUSTRE55A6ZT20090611.

123. "U.S. Missile Defense Policy a Phased, Adaptive Approach for Missile Defense in Europe," White House, Office of the Press Secretary, September 17, 2009.

Israel.[124] EPAA also had a fourth phase featuring an as-yet designed SM-3 IIB interceptor much smaller than a GBI or KEI that, from Europe, would theoretically be able to intercept intercontinental-range missiles.[125]

In February 2010, the administration released its *Ballistic Missile Defense Review* (BMDR), which set as its first priority "to defend the homeland against the threat of limited ballistic missile attack." It emphasized maintaining the nearly 30 GBIs that had already been emplaced while also completing Missile Field 2 at Fort Greely "as a hedge against the possibility that additional deployments become necessary."[126] The new policy review also reiterated the shift against GBIs in Europe and toward developing the SM-3 IIB.[127]

The notional SM-3 IIB was characterized as requiring burnout velocities of around 5.5 kilometers per second.[128] Subsequent studies revealed a number of difficulties with implementing the concept.[129] To achieve the necessary speed, the SM-3 IIB might have had to expand the diameter of the interceptor from 21 to 27 inches, which in turn would require a modification to the U.S. Navy's Mark 41 Vertical Launching System (VLS) to accommodate added width.[130] The SM-3 IIB concept also envisioned a throttleable solid motor, a new technology the development of which would have proved challenging for the administration's timeline.

The proposed deployment in Romania and Poland also was perhaps not the optimal location, given the slower velocity of an SM-3 IIB relative to a GBI. GAO concluded that while the Poland site could be effective with operational changes to launch interceptors during boost phase, a sea-based deployment would be more effective and would not require changes to firing doctrine.[131] Deployment on Aegis ships would have required either changing the proposed liquid propulsion system, or reversing a ban on liquid propellant systems on ships. Should an expanded VLS not have been possible, it may even have required deck mounting, a concept pursued as well for the previous KEI.

124. Henry A. Obering III, "The Future of Global Missile Defense" (speech, Huntsville, AL, August 15, 2016), Defense One Panel Discussion, http://www.defenseone.com/feature/cocktails-and-conversations/#watch-now.

125. Missile Defense Agency, "Missile Defense Agency Awards Contracts to Support Concept Definition and Program Planning for the Standard Missile 3 (SM-3) Block IIB Program," MDA news release, April 7, 2011.

126. Although MDA statements usually indicate 30 as the maximum number of interceptors "available" or which have been "emplaced" over time, the number emplaced at any given time more likely did not rise above 29 for the 2010–2012 period. The number of interceptors emplaced is not identical to the number operationally available. At any given day, as with other missile systems, some silos or interceptors may be operationally unavailable due to maintenance or upgrades.

127. U.S. Department of Defense, *Ballistic Missile Defense Review Report* (Washington, DC: DoD, 2010), iv.

128. Jaganath Sankaran, "Missile Defense against Iran without Threatening Russia," *Arms Control Today*, November 4, 2013, http://www.armscontrol.org/print/6020.

129. Senator Joseph Lieberman, "The President's Decision on Missile Defense in Europe" (statement during hearing of the Senate Armed Services Committee, 111th Cong., 1st sess., September 24, 2009).

130. U.S. Government Accountability Office (GAO), *Standard Missile-3 Block IIB Analysis of Alternatives*, GAO-13-382R (Washington, DC: U.S. Government Accountability Office, 2013), 7.

131. Ibid., 26.

Given the long development time anticipated with the SM-3 IIB, the Obama administration announced another programmatic shift in March 2013. Just weeks after a February 2013 nuclear test by North Korea, Secretary of Defense Chuck Hagel announced the cancellation of the EPAA's fourth phase.[132] This effectively killed the SM-3 IIB and eliminated the coupling of homeland defense with European deployments. Hagel also announced that the administration would reverse its previous decision to forgo deployment of an additional 14 GBIs to Alaska, bringing the number back to 44.[133]

Following this announcement, the Department of Defense submitted to Congress its *Homeland Defense Hedging Policy and Strategy* in June 2013. While describing a range of planned and potential activities, the report noted "risks to the nation associated with having too few deployed GBIs," and that "future ICBM threats from North Korea or Iran could increase in complexity, which could require a greater expenditure of interceptors to achieve an acceptable probability of engagement success."[134]

The report provided greater details on the shifts announced by Secretary Hagel in March, as well as a number of other steps the Obama administration would take to improve U.S. homeland missile defense against North Korea, including:

- Emplace an additional 14 GBIs at Fort Greely, including six at Missile Field 1 (MF-1), which would first be refurbished, and eight into Missile Field 2 (MF-2).
- Deploy a second forward-based TPY-2 radar to Japan.
- Conduct Environment Impact Statements to lay some of the groundwork for a potential third GBI site in the eastern United States.[135]
- Procure an additional 14 GBIs "to replace those that will now be deployed at Ft. Greely," in order to "maintain a robust testing program and sufficient operational spares."
- Restructure SM-3 IIB efforts into a common kill vehicle technology development program.

The future testing regime will reduce the number of operationally available GBIs to below 44.

Many of these steps have now been completed. The second TPY-2 was deployed to Japan in December 2014, and MDA is on track to refurbish MF-1 and emplace the full 14 additional GBIs by the end of 2017. It is not, however, apparent that MDA or the Department of Defense has a plan to procure the additional 14

132. David E. Sanger and Choe Sang-Hun, "North Korea Confirms It Conducted 3rd Nuclear Test," *New York Times,* February 11, 2013, http://www.nytimes.com/2013/02/12/world/asia/north-korea-nuclear-test.html.

133. "U.S. Scraps Final Phase of European Missile Shield," BBC, March 16, 2013, http://www.bbc.com/news/world-us-canada-21812161.

134. U.S. Department of Defense, "Homeland Defense Hedging Policy and Strategy" (Report to Congress, June 2013), 3.

135. These studies had been mandated by Congress in the FY 2014 National Defense Authorization Act.

Table 2.4. SDI/NMD/GMD Evolution

Phase	Time Frame	Goals
Technology Exploration	FY84–87	• Evaluate feasibility of potential technologies for defense of United States against ballistic missile attack
SDI Acquisition / Testing	FY87–91	• Begin acquisition of phased homeland ballistic missile defense system
GPALS	FY91–93	• Begin acquisition of defenses against limited attack
Shift to TMD	FY93–96	• Develop field theater missile defenses • Continue NMD as technology readiness program • Discontinue space-based intercept layer
NMD Development	FY96–98	• Concept development • Initial testing and preparation for possible limited deployment
NMD Deployment Readiness	FY98–00	• Deployment Readiness Review Report • 2000 Deferral of Deployment Decision
ABM Treaty Withdrawal	FY01	• Decision announced December 2001, withdrawal effective June 2002 • MDA creation 2002
Test Bed	FY02–04	• Test bed construction (Vandenberg AFB) • Build, test, and verify Initial Defensive Capability concurrent with Initial Defensive Operations • Incrementally improve capability
Mission Readiness Task Force (MRTF)	FY05–06	• Increase test realism • Verify booster and reduce risk • Test to verify rather than test to discover
Affordability Focus	FY06–08	• 10 additional silos at Fort Greely • 10 GBIs at European third site with 2-stage variant • Midcourse radar in Czech Republic • Upgrade Thule EWR

Table 2.4.

Phase	Time Frame	Goals
Presidential Mandate: Redirection	FY09	• Refocus on improving confidence through realistic testing • Limit fielding to 30 GBIs • Expand BMDS capability with EPAA
Return to Intercept	FY10–14	• FTG-06a failure resolved with successful tests • GBI reliability improvements • Missile Field 2 completion • Development and sustainment contract (DSC) award and transition
Secretary of Defense Mandate: 44 by 17	FY13–17	• Increase operational GBI fleet from 30 to 44 by CY 2017 • Missile Field 1 refurbishment • Interceptor reliability enhancements

GBIs for the purpose of testing and as operational spares. As a result, the future testing regime will reduce the number of operationally available GBIs to below 44.

The 2013 report also highlighted the potential for expanding interceptor capacity at Fort Greely well beyond the planned 44 interceptors, with “an additional 20 or more GBIs,” including a mix of two- and three-stage interceptors. The report noted that Fort Greely was originally designed to hold up to 100 interceptors spread across five fields. This latent potential for expansion makes a more “attractive option” for adding interceptor capacity, at least relative to the construction of a new East Coast site.[136] The administration did not, however, initiate any further expansion at Fort Greely. The recommendations of the 2013 report that have not yet been acted on are among the logical next steps for further expansion.

136. Department of Defense, “Homeland Defense Hedging Policy and Strategy,” 4–5.

03

The State of Homeland Missile Defense Today

Today's homeland missile defense efforts rest on an integrated system encompassing a wide range of sensors, interceptors, and command and control mechanisms. Since late 2004, these have provided a limited defensive capability against an unsophisticated ICBM threat posed by countries like North Korea and Iran. The system is currently optimized for North Korean threats, and past decisions have de-emphasized sensors and interceptor placement advantageous to countering long-range Iranian missile development, especially against the East Coast of the United States.

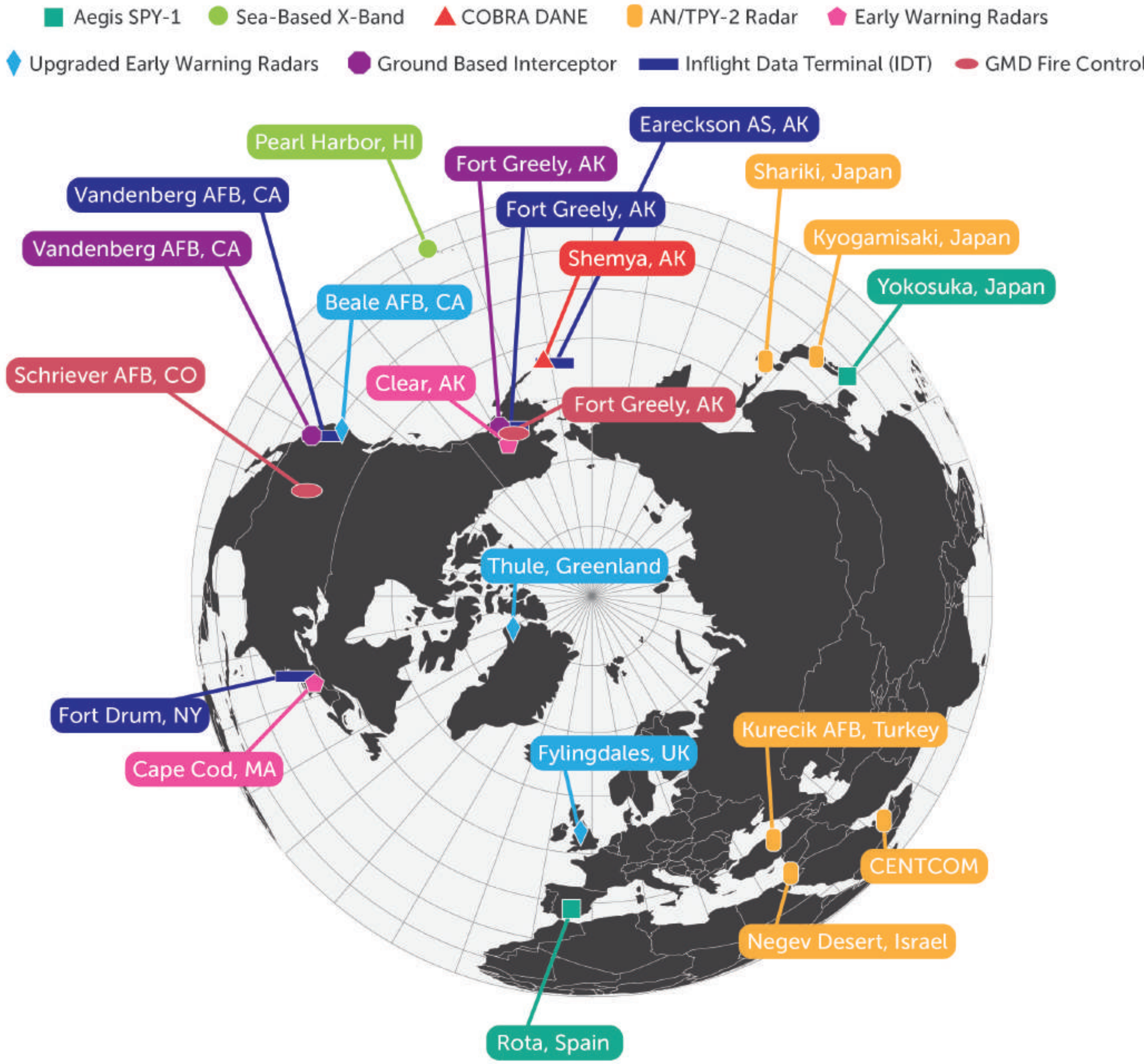
The current Ground-based Midcourse Defense (GMD) system is, however, also burdened with numerous interceptor configurations, older ground system hardware and software, and lower reliability. The qualitative improvements that were planned and expected to follow the initial defensive capability have not yet come to pass. Significant improvements are currently under way to address these issues, most notably with near-term improvements to discrimination, a redesigned kill vehicle, and improved sensors. Longer-term advanced technology programs, such as investments in directed energy and volume kill, are once again being explored after a hiatus of several years.

GMD and its associated systems span 15 time zones, including interceptors at two locations, seven types of sensors on land, sea, and space, and multiple and distributed fire control systems (see Table 3.1 and Figure 3.1). The challenge of deploying this global architecture in short order involved stitching together preexisting sensors and shooters from a wide array of Cold War–era systems that had not originally been designed for the mission.

Much of the technology employed in the Ground-based Interceptor (GBI) and its kill vehicle also stems directly from research and development done during the 1990s. These efforts were scrupulously designed to be compliant with the ABM Treaty, which had restricted the testing and development of interceptors to fixed, silo-based launchers and restricted the deployment of missile defense radars to within 150 kilometers from the interceptor sites themselves.[1]

1. U.S. Department of State, "Treaty between the United States of America and the Union of Soviet Socialist Republics on the Limitation of Anti-Ballistic Missile Systems," Article III, May 26, 1972.

Figure 3.1. Homeland Missile Defense Assets



The 2002 decision to field a limited defense capability by 2004 left little choice but to embrace and adapt these systems in prototype form. This left the initial GMD configuration with several deficiencies, most notably the lack of fully integrated, geographically dispersed radars. It also presented the daunting challenge of simultaneously fielding an operationally viable system while still developing many of its component elements and weeding out technical flaws in the system overall.

The United States has since made considerable progress in filling some of these gaps. Development of the Sea-based X-band (SBX) radar, upgrades to the Early Warning Radars, integration of Aegis SPY-1, and forward-based TPY-2 radars have greatly improved tracking and discrimination. The regime of GBI flight and intercept testing uncovered a number of system design flaws, some

Table 3.1. GMD at a Glance—Operational Elements

<table>
<tr><th></th><th colspan="2">Current Capabilities / Assets</th></tr>
<tr><td>Interceptors</td><td colspan="2">20 CE-Is
16 CE-IIs</td></tr>
<tr><td>Missile Fields</td><td colspan="2">Fort Greely, AK
• Missile Field 1: 6 silos (under refurbishment)
• Missile Field 2: 14 silos
• Missile Field 3: 20 silos

Vandenberg AFB, CA
• 5 silos (4 operational, 1 test silo)</td></tr>
<tr><td>Sensors</td><td>TPY-2 Radar
• Kyogamisaki, Japan
• Shariki, Japan
• Turkey
• Israel
• CENTCOM

Sea-based X-band Radar (Honolulu)
Aegis BMD SPY-1 Radar (33 ships)
Cobra Dane Radar (Shemya, AK)</td><td>Upgraded Early Warning Radar
• Beale AFB, CA
• Fylingdales, UK
• Thule, Greenland
• Clear AFS, AK (planned early 2017)
• Cape Cod, MA (planned 2018)

Defense Support Program Satellites
Space-Based Infrared System</td></tr>
<tr><td>Command and Control, Launch Support</td><td>GMD Fire Control (GFC)
• Schriever AFB, CO (2)
• Fort Greely, AK (2)

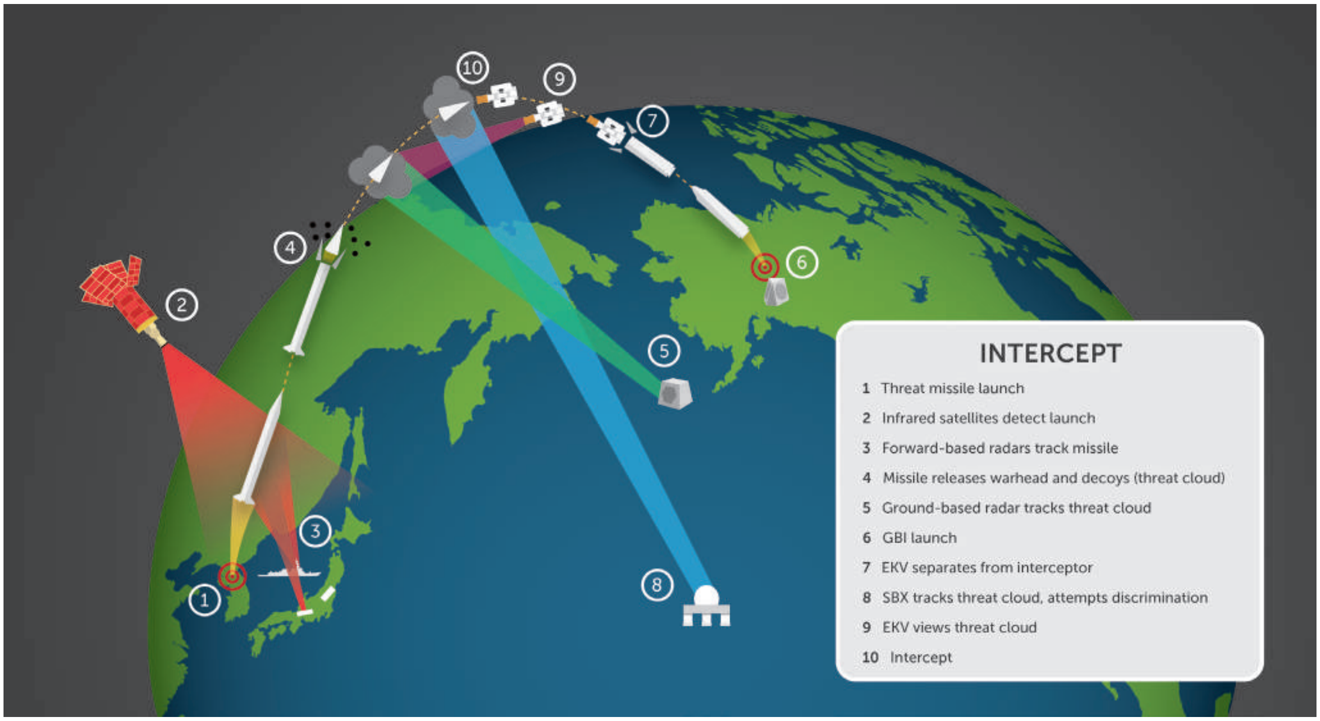
C2BMC Spiral
Fire Direction Center
• Fort Greely, AK

IDTs
• Vandenberg AFB, CA (2)
• Fort Greely, AK (2)
• Fort Drum, NY (1)
• Eareckson Air Station, AK (1)</td><td>Training Centers
• Schriever AFB, CO
• Fort Greely, AK

Command Launch Equipment (CLEs)
• Vandenberg AFB, CA
• Fort Greely, AK

Defense Satellite Communications System (DSCS)
• Fort Greely, AK
• Schriever AFB, CO</td></tr>
</table>

Figure 3.2. GMD Intercept Sequence



as simple as an error in a line of software code. Others, such as the "track gate anomaly," required significant efforts to investigate and correct.[2]

Despite much progress, the system remains in what might be described as an advanced prototype form, still owing much to technologies and a basic design dating from the 1990s. The evolving requirements of simultaneously developing, fielding, maintaining, and upgrading a complex, operational system have also resulted in a patchwork of kill vehicle types, lacking in uniformity with a high number of possible failure points. Less reliability also means a higher shot doctrine, which directly reduces the effective magazine.

HOW HOMELAND MISSILE DEFENSE WORKS

Upon the launch of a hostile long-range ballistic missile, a network of infrared satellites alerts the system, which cues another network of ground- and sea-based radars. These classify the threat, determine its trajectory, and compute a firing solution. One or more GBIs are then launched, which today are comprised of a three-stage booster carrying an Exoatmospheric Kill Vehicle (EKV). Terrestrial radars continue tracking the target missile, sending information into the GMD Fire Control (GFC), which is fed to the interceptor via one of six active In-Flight Interceptor Communications System (IFICS) Data Terminals, or IDTs, located throughout the United States.

2. James D. Syring, "Homeland Defense" (speech, 2014 Space and Missile Defense Symposium, Huntsville, AL, August 13, 2014).

Table 3.2. Current and Future Phases of GMD Evolution

Phase	Time Frame	Capability Goals
Enhanced Homeland Defense (EHD)	FY16–FY18	• 44 Ground-based Interceptors by end of CY17. • Reliability enhancements to EKV (8 upgraded CE-II and 8 CE-II Block 1)
Robust Homeland Defense (RHD)	FY18–FY21	• Complete development of Redesigned Kill Vehicle (RKV) and begin production/deployment • Integration of KV to KV communications, on-demand communications for RKV • Complete development of 2- or 3-stage selectable booster upgrade for C1, C2, and C3 boosters • Integration of Long Range Discrimination Radar in BMDS
Advanced Homeland Defense (AHD)	FY21+	• Development of Multi-Object Kill Vehicle (MOKV) • Advanced air- or space-based electro-optical/infrared (EO/IR) sensors • Improved track and discrimination software for BMDS radars

As the incoming missile begins to separate and deploy decoys, higher-resolution radars such as the SBX attempt to identify, or discriminate, the lethal warhead from within the accompanying cloud of debris and decoys. Data from these sensors are then fed to the interceptor. Upon burnout of the GBI's final stage, the kill vehicle separates and activates infrared and electro-optical sensors to locate the warhead. Using its Divert and Attitude Control System (DACS), the EKV maneuvers itself into the path of the warhead and collides with it, destroying it with the force of impact. Sensors then conduct a kill assessment to determine if the threat was destroyed or if additional interceptors are required. If the threat is not destroyed, and if time permits, a new firing solution can be formulated for an additional interceptor salvo.

ROADMAP FOR FUTURE EVOLUTION

To improve capacity and reliability, MDA's current path forward is roughly divided into three phases: Enhanced, Robust, and Advanced.[3] Although the phases overlap in terms of technology development, they reflect sets of development and deployment goals (Table 3.2).

3. Missile Defense Agency, "Roadmap for the Ground-based Midcourse Defense System" (report to Congress, February 15, 2016), 4–5.

Enhanced Homeland Defense

The first of these three phases is currently under way, under the umbrella of Enhanced Homeland Defense (EHD). Efforts to field 44 GBIs are on schedule to be completed by the end of calendar year 2017. That fleet of 44 will include a mix of three EKV configurations: 20 CE-Is, 16 CE-IIs, and 8 CE-II Block 1s (Figure 3.3).

During this period, MDA plans to only conduct two intercept tests. The first will fly a CE-II Block 1 EKV against an ICBM-class target in FY 2017. The second, slated for the end of 2017, will test a salvo of two interceptors (CE-I and CE-II), also against an ICBM-class target. MDA is also currently planning its first nonintercept flight test of an RKV with a two-stage/three-stage selectable booster in mid-2018, but slower development of either component would delay this timeline.

Robust Homeland Defense

The centerpiece of the Robust Homeland Defense (RHD) phase is the RKV, which will build on the lessons learned from nearly two decades of EKV fielding and testing. Although not a dramatic departure from the EKV in form or function, the RKV will have greater modularity, simplifying maintenance and upgrades while also reducing cost and points of failure. Some of these improvements will draw on existing capabilities found, for example, in the Standard Missile. Initial work is also under way to field the LRDR at Clear Air Force Station (AFS) in Alaska, with an expected delivery date in 2020 and operational capability sometime thereafter.[4]

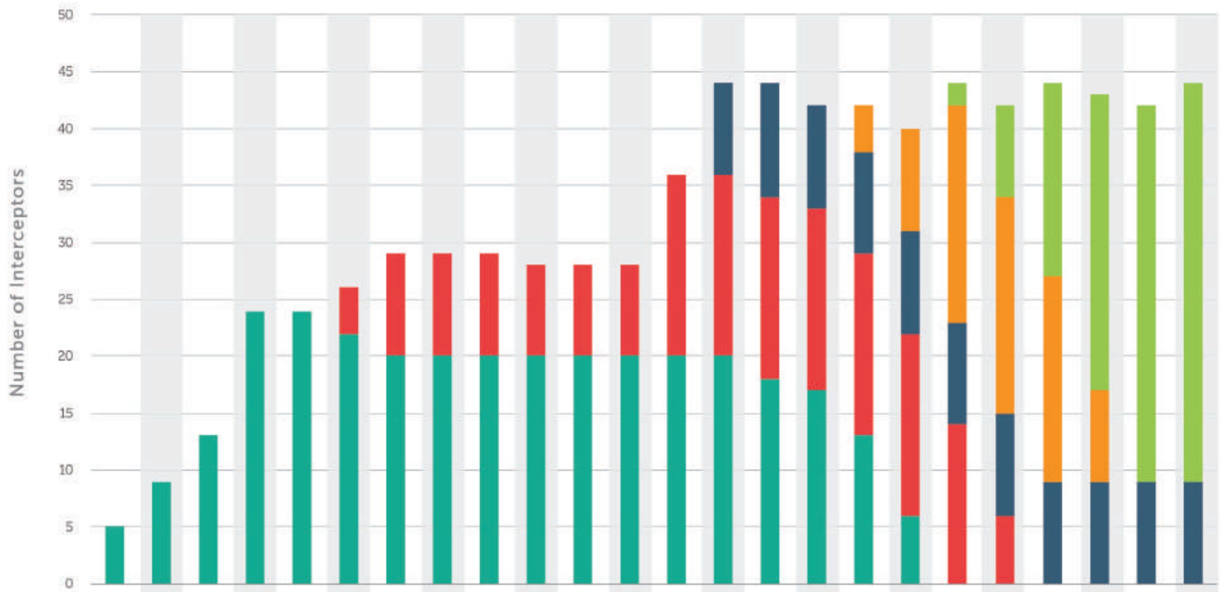
Another element of RHD concerns modifications to the booster. The planned changes will allow the warfighter the flexibility to select a two- or three-stage booster at will. One or the other may be preferable depending on when the interceptor is launched and where the threat missile is intended to be engaged. Currently deployed C1 and C2 boosters all have three stages, which limits them to longer range shots—all three stages must burn before the EKV may be deployed and engage an incoming missile. The ability to "shut off" or simply not fire the third stage, while not as optimal as a simple two-stage booster, will give the warfighter additional flexibility in firing doctrine and move toward a shoot-look-shoot ability.

