Shielded from Oversight

The Disastrous US Approach to Strategic Missile Defense

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Appendix 6: The Ground Based Interceptor and Kill Vehicle

Union of Concerned Scientists

The interceptor missile for the Ground-based Missile Defense (GMD) system is known as the Ground Based Interceptor (GBI). At present, 30 GBIs are deployed in silos, four at Vandenberg Air Force Base in California and the rest at Fort Greely in central Alaska. Current plans call for more GBIs to be deployed at Fort Greely until the total number of deployed interceptors reaches 44 by the end of 2017. The current procurement cost for each GBI is about $75 million.[1]

The GBI and the EKV

The GBI consists of a three-stage rocket booster, built by the Orbital ATK Company, and a kill vehicle. In operation, the rocket booster is launched and then flies out of the atmosphere towards its target, guided by information from ground-based sensors, such as an Upgraded Early Warning Radar. Once the booster completes its powered flight into the vacuum of outer space, the GBI releases an Exo-atmospheric Kill Vehicle (EKV), which continues to glide through space towards the target. The EKV uses on-board infrared sensors to detect the target threat cloud, and uses small rocket motors called divert thrusters to maneuver itself into a direct high-speed collision with the target. The EKV, manufactured by the Raytheon Company, has a mass of about 55 kg. It has a two-color infrared seeker that uses a pair of cooled infrared charge-coupled device (CCD) arrays for identifying and homing in on its target.

The GBI has a length of 16.6 m, a diameter of about 1.3 m, and a mass of 22,483 kg.[2] The first stage of the GBI booster uses an ATK Orion 50 XLG rocket motor, the second stage an Orion 50 XL motor, and the third stage an Orion 38 motor. It has a total thrust time of about 206–216 seconds.[3] The GBI reportedly has a design speed of 7.2 kilometers per second (km/s); the design speed is the maximum speed for the booster if it is fired vertically.[4] The burnout speed can be significantly higher on nonvertical trajectories, which don't need to overcome the effects of gravity as much as a vertical launch. For the GBI, the burnout speed reportedly can be as high as 8.3 km/s.[5]

EKV Prototypes and GBI Booster Surrogates

All the GMD intercept tests before GBI deployment began in the summer of 2004 involved the use of prototype kill vehicles and/or surrogate boosters. As the Government Accountability Office (GAO) noted in April

[1] This is the price per interceptor given by MDA Director Vice Admiral James Syring in July 2013 for the 14 additional GBIs to be deployed by 2017. Syring, J. 2013. Testimony before the Defense Subcommittee of the Senate Committee on Appropriations. July 17. Online at *www.gpo.gov/fdsys/pkg/CHRG-113shrg39104550/html/CHRG-113shrg39104550.htm*. Note: All URLs in footnotes to this appendix were accessed May 20–22, 2016.

[2] Missile Defense Agency (MDA). 2010. GBI Component Details. Briefing slide for Industry Week Ground-based Midcourse Defense development and sustainment contract, March 8-9. Available at *http://www.ucsusa.org/sites/default/files/images/2016/07/GBI-component-details.jpg*

[3] The 206 second burn time is based on first, second and third stage burn times of 68.4, 69.7, and 67.7 seconds respectively. Alliant Techsystems Inc. 2008. ***ATK space propulsion products catalog***. Elkton, MD. May 14. Online at *www.ltas-vis.ulg.ac.be/cmsms/uploads/File/DataSheetSolidATK.pdf*. However, curves in this catalog show the thrust continues at measurable levels for several seconds longer, at least for the first two stages. The 216-second burn time is based on stage burn times of 73.4, 72.5, and 69.6 seconds. APT Research, Inc. 2004. Insensitive munitions threat hazard assessment-Rev. A of the Ground Based Midcourse Defense Program: Ground Based Interceptors (GMD-GBI)—Final Report. C31-02000. March 1:19-22. See Table 1.

[4] Gronlund, L, D. Wright, G. Lewis, and P Coyle. 2004. ***Technical realities: An analysis of the 2004 deployment of a U.S. National Missile Defense system***. Cambridge, MA: Union of Concerned Scientists. May, 52. Online at *www.ucsusa.org/sites/default/files/legacy/assets/documents/nwgs/technicalrealities_fullreport.pdf*.

[5] Gronlund, 2004.

2004, "...none of the GMD components included in the initial defensive capability have been flight tested in their fielded configuration (i.e., with production-representative software and hardware)."[6]

The first eight GMD intercept tests (through December 2002) used surrogate boosters assembled from already existing types of rocket stages. The surrogate boosters had lower burnout speeds than the planned operational boosters and subjected the kill vehicle to less stress during the powered flight of the booster. The first flight of the operational Orbital Sciences Corp. (now Orbital ATK) booster did not occur until August 2003, and this flight did not include a kill vehicle. The first GBI test using an operational booster mated with an actual kill vehicle was the non-intercept test FT-1 in December 2005.[7]

The first eight GMD intercept tests also used prototype versions of the EKV, now designated by the Missile Defense Agency (MDA) as Capability Enhanced-0 (CE-0) EKVs. These early tests involved only 67 percent of the hardware and 62 percent of the software used in the operationally-configured EKVs that began deployment in mid-2004.[8] Two of the GMD intercept tests conducted after deployment of the GBIs began, FTG-13c in December 2004 and FTG-14 in February 2005, used an improved prototype EKV, designated CE-0+, but in both of these tests the interceptor failed to launch.

[6] General Accounting Office (GAO). 2004. ***Missile defense: Actions are needed to enhance testing and accountability***. GAO-04-409. April, 91. Online at ***www.gao.gov/assets/250/242141.pdf***.
[7] The first GBI interceptor was deployed in a silo at Fort Greely, Alaska, on July 22, 2004. Two additional intercept tests of GBI prototypes in December 2004 and February 2005 both failed when the interceptor failed to launch. The first intercept test (FTG-02) of an operationally-configured (production representative) GBI took place on September 1, 2006, and is classified by the MDA as a successful intercept.
[8] The MDA Director Lt. General Henry Obering, in response to a question by Senator John Cornyn, stated that: "We have flown the kill vehicle in a prototype fashion that is about 67 percent the same hardware and 62 percent the exact same software in those intercept tests that were successful several years ago." Obering, H. 2005. Testimony before the Committee on Armed Services. April 7, 167. Online at ***www.gpo.gov/fdsys/pkg/CHRG-109shrg21108/pdf/CHRG-109shrg21108.pdf***.

The CE-I EKV

Two main versions of the kill vehicle are currently deployed. The first is known as the Capability Enhancement-I, or CE-I, kill vehicle. This is the version that was initially deployed in July 2004; a total of 24 had been deployed by the end of September 2007, although several of these subsequently were replaced by newer CE-II EKV-equipped GBIs. A total of 33 CE-I EKVs were purchased and six have been expended in flight or intercept tests so far.[9]

The first flight (not intercept) test of an interceptor using a CE-I EKV was in December 2005. As discussed above, 10 earlier GMD tests had used prototype versions of the kill vehicle. Three reportedly successful intercept tests of the CE-I EKV-equipped GBI were conducted in September 2006, September 2007, and December 2008, respectively. However, it was subsequently revealed that in the 2006 test, the kill vehicle struck the target only with a "glancing blow" that did not result in a target "kill."[10]

The GAO reported in 2012 that each of the GMD flight tests conducted had revealed problems requiring either hardware or software changes to the interceptors.[11] In 2007, MDA initiated a program to refurbish the existing CE-I interceptors that would replace problematic components identified during manufacture or through testing. The GAO reported in 2012 that the refurbishment program was expected to continue for many more years and that it would cost between $14 and $24 million per GBI.[12]

[9] The figure of 33 CE-I EKVs is from Inspector General (IG). 2014. Department of Defense. ***Exoatmospheric kill vehicle quality assurance and reliability assessment – Part A***. DODIG-2014-111. September 8,7. Online at ***www.dodig.mil/pubs/documents/DODIG-2014-111.pdf***.
[10] "...the EKV achieved a "glancing blow" on the RV [reentry vehicle target]. Subsequent analysis indicated that the "glancing blow" would not have resulted in a kill. I score the FTG-02 flight test a hit, but not a kill." Gilmore, J.M. 2012. Testimony before the Strategic Forces Subcommittee of the House Armed Services Committee. Written response to a question by Representative Loretta Sanchez. March 6. Online at ***https://www.gpo.gov/fdsys/pkg/CHRG-112hhrg73437/pdf/CHRG-112hhrg73437.pdf***.
[11] Government Accountability Office (GAO). 2012. ***Missile defense: Opportunity exists to strengthen acquisitions by reducing concurrency***. GAO-12-486. April: 18-19. Online at ***http://gao.gov/assets/600/590277.pdf***.
[12] GAO 2012. 78.