MDA plans to begin recapping the GBI fleet with RKVs on existing C1 boosters after 2020. This effort will replace 19 of the oldest CE-I EKVs with RKVs, followed by recapping and reboosting the 16 CE-II EKVs with RKVs and the C3 booster upgrade between 2022 and 2024. The final tranche of work will be reboosting the original 19 GBIs with C3 boosters, between 2024 and 2027. Should this plan be fully realized by mid-2027, the fleet of 44 GBIs will consist of only two types; 35 equipped with RKV and C3 boosters, and 9 equipped with CE-II Block 1s atop C2 boosters (Figure 3.3).[5]

4. James D. Syring, "The Missile Defeat Posture and Strategy of the United States—The FY17 President's Budget Request" (unclassified statement before the House of Representatives Armed Service Committee, Strategic Forces Subcommittee, April 14, 2016).

5. Missile Defense Agency, "Roadmap for the Ground-based Midcourse Defense System," 4–5.

Figure 3.3. GBI Fleet Evolution: Past and Projected Deployments, 2004–2027



Fiscal Year	'04	'05	'06	'07	'08	'09	'10	'11	'12	'13	'14	'15	'16	'17	'18	'19	'20	'21	'22	'23	'24	'25	'26	'27
RKV (C3 Booster)																			2	8	17	26	33	35
RKV (C1 Booster)																	4	9	19	19	18	8		
CE-II Block 1														8	10	9	9	9	9	9	9	9	9	9
CE-II						4	9	9	9	8	8	8	16	16	16	16	16	16	14	6				
CE-I	5	9	13	24	24	22	20	20	20	20	20	20	20	20	18	17	13	6						

The RHD phase testing regimen is expected to include two intercept tests of RKVs with two-stage/three-stage selectable boosters, scheduled to take place in spring of 2019 and 2020. A third intercept test in the spring of 2021 will fly a two-interceptor salvo (RKV and CE-II Block I).[6]

Advanced Homeland Defense

In addition to the "enhanced and "robust" phases, MDA is making early investments in next-generation systems falling under the heading of Advanced Homeland Defense (AHD). The focal point of the "advanced" effort is the development of a Multi-Object Kill Vehicle. The MOKV concept is to equip a single GBI with multiple, smaller kill vehicles, as opposed to the single, large kill vehicle the GBIs currently employ.

Between 2022 to 2027, MDA plans one test per year of the RKV atop two-stage/three-stage selectable boosters, for a total of six intercept tests during the AHD phase.

POTENTIAL PITFALLS

Although MDA's current roadmap offers a cogent path forward, it also appears to include several potential shortcomings or limitations that have the potential to increase risk and cost or to decrease capacity and capability.

6. Ibid.

Procurement Gap

The first potential obstacle is the multiyear production gap between the batch of kill vehicles currently being emplaced and future ones. After the CE-II Block 1s are produced to reach 44 by 2017, no procurement of interceptors is planned until RKV goes into production, which could be 2020 or later. This gap will present challenges for maintaining an active production line and maintenance capability, and restarting it after several years of inactivity could be difficult. This lack of continuity could further increase cost and time when RKV goes into production. A decision to accept the gap would also mean accepting delays and cost for additional kill vehicle production should threats grow and greater capacity be required before RKV is fielded.

Capacity Dip

The second limitation in MDA's current plan is an underappreciated reduction in near-term capacity. Although MDA and the Department of Defense frequently tout the "44 by 17" milestone, this phrase belies the fact that the number of fielded interceptors will then go down shortly thereafter. The planned production gap will coincide with a dip in the number of operationally deployed interceptors, resulting in only 40 deployed interceptors by 2021 (Figure 3.3). The 10 percent reduction in capacity is a result of expending GBIs in tests without replacing them, or more precisely the absence of operational or testing spares as had been identified in the 2013 *Homeland Defense Hedging Policy and Strategy* report to Congress.[7] Additional rounds may be unavailable at any given time as they are taken in and out to recap the kill vehicles or upgrade the boosters. In a practical sense, current plans presuppose that the number of operationally available GBIs will be 40 or less in 2021.

Newest Kill Vehicles Atop the Oldest Boosters

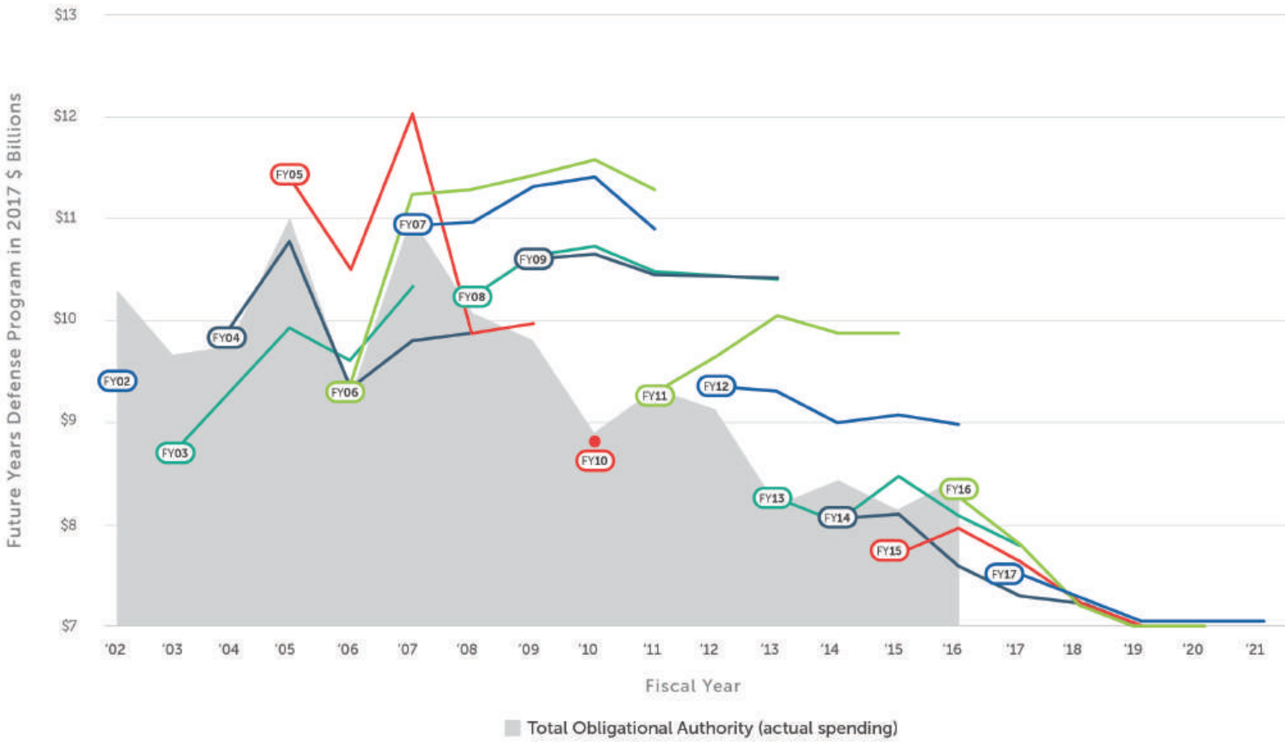
A third limitation is that under the current plan, the first RKVs produced in the 2020 time frame will go onto the older C1 boosters. C1 boosters have known reliability issues, including certain components that have reached obsolescence for which replacement parts can no longer be procured. Putting the newest kill vehicles atop the oldest boosters has the potential to undermine some of the reliability gains from RKV for several years.

Sensor Gaps

The final limitation concerns the lack of a persistent space-based sensor layer that has been a mainstay of every homeland missile defense architecture design across five administrations. Additional shortfalls include the midcourse discrimination gap over the Pacific which LRDR will not completely close, greater reliance on a fewer number of X-band radars, and the lack of an LRDR-like sensor for the Atlantic for threats from the Middle East.

7. U.S. Department of Defense, "Homeland Defense Hedging Policy and Strategy" (report to Congress, June 2013).

Figure 3.4. MDA Actual Spending and Future Year Defense Plans, 2002–2021



$ in Billions	FY02	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14	FY15	FY16
Then-Year	7.6	7.3	7.6	8.8	7.7	9.4	8.8	8.6	7.9	8.4	8.4	7.7	8.7	7.9	8.3
Inflation Adjusted	10.3	9.6	9.7	11.0	9.3	11.0	10.1	9.6	8.9	9.3	9.1	8.2	8.4	8.1	8.5

GMD BUDGET TRENDS

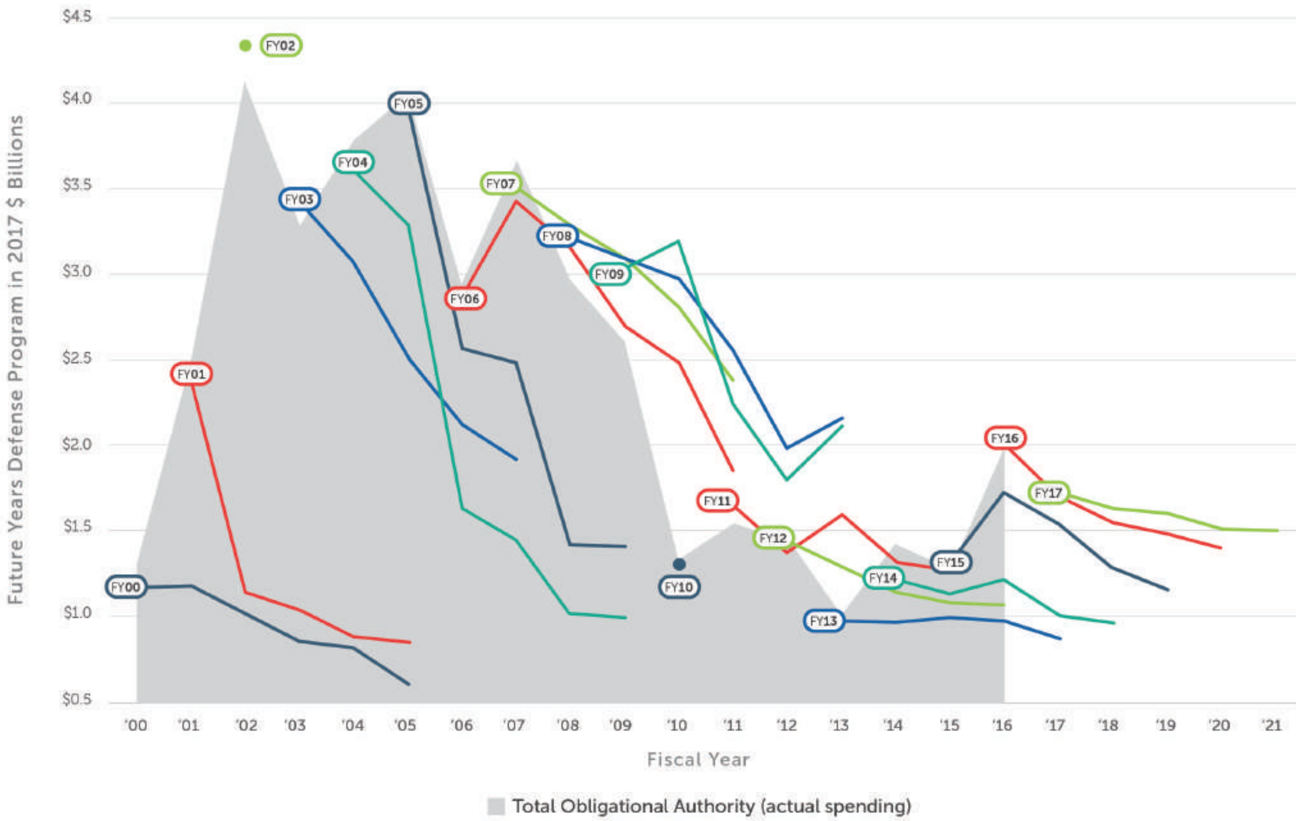
The story of homeland missile defense is also a story of budgetary decline, at least over the past decade. In general, the declining amounts for homeland missile defense (Figure 3.5) correlate to MDA's overall funding level (Figure 3.4).

Downward Pressure

Every year from 2006 to 2013, MDA as a whole received less in topline funding than the previous year projection. Over the past decade, between 2007 and 2016, a consistent trend emerges in homeland-specific programs and in missile defense funding overall (in adjusted 2017 dollars):

- MDA's topline: 23.4 percent decline, from $11 billion to $8.4 billion (Figure 3.4)
- Overall homeland missile defense: 46.5 percent decline, from $3.7 billion to $2 billion (Figure 3.5)
- GBI development: 35 percent decline, from $1.2 billion to $794.2 million (Figure 3.6)
- GMD base budget RDT&E: 53.6 percent decline, from $2.8 billion to 1.3 billion (Figure 3.7)
- GMD testing: 83.5 percent decline, from $400.6 million to $65.8 million (Figure 4.3)
- Homeland-related advanced technology: 60 percent decline, from $1.3 billion to $513.3 million (Figure 6.1)

Figure 3.5. Homeland Actual Spending and Future Year Defense Plans, 2000–2021



$ in Millions	FY00	FY01	FY02	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14	FY15	FY16
Then-Year	945	1,824	3,074	2,491	2,944	3,253	2,440	3,119	2,577	2,291	1,180	1,397	1,327	947	1,356	1,227	1,956
Inflation Adjusted	1,318	2,484	4,121	3,277	3,780	4,048	2,941	3,660	2,962	2,603	1,329	1,542	1,439	1,010	1,421	1,269	1,991

Programs include: GMD base, MKV/MOKV, SBX, Improved Homeland Defense Interceptors, LRDR, and GMD Test.

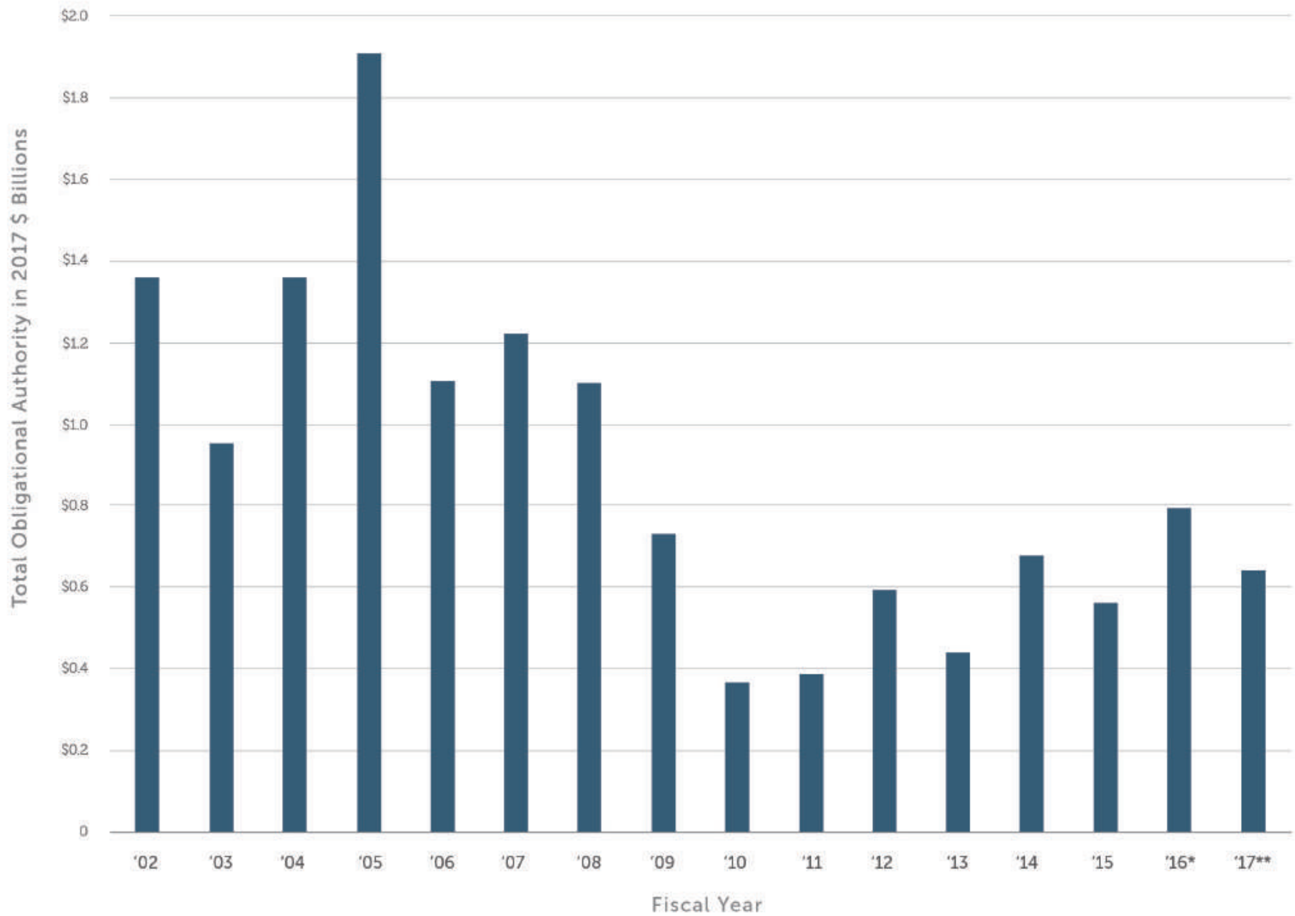
Comparing topline MDA spending to the projected Future Years Defense Program (FYDP) of the previous year's request also indicates budget instability and therefore difficulty with long-term planning. The shortfalls between enacted funding levels and previously FYDP projections can have a corrosive effect on programs. Occasionally, this has even included reductions for particular programs after the appropriations process had concluded. In 2011, for example, GMD received $100 million less than the amount originally enacted by Congress, including a cut of $94 million to BMDS level testing, due to congressional reductions and rescissions based on different DoD priorities.[8]

Caps put in place by the Budget Control Act of 2011 also played a part in this downward budget pressure.[9] In 2013, budget caps took effect and MDA funding fell to $7.7 billion, including a cut of $668 million in the third quarter of 2013 due to sequestration, the impact of which is still being felt

8. Missile Defense Agency, "Missile Defense Agency (MDA) Exhibit R-2 RDT&E Budget Item Justification," *Fiscal Year (FY) 2013 Budget Estimate: Missile Defense* Agency (February 2012), 2a-72.

9. Todd Harrison, *Defense Modernization Plans through the 2020s: Addressing the Bow Wave* (Washington, DC: CSIS, 2016), 2.

Figure 3.6. GBI Research, Development, Test, and Evaluation Budget, 2002–2017



*Based on FY 2016 enactment.

**Based on FY 2017 presidential budget request.

today.[10] A series of deals in Congress have kept actual funding above the original budget cap levels each year, including a return to an $8.3 billion topline in the 2016 enactment.[11]

The comparison of FYDP projections to actual spending on GMD and associated homeland missile defense programs demonstrates a similar trend of reduced toplines over time. Gaps between expected and actual funding levels began to show up in FY 2008, although the year-to-year discrepancies are less pronounced than for MDA as a whole.

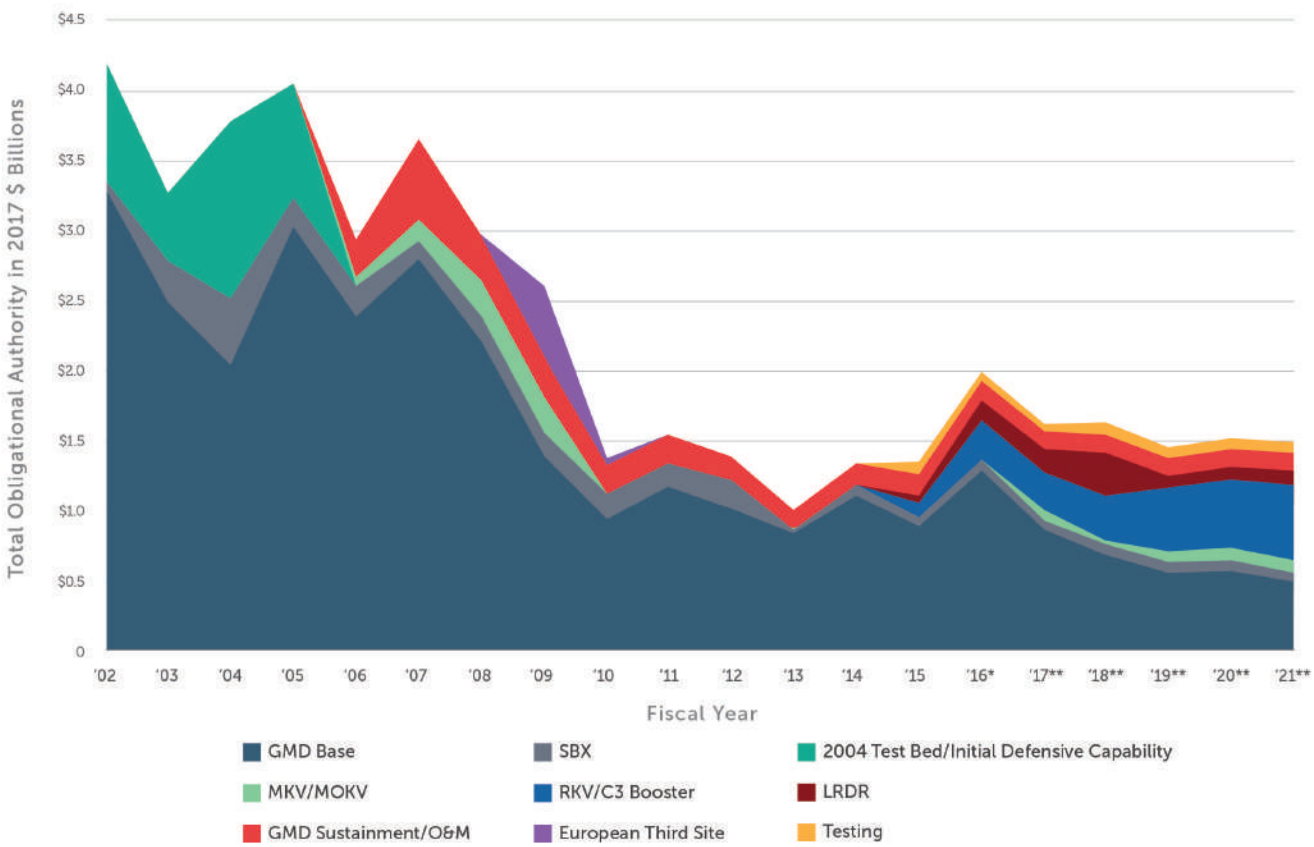
GMD and the Color of Money

Even more so than other components of the BMDS, the characteristics of GMD funding are distinct relative to other defense acquisition programs. This is due in large part to the special

10. Jeff Sessions, "Ballistic Missile Defense Policies and Programs" (remarks during hearing of the Senate Armed Services Committee, Subcommittee on Strategic Forces, 114th Cong., 2nd sess., April 13, 2016).

11. These include the American Taxpayer Relief Act of 2012, the Murray-Ryan compromise budget deal, and the Bipartisan Budget Act of 2015.

Figure 3.7. GMD Program Components, 2002–2021



*Based on FY 2016 enactment.
**Based on FY 2017 presidential budget request.

budgetary authority granted MDA to facilitate both rapid deployment of a limited homeland defense capability and continued evolution of an operational system.

This flexible acquisition authority has allowed MDA to use RDT&E money for activities that might otherwise be classified as procurement, military construction, or operations and maintenance (O&M). Retaining nearly all GMD activities within RDT&E allows for greater flexibility to redirect funds between and among subaccounts. To date, nearly all GMD funding has fallen under RDT&E. Whereas procurement for THAAD, Aegis, and other programs has begun to be moved to the procurement account, to date GMD "procurement" funding has remained exclusively within RDT&E. The exception is GMD's O&M, which has been classified as such since 2014.

Even separating out early "procurement-like" investments for initial defensive capability, however, GBI-specific RDT&E has continued to fall significantly (Figure 3.6).[12] Between 2002 and 2009, total GMD funding averaged $3.4 billion (2017 dollars) per year. Between 2010 and 2016 that average dips to $1.4 billion (2017 dollars) per year. Recent years and the projections into the FYDP show a slight rebound in funding for GMD and associated programs like Improved Homeland Defense

12. Includes MKV, MOKV, Test Bed GBI, and Improved Homeland Defense Interceptors.

Interceptors (which funds RKV and C3 booster development) and the LRDR. Homeland missile defense–related spending is not simply synonymous with the GMD budget, but the more complete picture of relevant programs also reflects steady decline (Figure 3.7).

The proper classification of GMD O&M beginning in 2014 is relevant to showing that operations will be a major cost driver in the future. MDA's projections for its internal O&M budget continue to rise, but future O&M responsibilities could outpace MDA's budget projections. Based on historical trends, O&M funding needs to grow at about 3 percent above inflation to meet current needs.[13] The MDA overall FYDP between 2017 and 2021 currently projects an average of 3 percent annual growth for O&M after inflation. For GMD, however, the average rate of change for O&M actually declines by 0.6 percent per year over the FYDP, suggesting that O&M costs may exceed projected levels.

By the end of 2017, there will be over a 50 percent increase in deployed GBIs relative to just a few years before, from 28 to 44. Non-GMD assets for homeland defense will also see additional expansion. Fort Greely will have a new missile field coming online in 2017, the LRDR will come online after 2020, and at-sea deployment time for the SBX could well rise for either testing or relocation to the East Coast of the United States or potentially eastern Canada. As homeland defense components grow, O&M will likely to continue to rise too, possibly at a rate greater than currently budgeted in the MDA's FYDP.

It is worth noting that the GMD program has never actually spent a single dollar classified as procurement, despite substantial "procurement-like" activity. Interceptors have been bought with funds from the RDT&E account. In 2016, GMD had for the first time a procurement line in the FYDP submitted to Congress, beginning with 2017. The procurement line for GMD later disappeared and that money was moved back into RDT&E, specifically into the Improved Homeland Defense Interceptors line.

At MDA's creation, its task was to develop and field missile defense systems with the intention of then transitioning them to the Services. PATRIOT, for instance, was returned from MDA to the U.S. Army in 2003. Full responsibility for procurement and operating costs for THAAD may eventually transition to the Army, and Aegis/SMs to the Navy. GMD, however, poses a more challenging question as to which service, if any, should assume responsibility for ongoing operations and budgeting. Budget responsibility for GMD is therefore more likely remain with an entity like MDA.