A refurbished CE-I interceptor, incorporating roughly 25 improvements, was tested in FTG-07 held on July 5, 2013.[13] However, the intercept attempt failed when the kill vehicle failed to separate from the final interceptor rocket stage. The MDA subsequently attributed the failure to a voltage shift resulting from a leak of battery electrolyte that caused the flight computer to shut down. To address the battery problem, MDA modified the software on each of the deployed CE-I GBIs to give them "a capability to reset and recover the flight computer following a voltage shift."[14]

When the planned total of 44 deployed GBIs is reached in 2017, 18 of them will be equipped with CE-I EKVs. However, as noted in a 2014 DOD Inspector General report, there are a number of "subconfigurations" within the CE-I GBIs as a result of the repairs and upgrades made to them.[15]

In the wake of the FTG-07 failure, there is no public information indicating that the CE-I refurbishment program is still ongoing, and it appears that only a few EKVs have received the planned repairs (other than the software fix for the battery voltage shift). Given that MDA plans to replace deployed CE-Is with brand new Redesigned Kill Vehicles (RKVs) beginning in 2020, the CE-I refurbishment program may have been cancelled. In 2015, it was disclosed that all of the CE-I EKVs have an additional problem with their divert thrusters (which maneuver the kill vehicle to its target in space) that produces known "performance issues."[16] There are no plans at present to fix the thruster problem for the currently fielded CE-Is.

[13] "We've incorporated over 20—I want to say 24 or 25 improvements to the current CE-I fleet that I'll demonstrate in flight within the next month, and that—those improvements and those continued—the continued improvements of the current fleet is part of my R&D request as well." Syring, J. 2013. Testimony before the Strategic Forces Subcommittee of the House Armed Services Committee. May 8. Online at *www.gpo.gov/fdsys/pkg/CHRG-113hhrg82459/pdf/CHRG-113hhrg82459.pdf*.

[14] Syring, J. 2015. Testimony before the Subcommittee on Strategic Forces of the House Armed Services Committee. March 19. Online at *www.mda.mil/global/documents/pdf/ps_syring_031915_hasc.pdf*.

[15] IG 2014, 4.

[16] GAO 2015. 64.

THE CE-II EKV

By 2005, the MDA had already begun development of a new version of the kill vehicle, the Capability Enhancement-II (CE-II) EKV. The new version was required because of the obsolescence of parts in the original CE-I version.[17] However, some improvements were also made. Then MDA Director Lt. General Patrick O'Reilly stated that the new version of the kill vehicle has greater sensitivity and capability.[18] The CE-II apparently includes a new processor with improved throughput and discrimination capabilities, the ability to track larger number of objects, and an improved infrared seeker.[19] CE-II GBIs began deployment in October 2008. After 10 of them had been deployed, the failure of the FTG-06a intercept test in December 2010 halted deployments.[20]

The first flight and intercept test of a CE-II GBI was FTG-06 on January 31, 2010. The intercept attempt reportedly failed due to a manufacturing error (an omitted lock pin) in the EKV. The second intercept test, FTG-06a on December 15, 2010, also failed. The second failure was eventually attributed to a design flaw in the EKV's guidance system.

Following the second CE-II test failure, MDA Director Lt. Gen. O'Reilly ordered further deliveries of EKVs to be suspended until the problem that caused the failure was found and corrected and a CE-II EKV was successfully intercept tested. In addition, the MDA announced that the 10 deployed CE-II GBIs would not be

[17] O'Reilly, P. 2011. Testimony before the Subcommittee on Strategic Forces of the House Armed Services Committee. March 31. Online at *www.gpo.gov/fdsys/pkg/CHRG-112hhrg65803/pdf/CHRG-112hhrg65803.pdf*.

[18] "We redesigned the system, upgraded it, and actually gave a greater sensitivity and greater capability." O'Reilly 2011.

[19] According to a GAO figure, the CE-II involves a "new processor." Government Accountability Office (GAO). 2009. ***Defense acquisitions: Production and fielding of missile defense components continue with less testing and validation than planned***. GAO-09-338. Washington, DC. March, 43. Online at *www.gao.gov/assets/290/287097.pdf*. See also Syring, J. 2014. Homeland defense. Presented at the 2014 Space and Missile Defense Conference. Briefing slides. August 13. Online at *www.ucsusa.org/sites/default/files/attach/2014/11/slides-jd-syring-symposium.pdf*.

[20] Government Accountability Office (GAO). 2011. ***Missile defense: Actions needed to improve transparency and accountability***. GA0-11-372. Washington, DC. March, 80. Online at *www.gao.gov/new.items/d11372.pdf*.

considered operational until after a successful intercept test of the kill vehicle.[21]

In January 2013 MDA conducted the non-intercept flight test CTV-01 in order to demonstrate a mitigation for the problem that caused the failure of FTG-06a. As discussed in more detail in the main text of "Shielded from Oversight," the problem was eventually identified as a long-standing problem in which vibrations produced by the EKV's divert thrusters led to a "track gate anomaly" in its guidance system. The CTV-01 test used a CE-II EKV with mitigations to address the problems believed to cause the FTG-06a failure. The CTV-01 test was reportedly successful, clearing the way for an intercept test using a repaired version of the CE-II kill vehicle. That new intercept test, FTG-06b, was successfully conducted on June 22, 2014, permitting deliveries of CE-II GBIs to resume. The last eight CE-II EKVs have already been delivered with the FTG-06b–derived repair. The eight earlier CE-II EKVs that will remain in service will be repaired by the end of 2016.

All of the CE-II EKVs (including the ones not yet delivered) have the same divert thruster problem as the CE-I EKVs. In addition, they all also have a defective wiring harness (due to a soldering error), which raises their risk of failure.[22] At present, the MDA has decided to accept the risks associated with both problems and does not intend to repair the EKVs for them. The MDA has procured a total of 24 CE-II EKVs, with five already expended in tests; as with the CE-I EKVs, there are different subconfigurations within the baseline CE-II EKV design.[23]

CE-II Block 1 EKV

The CE-II Block 1 program began in 2010. It was intended to be a redesign of the EKV that would both deal with obsolescence issues and improve the producibility, reliability, availability, and maintainability of the kill vehicle.[24] However, many of those original objectives were subsequently deferred to the planned future Redesigned Kill Vehicle, and the CE-II Block 1 improvements were scaled back.

The CE-II Block 1 will, at a minimum, incorporate new components to address the guidance failure in FTG-06a and the battery-related failure in FTG-07. It will also incorporate the new Alternate Divert Thruster (ADT) system intended to address the divert thruster problem in the earlier EKVs. It has not been publicly stated if it will resolve the wiring harness problem of the CE-II EKVs, although it will have electrical improvements.[25] The Block 1 is also intended to have increased reliability relative to the previous CE-II EKVs, including reliability improvements to its inertial measurement system.

The first flight test of the CE-II Block 1 is currently planned to be the FTG-15 intercept test in late 2016. It will be the first test of an operationally-configured GBI against an ICBM-range target and will also test an upgraded booster rocket. Despite the problems resulting from deploying the CE-I and CE-II EKVs before they were tested, the MDA started building CE-II Block 1 kill vehicle GBIs for deployment more than two years before the currently scheduled test date for FTG-15.[26]

If FTG-15 is successful, eight CE-II Block 1 kill vehicle interceptors will be delivered and deployed in 2017, bringing the total number of deployed GBIs to the MDA's goal of 44 by the end of 2017. The remaining two CE-II Block 1 EKVs would be delivered in early 2018.[27] The GBI fleet would then consist of 18 CE-I EKVs, 16 CE-II EKVs, and 10 CE-II Block 1 EKVs.

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[21] "MDA officials told us that they will not add the CE-II EKV to the operational baseline until after the successful completion of an intercept test." GAO 2011, 86.

[22] Government Accountability Office (GAO). 2015. ***Missile defense: Opportunities exist to reduce acquisition risk and improve reporting on system capabilities***. GAO-15-345. Washington, DC. May, 21. Online at *www.gao.gov/assets/680/670048.pdf*.

[23] IG 2014, 4.

[24] GAO 2015, 65.

[25] Missile Defense Agency (MDA). 2015. ***Research, development, test & evaluation, defense wide***. Defense wide justification book volume 2a of 2 of ***Fiscal Year (FY) 2016 president's budget submission***. Washington, DC: Department of Defense. February. Online at *http://comptroller.defense.gov/Portals/45/Documents/defbudget/fy2016/budget_justification/pdfs/03_RDT_and_E/MDA_RDTE_MasterJustificationBook_Missile_Defense_Agency_PB_2016_1.pdf*, 2a-121.

[26] GAO 2015, 22.

[27] GAO 2015, 22. The delivery of the last two Block 1s in 2018 does not necessarily mean the goal of deploying 44 GBIs by the end of 2017 cannot be met, since the MDA could delay the removal of several CE-I GBIs that are to be replaced by CE-II Block 1s.

Booster Upgrade

The current CE-1 and CE-II EKV-equipped GBIs all use the original baseline (designated C1) version of the three-stage Orbital ATK booster rocket. The CE-II Block 1 GBIs will introduce an upgraded (designated C2) booster. The new booster design will address some hardware obsolescence issues and will have upgraded avionics. It will be flight-tested for the first time in the FTG-15 intercept test in late 2016.