13. Todd Harrison, *Analysis of the FY 2017 Defense Budget* (Washington DC: CSIS, 2016), 20–22.

04

Ground-based Interceptor Development

Perhaps the most recognizable component of homeland missile defense is the Ground-based Interceptor (GBI) itself, which represents the product of a long line of hit-to-kill interceptors dating back to the 1980s (Figure 4.1). Many of the same basic concepts and technologies that brought the HOE to collide with a dummy warhead in 1984 are still employed in the kill vehicles aboard today's interceptors. The GBI testing regime since 1999 has likewise helped to identify numerous technical issues that have further refined the system. These advancements in hit-to-kill technology have been buoyed by the creation of an integrated network of sensors and command and control infrastructure. As of 2016, there are 36 GBIs deployed, the bulk at Fort Greely, Alaska, and a handful at Vandenberg AFB in California.[1] Some 44 GBIs are expected to be deployed by the end of 2017.[2]

GBI VARIANTS

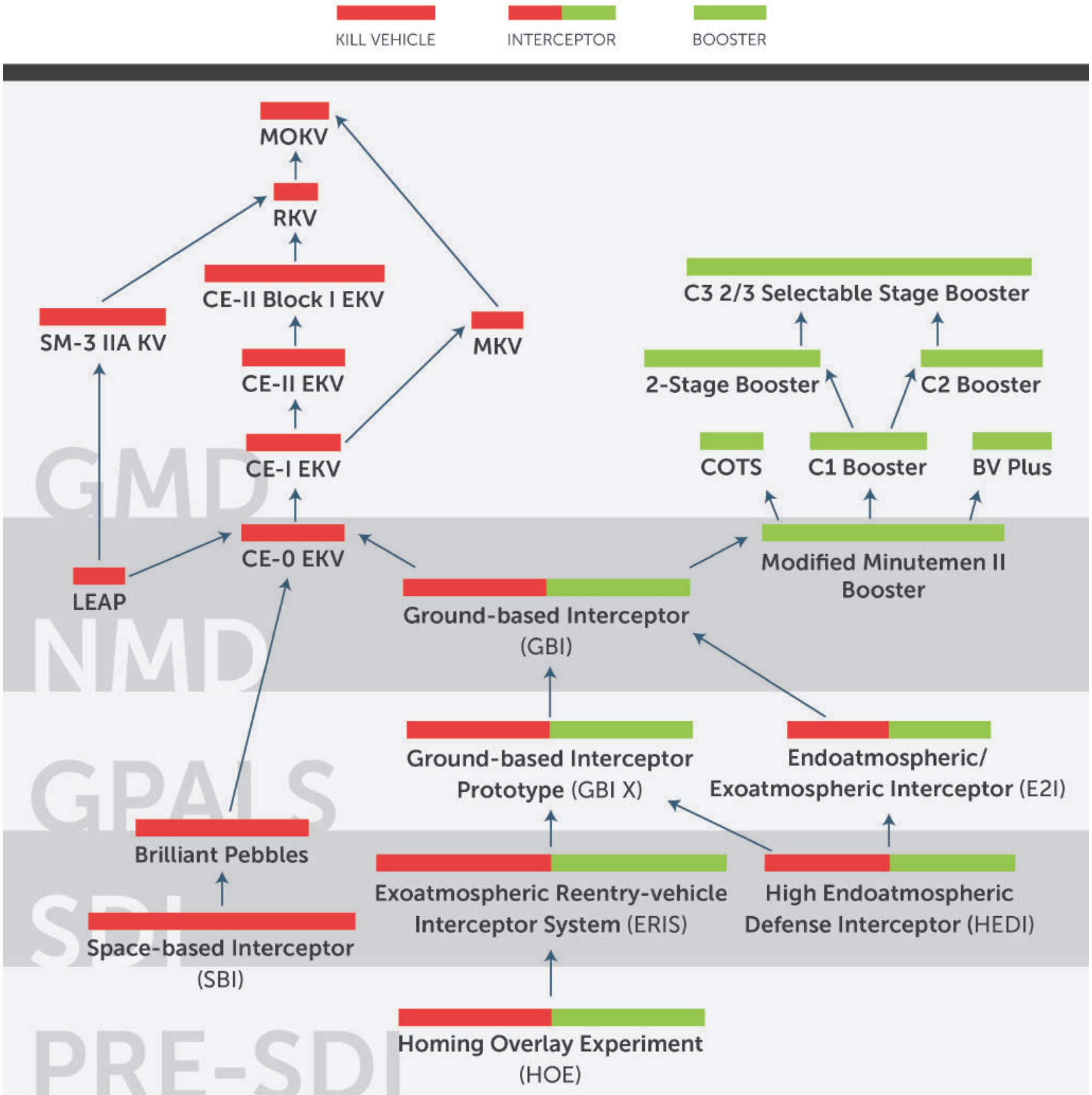
Because the 2002 decision for deployment essentially fielded an advanced prototype, every early kill vehicle was unique, handmade in about 130,000 steps. The gradual progress of modernization and increases in capacity have resulted in a further diversity in the actual interceptors deployed. Five main variants of GBIs are currently fielded, in the process of being deployed, or in development. These vary based on their combinations of the kill vehicle and booster (Table 4.1).

The Redesigned Kill Vehicle (RKV) will decrease both the diversity and complexity across the fleet, aiding in the production and improving reliability. Even after RKV is fully deployed in 2027, however, the planned fleet of 44 will still include nine comparatively older GBIs equipped with CE-II Block 1 kill vehicles.

1. Vandenberg AFB serves as the test bed for the GMD system, from which GBIs are usually launched at targets fired from the Kwajalein Atoll.

2. James D. Syring, "Ballistic Missile Defense System Update" (speech, Center for Strategic and International Studies, Washington, DC, January 20, 2016).

Figure 4.1. Long-range Hit-to-Kill Interceptor Evolution



LIST OF ACRONYMS

CE Capability Enhancement
COTS Commercial off the Shelf Booster
LEAP Lightweight Exoatmospheric Projectile
MKV Multiple Kill Vehicle
MOKV Multiple Object Kill Vehicle
RKV Redesigned Kill Vehicle
SM Standard Missile

Table 4.1. Current and Future GBI Configurations

Model	Kill Vehicle	Booster	2017 Fleet
GBI Block 1	CE-I	C1	20
GBI Block 2A	CE-II	C1	16
GBI Block 2B	CE-II Block 1	C2	8
GBI Block 3A	RKV (in development)	C1	–
GBI Block 3B	RKV (in development)	C3	–

Exoatmospheric Kill Vehicles (EKVs)

Four main variants of the EKV have been tested since GMD began intercept tests in 1999: CE-0, CE-I, CE-II, and CE-II Block 1. The CE-0 name signifies a prototype only used in testing and never deployed. The CE-I is the operationally deployed version of the original prototype. In 2008, MDA began replacing obsolete components on some of the CE-I EKVs, along with other upgrades, which resulted in the CE-II EKV. The CE-II, first tested in January 2010, underwent a reconfiguration based on the results of its intercept and flight testing. The newest variant tested, the CE-II Block 1, features an upgraded set of alternate divert thrusters and is currently being applied to the nine additional GBIs being deployed to Fort Greely.

Booster Vehicles

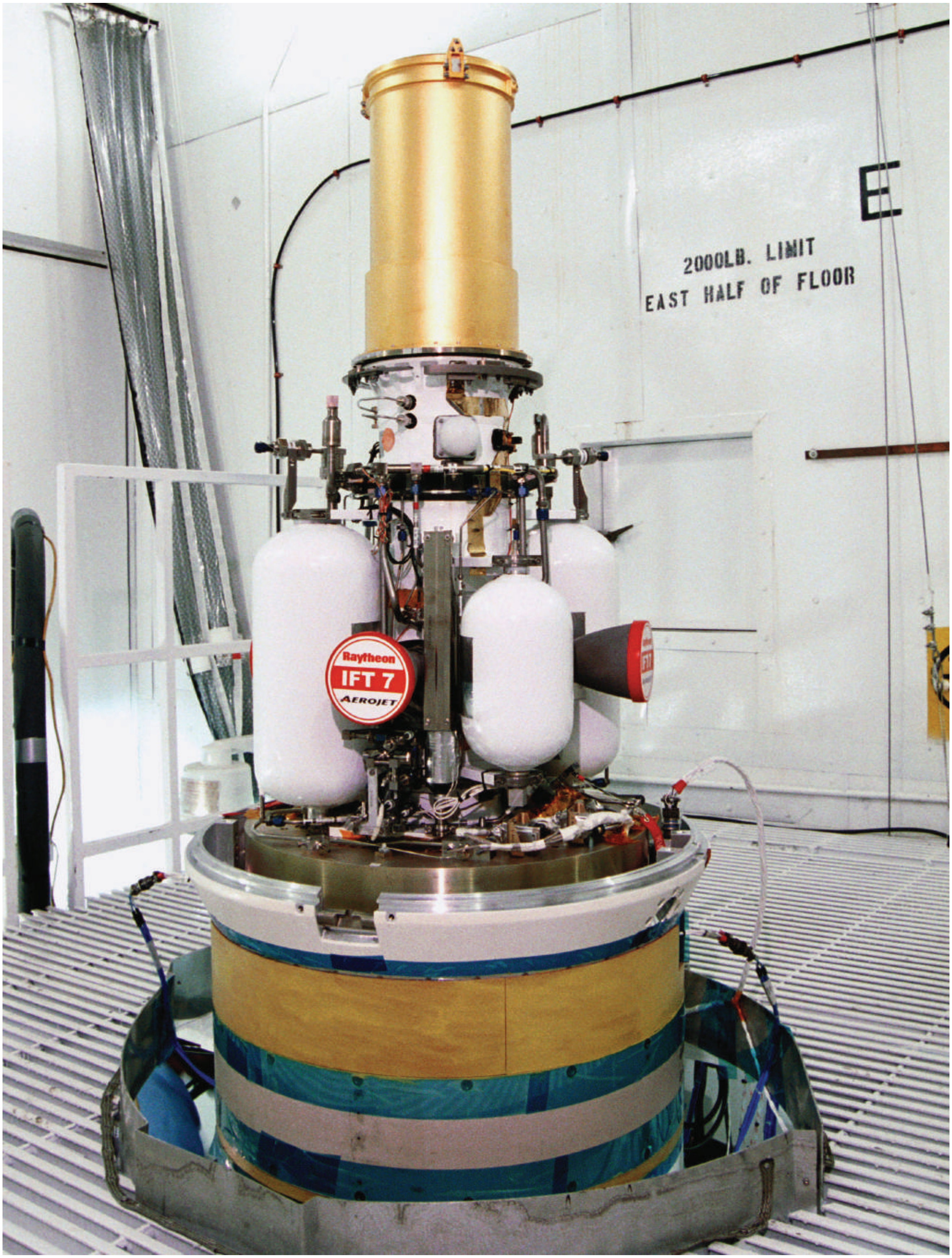
Two variants of booster are present in today's GBI fleet, the C1 and C2, both of which have three stages. The third stage gives the current GBIs extended range, but limits their ability to conduct intercepts later in a target missile's flight, as the third stage must first burn before the EKV can be deployed.

The C1 booster is nearing obsolescence due to lack of available of spare parts. C2 boosters feature an upgraded avionics package to increase reliability, as well as obsolescence upgrades. There are, however, no current plans to upgrade the existing C1 fleet to C2, and the C1 is expected to remain in service into the 2024–2025 time frame.

TESTING AND DEPLOYMENT HISTORY

One of the most important parts of the GMD development effort has been the regime of GBI flight and intercept testing. Intercept tests typically involve the launch of an IRBM or ICBM representative target, followed by the launch of a single GBI to engage it. Other flight tests involve only the launch of an interceptor to prove out kill vehicles or other sensor systems. MDA also carries out various ground and sensor-only tests to exercise GMD's support systems.

Figure 4.2. Exoatmospheric Kill Vehicle



Source: Missile Defense Agency.

Since 1997, there have been 31 GBI flight and intercept tests.[3] When examined together, these tests reveal several basic insights:

- Flight and intercept testing has been among the best ways to discover system flaws not otherwise revealed through ground testing and to validate the fixes meant to resolve them.
- GMD's flight and intercept testing cadence has been irregular, in part due to the need to investigate several test failures and also a decline in the overall GMD testing budget (Figure 4.3).
- The GMD testing regime has not revealed fundamental flaws in the technological foundations behind hit-to-kill missile defense. The vast majority of intercept failures have been the result of inconsistencies in interceptor manufacturing as well "test anomalies," such as malfunctions in test-only equipment, such as with surrogate boosters not originally designed to carry a kill vehicle and with the silos themselves.
- The historical progression of GMD tests reflects significant growth in the number of operational components, particularly the integration of sensors (Table 4.2).
- MDA has made efforts to improve the operational realism of its intercept tests, including with the employment of countermeasures, but it is difficult to assess whether these improvements have made the tests as realistic as they could be.

The following sections describe the history and lessons learned from over 19 years of GBI tests.

Early Testing

The first tests of the EKV were in 1997 and 1998 as part of the National Missile Defense (NMD) program, followed by an intercept test in October 1999.[4] In that test, a CE-0 prototype carried on a modified Minuteman II ICBM successfully collided with a dummy warhead deployed by another modified Minuteman.[5] The target missile reportedly also deployed a decoy balloon, demonstrating a nascent ability for the EKV to discriminate between lethal and nonlethal objects.[6] The test did not involve the use of an external radar. Instead the dummy warhead and decoys were equipped with C-band transponders to signal their locations, approximating tracking information that would have been provided by a ground-based radar.[7]

A follow-on intercept test in January 2000 failed, resulting from blockage within the EKV's coolant system that interfered with the performance of the kill vehicle's seeker. Another test failure occurred in July the same year, a result of a failure in the booster's data bus that prevented the kill vehicle from separating. This failure was somewhat anomalous, as the modified Minuteman

3. This number includes intercept tests involving and GBI and a target, GBI-only flight tests, and GBI booster-only characterization tests. It does not include ground tests and sensor-only tests.

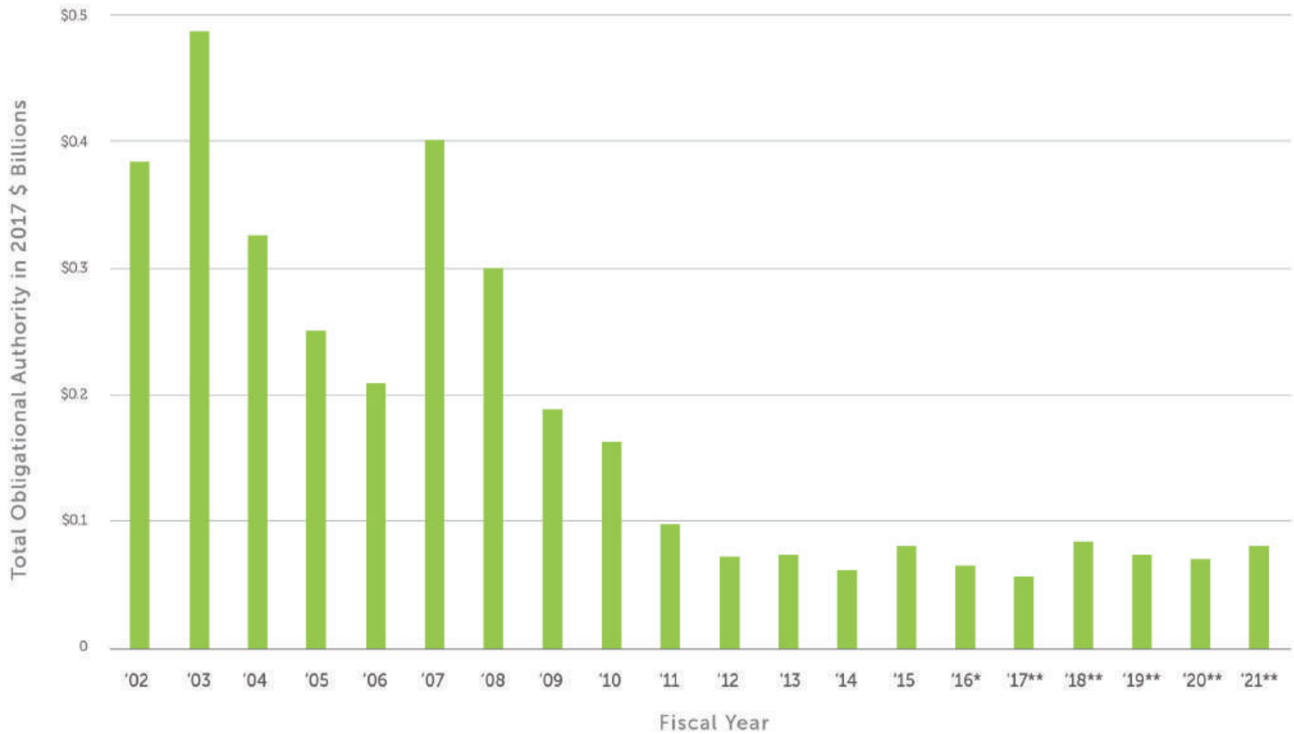
4. Office of the Director, Operational Test and Evaluation (hereafter DOT&E), "FY 2000 Annual Report," February 2001, VI-8.

5. Richard Stevenson, "Missile System Passes a Test as a Target Is Destroyed," *New York Times*, October 4, 1999, http://www.nytimes.com/1999/10/04/us/missile-system-passes-a-test-as-a-target-is-destroyed.html.

6. Ibid.

7. DOT&E, "FY 2001 Annual Report," February 2002, VI-5-7.

Figure 4.3. GMD Testing Budget, 2002–2021



*Based on FY 2016 enactment.
**Based on FY 2017 presidential budget request.

surrogate booster was not originally designed to carry the EKV and would not have been part of any deployed missile defense system.[8] It was nevertheless part of the basis on which President Clinton deferred a deployment decision in late 2000.

These two failed tests were then followed by four confirmed intercepts in a row from July 2001 to October 2002. In each of these intercepts, the target deployed penetration aids to test the system's discrimination capabilities. According to MDA, the October 2002 intercept test contained five objects in the threat cloud, three of which were decoys.[9]

The final test using the CE-0 kill vehicle failed to intercept due to flaws with the Laser Firing Unit, later described as a "very simple, mechanical type of issue."[10]

Concurrent with these early tests of the EKV was the development of a dedicated booster to carry the EKV. This element of the GBI development went through several "fits and starts," with several potential boosters being considered.[11]

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8. James D. Syring, "Homeland Defense" (speech, 2014 Space and Missile Defense Symposium, Huntsville, AL, August 13, 2014).

9. Missile Defense Agency, "Missile Intercept Successful," MDA news release, October 14, 2002.

10. Syring, "Homeland Defense."

11. Ibid. Syring noted that the program "initially started with a Boeing booster program, then went to a . . . varied Lockheed Martin booster program with multiple missions, and then finally setup the Orbital booster program in the 2002 timeframe."

Figure 4.4. IFT-7, December 3, 2001

Source: Missile Defense Agency.

In 2002, the Director of the Operational Test and Evaluation (DOT&E) office identified two main weaknesses of the GBI program and its testing regimen: the lack of a deployable boost vehicle, and the lack of realistic testing. Specifically, the DOT&E report noted that all intercept tests to that point had "similar fly-out and engagement procedures." Further intercept testing was suspended in 2002 until MDA had a dedicated and flight-tested booster.[12]

Limited Defensive Operations

In accordance with President George W. Bush's NSPD-23, MDA began preparing GMD for deployment and initial operations. In January 2004, the Orbital booster achieved a successful simulated intercept, and became MDA's choice for initial deployment.[13] This paved the way for the completion of a new test bed at Vandenberg AFB and the resumption of intercept testing. Initial planning called for six GBIs at Fort Greely and four at Vandenberg AFB by 2004, with another 10 to be in place at Fort Greely by 2005.[14]

Two GBI launch failures in late 2004 and early 2005 (IFT-13c, IFT-14) halted further testing, pending the findings of an independent review team. The December 2004 failure resulted from a booster "software design error in an automated diagnostic check run prior to launch."[15] Another in February 2005 failed to even launch due to a rusted silo arm that failed to fully retract. A defect in the test bed silo caused the malfunction, not an operational silo designed to house the interceptors long-term. MDA characterized both as "built in test anomalies" that did not necessarily reflect failures of the interceptors or the overall GMD system.[16] The 2005 DOT&E report cited "quality, workmanship, and inadequate ground testing . . . as contributing factors."[17]

In response to recommendations of the review panel, MDA conducted a series of nonintercept tests throughout 2005. These included six ground tests, two target-only flight tests to gauge ground radar performance, and one interceptor-only demonstration flight test (FT-1).[18] FT-1 was the first flight test of a GBI tipped with the CE-I kill vehicle. By the end of FY 2005, nine operational GBIs had been emplaced at Fort Greely.[19] Between 2006 and 2008, MDA adopted an annual testing cadence that saw three successful intercept tests of the CE-I EKV and Orbital booster (FTG-02, FTG-03a, FTG-05).

In December 2008, FTG-05 was the first intercept test using track data from multiple BMDS sensors.[20] The interceptor experienced an unidentified malfunction but nonetheless achieved a

12. DOT&E, "FY 2002 Annual Report," 13.

13. DOT&E, "FY 2004 Annual Report," 330.

14. DOT&E, "FY 2002 Annual Report," 12.

15. DOT&E, "FY 2005 Annual Report," December 2005, 258.

16. Syring, "Homeland Defense."

17. DOT&E, "FY 2005 Annual Report," December 2005, 258.

18. Ibid., 257.

19. Ibid.

20. Sensors used in FTG-05 included an A/N TPY-2, A/N SPY-1, the SBX, and the Upgraded Early Warning Radar (UEWR) at Beale.

Table 4.2. GBI Testing History

Flight / Intercept Test	Date	KV	Sensor Systems Employed						Notes	
			UEWR	SPY-1	SBX	TPY-2	STSS	OPIR	Intercept?	
IFT-1	17-Jan-97	CE-0							n/a	Data link malfunction-launch aborted
IFT-1a	7-Jul-97	CE-0							n/a	Flight test only
IFT-2	15-Jan-98	CE-0							n/a	Flight test only
IFT-3	2-Oct-99	CE-0							Y	Single decoy
IFT-4	19-Jan-00	CE-0							N	EKV foreign object coolant blockage
IFT-5	8-Jul-00	CE-0							N	Failed booster separation
BV-1	28-Apr-01								n/a	Vehicle did not launch; Boeing Booster Vehicle
IFT-6	14-Jul-01	CE-0							Y	
BV-2	31-Aug-01								n/a	Boeing Booster Vehicle
IFT-7	3-Dec-01	CE-0							Y	
BV-3	13-Dec-01								n/a	Flight test failure; Boeing Booster Vehicle
IFT-8	15-Mar-02	CE-0							Y	
IFT-9[1]	14-Oct-02	CE-0		•					Y	

(continued)

Table 4.2. (continued)

Flight / Intercept Test	Date	KV	Sensor Systems Employed						Notes	
			UEWR	SPY-1	SBX	TPY-2	STSS	OPIR	Intercept?	
IFT-10	11-Dec-02	CE-0		•					N	EKV failed to separate
BV-6	16-Aug-03								n/a	Successful booster test; Orbital Booster Vehicle
BV-5a	9-Jan-04								n/a	Successful booster test: Lockheed Martin BV+Vehicle
IFT-13b[2]	24-Jan-04			•					n/a	Successful test of Orbital Booster Vehicle
IFT-13c	15-Dec-04	CE-0+		•					N	Failed to launch, software design error
IFT-14	14-Feb-05	CE-0+							N	Failed to launch
FT-01	13-Dec-05	CE-I							n/a	Nonintercept test
FTG-02[3]	1-Sep-06	CE-I	•	•	•			•	Y	
FTG-03[4]	25-May-07	CE-I	•		•	•		•	n/a	No test (target failure)
FTG-03a	28-Sep-07	CE-I	•	•	•	•		•	Y	
FTG-05[5]	5-Dec-08	CE-I	•	•	•	•		•	Y	
FTG-06	31-Jan-10	CE-II	•	•	•			•	N	Missing DACS lock wire, SBX malfunction

Table 4.2.

Flight / Intercept Test	Date	KV	Sensor Systems Employed						Notes	
			UEWR	SPY-1	SBX	TPY-2	STSS	OPIR	Intercept?	
BVT-01	6-Jun-10					•	•		n/a	2-stage booster test only; Orbital Booster Vehicle
FTG-06a	15-Dec-10	CE-II	•	•	•	•		•	N	Track gate anomaly
GM CTV-01	26-Jan-13	CE-II							n/a	Nonintercept test
FTG-07[6]	5-Jul-13	CE-I		•	•		•	•	N	Battery power loss
FTG-06b[7]	22-Jun-14	CE-II		•	•			•	Y	
GM CTV-02+	28-Jan-16	CE-II Block 1			•	•			n/a	Nonintercept test

Note: This table includes GBI flight and intercept tests. MDA conducts numerous other kinds of GMD tests, including sensor-only tests and ground tests. While important, these tests are not listed here.

[1] Edward C. Aldridge Jr., "Ballistic Missile Defense System (BMDS) Integrated Flight Test-9 (IFT-9)," Office of the Undersecretary of Defense, Memorandum, October 14, 2002.

[2] DOT&E, "FY 2004 Annual Report," 330.

[3] DOT&E, "FY 2006 Annual Report," 230.

[4] The FTG-03 test was planned to utilize UEWR, but due to the missile failing before entering the radar's coverage area, no data was collected. Office of Director, Operational Test and Evaluation, "FY 2007 Annual Report," December 2007, 230.

[5] Missile Defense Agency, "Missile Defense Flight Test Results in Successful Intercept," MDA news release, December 5, 2008.

[6] Syring, "Homeland Defense."

[7] James D. Syring, "Ballistic Missile Defense Overview" (slide presentation, 2013 Space and Missile Defense Symposium, Huntsville, AL, August 14, 2013).

successful intercept.[21] By the end of 2008, a total of 24 CE-I GBIs had been deployed, 21 at Fort Greely, with another three at Vandenberg, as well as the completion of the necessary infrastructure, including silos and power needs, to support 30 interceptors between the two sites.[22]

CE-II Reconfiguration and the Track Gate Anomaly

Near the end of 2008, MDA began upgrading obsolete elements of the kill vehicles, primarily the processor and software, as well as making "minor" improvements for producibility.[23] The sum of these alterations resulted in the CE-II EKV. MDA attempted an intercept test with a CE-II EKV in January 2010, but it failed. Test diagnostics identified the cause of the failure as a "missing lock-wire in the DACS" and "undesirable performance of the Sea-based X-band Radar."[24]

The CE-II experienced a second failed intercept in December 2010. This failure was a result of a "track gate anomaly" within the kill vehicle. This anomaly had been a "long historical issue," first noticed in IFT-06 in 2001.[25] Initially thought to be caused by electromagnetic interference, the problem was ultimately determined to be the result of high frequency vibrations within the kill vehicle. Specifically, the vibrations affected the EKV's Inertial Measurement Unit (IMU), which caused the tracks to "shift," resulting in an inaccurate target picture of the incoming warhead (Figure 4.5). Although the anomaly had been known to exist since 2001, the issue had not affected EKV performance until FTG-06, when it corresponded with the inclusion of a more sensitive IMU.

Return to Intercept

Once isolated, MDA corrected the track gate anomaly by updating IMU firmware and adding an isolation "cradle" around the IMU to better shield it from vibration. MDA then conducted a successful interceptor-only EKV characterization flight test, CTV-01, in January 2013. This flight test was then followed by the CE-II's first successful intercept, FTG-06b, in June 2014. Beyond validating the fixes to the IMU firmware, FTG-06b included a target missile that approached ICBM speeds. The EKV also demonstrated the ability to correctly discriminate and intercept a reentry vehicle in the presence of operationally realistic countermeasures.[26]

In January 2016, MDA conducted a nonintercept flight test (CTV-02+) to prove out an upgraded system of divert thrusters, which allow the EKV to maneuver in space. These thrusters were designed to further reduce the effects of vibration of the IMU, the root cause of failed intercept tests in 2010.[27] This upgraded version of the CE-II, designated the CE-II Block 1, also features a redesigned fuel tank for greater producibility and reliability. Although interception was not the goal of

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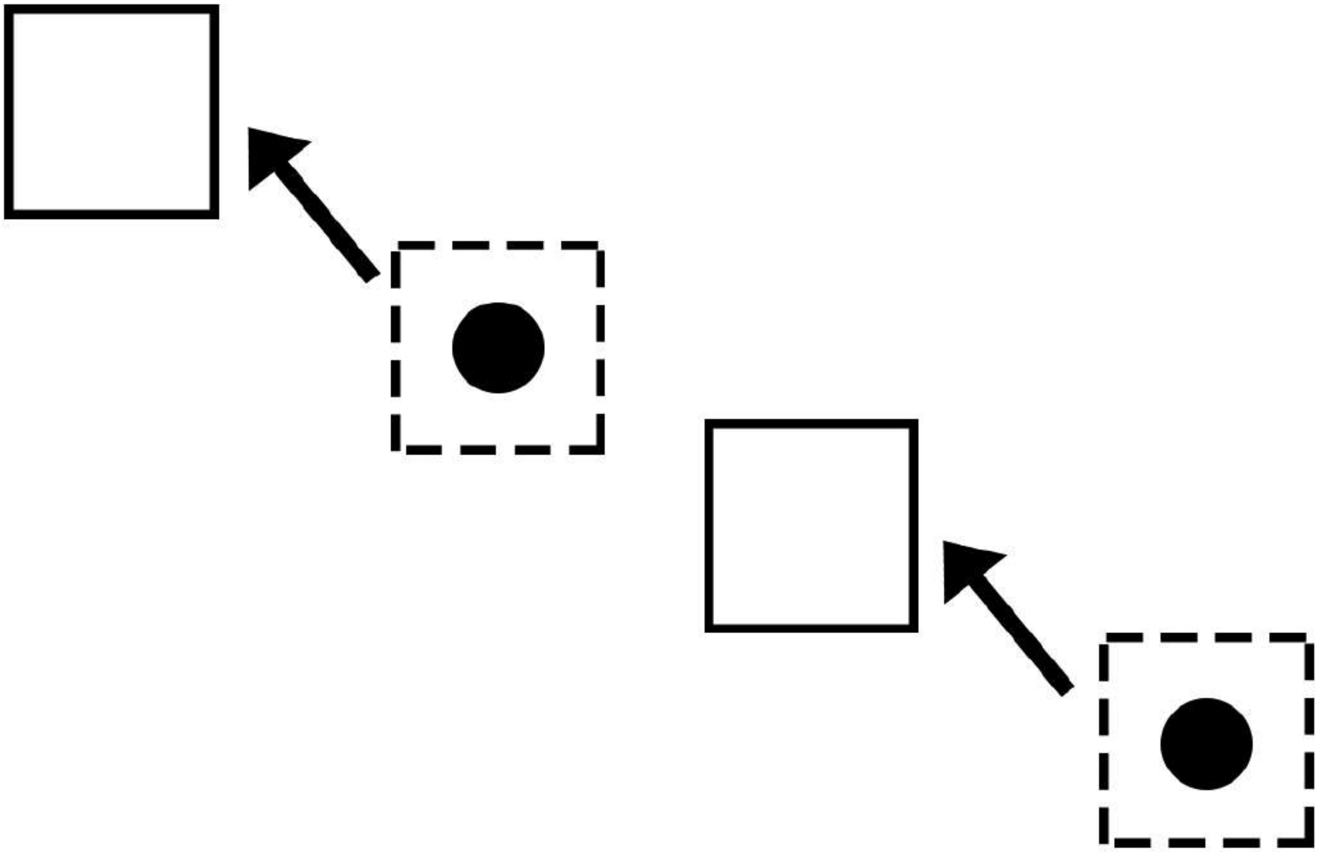
21. Office of the Director, Operational Test and Evaluation, "FY 2009 Annual Report," December 2009, 245.
22. Syring, "Homeland Defense."
23. Ibid.
24. Ibid. See also DOT&E, "FY 2010 Annual Report," December 2010, 234.
25. Syring, "Homeland Defense."
26. Ibid.
27. Syring, "Ballistic Missile Defense System Update."

Figure 4.5. Notional Representation of Track Gate Anomaly



the test, a target IRBM was launched, allowing the sensor network to gather data for future discrimination techniques.

Utility of Testing

GBI testing since 1999 has uncovered several critical shortcomings of the GMD system. In most cases, however, these issues have been indicative of the kind of issues that are to be expected during an engineering cycle (Table 4.3). Indeed, with the exception of the track gate anomaly, no identified malfunction has ever affected the results of more than one test. As MDA Director Vice Admiral James Syring noted in 2014:

> So these were the eight failures that we account for . . . the top five are on the CE-0 venture, [and] again the direction [was] to rapidly field a prototype, but it was a test bed at the time with a design cycle, I would even say half complete. So that, to me, would not be unexpected . . . nothing unexpected in a prototype for a test bed. More issues . . . that you work out in the test phase of a program.[28]

28. Syring, "Homeland Defense."

Table 4.3. GMD Test Failures

Test	Date	Cause
IFT-1	17-Jan-97	Data link malfunction, launch aborted
IFT-4	19-Jan-00	EKV foreign object coolant blockage
IFT-5	8-Jul-00	Failed booster separation, booster avionics package failure
IFT-10	11-Dec-02	EKV failed to separate, failure in laser firing unit
IFT-13c	15-Dec-04	Failed to launch, software design error
IFT-14	14-Feb-05	Failed to launch, silo support arm failure
FTG-06	31-Jan-10	Missing DACS lock wire, SBX malfunction
FTG-06a	15-Dec-10	Track gate anomaly
FTG-07	5-Jul-13	Battery power loss

None of the issues that have arisen over 19 years of GBI testing challenge the basic technological soundness of hit-to-kill technology or of the GMD system overall.

These details help put the long history of NMD/GMD testing record into context. What makes GMD relatively unique is not the presence of failures, but rather that the system is operational even while design flaws are worked out and enhancements made. None of the issues that have arisen over 19 years of GBI testing challenge the basic technological soundness of hit-to-kill technology or of the GMD system overall.

CURRENT INTERCEPTOR LIMITATIONS

One major limitation on the effectiveness of the current GBI fleet is the lack of regular in-flight updates to the EKV. As MDA has noted, ground systems currently "don't communicate very often today with the kill vehicle."[29] Today's GMD in-flight communications are inferior in this respect to more recently developed regional systems such as the Standard Missile-3.

The current three-stage booster configuration also limits flexibility to perform shorter-range shots at incoming missiles later in flight, since all three stages of the booster must burn out before the

29. James D. Syring, "The Future of Ballistic Missile Defense" (speech, 2015 Space and Missile Defense Symposium, Huntsville, AL, August 12, 2015).

kill vehicle can be deployed. A shorter-range shot later in the missile's trajectory may be necessary if an initial GBI salvo fails to intercept, or if there is insufficient warning time. A fleet composed of only three-stage boosters compresses the battlespace that operators have to engage a set of incoming targets and reduces the ability to intercept "leakers" if initial interceptors fail.

Notwithstanding MDA's chartered mission to defeat missiles in all phases of flight, the ability to intercept missiles in the boost phase is lacking from not only the current BMDS configuration but also near-term planning within MDA. Such capabilities would of course require means of intercept other than GBIs. The 2010 budget request included language in its cancellation of the Multiple Kill Vehicle (MKV) stating that "we decided to focus resources instead on technologies that are designed to defeat advanced countermeasures of launched missiles in their ascent phase."[30] That 2010 request did not, however, contain any new spending on ascent-phase programs. The only ascent-phase intercept program of record at the time, the Airborne Laser (ABL), saw its spending reduced that year to $187 million, down from $401 million the previous fiscal year.[31] The program was terminated shortly thereafter, though recent years have seen some movement to begin funding a low-power laser demonstrator aboard a UAV platform that could have ascent-phase applications.[32]

PLANNED IMPROVEMENTS

Several programs are under way to increase the reliability and flexibility of the GBIs, as well as reduce costs. These include both second- and third-generation kill vehicle programs (RKV, MOKV) as well as a selectable-stage booster.

Redesigned Kill Vehicle (RKV)

Currently in full-scale development, the RKV is being designed to improve on and eventually replace the existing fleet of prototype CE-I and CE-II EKVs. While not a radical departure from the current EKV, the RKV will feature a streamlined design, making it more modular and more producible. The new design will also reduce the number of failure points, increasing its reliability and warfighter confidence. The streamlined design is expected to have significantly fewer parts with easier accessibility, simplifying maintenance. MDA has said that the RKV will "increase performance to address the evolving threat, improve in-flight communications to better utilize off-board sensor data, and enhance Combatant Commanders' situational awareness via hit/kill assessment messages."[33]

This effort to improve on EKV is both welcome and long overdue. The 2002 deployment decision required the fielding of a kill vehicle that was little more than an advanced

This effort to improve upon EKV is both welcome and long overdue.

30. Missile Defense Agency, "Missile Defense Agency Fiscal Year (FY) 2010 Budget Estimates: Overview," April 27, 2009, 13.

31. Ibid., 11.

32. Sydney Freedberg Jr., "Return of the ABL? Missile Defense Agency Works on Laser Drone," *Breaking Defense*, August 17, 2015, http://breakingdefense.com/2015/08/return-of-the-abl-missile-defense-agency-works-on-laser-drone/.

33. Missile Defense Agency, "Missile Defense Agency Fiscal Year (FY) 2017 Budget Estimates: Overview," February 2016, 2.

prototype and had been created under the strictures of the ABM Treaty. Vice Admiral Syring has described RKV as the first effort "since the 1990s, to improve dramatically upon the EKV, using a modular open architecture based on common interfaces and standards. This effort is designed to improve reliability, availability, maintainability, testability, producibility, and unit manufacturing cost."[34] Various advances have been made over the past 15 years that have been applied to other parts of the BMDS, but similar qualitative improvements have thus far been mostly lacking for GBIs. Even RKV is not a major improvement on EKV in terms of basic concept or design.

Some RKV elements have already undergone some flight testing, such as the upgraded divert thrusters tested in January 2016 as part of the CE-II Block 1 EKV.[35] Vice Admiral Syring has also stated that the RKV will feature "on demand communication . . . [which] will allow us to update the kill vehicle much more frequently," noting that this capability is already available for the Aegis system and Standard Missiles.[36] The previous Common Kill Vehicle (CKV) effort prepared the way for applying preexisting or common features, such as on-demand communications, that already exist. RKV is also expected to have the ability to communicate with other kill vehicles to reduce the chance that two or more kill vehicles will engage the same object within the threat cloud. Should this effort be successful, GBIs could come to have reliability similar to the Standard Missile and other regional missile defenses.

GBIs could come to have reliability similar to the Standard Missile and other regional missile defenses.

From 2015 to 2016, Congress appropriated $373.6 million to develop RKV, with an additional budget request of $274.15 million for RKV in 2017. In February 2015, Vice Admiral Syring estimated the total cost of RKV development at $658 million.[37]

MDA expects to begin RKV flight testing in the 2018 time frame. Planned intercept tests include a two-stage GBI with an RKV engaging an IRBM target in summer of 2019, and a two- or three-stage selectable GBI with an RKV against an ICBM-class target in winter 2019–2020. Initial production deliveries are expected around 2020.

Multi-Object Kill Vehicle (MOKV)

The MOKV represents a third-generation kill vehicle, building on EKV, RKV, and other current BMDS elements, such as SM-3. It, too, is intended to improve the capacity, reliability, communications, and discrimination of homeland missile defense. MOKV is tailored to the goal of "volume kill," meaning hitting a number of targets within the threat cloud created by a given threat missile launch. Rather than equipping a single GBI with the single kill vehicle, each booster would carry several smaller kill vehicles, each with some degree of independent

34. Syring, "The Future of Ballistic Missile Defense."

35. James D. Syring, "Department of Defense Briefing by Vice Adm. Syring on the Fiscal Year 2016 Missile Defense Agency Budget Request in the Pentagon Briefing Room" (news transcript, Department of Defense, Washington, DC, February 2, 2015).

36. Syring, "Ballistic Missile Defense System Update."

37. Syring, "Department of Defense Briefing by Vice Adm. Syring on the Fiscal Year 2016 Missile Defense Agency Budget Request."

guidance. The MOKV could reduce some of the expectation for ground-based sensors to adequately discriminate warheads from debris and decoys, allowing a single GBI to engage multiple objects within a single threat cluster, or perhaps take more than one shot at a single object.

During congressional testimony in 2009, General James Cartwright, the vice chair of the Joint Chiefs of Staff, spoke to the shot doctrine issue, noting that the previously planned deployment of 10 GBIs to Europe would only have been able to intercept a maximum of five missiles, "assuming a shot doctrine of two interceptors against each threat missile."[38] The reference to two per target is a sort of minimum for reliability, but the statement presupposes the optimistic assumption of perfect discrimination of the threat cloud, and the GBI shot doctrine is almost certainly higher given the current reliability of today's system. A more complete description might have described a shot doctrine of at least two (perhaps more) kill vehicles per object within the missile threat cloud that *might* be a warhead. MDA has described MOKV as "allow[ing] us to go not just to the most lethal object but to the next one and the next one and the next one. And if you can do that, you can kill everything on the scene and you'll be sure that you got it."[39] Given that these kill vehicles would be smaller and lighter than today's family of EKVs, an MOKV cluster might look more like a cluster of SM-3 IIA-sized kill vehicles, or even smaller.

A previous "volume kill" program, the Multiple Kill Vehicle (MKV) program, was canceled by the Obama administration in 2009. The MKV completed a hover test on December 2, 2009. According to MDA, the MKV's "propulsion system demonstrated maneuverability while tracking a target" and "transmitted video and flight telemetry to the ground."[40]

Putting more than one interceptor on a given GBI round has significant potential to improve shot doctrine and therefore increase effective inventory capacity.

Putting more than one interceptor on a given GBI round has significant potential to improve shot doctrine and therefore increase effective inventory capacity. Figure 4.6 illustrates the relative improvements in magazine capacity that MOKV could afford under the conservative assumption of 44 GBIs equipped with five kill vehicles each. This notional representation illustrates how the number of targets that can be engaged grows as a multiple of the number of kill vehicles deployed. The figure also illustrates how the currently planned field of 44 GBIs compares to previous Clinton-era proposals for 100 and 250 GBIs.

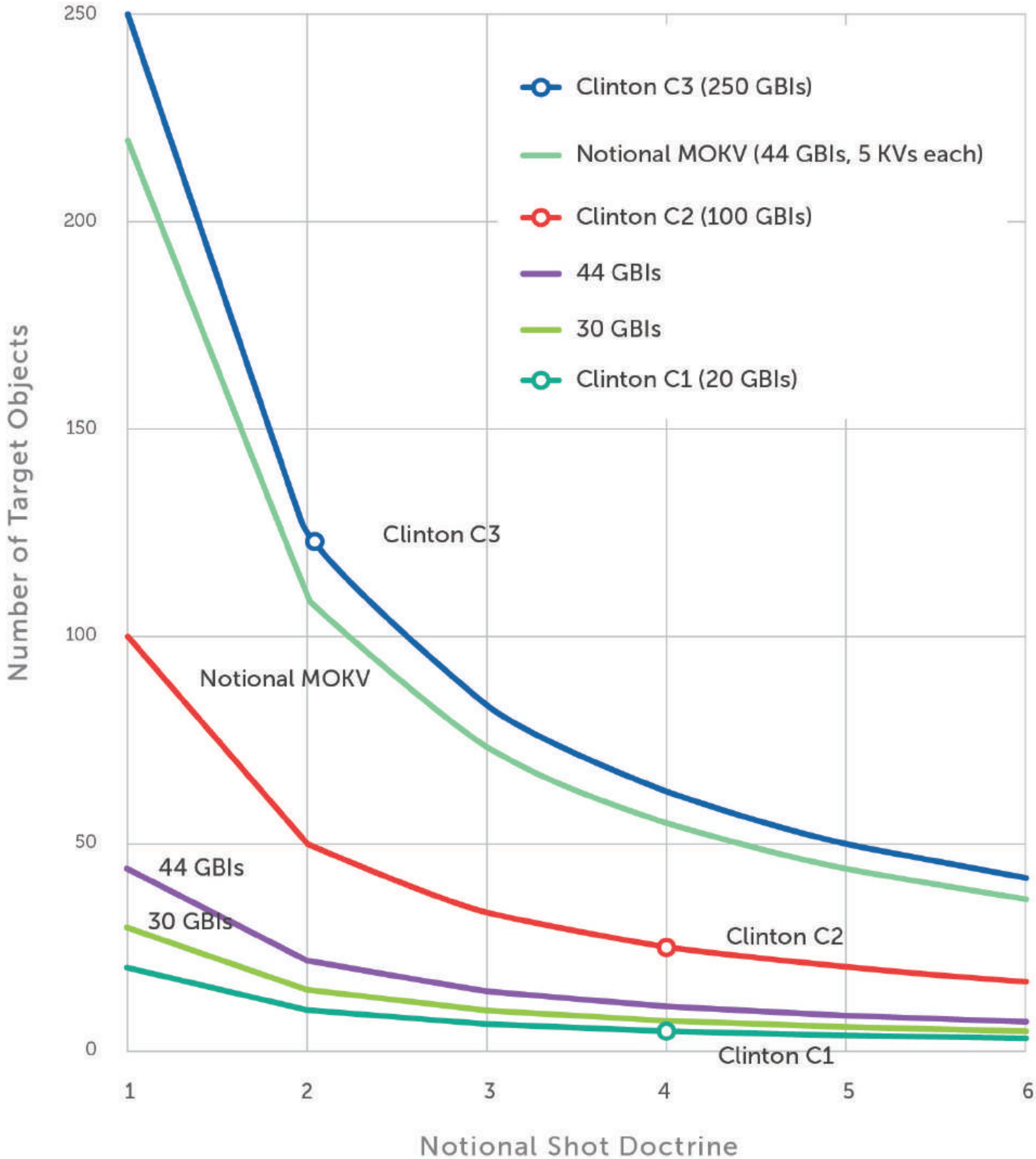
At least two operational concepts of MOKV are being considered. One of them includes a cluster of more or less identical kill vehicles on a separating adapter in which each kill vehicle would remain essentially autonomous. A second concept uses a single booster/bus, in which the multiple

38. James A. Cartwright, "President Obama's New Plan for Missile Defenses in Europe and the Implications for International Security" (statement at hearing of the House Armed Services Committee, 111th Cong., 1st sess., October 1, 2009).

39. Syring, "Ballistic Missile Defense System Update."

40. Missile Defense Agency, "Multiple Kill Vehicle Completes Hover Test," MDA news release, December 3, 2008.

Figure 4.6. Relation of KVs to Targets: Notional Shot Doctrines



Note: The C1 marker includes the ability to hit five missiles with four additional countermeasures, for a total of 25 target objects with 100 interceptors. The C3 marker represents the ability to intercept 20 targets with five additional countermeasures for a total of 120 targets with 250 interceptors. These numbers align with other estimates from the Clinton era that 80 interceptors would be required to hit 20 targets in the full C1 configuration, suggesting a four interceptor shot doctrine may have been presupposed at that early stage of the program.

kill vehicles are linked through a single "mothership," possibly sharing sensors or other support systems.

The MOKV development also holds broader potential. The continuing trend toward kill vehicle miniaturization, integration with the larger sensor suite, and improved communications portfolio might also permit a mix-and-match modular approach with other payloads. A GBI carrying a cluster of small kill vehicles might, for instance, be loaded with one fewer in favor of some other payload, such as a dedicated sensor to analyze the threat cloud and communicate that information to the MOKV swarm and to the ground. Payloads might also include nonkinetic effectors, such as a directed energy weapons or some other electromagnetic means to interact with the threat cloud, by clearing debris, heating or popping balloons, or otherwise affecting the warhead and other countermeasures. The MOKV concept might also be a path towards countering the threat posed by missiles with multiple independently-targetable reentry vehicles (MIRVs).

In 2016, the MOKV program received $99.5 million in appropriations. The 2017 budget requested only $71.5 million, but with a five-year projection of $388.7 million out through 2021. The program completed its planning and review phase in November 2015.

Selectable-Stage Booster

The current three-stage C1 and C2 boosters give the GBIs considerable range to engage targets in midcourse. Long reach was necessary in part to provide coverage from Alaska for threats to all 50 states. A booster that burned only the first two stages, however, would allow the interceptor to engage a target warhead later in the threat missile flight, thereby opening up opportunities for a second shot should a first salvo fail to intercept.

The idea of a two-stage booster for GBI is not new; the 10 GBIs that were to be put in place in Europe as part of President George W. Bush's European third site were to be two-stage interceptors. With the cancellation of the third site in 2009, the impetus behind the two-stage booster was also reduced.

Rather than develop the two-stage booster, however, MDA is presently working to make the burning of the third stage optional rather than automatic. As Vice Admiral Syring explained, "It really is not a different design from a booster standpoint. It's going to be done through software and the warfighter will be able to choose between a two stage and a three stage."[41] The trade-off, however, is a modestly slower interceptor, since it still has to carry the unused third stage as dead weight.

A two- or three-stage selectable booster could allow for increased flexibility of any given GBI, as well as a more uniform fleet of common boosters, as opposed to a mixed fleet of two- and three-stage boosters. MDA plans to test this booster configuration in a nonintercept test in 2018.

41. Syring, "Ballistic Missile Defense System Update."

05

Sensors and Command and Control

No missile defense system is better than the sensors and command and control systems that determine where the threat is and how to kill it. While interceptors tend to capture the imagination, sensors are the underappreciated backbone of missile defense operations. Sensors are required across the entire intercept cycle: early warning, tracking, fire control, discrimination, and kill assessment. Homeland missile defense depends on sensor information from a wide array of ground- and sea-based radars as well as overhead satellites (Table 5.1). These individual sensors feed information about the target to the GMD Fire Control (GFC) component at Schriever AFB in Colorado Springs. Supported by Command, Control, Battle Management, and Communications (C2BMC) software, GFC integrates and transmits this information to GBIs in-flight via In-Flight Interceptor Communications System (IFICS) Data Terminals (IDTs).

While interceptors tend to capture the imagination, sensors are the underappreciated backbone of missile defense operations.

The perennial desire with sensors is to have as many as possible, from as many different vantage points as possible, with as many different technologies or phenomenology as possible, and then to effectively integrate their inputs and make sense of them through a centralized command and control network. The importance of sensors cannot be overstated. Improvements in sensors may, at the margin, be one of the best ways to improve lethality, raise effective magazine capacity, and contribute to a more robust defense. As one study observed, "redundancy of sensors is another form of layering."[1] Like other elements of GMD, however, budgets for modernizing and expanding the sensor network have been depressed since 2009 (Figures 5.2. and 5.3).

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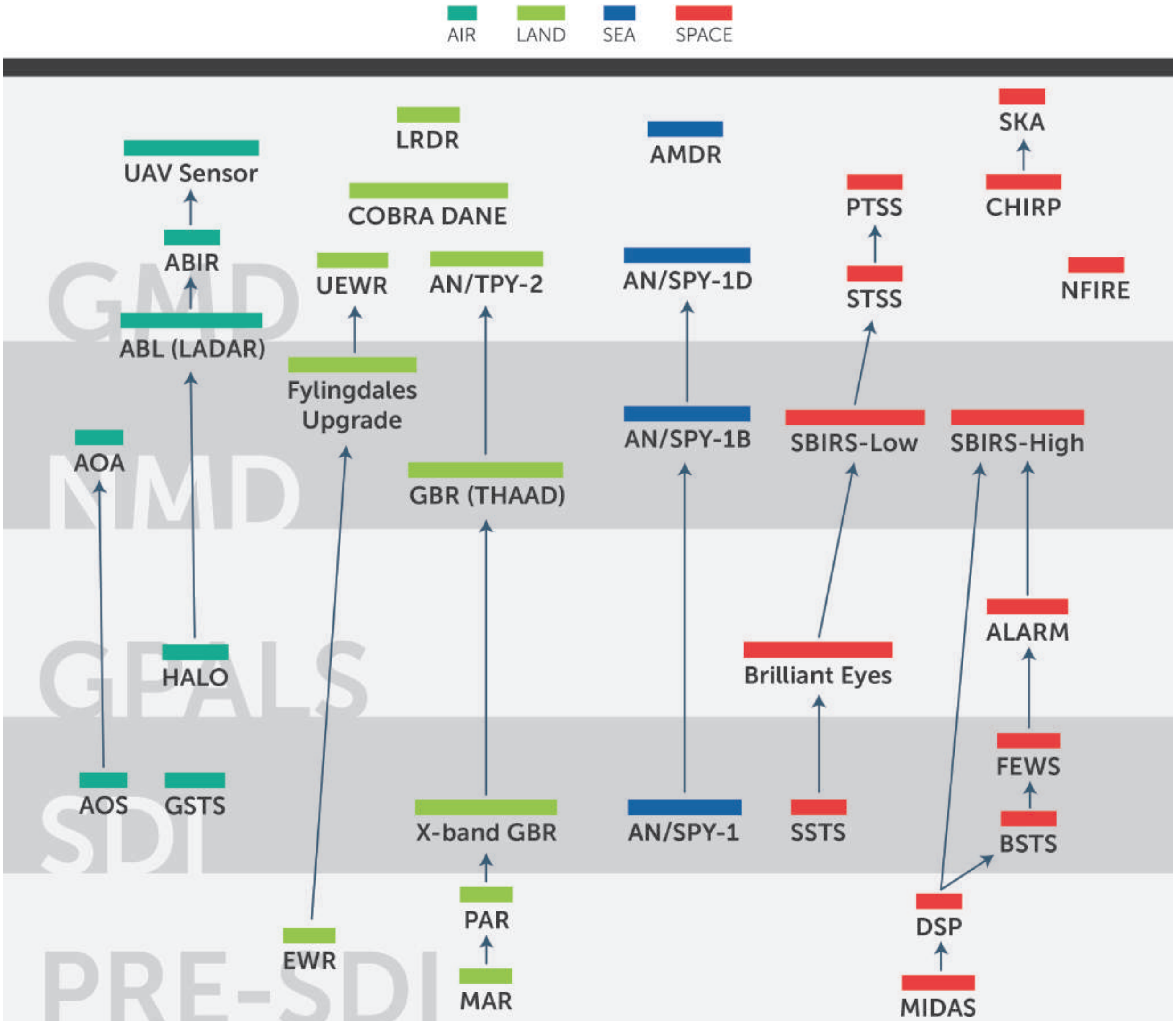
1. Committee on an Assessment of Concepts and Systems for U.S. Boost-Phase Missile Defense in Comparison to Other Alternatives, Division on Engineering and Physical Science, National Research Council, *Making Sense of Ballistic Missile Defense: An Assessment of Concepts and Systems for U.S. Boost-Phase Missile Defense in Comparison to Other Alternatives* (Washington, DC: National Academies Press, 2012), 152.

Table 5.1. Deployed Homeland Sensors at a Glance

Sensor	Location	Date Fielded	Technology
Sea-based			
SBX	Pearl Harbor, Hawaii (mobile radar)	2005	X-band
SPY-1D	Deployed on 34 Aegis Ships	1992	S-band
Land-based			
Forward-based AN/TPY-2	Kyogamisaki and Shariki, Japan; Negev Desert, Israel; Kürecik, Turkey; CENTCOM	2008	X-band
Cobra Dane	Shemya, Alaska	First operational 1977; completed upgrade for BMDS in 2004	L-band
Beale UEWR	Beale AFB, California	EWR Operational in 1980; upgraded in 2005	UHF-band
Fylingdales UEWR	Fylingdales, UK	EWR Operational in 1963; upgraded in 2007	UHF-band
Thule UEWR	Thule AFB, Greenland	EWR Operational in 1960; upgraded in 2009	UHF-band
Space-based			
DSP	Geosynchronous orbit	1970	Infrared
SBIRS	Geosynchronous and high-elliptical orbit	HEO payload launched in 2006; first GEO launched in 2011	Infrared
STSS-D	Low-earth orbit	2009 demonstrations, not fully integrated	Variable wave-band infrared

GMD sensor coverage has deepened dramatically since 2004, but significant work still remains, most notably in terms of persistent birth-to-death tracking and improving discrimination. The problem of discrimination has been a focus of considerable effort since, and even before, the 1980s. As long as the United States continues to focus on exoatmospheric intercept for homeland

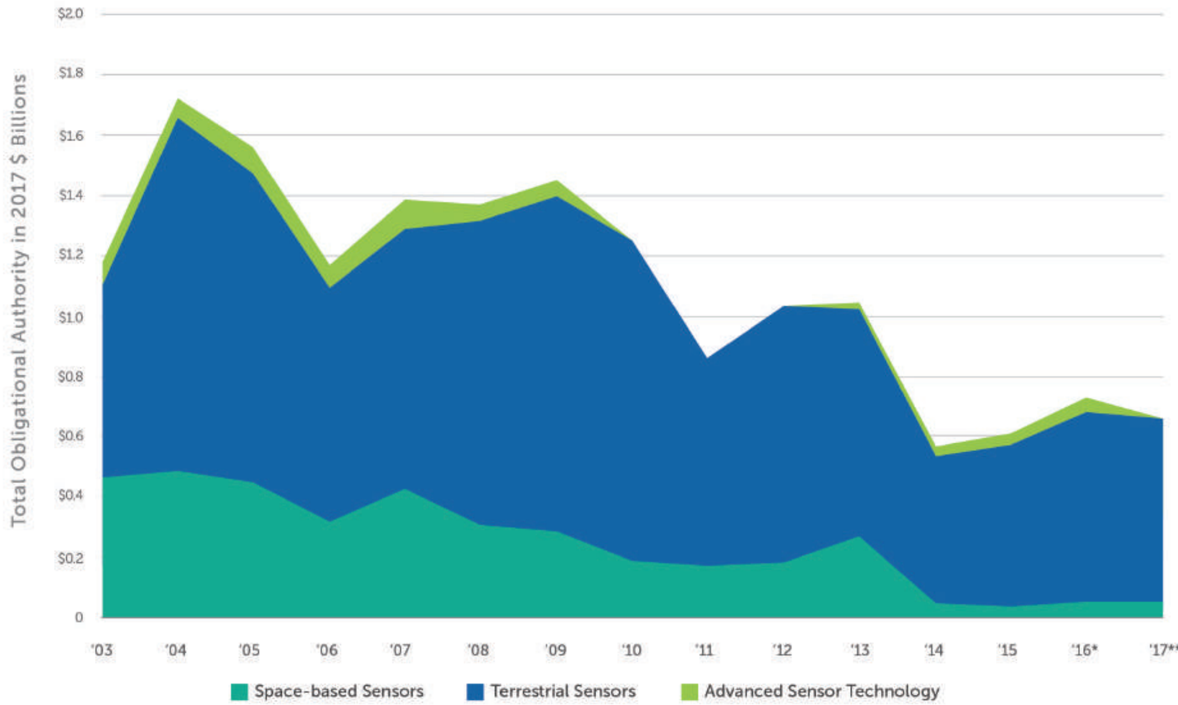
Figure 5.1. Long-range Homeland Sensor Evolution



LIST OF ACRONYMS

ABIR Airborne Infrared
ABL (LADAR) Airborne Laser (Laser Radar)
ADMR Air and Missile Defense Radar (AN/SPY-6)
ALARM Alert, Locate, and Report Missiles
AOA Airborne Optical Adjunct
AOS Airborne Optical Sensor
BSTS Boost Surveillance and Track System
CHIRP Commercially Hosted Infrared Payload
DSP Defense Support Program
EWR Early Warning Radar
FEWS Follow-on Early Warning System
GBR (THAAD) Ground-based Radar (Terminal High Altitude Area Defense)
GSTS Ground-Based Surveillance and Tracking System
HALO High-altitude Observatory
LRDR Long Range Discrimination Radar
MAR Multifunction Array Radar
MIDAS Missile Defense Alarm System
NFIRE Near Field Infrared Experiment
PAR Perimeter Acquisition Radar
PTSS Precision Tracking Space System
SBIRS-High Space Based Infrared System High
SBIRS-Low Space Based Infrared System Low
SKA Space-based Kill Assessment
SSTS Space-based Surveillance and Tracking System
STSS Space Tracking and Surveillance System
UEWR Upgraded Early Warning Radars
X-band GBR X-band Ground-based Radar

Figure 5.2. Selected Sensor Modernization by Category, 2003–2017



*Based on FY 2016 enactment.
**Based on FY 2017 presidential budget request.

defense, "the hard fact is that no practical missile defense can avoid the need for midcourse discrimination."[2]

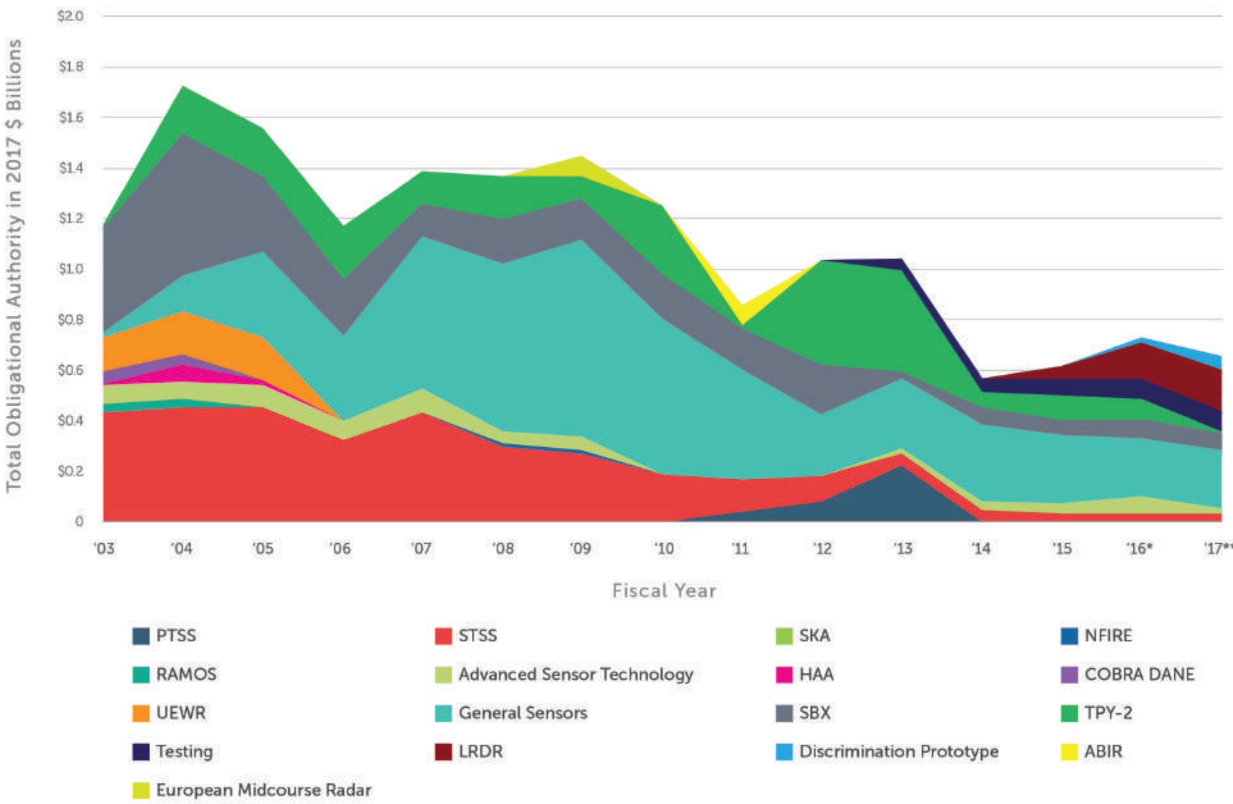
TERRESTRIAL RADARS

Terrestrial radars operate by emitting directed radio waves into the atmosphere and space. These radio waves reflect off objects. Some of these waves bounce back to the radar station, which it collects and analyzes to determine the object's location and form an image. Since radar was first employed during World War II to detect formations of German aircraft flying toward Britain, significant advances have been made in the fidelity of imagery available and in the ability to process that information into firing solutions.

Many of the limitations of today's homeland missile defense sensors used for homeland defense are inherent in radars located on the earth's surface. The shape of the earth limits the field of view of any terrestrial radar as the earth curves away from the arrays, which requires terrestrial radars to be distributed forward, closer to likely adversary missiles. The inherent trade-offs between radar frequencies and power limitations can restrict a given radar to serving either the tracking or the discrimination mission. These factors increase the number of required radars to produce adequate coverage.

2. Ibid., 10.

Figure 5.3. Selected Sensor Modernization by Program, 2003–2017



*Based on FY 2016 enactment.
**Based on FY 2017 presidential budget request.

GMD draws data, or phenomenology, from multiple radars around the globe. These include some of the newest sensing systems the United States fields, such as the TPY-2 X-band radar. Others are among the oldest still operating, such as the PAVE PAWS network of Early Warning Radars built during the late 1970s and early 1980s that provide early detection of a Soviet nuclear attack. These have been upgraded to provide missile defense tracking capability. Based on their geographic positions and the frequencies of radio waves they emit, each radar brings certain strengths to the homeland missile defense mission. Each also has weaknesses, for which other sensors must somehow compensate.

Bandwidths

One differentiator of radar capability is the frequency of radio wave it emits. Higher frequencies, such as X-band, provide high fidelity images, the kind useful for discriminating warheads from debris and other objects in a threat cloud. This frequency, however, can limit an X-band radar to scanning a narrow area, making it somewhat less useful for detection and tracking over a wider area. Lower frequencies, such as L-band and Ultra-High Frequency (UHF), lack similar sharpness but are capable of covering much larger areas at lower power output. This makes them suitable for tracking the position of a threat object over great distances. S-band, a sort of "middle" frequency, can provide a balance between discrimination and tracking capability.

Upgraded Early Warning Radars

Upgraded Early Warning Radars (UEWR) are long-range solid-state phased array radars that operate in the UHF band, which allows them to provide detection, tracking, and classification data to the BMDS, but little ability to discriminate objects.[3] Currently, the United States has three UEWRs, located at Beale Air Force Base (AFB) in California, Fylingdales in the United Kingdom, and Thule AFB in Greenland. Upgrades are under way on the Early Warning Radars at Cape Cod, Massachusetts, and Clear, Alaska. UEWRs also perform space situational awareness missions for the Air Force Space Command, which sustains the radars.[4]

The difference between an Early Warning Radar and an Upgraded Early Warning Radar is mostly software that allows the radars to more effectively track missiles and to then communicate effectively with the broader BMDS. UEWRs have an upgraded receiver exciter and frequency time standard, allowing them to do target classification and missile tracking to cue other sensors and interceptors.[5] This does not preclude UEWRs from performing the same missions as the other EWRs, but gives them an advanced capability and the ability to communicate with other missile defense assets.[6]

Each panel of an Early Warning Radar has a 120-degree azimuth. The sites at Beale AFB and Thule each have two-panel configurations for 240-degree coverage, while the radar at Fylingdales has a three-panel configuration, allowing the system to have full 360-degree tracking capability.[7]

The first EWR reconfigured for the missile defense mission was that at Beale Air Force Base in California, which completed its upgrade in 2005—after limited defensive operations began in late 2004.[8] The Beale UEWR participated in its first GMD test in 2006, proving its capability to track a target and relay information to other GMD components.[9] Because of its proximity to the GMD interceptor site at Vandenberg AFB, the Beale UEWR has been used in every GMD test within its operational range, serving as the demonstration platform for the other UEWRs that are farther

3. Missile Defense Agency, "Upgraded Early Warning Radars, AN/FPS-132," MDA fact sheet, July 23, 2014, https://www.mda.mil/global/documents/pdf/uewr1.pdf.

4. Office of the Director, Operational Test and Evaluation (hereafter DOT&E), "2014 Assessment of the Ballistic Missile Defense System," March 2015, 7.

5. John Keller, "Air Force Eyes Upgrades to PAVE PAWS, BMEWS, and PARCS Ballistic Missile Warning Radar," *Military and Aerospace Electronics*, February 1, 2012, http://www.militaryaerospace.com/articles/2012/02/air-force-to-upgrade-pave-paws-and-bmews-and-parc-radar-systems.html.

6. DOT&E, "2014 Assessment of the Ballistic Missile Defense System," 7–8.

7. Ibid.

8. Lieutenant General Henry A. Obering III, Director, Missile Defense Agency, "Missile Defense Program and Fiscal Year 2006 Budget" (statement at hearing before the Senate Appropriations Committee, Subcommittee on Defense, 109th Cong., 1st sess. May 11, 2005).

9. "Raytheon's Upgraded Early Warning Radar Participates in Successful Missile Test," *Microwave Journal*, May 11, 2006, http://www.microwavejournal.com/articles/1273-raytheon-s-upgraded-early-warning-radar-participates-in-successful-missile-test.

Figure 5.4. Beale Upgraded Early Warning Radar

Source: Missile Defense Agency.

from testing regions.[10] Fylingdales became the site of the second operational UEWR in 2007.[11] The Thule AFB UEWR completed its first shift with upgraded software in 2009.[12]

The near-term improvements to the BMDS sensor network include the EWRs at Cape Cod and Clear. Cape Cod will likely be upgraded in late-2017 and the Clear site will be operational in mid-2017.[13] When they become UEWRs, they will provide additional coverage for missile tracking for both the East and West Coasts.

10. DOT&E, "FY 2014 Annual Report," January 2015, 315.

11. "Fylingdales Radar Upgrades Complete," *Nuclear Threat Initiative*, August 16, 2007, http://www.nti.org/gsn/article/fylingdales-radar-upgrades-complete/.

12. Lisa Meiman, "Thule's Radar Moves Nation One Step Closer to Possible Missile Defense System," *Air Force Space Command*, June 25, 2009.

13. James D. Syring, "Hearing on the FY 2017 Missile Defense Agency Budget Request" (unclassified statement before the Senate Appropriations Committee, Defense Subcommittee, April 13, 2016).

Cobra Dane

The Cobra Dane Radar Upgrade is an L-band radar with a single face with a 136-degree azimuth located on Shemya Island, Alaska, at Eareckson Air Station. At 95 feet in diameter, the radar face is larger than the UEWRs. Cobra Dane can detect objects out to 2,000 miles to provide missile tracking and classification data sufficiently accurate to commit the launch of interceptors and update target tracks during interceptor flight.[14] Information used from this classification is stored and integrated into intercept plans. How a given missile looked and behaved in past launches both helps identify it and show characteristics that would help in its defeat.

Due to the location of the Cobra Dane radar at the far western edge of the Aleutian Islands, MDA has never been able to use it for a GMD intercept test, though it has probably been used to track test flights of Soviet and Russian ballistic missiles.[15] Cobra Dane was integrated for ballistic missile defense missions in 2004, and in February 2009 was transferred from MDA to the Air Force for sustainment.[16]

The major difference between the Cobra Dane and UEWRs is its L-band frequency rather than the UHF band used by UEWRs. This allows Cobra Dane to perform more accurate classification of objects—for instance, Russian ICBMs heading to the Kamchatka test range, 1,200 miles from Shemya. As its deputy program manager explained in 2015, "The radar's small object detectability performance is better than any of the other Space Surveillance Network phased-array sensors currently available."[17] This historical purpose explains why Cobra Dane also has only one radar panel, limiting its observation azimuth, in contrast with the multipaneled UEWRs.[18]

In 2013, the United States Air Force proposed to operate Cobra Dane at a quarter power as a means to save $5 million, reducing the radar's ability to track objects in space. In response to provocations by North Korea, however, the Air Force opted to keep the radar at full power.[19]

Cobra Dane is part of a larger "Cobra" family of sensors dedicated to missile tracking and classification. The Air Force also operates the Cobra King, a ship-based dual X-band and S-band radar, for missile tracking missions. The radar is much smaller than the Sea-based X-band Radar (SBX) and has a shorter range, but being based on a ship rather than a converted oil drilling rig gives it greater mobility and forward reach. The predecessor to Cobra King, the Cobra Judy, was commissioned in 1985 as a means to track and gather data on the terminal phase of ballistic missile flights.

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14. Missile Defense Agency, "Cobra Dane Upgrade," MDA fact sheet, July 23, 2014, https://www.mda.mil/global/documents/pdf/cobradane.pdf.

15. Bart Hendrickx, "Snooping on Radars: A History of Soviet/Russian Global Signals Intelligence Satellites," *Space Chronicle JBIS* 58, no. 1 (2005): 11.

16. Missile Defense Agency, "Cobra Dane's Missile Defense Capability Transferred to U.S. Air Force," MDA news release, February 19, 2009, https://www.mda.mil/global/documents/pdf/09news0002.pdf.

17. Justin Oakes, "Cobra Dane Team Moves Forward with Radar's Sustainment Plan," Hanscom Air Force Base, July 6, 2015, http://www.hanscom.af.mil/News/Article-Display/Article/846999/cobra-dane-team-moves-forward-with-radars-sustainment-plan.

18. DOT&E, "FY 2014 Annual Report," 313.

19. "North Korea Tensions Prompt Change in U.S. Air Force Radar Plans," Reuters, April 9, 2013, http://www.reuters.com/article/us-korea-usa-airforce-idUSBRE93814N20130409.

Cobra King began operations in 2014 and was upgraded to simplify repairs and allow the X-band and S-band radars to function independently.[20] The Air Force also operates Cobra Ball, a modified C-135B that can observe ballistic missile flights at long range, and previously operated Cobra Eye, which used a sensor on an RC-135X that tracked reentry vehicles from ICBMs.[21] These systems gather useful data that informs U.S. missile defense databases and algorithms, but while their concept of operations points to the utility of airborne and seaborne platforms for missile tracking, these systems are not actively integrated into the BMDS.

TPY-2 X-band Radar

The Army-Navy Transportable Radar Surveillance and Control Model-2 (AN/TPY-2, or TPY-2) radar is a high resolution, phased array X-band radar designed and built specifically for missile defense. The TPY-2 can be deployed in one of two modes: terminal or forward-based. In terminal mode, it is integrated with a Terminal High Altitude Area Defense (THAAD) system, serving as its primary sensor. In forward-based mode, the radar is integrated with the broader BMDS and provides sensor tracks of missiles in boost and early midcourse.

By the end of 2017, the United States will have 12 TPY-2s, seven of which will be in terminal mode assigned to THAAD units.[22] The terminal mode TPY-2 supporting the THAAD on the island of Guam contributes to homeland missile defense in the sense of defending U.S. territory.[23] Another five are already in forward-based mode (FBM), two of which are deployed to Japan, monitoring North Korean missile activity.[24] Those in Japan have been called "redundant," but are perhaps better understood as complementary, given their different latitudes and orientations.[25] The remaining three are deployed in Turkey, Israel, and the Persian Gulf region. By way of comparison, earlier NMD architecture had envisioned nine homeland defense X-band radars to be both colocated with the several UEWRs as well as at a few other sites.[26] The 2012 NAS study recommended five ground-based X-band radar sites, but stacking two TPY-2s atop each other at each site to enhance their ranges.[27]

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20. Cobra King was formerly designated the "Cobra Judy Replacement."

21. Dan Taylor, "USAF Missile Defense—From the Sea," *Journal of the Air Force Association: Air Force Magazine* 98, no. 1 (January 2015): 48.

22. Syring, "Hearing on the FY 2017 Missile Defense Agency Budget Request."

23. Missile Defense Agency, "Fact Sheet: Army Navy / Transportable Radar Surveillance (AN/TPY-2)," July 26, 2016, https://www.mda.mil/global/documents/pdf/an_tpy2.pdf.

24. The United States deployed the first TPY-2 to Shariki, Japan in 2007. The second was deployed to Kyogamisaki in December 2014. "Second Missile Defense Radar Deployed to Japan," DoD news release NR-630-14, December 26, 2014, http://www.defense.gov/News/News-Releases/News-Release-View/Article/605330/second-missile-defense-radar-deployed-to-japan.

25. Gary Pennett, "Ballistic Missile Defense PB15 Program Change Overview" (presentation, March 24, 2014).

26. James M. Lindsay and Michael E. O'Hanlon, *Defending America: The Case for Limited National Missile Defense* (Washington, DC: Brookings Institution, 2004), 90.

27. *Making Sense of Ballistic Missile Defense*, 152.

Figure 5.5. Sea-based X-band Radar

Source: Missile Defense Agency.

From forward locations, the TPY-2s are able to detect and track missiles in their boost and early midcourse phases, determining information such as speed and trajectory. The high resolution imagery also allows the radar to identify the type of missile fired. TPY-2s focus their beams narrowly, cannot provide 360-degree coverage, and are further limited by the curvature of the earth. This means that long-range missiles heading toward the United States will eventually fly out of the forward-based TPY-2's field of view, requiring rearward radars to pick up the track.

Sea-based X-band Radar (SBX)

The SBX is a unique X-band radar based atop a North Sea oil rig platform. The SBX produces very high resolution images of incoming threat clouds. Its high fidelity imagery provides information that helps the kill vehicle discriminate between lethal objects and debris within the threat cloud. The SBX has contributed to 12 tests of the GMD system and provided tracking and kill assessment for Operation Burnt Frost in February 2008, when an Aegis BMD destroyer and an SM-3 interceptor, modified for the mission, shot down a U.S. government satellite falling out of orbit, out of concern that the satellite's toxic fuel payload might pose a danger to populations. It has also been deployed on numerous occasions to monitor North Korea's long-range missile tests and routinely participates in flight tests of U.S. intercontinental ballistic missiles. The SBX program was approved by MDA in October 2002, began sea trials in 2005, and has been in service since. The operational SBX is technically designated "SBX-1," reflecting an initial expectation that one or more platforms would be built, with the second perhaps being located in the Atlantic.[28]

Initial plans intended the SBX to be permanently stationed at Adak Island, Alaska. MDA constructed a special mooring station for SBX there, completed in 2007. MDA ultimately determined that the cost of maintaining a fixed mooring was greater than keeping SBX mobile, however, and SBX has since been stationed at Pearl Harbor. News reports in late 2016 indicate that the SBX operated for a period of time near the Korean peninsula to monitor North Korean missile launches.[29]

SBX also has performance limitations. The radar cannot operate as a stand-alone sensor. The cost of its high resolution is its relatively narrow 25-degree viewing arc, which has been compared to looking through a drinking straw. SBX has a limited ability to track an incoming missile but relies on other sensors to provide the target's location and trajectory. While in some cases it is an asset, SBX's mobility also presents a drawback: it must sail from port in Hawaii to the western Pacific for optimal positioning. Weighing over 4 million pounds, SBX is quite slow (eight knots per hour), requiring significant warning time to relocate the platform prior to the launch of an enemy missile. Another challenge of SBX is the high operating costs at sea.[30]

Aegis (SPY-1 Radar)

Another important component of homeland missile defense is the fleet of Aegis BMD ships, each equipped with a SPY-1 S-band radar capable of tracking and providing discrimination data on ballistic missiles. As BMD ships are typically forward-deployed, they are often positioned to observe a hostile missile's late boost and early midcourse phase, perhaps after the missile passes over a forward-deployed TPY-2 and before it would be acquired by a longer-range sensor. Since October 2002 (IFT-9), Aegis BMD ships have participated in every GMD intercept test. As of late 2016, 34 Aegis BMD ships in the U.S. Navy were equipped to carry out this mission. These include 5 *Ticonderoga*-class cruisers and 29 *Arleigh Burke*–class guided missile destroyers. The degree to which Aegis ship-based radars are able to contribute to tracking and discrimination is contingent upon advance warning, their location at the time, and their preoccupation with other missions.

Aegis BMD ships use S-band radars, but they have a more limited range than the SBX or TPY-2s. Supporting homeland missile defense is but one of their many missions, including fleet defense, regional missile defense and offensive operations. These ships are a high demand, low density asset, with geographic, operational, and technical limitations on their availability to support GMD. The limited range of the SPY-1 radars also requires careful placement to contribute to homeland defense.

28. Ronald Kadish, "Missile Defense Program and Fiscal Year 2005 Budget" (testimony before the Senate Appropriations Committee, Subcommittee on Defense, April 1, 2004), https://www.mda.mil/global/documents/pdf/ps_spring04.pdf.

29. Sam LaGrone, "Report: SBX-1 Operated Near North Korea," *UNSI News*, November 1, 2016, https://news.usni.org/2016/11/01/report-sbx-1-radar-operated-near-north-korea.

30. Missile Defense Agency, *A Brief History of the Sea-based X-band Radar-1* (Washington, DC: Missile Defense Agency History Office, 2008), 4, https://www.mda.mil/global/documents/pdf/sbx_booklet.pdf.

Upgrades to Aegis Baseline 9C hardware have now become available, allowing the ships to perform both air defense and ballistic missile defense simultaneously. The majority of the Navy's contingent of Flight IIA *Arleigh Burke*–class destroyers (not currently BMD capable) are being upgraded to Baseline 9C hardware, which may make them capable of tracking ballistic missile threats to the U.S. homeland, in addition to air and fleet defense.[31]

The Flight III *Arleigh Burke* destroyers will feature the SPY-6 radar, also referred to as the Air and Missile Defense Radar (AMDR). The new radars will include an active electrically scanned array (AESA) said to be 30 times more powerful than the current SPY-1 radar. The system will also enable digital beam forming, allowing more precise tracking as well as the potential to itself execute electronic attacks, perhaps serving as a nonkinetic effector.[32] The final ship ordered in FY 2016 will be the first Flight III built and the first to deploy the AMDR.[33]

Long Range Discrimination Radar

The Long Range Discrimination Radar (LRDR) is a large solid-state, two-faced, phased array S-band radar currently under development, expected to become operational by 2020. In January 2016, Vice Admiral James Syring described the LRDR as providing "24/7 long-range discrimination, precision tracking and hit estimate . . . to give the warfighter confidence that the shot doctrine can be reduced with much more up-to-date and much more relevant information for the more complex threats."[34] The choice of S-band for the LRDR will somewhat reduce its discrimination capability relative to X-band but enhance its capability to track incoming missiles over greater distances, with a much larger field of view. Cost control was also likely a motivation for keeping the LRDR at S-band.[35]

MDA announced in May 2015 its intention to locate the LRDR at Clear Air Force Station in Alaska.[36] Another site option was on Shemya Island at the far edge of the Aleutian Islands, also the site of Cobra Dane. Locating LRDR on Shemya would have placed it around 2,400 kilometers closer to North Korea, thus making it more capable of tracking North Korean missiles earlier in their flight.

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31. There are currently 34 Flight IIA *Arleigh Burke*–class destroyers not currently configured for BMD. All 34 were initially slated for Baseline 9C upgrades, but this number was cut to 29 in the Navy's FY 2016 budget. Sam LaGrone, "Navy Again Reduces Scope of Destroyer Modernization, 5 Ships Won't Receive Any Ballistic Missile Defense Upgrades," *USNI News*, March 3, 2015, http://news.usni.org/2015/03/03/navy-again-reduces-scope-of-destroyer-modernization-5-ships-wont-receive-any-ballistic-missile-defense-upgrades.

32. Dave Majumdar, "Raytheon Enters New Phase of Next Generation Radar Development," *USNI News*, June 24, 2014, https://news.usni.org/2014/07/24/raytheon-enters-new-phase-next-generation-radar-development.

33. Sam LaGrone, "Stackley: Arleigh Burke Flight III Destroyer, Air Missile Defense Radar Development on Track," *USNI News*, April 7, 2016, https://news.usni.org/2016/04/07/stackley-arleigh-burke-flight-iii-destroyer-air-missile-defense-radar-development-on-track.

34. James D. Syring, "Ballistic Missile Defense System Update" (speech, Center for Strategic and International Studies, Washington, DC, January 20, 2016).

35. "The Long Range Discrimination Radar at S-band?," *Mostlymissiledefense.com*, April 20, 2015, https://mostlymissiledefense.com/2015/04/20/the-long-range-discrimination-radar-at-s-band-april-20-2015/.

36. "Department of Defense Identifies Planned Site of Future Long Range Discrimination Radar (LRDR)," DoD news release NR-193-15, May 22, 2015, http://www.defense.gov/News/News-Releases/News-Release-View/Article/605521.

Indeed, Shemya was the location originally selected for an X-band radar during the Clinton administration to serve this same purpose.[37] Costs and other operational difficulties associated with such a remote location were likely factors in the choice of Clear.

The deployment of LRDR may reduce reliance on the SBX in the Pacific, potentially allowing it to move elsewhere, such as the East Coast. Such a relocation would provide additional coverage for missiles coming from Iran.

SPACE-BASED SENSORS

Space-based sensors offer perhaps the best opportunity to detect and track incoming missiles as well as determine the results of an intercept attempt. Space-based sensors offer significant range advantages over their terrestrial counterparts, but in return often must sacrifice detail to get a wider picture. Space-based platforms offer the promise of the "holy grail" of missile tracking, following a missile from launch to reentry or intercept. The United States has, nevertheless, no plans to build or field space-based tracking sensors, and today's STSS demonstrators are not operationally integrated into the BMDS.

Overhead Persistent Infrared (OPIR)

OPIR is a family of satellite constellations overseen by the U.S. Remote Sensing Systems Directorate located at Los Angeles Air Force Base. Among the four main satellite groups for which the Directorate is responsible, two contribute to homeland missile defense: the Defense Support Program and the Space-based Infrared System.[38]

Defense Support Program (DSP). DSP consists of a constellation of infrared sensing satellites operated by the U.S. Air Force Space Command. These sensors have been in operation since 1970 and provide launch warning of enemy missiles by detecting the intense heat created by the plume of exhaust of a boosting missile. Incoming information from DSP is gathered and disseminated by the Air Force's 2nd Space Warning Squadron, a unit within the 460th Space Wing located at Buckley AFB, Colorado.[39] The unit has performed this role since 1992. The last DSP launch took place in 2007 (DSP-23). According to media reports, however, DSP-23 unexpectedly stopped working in September 2008.[40] The loss underscored the need to accelerate replacement of the aging constellation.

Space-based Infrared System (SBIRS). To replace the DSP satellites, the United States Air Force has begun deploying the SBIRS constellation. These satellites include dual sensor platforms that can both scan over wide territories to detect activity and also stare at areas of interest to detect lower

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37. Lindsay and O'Hanlon, *Defending America*, 83.

38. "Remote Sensing Systems Directorate," Los Angeles Air Force Base, June 24, 2016, http://www.losangeles.af.mil/About-Us/Fact-Sheets/Article/812306/remote-sensing-systems-directorate.

39. "Defense Space Program," Buckley Air Force Base, August 19, 2015, http://www.buckley.af.mil/About-Us/Fact-Sheets/Display/Article/731843/defense-space-program.

40. Andrea Shalal-Esa, "U.S. Missile-warning Satellite Fails," Reuters, November 24, 2008, http://www.reuters.com/article/us-usa-satellite-idUSTRE4AN8FK20081124.

heat signature events like the launch of short-range tactical ballistic missiles. The sensors are independently tasked, meaning the satellite can simultaneously scan a wide territory and stare at a particular area of concern. The first SBIRS satellite, SBIRS GEO-1, was launched in 2011, followed by SBIRS GEO-2 in 2013.[41] SBIRS GEO-3 was successfully launched in January 2017.[42] In addition to the dedicated satellites, SBIRS also includes missile warning sensors hosted on classified satellites in high elliptical orbit. There are currently two of those sensors in orbit and they were launched in November 2006 and June 2008.[43]

Missile Defense Agency Satellite Programs

Space Tracking and Surveillance System (STSS). In 2001, MDA took what was originally the low earth orbit part of the SBIRS program (SBIRS-low) and renamed it the Space Tracking and Surveillance System. STSS is designed to provide persistent, "birth-to-death" sensor coverage, in depth, of missiles from space. This vantage point helps discrimination because it allows the sensors to see where decoys deploy or debris is created.

The first two demonstration STSS-D satellites launched in September 2009.[44] In March 2011, the STSS-D demonstrated birth-to-death tracking of a test ballistic missile for the first time.[45] This tracking and warning significantly expands the defended area by permitting "launch on remote," the earlier launch of intercept missiles before the threat comes into view of a terrestrial radar. In February 2013, STSS-D provided firing data to an Aegis destroyer for the first time during an intercept test of a medium-range ballistic missile, extending the range of the SM-3.[46]

Near Field Infrared Experiment (NFIRE). The development of STSS was also informed by an earlier technology project known as the Near Field Infrared Experiment. Launched April 2007, NFIRE was a low-earth orbit satellite designed to collect imagery of boosting missiles and rockets to improve discrimination, as well as aid the development of future space trackers and kill vehicle seekers. NFIRE was initially intended to be equipped with an experimental kinetic kill vehicle, but this element was scrapped prior to launch. In its place went a secondary payload designed to conduct experiments on using lasers for space-to-space and space-to-ground communication. Although only intended for a maximum of two years in orbit, MDA decommissioned NFIRE in August 2015 after eight years in operation.

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41. "Space-based Infrared System," Buckley Air Force Base, August 19, 2015, http://www.buckley.af.mil/About-Us/Fact-Sheets/Display/Article/731842/space-based-infrared-system.

42. James Drew, "U.S. Air Force Missile Warning Satellites Lifts Off," *Aviation Week,* January 21, 2017, http://aviationweek.com/defense/us-air-force-missile-warning-satellite-lifts.

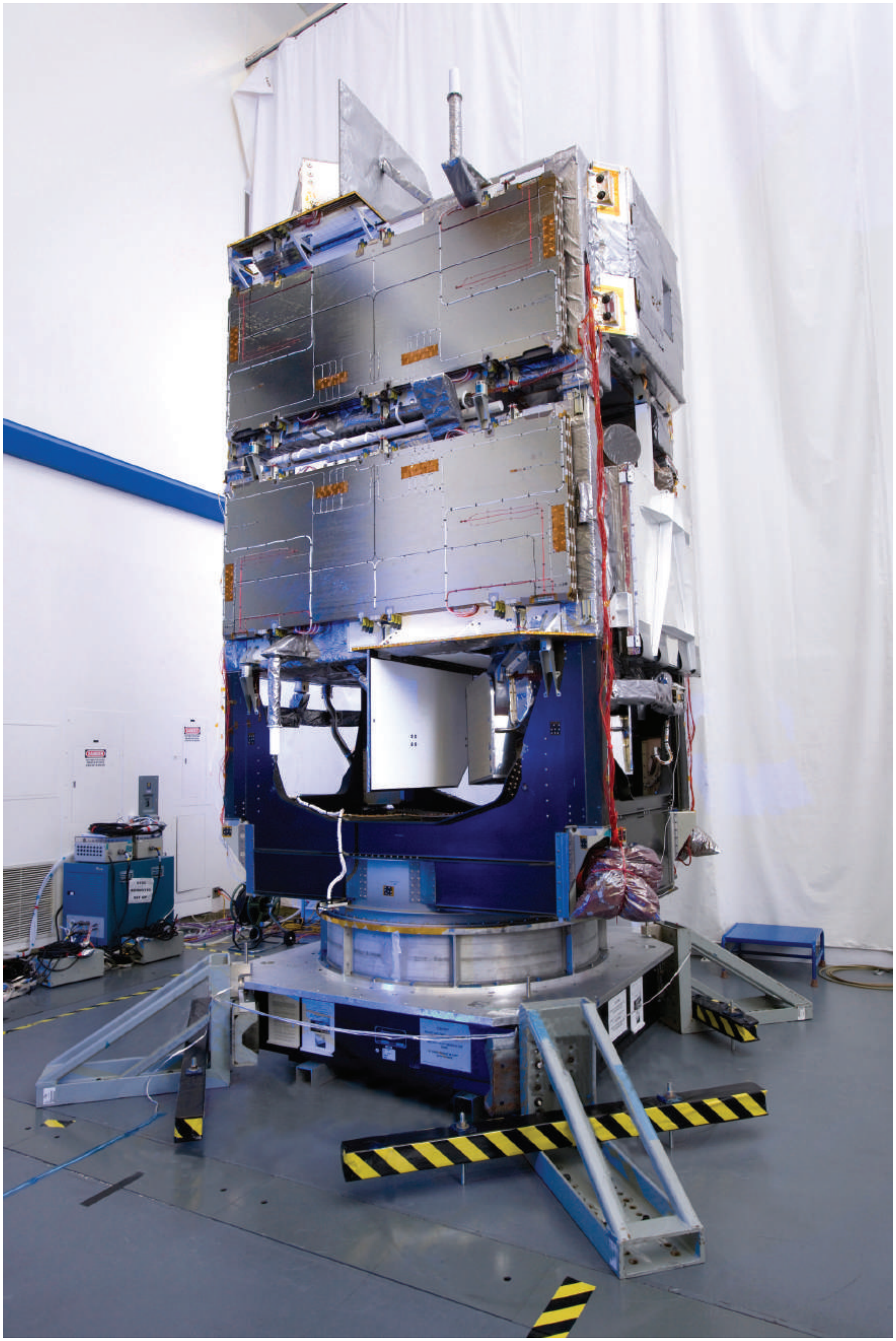
43. "Space-based Infrared System."

44. Missile Defense Agency, "Space Tracking and Surveillance System," MDA fact sheet, July 28, 2016, https://www.mda.mil/global/documents/pdf/stss.pdf.

45. Turner Brinton, "STSS Satellites Demonstrate 'Holy Grail' of Missile Tracking," *SpaceNews*, March 23, 2011, http://spacenews.com/stss-satellites-demonstrate-holy-grail-missile-tracking/.

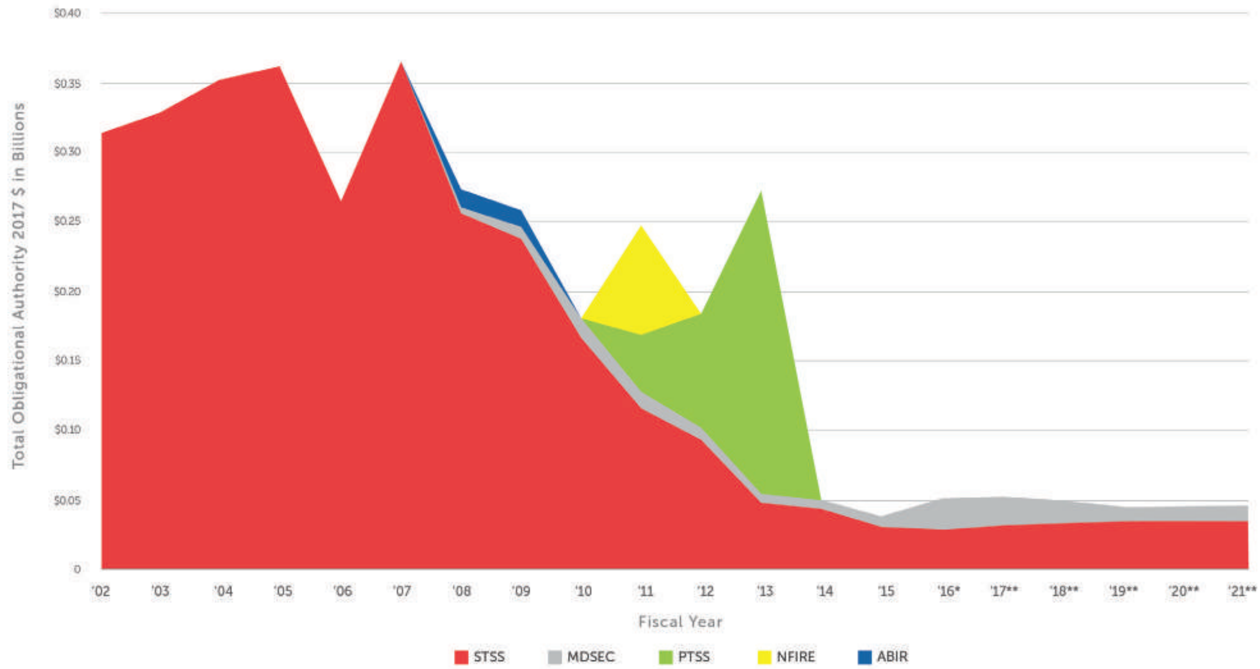
46. Mike Gruss, "Satellites Play Key Role in Successful Anti-Missile Test," *SpaceNews*, February 13, 2013, http://spacenews.com/33652satellites-play-key-role-in-successful-anti-missile-test/.

Figure 5.6. Space Tracking and Surveillance Satellite



Source: Missile Defense Agency.

Figure 5.7. MDA Space and Near-Space Activities Total Obligational Authority



Note: MDSEC stands for Missile Defense Space Experimentation Center, which since 2015 has housed the Space-based Kill Assessment program.
*Based on FY 2016 enactment.
**Based on FY 2017 presidential budget request.

Space-based Kill Assessment (SKA). The Space-based Kill Assessment program is an experimental program pursued by MDA to determine the efficacy of using commercially hosted satellite payloads to place sensors in orbit.[47] The sensors will assess intercept success rates and relay information to the warfighter, improving shot doctrine by ensuring that extra interceptors are not launched at a threat that has already been neutralized. This is done by providing sensor data on intercept characteristics, like the energy radiating from the intercept's so-called fireball, that provide clues about payload type for the target object as well as how the intercept occurred.[48] Initial work on the program has been funded by leftover money from the canceled Precision Tracking Space System (PTSS) program. MDA expected to launch the first SKA payload in FY 2016, but due to a reduced budget, the first launch is now scheduled for mid-2017.[49]

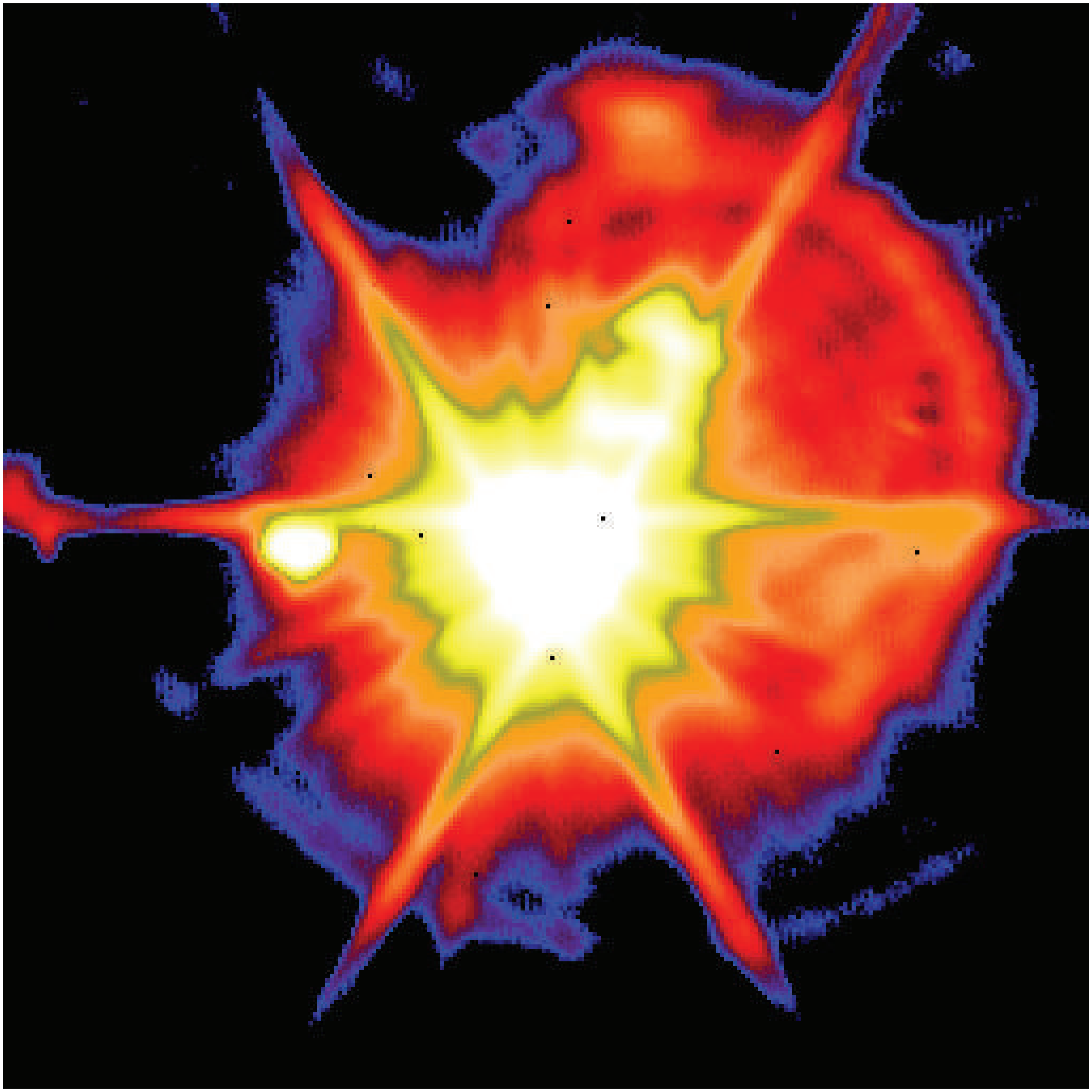
Precision Tracking Space System (PTSS). A proposed follow-on to STSS, the Precision Tracking Space System featured satellites that would have prioritized a larger telescope and relied on subtle movements in space for tracking instead of a complicated gimballed system. This constellation

47. Mike Gruss, "MDA Kill Assessment Sensors Would Be Commercially Hosted," *SpaceNews*, March 20, 2015, http://spacenews.com/mda-kill-assessment-sensors-would-be-commercially-hosted/.

48. Robert E. Erlandson et al., "Development of Kill Assessment Technology for Space-based Applications," *Johns Hopkins APL Technical Digest* 29, no. 3 (2010): 293.

49. Mike Gruss, "U.S. Missile Defense Agency's Hosted Payload Delayed until Mid-2017," *SpaceNews*, April 21, 2016, http://spacenews.com/u-s-missile-defense-agencys-hosted-payload-delayed-until-mid-2017/.

Figure 5.8. GMD Intercept "Fireball"



would have grown to between 9 and 12 satellites operating in orbit around the earth's equator. PTSS was canceled in 2013, shortly after the successful Aegis intercept, based on concerns about the cost of the program.[50] A National Academy of Sciences report argued in 2012 that PTSS "does not appear to be justified in view of its estimated life-cycle cost versus its contribution to defense effectiveness."[51] The report concluded that PTSS would only provide marginal improvements in

50. Amy Butler, "PTSS Kill Leaves Hole in Missile Defense Sensor Plan," *Aviation Week*, April 29, 2013, http://aviationweek.com/awin/ptss-kill-leaves-hole-missile-defense-sensor-plan.

51. *Making Sense of Ballistic Missile Defense*, 121.

discrimination capability over less costly terrestrial radar alternatives, and that the proposed constellation size was too small to provide effective coverage. Congress seemed to agree, and the program was eliminated.

Gaps in Space Coverage

Unfortunately, a space-based missile tracking solution is still not under way. As MDA Director Syring has observed, "There is no plan today for STSS or PTSS follow on."[52] MDA and the Air Force are nevertheless considering cooperative efforts that could contribute to the missile defense mission. These efforts would focus on putting up multi-mission satellites that could do both missile defense tracking and space situational awareness, for example.[53] Such an arrangement could be a way for MDA to defray the large costs of building a large constellation of satellites by sharing them with other Services. At the same time, the history of SBIRS carries a cautionary tale: stacking too many missions onto a single platform can inadvertently drive up cost and slow delivery. An alternative approach would be to take the missile warning payload and modularize it, to be hosted on a wide variety of other satellites.

"There is no plan today for STSS or PTSS follow on."

In the absence of operational space-based sensors overhead, the homeland missile defense mission is dependent on only terrestrial radars for tracking and discrimination. This places a larger burden on the sensor network, which makes it harder to identify the objects within the threat cloud of an incoming missile. As such, more of the objects within the cloud would need to be engaged to ensure the warhead is destroyed. This in turn means firing more interceptors at a single threat cloud, reducing the effective capacity of the GBI magazine.

COMMAND AND CONTROL

The command and control network for GMD operates in the first instance through GMD Fire Control (GFC) and is supported in some ways by the broader Command and Control, Battle Management, and Communications (C2BMC) network for the broader BMDS. Data from various sensors is sent to the GBI launch sites via Defense Satellite Communications System (DSCS) facilities or by redundant ground-based communication lines.

To maintain GMD readiness, personnel stationed at Fort Greely and Vandenberg AFB conduct daily missile engagement simulations.

GMD Fire Control (GFC)

Operated at both Schriever AFB in Colorado and Fort Greely in Alaska, the GFC system collects data from the many space- and land-based radars and sensors. GFC receives data from a

52. James D. Syring, "Department of Defense Briefing by Vice Adm. Syring on the Fiscal Year 2016 Missile Defense Agency Budget Request in the Pentagon Briefing Room" (news briefing, Washington, DC, February 2, 2015).

53. Mike Gruss, "MDA Eyes Shared Constellation for Missile Tracking, Space Surveillance," *SpaceNews*, July 30, 2015, http://spacenews.com/mda-eyes-shared-constellation-for-missile-tracking-space-surveillance/.

worldwide network of radars and satellites on incoming missile and aerospace threats via the DSCS sites at Fort Greely and Vandenberg AFB. Information is communicated to the Command Launch Equipment (CLE), and the CLEs then formulate firing solutions.

The operators then use that data to task and support the intercept of targets using GBIs. After an interceptor is launched, the In-Flight Interceptor Communications System (IFICS) Data Terminals (IDTs) communicate this information to the GBIs in flight, either westward through Fort Greely and Vandenberg, or through Fort Drum, New York, for an eastern trajectory.[54] Two upgrades are currently planned for GFC.[55]

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

The IDTs are facilities that relay communication between the GMD Fire Control and the GBIs while in flight. There are currently six IDT facilities: two at Fort Greely, two at Vandenberg, one at Fort Drum, and one at Eareckson Air Station. Construction of the Fort Drum IDT facility was completed in 2015, and it became operational in March 2016. This latter IDT is particularly important for the capability to intercept a future Iranian ICBM because communication to the GBI must be line-of-sight. Additionally, enhancements are currently being made to the IDT systems at large to enable on-demand communications with the kill vehicle (KV).

Command and Control, Battle Management, and Communications (C2BMC)

C2BMC is an operational software and network program. It is the "integrating element" that collects and processes sensor information to provide a complete picture of the missile defense battlespace to Combatant Commanders and other high-ranking defense officials to facilitate decisionmaking.[56] Not all sensors use the C2BMC network to transmit data to GFC. The UEWRs, Cobra Dane, and SBX, for example, send their data directly to GFC.

C2BMC first became operational in 2004 and has since gone through nine phases of development, or "spirals."[57] Each spiral has incrementally improved the system's ability to integrate sensors and interceptors, as well as provide a more complete, uniform, and robust picture of the battlespace. The most current spiral, S6.4, is expected to be replaced by S8.2-1 in the 2017–2018 time frame. This spiral will be fielded to NORTHCOM and PACOM and will allow C2BMC to integrate data from TPY-2 radars, SBX, UEWRs, Cobra Dane, and various space sensors. It will also reportedly give the system five times more tracking capability. Upgrade 8.2-5 will begin supporting LRDR sensor management.[58]

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54. Syring, "Hearing on the FY 2017 Missile Defense Agency Budget Request," 11.

55. Ibid. "The first, GFC 6B3, provides the Warfighter the capability to operate with 44 GBIs, improves discrimination capability, and adds several Warfighter requested upgrades to improve operational capability. The second, GFC 7A, improves fail-over between redundant systems and system availability by removing the aging Command and Launch Equipment and streamlining the GMD fire control system architecture."

56. "Command and Control, Battle Management, and Communications (C2BMC)," Missile Defense Agency, https://www.mda.mil/system/c2bmc.html.

57. DOT&E, "FY 2004 Annual Report," 327.

58. Syring, "Hearing on the FY 2017 Missile Defense Agency Budget Request."

According to a recent GAO report, the C2BMC program has in recent years been a source of delay for the overall BMDS architecture. C2BMC's purpose is to integrate various elements of the system, but schedule slips, funding reductions, and changing priorities have required human operators to direct some of the system's tasks instead of using a more automated option. Related improvements are expected to be deployed in 2020.[59]

Manning GMD

Dedicated homeland missile defense units fall under the purview of the U.S. Army's 100th Missile Defense Brigade, which is based out of Schriever Air Force Base in Colorado Springs. The unit is a multicomponent brigade made up of both regular Army Soldiers and Army National Guardsmen.[60] The 49th Missile Defense Battalion mans the GBI site at Fort Greely, consists of Alaska National Guardsmen, and reports to the commander of the 100th Missile Defense Brigade.[61] The California Army National Guard mans the Vandenberg site as part of Detachment 1, another subcomponent of the 100th Missile Defense Brigade.[62]

These units, assigned to the U.S. Army Space and Missile Defense Command for force provision, are under the operational control of USNORTHCOM. Although comprised of National Guardsmen, they operate full-time and conduct missile engagement simulations on a daily basis.

At MDA's creation, its task was to develop and field missile defense systems with the intention of then transitioning them to the Services. PATRIOT, for instance, was returned from MDA to the Army in 2003. Full responsibility for procurement and operating costs for THAAD may eventually transition to the Army, and Aegis/SMs to the Navy. GMD, however, poses a more challenging question as to which Service, if any, should assume responsibility for ongoing operations and budgeting. While the budget for GMD remains in MDA, manning has always been the purview of the Army. The UEWRs and Cobra Dane radars, however, are all operated and sustained by the Air Force.

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59. U.S. Government Accountability Office, *Missile Defense: Ballistic Missile Defense System Testing Delays Affect Delivery of Capabilities*, GAO-16-339R (Washington, DC: U.S. Government Accountability Office, 2016), 34–35, http://www.gao.gov/assets/680/676855.pdf.

60. "100th Missile Defense Brigade," U.S. Army SMDC/ARSTRAT, http://www.smdc.army.mil/2008/100thMDB.asp.

61. William Yardley, "A Missile Defense System Is Taking Shape in Alaska," *New York Times*, December 10, 2006, http://www.nytimes.com/2006/12/10/us/10greely.html?_r=0.

62. Steve Bauer, "Vandenberg's Army Detachment Critical for U.S. Missile Defense," Vandenberg Air Force Base, January 22, 2010, http://www.vandenberg.af.mil/News/Article-Display/Article/339953/vandenbergs-army-detachment-critical-for-us-missile-defense.

06

Future Options

This study has so far examined the policy and strategic context for homeland missile defense, the historical background and basis for today's architecture, the state of GMD today, and currently planned upgrades. We turn now to additional or alternative options.

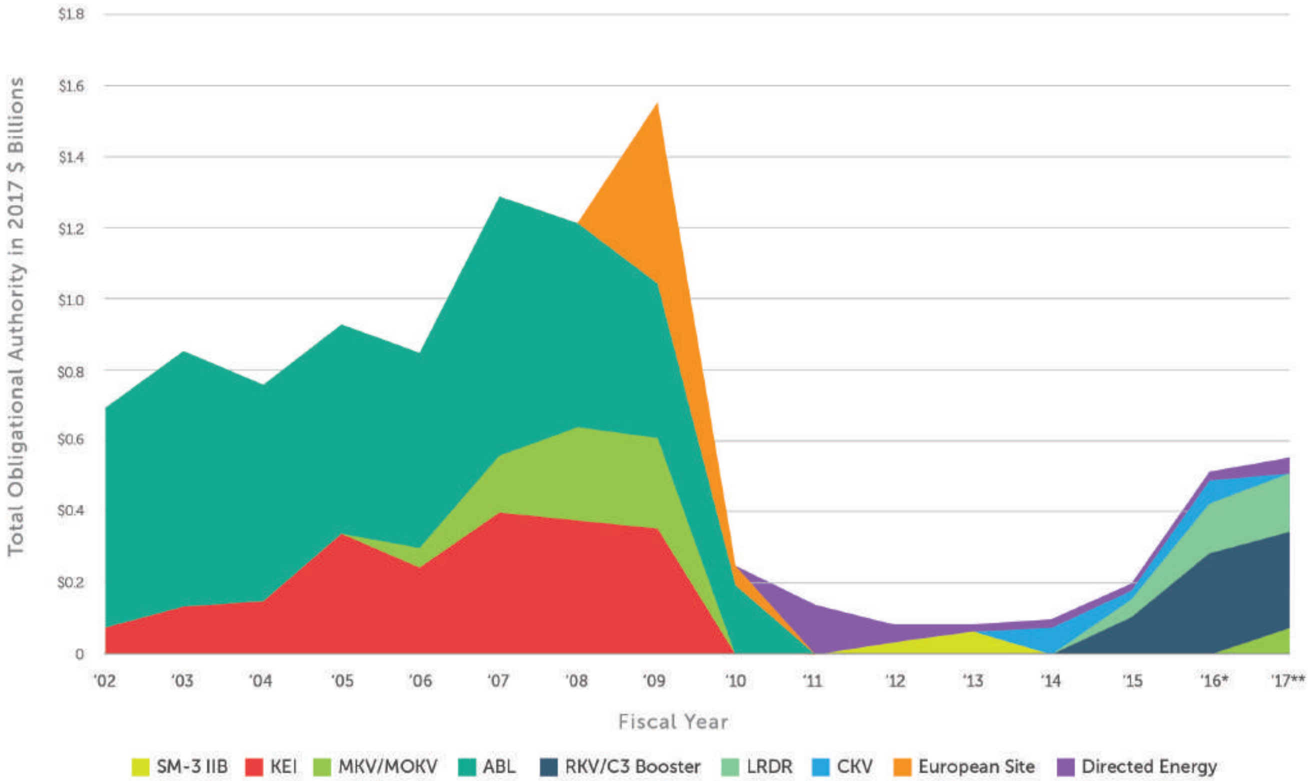
To protect the homeland, the United States currently relies almost exclusively on the GMD program and associated assets for midcourse intercept of a limited threat set of long-range ballistic missiles. In the future, the U.S. homeland missile defense posture will likely have to expand GMD, but also broaden to include additional programs.

In recent years, more advanced missile defense efforts have suffered from underinvestment. For those specifically related to homeland defense, a kind of budgetary valley appeared between 2010 and 2015 (see Figure 6.1). Much of the drop-off around 2009 to 2010 was the result of program cancellations, such as the MKV, ABL, and KEI. The modest uptick in funding for new programs that has occurred since 2014 has been fueled largely by investments in RKV and LRDR. The LRDR, while significant in the capability it will bring, does not represent a major technological advancement but simply an additional S-band radar. RKV also represents a more incremental improvement over the existing EKV, rather than a dramatic advance.

One MDA-wide metric for measuring investment in next-generation, "leap-ahead" concepts is Budget Activity 3 within MDA's broader RDT&E account (Figure 6.2).[1] This category, which funds research into less mature but promising technologies, has been subject to a general decline. For many of the options described in this chapter, however, MDA's research and development budget would require both more stability and more investment.

1. Budget Activity 3 is defined as "efforts necessary to evaluate integrated technologies, representative modes, or prototype systems in a high fidelity and realistic operating environment." U.S. Department of Defense, "Research, Development, Test, and Evaluation Appropriations," chap. 5 in *DoD Financial Management Regulation*, vol. 2B, 5-2.

Figure 6.1. Homeland Missile Defense Advanced Technology: Select Programs, 2002–2017



*Based on FY 2016 enactment.
**Based on FY 2017 presidential budget request.

IMPROVING CAPACITY

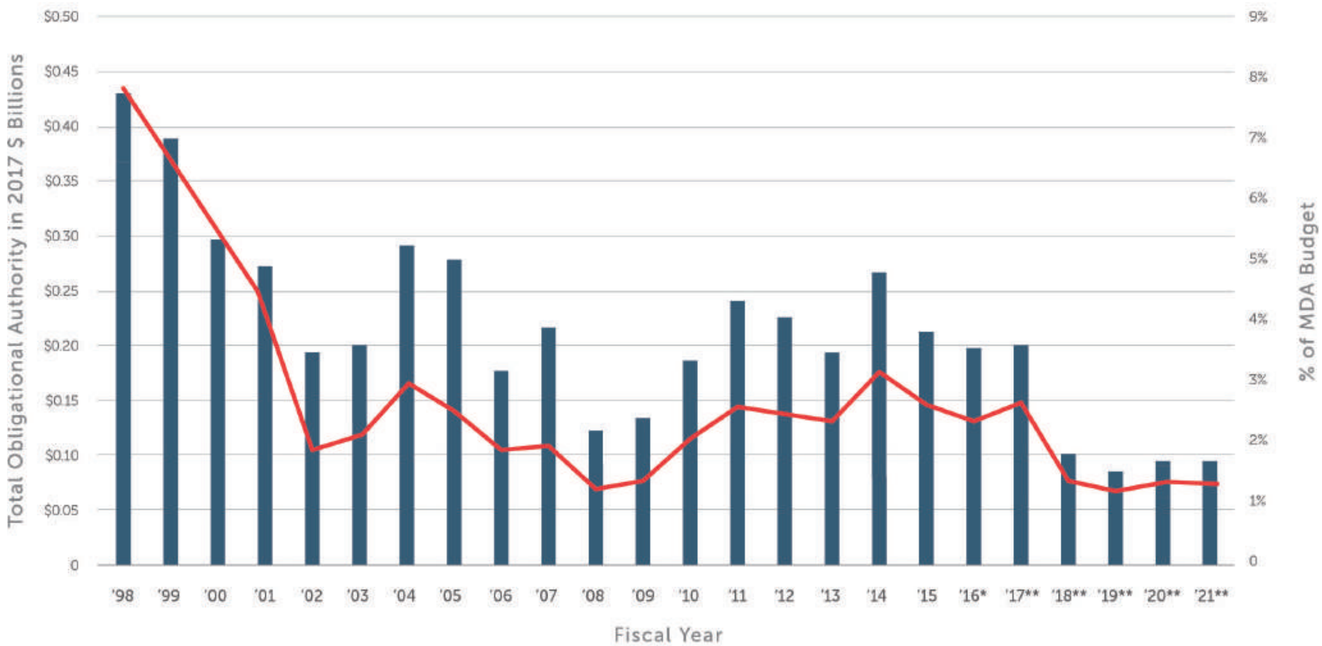
The United States currently has no plans to expand the number of homeland defense interceptors beyond 44 by the end of 2017. Indeed, the number 44 in some ways overstates the effective inventory, since the currently scheduled test regime will bring this number down by 10 percent from 44 to 40 by 2021, and not recover to the full 44 until 2022 or later—assuming, that is, the RKV development, testing, and production program stays on MDA's ambitious schedule. This decrease in the GBI magazine between 2019 and 2022 leaves much to be desired in the face of North Korea's current and potential future missile development. Given a shot doctrine of two to four kill vehicles per target, and given multiple targets per missile, an inventory of 40 to 44 interceptors could well be challenged by serial production of North Korean ICBMs.

This decrease in the GBI magazine between 2019 and 2022 leaves much to be desired.

Activating the Hedge: Expanding Interceptor Fields at Fort Greely

As highlighted by the 2013 report to Congress on *Homeland Defense Hedging Policy and Strategy*, the most cost-effective near-term option for increasing homeland interceptor capacity would

Figure 6.2. RDT&E Budget Activity 3: Amounts and Percent of MDA Budget, 1998–2021



*Based on FY 2016 enactment.

**Based on FY 2017 presidential budget request.

probably be to complete and fill the additionally planned missile fields at Fort Greely.[2] The 2013 report noted that these "additional interceptors could be deployed for a lower cost and more quickly" at Fort Greely than at Vandenberg or at an entirely new site. This is due in large part to the preexisting infrastructure at Fort Greely to support additional emplacements, and other environmental and regulatory restrictions.

Interceptor expansion of Fort Greely has at least three potential parts. First, with the refurbishment of Missile Field 1, 14 additional silo "sleeves" could be available relatively soon to be completed and filled. Such a step would boost the number of deployed interceptors at Fort Greely from 40 to 54, for a total of 58, including the GBIs at Vandenberg AFB. Second, Missile Field 2 could be expanded from 14 to 20 silos, bringing the number to 60 at Fort Greely and to 64 at both sites. As compared to completing Missile Field 1, this step may require more new construction. Finally, Fort Greely has areas predesignated for a fourth and fifth missile field of 20 interceptors each.[3] An additional 40 silos would bring the full capacity to 104 GBIs between both sites—just above the number envisioned for the expanded Capability-1 architecture proposed by the Clinton administration in 1996 (see Figure 6.3 and Table 6.1).

2. U.S. Department of Defense, "Homeland Defense Hedging Policy and Strategy" (report to Congress, June 2013), 4.

3. The Environmental Impact Statement (EIS) for the site was tailored to 100 interceptors, so such a growth should not incur any unexpected additional delays. Office of the Secretary of Defense, "Notice of Availability of the National Missile Defense Deployment Final Environmental Impact Statement," *Federal Register* 65, no. 242 (December 15, 2000): 78475.

Figure 6.3. Fort Greely Additional Interceptor Capacity

Source: CSIS.

CONUS Interceptor Site

With the cancellation of the third GBI site in Europe in 2009 and the termination in 2013 of the forward-based SM-3 IIB, Congress has displayed considerable interest in a potential GBI field somewhere in the eastern United States.[4] The 2013 National Defense Authorization Act directed the secretary of defense to begin a site selection survey, including Environmental Impact Statements (EIS), for potential location at one of four sites: Fort Drum, New York; the SERE Training Center in Maine; Camp Ravenna, Ohio; and Fort Custer, Michigan. In January 2016, MDA announced that it was no longer considering the SERE Training Center as a candidate site.[5] Whereas

4. National Defense Authorization Act for Fiscal Year 2013, Pub. L. No. 112-239, 126 Stat. (2013): 1678–1679:

> The Secretary of Defense shall conduct a study to evaluate at least three possible additional locations in the United States, selected by the Director of the Missile Defense Agency, that would be best suited for future deployment of an interceptor capable of protecting the homeland against threats from nations such as North Korea and Iran. At least two of such locations shall be on the East Coast of the United States.

5. Missile Defense Agency, "SERE East Designated as Alternative Considered but Not Carried Forward," MDA news release, January 15, 2016, https://mda.mil/news/16news0001.html.

Table 6.1. Planned and Potential GBI Capacity—Fort Greely and Vandenberg Air Force Base

	End of 2017	Full Capacity
FGA Missile Field 1	6	20
FGA Missile Field 2	14	20
FGA Missile Field 3	20	20
FGA Missile Field 4	0	20
FGA Missile Field 5	0	20
VAFB	4	4
Total	44	104

Fort Greely was evaluated for 100 interceptors in its EIS, the plans for the East Coast site only include 60.

Benefits. During the Clinton administration, some advocates of national missile defense recommended that GBIs be located not in Alaska, but in North Dakota, perhaps at the site of the old Safeguard system. Such a location would extend reaction time and provide better protection to the continental United States and the East Coast, both for North Korea and Middle Eastern threats.[6] Such a location would probably have made much sense, but was curtailed by both the political mandate for 50-state coverage and the desire to limit deployments to one site in order to remain more or less compliant with the ABM Treaty.

An East Coast site "would add battlespace and interceptor capacity should it be deemed necessary to proceed with deployment."

The MDA director, Vice Admiral James Syring, has testified that an East Coast site "would add battlespace and interceptor capacity should it be deemed necessary to proceed with deployment."[7] Being positioned closer to the source of the incoming missile, and closer to the targeted region, would allow for more time to engage the target, conduct a kill assessment, and launch additional intercep-

6. James M. Lindsay and Michael E. O'Hanlon, *Defending America: The Case for Limited National Missile Defense* (Washington, DC: Brookings Institution, 2004), 24.

7. James D. Syring, "Fiscal Year 2015 National Defense Authorization Budget Request for Missile Defense Programs" (statement before the House of Representatives Armed Services Committee, Strategic Forces Subcommittee, March 25, 2014).

tors if necessary.[8] The Obama administration's 2013 hedging strategy echoed these potential benefits, adding that a Continental United States (CONUS) site would permit "additional decision-making time and support the future option to employ a Shoot-Assess-Shoot engagement strategy."[9]

An additional distribution at one or more other sites would also reduce the vulnerability of the existing interceptor inventory. Although MDA and defense officials have testified that the interceptors in Alaska could defend the eastern United States, the short window to conduct such an engagement would likely reduce the chance of success. The National Academy of Sciences (NAS) described the operational benefits thusly:

> While it is kinetically possible to defend the eastern part of CONUS against threat ICBMs from the Middle East using GBI sites at Ft. Greely and Vandenberg AFB, an additional GBI site located in northeastern CONUS would be much more effective and reliable and would allow considerably more battle space and firing doctrine options.[10]

Limitations. Defense officials have expressed reservations about an additional GBI site, arguing that it would divert limited resources away from investment in making the existing number of interceptors more reliable. Qualitative improvements to GMD have been neglected in the past, and it would be unfortunate to repeat the pattern.

Despite general recognition of the technical benefits of such a site, the Obama administration's view has been that other improvements should take precedence. Then principal deputy undersecretary of defense for policy, Brian McKeon, described some of the Pentagon's reservations:

> The cost of building an additional missile defense site in the United States is very high. Given that the ICBM threat from Iran has not yet emerged, and the need to fix the current GBI kill vehicles, the highest priorities for the protection of the homeland are improving the reliability and effectiveness of the GBI and improving the GMD sensor architecture. The current GMD system provides coverage of the entire United States from North Korean and potential Iranian ICBMs.[11]

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8. General Charles H. Jacoby Jr., Commander, U.S. Northern Command, and Commander, North American Aerospace Defense Command (statement on U.S. European Command, U.S. Northern Command, and U.S. Southern Command, hearing before the Senate Committee on Armed Services, 113th Cong., 1st sess., March 19, 2013).

9. Department of Defense, "Homeland Defense Hedging Policy and Strategy," 5.

10. Committee on an Assessment of Concepts and Systems for U.S. Boost-Phase Missile Defense in Comparison to Other Alternatives, Division on Engineering and Physical Science, National Research Council, *Making Sense of Ballistic Missile Defense: An Assessment of Concepts and Systems for U.S. Boost-Phase Missile Defense in Comparison to Other Alternatives* (Washington, DC: National Academies Press, 2012), 85.

11. Brian McKeon, "Fiscal Year 2016 National Defense Authorization Budget Request for Missile Defense Programs" (statement before the House of Representatives Armed Services Committee, Strategic Forces Subcommittee, March 19, 2015).

This position does not rule out an additional site located in the continental United States, but is rather an expression of priorities at the margin. Absent direction from Congress and a raised topline to accommodate site construction, its prioritization will likely not occur until at least after MDA has achieved the goals falling under the category of "Robust Homeland Defense." The relative trade-offs between expanding nominal capacity and location versus greater investment in reliability improvements will, however, need to be reconsidered by the next administration in light of increased North Korean missile activity.

Transportable GBIs

One potential alternative to a dedicated East Coast site would be a GBI or other interceptor that could be relocated during times of heightened threat, or as a temporary measure. Rather than being emplaced in a silo, a transportable interceptor could be carried by truck and erected on a small pedestal for launching. The concept had been floated since around 2009 as a possible alternative to GBI silos in Poland.[12]

Having the capability to deploy transportable GBIs would allow for an augmentation of interceptor capacity while still maintaining flexibility for responding to threats emanating from other regions.

There would still be limitations, however, as to where transportable GBIs could be effectively deployed, given the need for communications and line-of-sight updates from the ground. Such locations would therefore be limited by the availability and presence of both sensor assets and IDTs.

A transportable GBI's flexibility could also be limited by booster configuration. More forward deployments, such as to Europe, might require a two-stage booster, while CONUS deployments might benefit from a three-stage variant.

The 2017 National Defense Authorization Act contains a provision instructing MDA to submit a report on the feasibility and value of a transportable ground-based interceptor for homeland missile defense, including costs and testing requirements.[13]

Interceptor Underlay

Another possible way of enhancing homeland ballistic missile defense is to use an underlay of shorter-range and less expensive interceptors. An analogous underlay concept had been part of the notional architecture for SDI Phase 1 and was further explored for GPALS during the George H. W. Bush administration, but was canceled in the Clinton administration. Such a layered defense was deployed at Grand Forks with the Safeguard architecture of Spartan and Sprint interceptors and was part of the notional ALPS concept, using ERIS and HEDI.[14]

12. Jim Wolf, "Boeing Floats New Anti-missile Idea for Europe," *Reuters*, August 20, 2009, http://www.reuters.com/article/idUSB327847.

13. National Defense Authorization Act for Fiscal Year 2017, H.R. Rep. 114-328, Conference Report to Accompany S.2943, Sec.1694 (2015–2016).

14. James Walker, Lewis Bernstein, and Sharon Lang, *Seize the High Ground: The U.S. Army in Space and Missile Defense* (Huntsville, AL: U.S. Army Space and Missile Defense Command, 2003), 64.

Such an underlay might be either exoatmospheric, such as an Aegis Ashore site with SM-3 IIA, or it might be endo- and exoatmospheric, such as an extended-range THAAD. Both have advantages and disadvantages. THAAD's endo- and exoatmospheric capability allow it to engage in both the late-midcourse and terminal phase, and its endo-atmospheric capability enables the use of the atmosphere to mitigate the discrimination challenge (as decoys and debris would burn up or be stripped away on reentry). An Aegis Ashore site on the East Coast with SM-3 IIA or IIA follow-on would provide a relatively greater defended area, especially with launch-on-remote. For either option to improve coverage against Iranian missiles, however, more sensor assets would be required. Neither system has yet been tested against an intercontinental ballistic missile that could well challenge their abilities.[15]

Either system would have considerably less reach and defended area than a GBI, but may offer the corollary advantage of intercept later than even a selectable two-stage GBI. Adding a lower tier to the homeland missile defense system could alleviate some pressure on GMD and add an additional "shoot-look-shoot" option at relatively less cost.

Such a lower-tier underlay would not be suited to continental-wide coverage, but could make sense for particular areas, such as Hawaii, Alaska, Guam, or other selected locations. Certain regions or sites could well merit additional defense, such as cities, the National Capital Region, or strategic assets. Such an underlay would not be a replacement for GMD but rather an augmentation.

More Energetic GBI Booster

As discussed in Chapter 4, the three-stage GBI booster configuration requires relatively early launch, both due to the slower speed of the heavier three-stage booster and the requirement to burn out all three booster stages before the EKV can be deployed. This in turn constrains the ability to fire a second round of interceptors should the first attempt fail. The two-stage/three-stage selectable booster under development attempts to address this issue, but the interceptor would still carry dead weight when in two-stage mode.

Some faster interceptor, either a simple two-stage GBI or perhaps a new and more energetic booster drawing on research from KEI efforts or continued block development of the Standard Missile, could be the basis for a comparatively faster and cheaper interceptor.[16] Since faster boosters can be fired later, they increase the time that can be spent on discrimination. Such an interceptor could have the benefit of full or near-full CONUS coverage, while providing a shoot-look-shoot option. The 2012 NAS study recommended a booster with a burnout velocity of six kilometers per second.[17] A newer and faster GBI booster could in principle be

15. In fact, development of THAAD was constrained for a period of time to limit its ability to counter longer-range ballistic missiles, so as not to run afoul of the ABM Treaty. "THAAD Cleared for ABM Treaty Compliance, Kaminski Says," *Aerospace Daily and Defense Report*, October 1, 1996, http://aviationweek.com/awin/thaad-cleared-abm-treaty-compliance-kaminski-says.

16. *Making Sense of Ballistic Missile Defense*, 146.

17. Ibid., 131, 145.

designed to benefit from more energetic solid fuel, strap-on boosters, or even a liquid fueled stage.

BOOST PHASE

MDA's chartered mission is to develop and deploy defenses against "enemy ballistic missiles in all phases of flight," but recent efforts have focused on midcourse intercept to the near exclusion of the boost phase. Engaging missiles while their engines are still burning holds the promise of preempting the deployment of post-boost vehicles, reentry vehicles, and countermeasures, thereby avoiding the midcourse discrimination problem. During the boost phase, the missile remains in one piece, making it easier to identify and target. The missile's body is also weaker than the insulated and shielded reentry vehicle. Even a limited boost phase layer could assist with "thinning the herd" and disrupting structured attacks.[18] Boost-phase defense also has the advantage of defeating a threat missile as far away from the U.S. homeland as possible, potentially over the enemy's own territory.

The compressed timeline between ignition and burnout, however, makes the task challenging. Advanced ICBM and SLBM programs are designed to have an especially short boost period. The KEI program was one attempt to kinetically destroy missiles in their ascent phase, but was challenged by the need for near instantaneous reaction time and the difficulty of getting close enough to an inland launch site. Directed energy systems could help mitigate this short time window.

Airborne Directed Energy

Deputy Secretary of Defense Robert Work has remarked that "the first aspect of the third offset strategy is to win a guided munitions salvo competition." He added, though, that the best way to accomplish this may not be by using kinetic interceptors, insisting, "It's got to be something else."[19] Kinetic interceptors are comparatively expensive, and missile defense batteries and ships can only carry so many missiles before they run out.

Acknowledging the relative cost and capacity limitations of kinetic hit-to-kill interceptors, both Congress and MDA have shown long-standing interest in directed energy weapons, and airborne lasers in particular. Since the 1960s, the Department of Defense has been experimenting with lasers in the hope they could be used for ballistic missile intercept, including the Airborne Laser Lab (ALL), the Mid-Infrared Advanced Chemical Laser (MIRACL), and the manned 747-mounted Airborne Laser (ABL) program of the early 2000s, which, despite its later cancellation, demonstrated that intercepting ballistic missiles in boost phase with directed energy was possible.[20]

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18. Ole Knudson, "MDA and the Color of Money" (speech, Center for Strategic and International Studies, Washington DC, July 29, 2015).

19. Sydney J. Freedberg Jr., "Work Elevates Electronic Warfare, Eye on Missile Defense," *Breaking Defense*, March 17, 2015, http://breakingdefense.com/2015/03/raid-breaker-work-elevates-electronic-warfare-eye-on-missile-defense/.

20. Missile Defense Agency, "Airborne Laser Test Bed Successful in Lethal Intercept Experiment," MDA news release, February 11, 2010.

Although these programs represented technological advances, the size of the platforms, the operational constraints and challenges, the focus on chemical lasers, and cost considerations made these systems less practical for actual operations.

Another concept of operations consists of long endurance UAV-mounted lasers, flying at high altitudes (65,000 feet). Research and development of the concept has been under way since 2006.[21] MDA officials now suggest that both UAV and laser technology have matured to the point that developing a UAV-borne missile defense laser may soon be within reach. Two basic technologies have been identified as most promising: a diode-pumped alkali laser and a fiber-combined laser.[22] Director Syring has testified that "both lasers achieved record power levels within the last year. MDA will continue high energy efficient laser technology development with the goal of scaling to power levels required for a broad spectrum of speed of light missile defense missions."[23]

With a UAV-borne laser, a ballistic missile could conceivably be defeated during boost phase by disrupting the missile airframe and causing it to collapse and explode. MDA's 2017 budget request included $47.7 million for continued development of this concept.[24]

Other directed energy programs under way include the Air Force's Demonstrator Laser Weapon System (DLWS), the Army's truck-mounted High Energy Laser-Mobile Demonstrator (HEL-MD), and the Navy's Laser Weapon System (LaWS). These demonstrators have shown the ability to generate tens of kilowatts at short ranges. Significant increases in transmitted power, expanded range, and miniaturization will be required before these prototypes can be put onto a UAV and tested against boosting missiles. Specifically, this will involve increasing from hundreds of kWs to a megawatt-plus class laser, improved beam stabilization, and higher altitude UAVs. This trade-off between increased power and size is measured in kilograms per kilowatt. The ABL had some 55 kilograms of weight per kilowatt (kg/kW). The DPALS is said to be around 35 kg/kW. MDA's stated goal is 2 kg/kW.

The stated concept of operations would be a UAV at 65,000 feet, with endurance of days at a time.[25] With a significantly thinner atmosphere, the beam transmission is said to be 18 times more efficient than at 40,000 feet, which was ABL's altitude.[26] Demonstrations to date have included the Phantom Eye UAV, but others with the Reaper are planned for the 2017–2018 time frame.[27]

Benefits. The successful development of compact and powerful directed energy weapons could, in MDA's words, "revolutionize missile defense by dramatically reducing, if not eliminating, the role

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21. James D. Syring, "The Future of Ballistic Missile Defense" (slide presentation, 2015 Space and Missile Defense Symposium, Huntsville, AL, August 12, 2015), slide 14.

22. Syring, "The Future of Ballistic Missile Defense," slide 20.

23. James D. Syring, "Ballistic Missile Defense Policies and Programs" (statement before the Senate Armed Services Committee, Strategic Forces Subcommittee, April 2, 2014), 21.

24. Syring, "The Missile Defeat Posture and Strategy of the United States—The FY17 President's Budget Request," April 14, 2016.

25. Syring, "The Future of Ballistic Missile Defense," slides 16–19.

26. Missile Defense Agency, "Boost Phase Missile Defense Options," MDA news release, January 3, 2014.

27. Syring, "The Future of Ballistic Missile Defense," slide 22.

of very expensive interceptors."[28] A UAV-borne laser would be able to intercept ballistic missiles at a fraction of the cost of a kinetic interceptor, or even a ballistic missile, putting missile defense on the right side of the cost curve.[29]

By putting a laser or some other directed energy weapon on a UAV instead of a conventional manned aircraft, the military could continuously operate aircraft on station, much the same way the military currently operates UAVs for Intelligence, Surveillance, and Reconnaissance (ISR) missions. A UAV-borne laser might also have other applications as well, including against enemy fighter aircraft or even against an adversary's air-to-air missiles, thereby protecting its own patrol.[30]

Limitations. The primary limitation of UAV-borne directed energy weapons is the need to get close enough to the missile to destroy it, yet remain far enough away to be protected from enemy air defenses. As Undersecretary of Defense Frank Kendall noted, it would then be a matter for the military of figuring out "how it will get its UAVs close enough to the launch site to destroy missiles, how it will know when to launch the aircraft, and how the UAVs will survive given their proximity to enemy airspace."[31]

A UAV-borne laser would need a great deal of power to hit targets from a standoff range. Space and energy come at a premium onboard a UAV. These constraints create a trade-off between range, altitude, and power. Unless and until this power-to-weight ratio is achieved, the applications will be relatively more limited. While North Korea's proximity to international waters and the trajectory of its ballistic missiles toward the United States would make the concept of operations especially well suited to this threat, its application may be harder for missiles launched further away or inland, such as from Iran.

Although directed energy could one day make interceptors obsolete, that day is likely still far away. For the foreseeable future, missile defenses are likely to rely on chemically powered rockets carrying kinetic kill vehicles to defeat other chemically powered rockets.

ORBITAL BASING

Space-based interceptors were a key component of SDI and GPALS. The concept evolved from garages of space-based interceptors into the concept of individual Brilliant Pebbles and eventually was adopted as part of the GPALS architecture before getting cancelled in 1993. The debate over the feasibility and utility of space-based interceptors continues to this day.

The 2017 Defense Authorization Act contained a provision calling on MDA to "commence coordination and activities associated with research, development, test and evaluation" of a space-based

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28. Syring, "The Missile Defeat Posture and Strategy of the United States."

29. Kenneth E. Todorov, "Missile Defense: Getting to the Elusive Right Side of the Cost Curve," Center for Strategic and International Studies, April 8, 2016.

30. Sydney J. Freedberg Jr., "Return of the ABL? Missile Defense Agency Works on Laser Drone," *Breaking Defense*, August 17, 2015, http://breakingdefense.com/2015/08/return-of-the-abl-missile-defense-agency-works-on-laser-drone/.

31. Ibid.

ballistic missile intercept and defeat layer.[32] Over the last decade, MDA has had occasional requests for a "space test bed" budget line item to research the possibility of a boost-phase intercept layer in space. MDA apparently canceled the program in 2009.[33] The 2009 Defense Appropriations Act directed a study on the issue, which was conducted by the Institute for Defense Analyses (IDA) in 2011.[34] IDA reportedly concluded that "the technology maturity exists such that the space-based interceptor layer that was considered in this study could be developed within ten years," while conceding launch costs would be a major limitation.[35] Given the current absence of a space test bed or other serious consideration currently under way, it remains an open question what twenty-first-century possibilities might be for a smaller, Brilliant Pebbles–like constellation.

Benefits. As a first layer of protection, a space interceptor overlay could augment and supplement GMD by defeating limited threats before their midcourse phase, reducing the number of targets requiring midcourse interception. Such a constellation could be part of a layered defense architecture and would have the role of thinning salvos for subsequent intercept by other terrestrial elements of the system, especially against missiles launched from nations with deeper interiors. Technological advances since the late 1980s and early 1990s might also allow for lower weight, cheaper, and more reliable interceptors.[36] Lighter kill vehicles and fuel would also affect launch costs.

Limitations. At the same time, significant hurdles still remain, including launch costs. Due to the natural orbital motions of a satellite and the fact it would be on station for a given threat for only a fraction of its orbit, a significant number of parallel orbits could be required to intercept salvo attacks.[37] The cost of procuring and launching a sufficiently large constellation would also not be insignificant. In April 2016, MDA director Syring expressed "serious concerns about the technical feasibility of interceptors in space."[38] Russia and China have also both tested various anti-satellite and counterspace weapons that would challenge the survivability of space-based interceptors.

FUTURE SENSOR OPTIONS

In recent years, MDA has emphasized the serious need to address tracking and discrimination shortfalls of the BMDS for homeland missile defense. Advancements include the deployment of an additional TPY-2 radar in Japan for early tracking of missiles from North Korea, completing the integration of Early Warning Radars into the BMDS, and breaking ground on the LRDR in Alaska.

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32. National Defense Authorization Act for Fiscal Year 2017, *Conference Report to Accompany S.2943*, Sec. 1683, 629.

33. *Making Sense of Ballistic Missile Defense*, 38.

34. Jim Wolf, "U.S. to Study Possible Space-based Defense," Reuters, October 17, 2008, http://www.reuters.com/article/us-missiles-usa-space-idUSTRE49H05Y20081018.

35. "Space Base Interceptor (SBI) Element of Ballistic Missile Defense: Review of 2011 SBI Report," Institute for Defense Analyses, James D. Thorne, February 29, 2016, quoted in Rebeccah L. Heinrichs, *Space and the Right to Self Defense* (Washington, DC: Hudson Institute, 2016), 22.

36. Independent Working Group, *Missile Defense, the Space Relationship, and the Twenty-First Century* (Washington, DC: Institute for Foreign Policy Analysis, 2008), 38.

37. *Making Sense of Ballistic Missile Defense*, 58, 71.

38. Syring, "The Missile Defeat Posture and Strategy of the United States."

These additional ground-based radars afford much needed capability, but overcoming the discrimination problem especially will require greater variation in sensor types and locations.

Space-based Tracking and Discrimination

With the cancellation of the Precision Tracking and Surveillance System (PTSS), the future of space-based tracking sensors for missile defense has become uncertain. Currently there are two STSS demonstration satellites in low-earth orbit. Launched in 2009, STSS will likely remain in orbit through 2021.[39] As Director Syring noted in 2015, however, "There is no plan today for STSS or PTSS follow on."[40]

Future space-based tracking constellations could perform a number of functions, including kill assessment and midcourse discrimination. MDA officials have noted that for any future system for missile tracking and discrimination, they would likely work more closely with the Air Force and other Defense Department agencies.[41] Should the development of space-based tracking and discrimination become reinvigorated, several options could be considered.

The projected longevity of STSS demonstrators gives MDA slightly more time to find a more permanent alternative. Currently, MDA and the Pentagon are undergoing an analysis of longer-term possibilities and needs. In June 2015, Vice Admiral Syring remarked that MDA is "working through concepts on what might be possible" for a follow-on program to STSS. As yet, however, there is no plan for it. In June 2015, industry representatives told reporters that if the STSS program were expanded to a constellation of 10 satellites, the constellation would then provide global coverage, applicable to both homeland and regional defenses.[42]

Benefits. Space-based tracking offers the opportunity for birth-to-death tracking of a target missile, sometimes referred to as the "holy grail" of missile defense. A constellation that enables such a capability would enhance discrimination not only with persistent coverage from an advantageous vantage point, but also through the ability to detect when countermeasures and debris are created. The global perspective from space also allows the BMDS to deal with "numerous, undefined azimuths of attack."[43] Space also allows the United States to deploy sensors without having to negotiate basing agreements.[44]

Limitations. Space-based tracking also comes with a unique set of challenges. The primary hurdle is the high cost of launching satellites into orbit, which is exacerbated by the size of the

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39. Mike Gruss, "MDA Study Could Eventually Lead to Additional Missile-tracking Satellites," *SpaceNews*, June 8, 2015, http://spacenews.com/mda-study-could-eventually-lead-to-additional-missile-tracking-satellites/#sthash.RHFLU7bD.Iqf3sth8.dpuf.

40. James D. Syring, "Department of Defense Briefing by Vice Adm. Syring on the Fiscal Year 2016 Missile Defense Agency Budget Request in the Pentagon Briefing Room" (news transcript, Department of Defense, Washington, DC, February 2, 2015).

41. Gruss, "MDA Study Could Eventually Lead to Additional Missile-tracking Satellites."

42. Ibid.

43. Steven Lambakis, *The Future of Homeland Missile Defenses* (Fairfax, VA: National Institute Press, 2014), 53.

44. Steven Lambakis, *On the Edge of Earth: The Future of American Space Power* (Lexington: University Press of Kentucky, 2001), 79.

constellations required to provide persistent and complete coverage of the earth's surface. The relatively high cost of a space-based option like PTSS in comparison to terrestrial alternatives led the NAS report to conclude that the lifecycle costs of the system outweighed the additional sensor capabilities it could have provided.[45] Space-based tracking systems are also difficult to repair and maintain, driving up the cost over time. Space-based sensors suffer from additional vulnerability to ASATs that use technology similar to the ballistic missiles that they are trying to detect. Larger constellations could acquire resilience through numbers and dispersion.

To offset costs, a number of approaches are being considered for the future. MDA's C4ISR program executive Richard Ritter has suggested that hosted or shared payloads across Service missions would not only reduce costs from MDA's perspective, but also help with survivability by distributing the capabilities across satellites, making each a less lucrative target for adversaries.[46] The model of commercial hosting forwarded by the Space-based Kill Assessment program promises another way to defray launch costs, though it is unclear that commercial hosts can support the kinds of payloads required for larger missions.

High-Altitude Tracking and Discrimination

One alternative or supplement to space-based tracking and discrimination is to have the function performed at high, near-space altitudes. In 2013, MDA moved to acquire the Phantom Eye high-altitude UAV designed for persistent ISR missions.[47] Director Syring has remarked that tests have "helped us learn a lot about platform jitter and the altitude that it went to and the importance of high altitude and above the cloud flight."[48] He further noted that during the five tests conducted so far, the demonstrator achieved a record altitude of 53,241 feet.[49]

While these tests are slowly building toward an intercept capability, the nearer-term application is to use lasers for high-altitude tracking and discrimination. The requirement for laser power is much less than for interception, but would require greater operational cost compared to space-based satellites and would not be as persistent.[50]

Past Suborbital and Near-Space Sensor Experiments. The concept of high-altitude tracking and discrimination is not new, and the United States has conducted several experiments on air-based platforms in suborbital space, which could provide some foundations for continue concept exploration. One such experimental program, the Queen Match, sought to replace Cobra Ball aircraft in

45. *Making Sense of Ballistic Missile Defense*, 119–120.

46. Richard Ritter, "Congressional Roundtable on Future Missile Defense" (speech, MDAA Congressional Roundtable, Capitol Visitors Center, Washington, DC, July 30, 2015).

47. Bill Carey, "Missile Agency is First Phantom Eye Payload Customer," *AINonline*, June 11, 2013, http://www.ainonline.com/aviation-news/defense/2013-06-11/missile-agency-first-phantom-eye-payload-customer.

48. James D. Syring, "Ballistic Missile Defense System Update" (speech, Center for Strategic and International Studies, Washington, DC, January 20, 2016).

49. James D. Syring, "Hearing on the National Defense Authorization Act for Fiscal Year 2016 and Oversight of Previously Authorized Programs" (statement before the House of Representatives Armed Services Committee, Strategic Forces Subcommittee, March 19, 2015).

50. Ritter, "Congressional Roundtable on Future Missile Defense."

Figure 6.4. MDA Advanced Sensor Test Bed

monitoring Soviet missile launches in eastern Siberia. Rather than an aircraft, an Aries rocket with a payload of sensors would be launched in tandem with a Soviet missile launch to gather discrimination data. The program suffered a failed launch during its first test in 1986, but was successfully tested in 1989. The program was canceled in 1991 after the collapse of the Soviet Union.

Launched in 1996, the Midcourse Space Experiment (MSX) was a satellite designed to demonstrate a suite of space-based sensors and collect data for midcourse sensor development. The sensors aboard could detect plumes from launches, discriminate between RVs and decoys, and perform kill assessment to determine if terminal defenses would need to be employed. In September 1996, the BMDO targets program deployed 26 objects for the MSX to observe.[51]

The High Altitude Learjet Observatory (HALO) tested in 1998 was an aircraft-based sensor package designed to observe and conduct kill assessment during intercept tests. The aircraft would take off before the launch of test missiles and cruise at 14,000 meters, staying within 650 to 900 kilometers of the interceptor until intercept occurred, tracking the flight of the interceptor rather than the target missile.[52]

51. Walker, Bernstein, and Lang, *Seize the High Ground*, 196, 219.

52. Katie Walter, "A View to a Kill," *Lawrence Livermore National Laboratory Science & Technology Review* (November 2002): 19–21.

Stacked TPY-2s

Among the recommendations from a 2012 report from the National Academy of Sciences was the proposal to increase the covered area of high-resolution X-band radars by deploying dual-emplaced TPY-2 radars, stacked atop one another. This configuration would extend the range of the TPY-2 radars by allowing both a wider field of view and greater possibilities to focus the energy of one or the other radar in a particular place.

NAS recommended that stacked TPY-2s should be colocated with certain UEWR locations, particularly at Cape Cod, Thule, and Fylingdales, and mounted on a rotating azimuth turntable for 360-degree coverage. They would be supplemented by an additional stacked TPY-2 radar at Clear, Alaska.

Filling LRDR Coverage Gaps

The Long Range Discrimination Radar under construction in Clear, Alaska, will do much to fill in radar coverage gaps along likely ballistic missile flight paths from North Korea, but some gaps will remain, particularly in the early midcourse phase over the northern Pacific Ocean and over Hawaii. Currently, this role is filled by forward-based TPY-2 radars in Japan and SPY-1 radars onboard Aegis BMD ships. However, these systems have limitations in the length of time that they can hold a track (TPY-2) and a relatively short range and lack of persistence (SPY-1). This gap has inspired MDA's interest in the potential deployment of another Medium Range Discrimination Radar (MRDR), likely to be based in Hawaii, as Hawaii would fall outside of LRDR's coverage.

In February 2016, MDA issued a solicitation for information "to determine industry interest and capability for development, installation, and initial operations/sustainment of a land-based Medium Range BMD Sensor Alternatives for Enhanced Defense of Hawaii concept," with an aim to "expand the persistent midcourse and terminal . . . discrimination capability . . . to defend the United States from ballistic missile attacks."[53] One potential option for this effort would be to simply operationalize the SPY-1 radar currently emplaced at the Pacific Missile Range Facility as part of the Aegis Ashore test bed.

INTEGRATING LEFT OF LAUNCH

Another closely related set of concepts for countering missile threats are measures that can disable a missile prior to its launch, also called "left of launch." This concept has achieved new salience of late with increased budget pressures and the inability of the DoD to supply the quantity of missile defenses demanded by combatant commanders.[54] Left of launch efforts are nothing new, but U.S. defense planners

"Left of launch is far more than just Scud hunting."

53. Missile Defense Agency, *Medium Range Ballistic Missile Defense (BMD) Sensor Alternatives for Enhanced Defense of Hawaii* (request for information HQ0147-15-R-0003, Missile Defense Agency, February 10, 2015).

54. Jonathan W. Greenert and Raymond T. Odierno, "Adjusting the Ballistic Missile Defense Strategy," Memorandum, November 5, 2014.

have begun to consider new concepts for left of launch operations. This might include kinetic efforts such as "Scud hunting" and other offensive means to strike the launcher on the ground. As Lieutenant General (ret.) Richard Formica, the former commander of the Army Space and Missile Defense Command, has pointed out, however, "left of launch is far more than just Scud hunting."[55]

Some attention, for example, has focused on ways to disrupt adversary kill chains.[56] As the director of the Joint Integrated Air and Missile Defense Organization (JIAMDO), Rear Admiral Jesse Wilson, observes:

> The enemy has to do all the things that we do in the kill chain to be effective. They've got to find, they've got to fix, they've got to track, target, and engage. . . . If I can disrupt other [p]arts of the adversary's kill chain, I don't have to fire an SM-3, I don't have to fire a Patriot, I don't have to fire a THAAD.[57]

Such concepts apply directly to homeland missile defense as well. If it can be done reliably, defeating a North Korean missile on its mobile launcher or during its manufacturing contributes to lessening the burden on GBIs or other active defenses.

Both Deputy Secretary of Defense Work and Undersecretary Kendall have championed the use of electronic warfare as a means to disrupt adversary precision-guided munitions, undermining their accuracy and reducing the number of required interceptors to defend a certain target.[58] Others have discussed the potential value of cyber tools to complicate the launch process. One difficulty, of course, is the challenge of knowing reliably in advance whether the efforts were successful. Active missile defenses have always been considered in light of other means to quiet a missile launcher, but represent an insurance policy should those efforts fail.

Finally, there are kinetic means to destroy missiles on launch pads, comparable to the long-standing Air Force doctrine to destroy enemy aircraft on the ground.[59] Early historical analogies include attempts by the Royal Air Force and the U.S. Army Air Corps to destroy V-2 rockets at their launch sites before they could be launched against London. Just as boost-phase missile defenses can thin the herd and mitigate the task for subsequent midcourse intercept, so too should left and right of launch be seen as complementary parts of a "layered defense." Attacking "archers" left of launch reduces the number of "arrows" that missile defense systems must contend with. Strikes and jamming can also reduce or degrade an adversary's command and control and logistics capabilities, potentially reducing the capacity to fire missiles even if inventory remains. Left of

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55. Richard Formica, "Full Spectrum Missile Defense" (speech, Center for Strategic and International Studies, Washington, DC, December 4, 2015).

56. Former MDA deputy director Kenneth Todorov emphasized that "the first thing we've got to do is advance the conversation and sort of come to some common understandings on what these things really mean." Kenneth Todorov, "Full Spectrum Missile Defense" (speech, Center for Strategic and International Studies, Washington, DC, December 4, 2015).

57. Sydney J. Freedberg Jr., "Army Explores New Missile Defense Options," *Breaking Defense*, February 18, 2015, http://breakingdefense.com/2015/02/army-explores-new-missile-defense-options/.

58. Freedberg, "Work Elevates Electronic Warfare, Eye on Missile Defense."

59. U.S. War Department, *Command and Employment of Air Power*, FM-100-20 (Washington, DC: U.S. Government Printing Office, 1943), 6.

launch also conserves interceptors by leaving them as a defense of last resort, and improves their effectiveness by limiting the threats to the system.

Employing such means also imposes costs on the adversary by forcing investment in a greater number of launchers or in their dispersal or hardening. Jamming and blinding an adversary's ISR and C2 assets forces an adversary to invest in redundant capabilities or to forgo further strikes. Lieutenant General David Mann, a former Army Space and Missile Defense commander, has called left of launch a means of "adding more arrows to the quiver and more capabilities for the warfighter."[60]

As the U.S. military discovered in Operation Desert Storm, Scud hunting is difficult even in an open desert and with complete air superiority.[61] In the context of homeland ballistic missile defense, left of launch capabilities would likely require large-scale offensive operations against enemy missile silos and possible Transporter Erector Launcher (TEL) locations with ballistic missiles.

Successfully carrying out left of launch offensive operations will also require a range of capabilities and significant coordination between their operators, as well as a posture ready to defeat them within the left of launch time window. First among several challenges is timely and accurate intelligence, the lack of which may hinder the ability to rely only on left of launch strikes. Even with excellent intelligence, however, as Rear Admiral Archer Macy points out, "as we include more capabilities that are not part of traditional intercept . . . command organization and planning for air and missile defense, the more complicated it can become."[62]

Left of launch operations may also look a lot like preemption or escalation, making their employment more politically costly and thus perhaps less credible.[63] To address these matters, the defense authorization bill passed in December 2016 requires the Department of Defense to provide both declaratory policy and a strategy for defeating missiles both left and right of launch, including cruise and ballistic missiles, and using kinetic and nonkinetic means.[64]

THE FUTURE MISSILE DEFENSE AND DEFEAT POSTURE

The United States homeland missile defense currently depends almost exclusively on GMD for exoatmospheric midcourse intercept of a quite limited number of long-range missiles from certain quarters of the world. Relatively little effort exists for boost-phase intercept, directed energy, space sensor or interceptor layers, and homeland cruise missile defense.

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60. Sydney J. Freedberg Jr., "Joint Staff Studies New Options for Missile Defense," *Breaking Defense*, September 16, 2015, http://breakingdefense.com/2015/09/joint-staff-studies-new-options-for-missile-defense/.

61. William Rosenau, *Special Operations Forces and Elusive Enemy Ground Targets: Lessons from Vietnam and the Persian Gulf War* (Santa Monica, CA: RAND, 2001).

62. Archer Macy, "Full Spectrum Missile Defense" (speech, Center for Strategic and International Studies, Washington, DC, December 4, 2015).

63. Todorov, "Full Spectrum Missile Defense."

64. National Defense Authorization Act for Fiscal Year 2017, *Conference Report to Accompany S.2943*, Sec.1684, 629.

In sum, today's homeland missile defenses remain too limited. As missile threats to the homeland continue to evolve, a broader and more comprehensive approach and posture may be required. The options and analysis in this chapter represent part of a menu that future policymakers may find useful to consider.

The currently planned enhancements likely account for what MDA will be capable of achieving, assuming the current budgetary topline remains more or less steady. An increase in the topline budget for missile defense would be necessary for additional steps, as well as buy-in from Combatant Commands to support their operational aspects. This will not come easy if overall defense expenditures continue to stagnate.

As the Donald J. Trump administration reviews and formulates its national security policies, the strategy, policies, and programs relating to missile defense will also require new scrutiny. Assuming some degree of constancy about the strategic utility of missile defenses, there seems little doubt that GMD and related programs will continue in some form, and likely expand. Significantly more can be done to improve on the capacity, capability, and reliability of today's homeland missile defenses.

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