A further booster upgrade (C3), planned for deployment starting in 2020 will provide further improvements and will introduce a two or three-stage selectable configuration of the GBI (see below). The first flight test for the two-stage C3 GBI is GM CTV-03 in 2018 and the first intercept test will be FTG-17, currently scheduled for 2019. (A successful flight test of a two-stage version of the C1 booster took place in 2010.)

Redesigned Kill Vehicle (RKV)

The Redesigned Kill Vehicle will incorporate largely existing kill vehicle components and subassemblies into a new modular design. It has also been referred to as the "EKV CE-III."[28] According to the MDA Director Admiral James Syring: "The new EKV will improve reliability and be more producible, testable, reliable and cost effective and eventually will replace the kill vehicle on our current GBI."[29] A particular focus is on reducing the number of steps involved in assembling the kill vehicle.[30] In addition, the RKV will also have improved target acquisition and discrimination capabilities and provide for on-demand communications between the RKV and the GMD fire control system. MDA requested $229 million for RKV development in fiscal year (FY) 2016, with total development spending planned to be $658 million through FY 2020.

In August 2015, Raytheon, the Boeing Company and the Lockheed Martin Corporation each received contracts worth just under $10 million to develop MDA-specified subsystems for the RKV. In December 2015, the MDA announced that it intended to award a six-year RKV development and production contract to Boeing.[31] The contract specified that Boeing would work with Raytheon and Lockheed Martin to "provide a consolidated product that includes the collective knowledge of all three Contractors." Under current plans, the RKV will have a first non-intercept flight test in FY 2018 followed by an intercept test in FY 2019. If the two tests are successful, initial production of eight RKVs would begin. Following a second successful intercept in FY 2020, full production of another 37 RKVs and RKV deployment would begin.[32]

Common Kill Vehicle Program and Multi-Object Kill Vehicles (MOKV)

The Common Kill Vehicle (CKV) program is a two-phase effort aimed at developing strategies and technologies for "the next generation of our exo-atmospheric kill vehicles."[33] The MDA requested $47 million for the CKV program in FY 2016 and plans to spend $380 million on the program through FY 2020. In the first phase of the CKV program, begun in 2014, concepts and requirements were developed for the RKV.

The second phase, to begin in FY 2016, will involve developing concepts for Multi-Object Kill Vehicles (MOKV). The MOKV program is essentially a revival of the Multiple Kill Vehicle (MKV) program that was started by the MDA in 2004 but was cancelled in 2009 in order to divert resources to now discredited ascent phase intercept approaches.[34] At an April 2009 press

[28] Butler, A. 2014. Reprieve and refocus. ***Aviation Week & Space Technology***, September 1, 21-22.

[29] Syring, J. 2014. Testimony before the Defense Subcommittee of the Senate Appropriations Committee. June 11. Online at *www.mda.mil/global/documents/pdf/ps_syring_061114_sacd.pdf*.

[30] Gruss, M. 2015. MDA progressing on redesigned kill vehicle. ***Space News***, August 14. Online at *http://spacenews.com/mda-progressing-on-redesigned-kill-vehicle/*.

[31] Missile Defense Agency (MDA). 2015. Re-designed Kill Vehicle (RKV) development. Presolicitation Notice HQ0147-12-C-0004. December 4. Online at *www.fbo.gov/index?s=opportunity&mode=form&id=27d65c6792dc2200f1185c21fbc6bea5&tab=core&_cview=0*.

[32] Government Accountability Office (GAO). 2016. ***Missile defense: Assessment of DOD's reports on the status of efforts and options for improving homeland missile defense***. GAO-16-254R. February 17, 9–10. Online at *www.gao.gov/assets/680/675263.pdf*.

[33] Syring, J. 2015. Testimony before the Subcommittee on Defense of the Senate Appropriations Committee. March 18. Online at *www.mda.mil/global/documents/pdf/ps_syring_031815_sacd.pdf*.

[34] The ascent phase includes both a missile's boost phase plus the ascending portion of the missile's trajectory after the missile burns out. Ascent phase defenses typically aim to intercept a

conference, Defense Secretary Robert Gates stated that "We will terminate the Multiple Kill Vehicle program because of its significant technical challenges and the need to take a fresh look at the requirement.[35] Prior to abandoning it, the MDA spent nearly $700 million on the MKV program.

The MOKV program's objective is to produce a kill vehicle small enough that several or many could be placed on a single interceptor, with each MOKV able to intercept a separate target. This approach aims to reduce the problem of discrimination (identifying an enemy warhead from decoys or debris) by allowing every credible object in a threat cloud to be attacked. According to the MDA Director Syring: "Ultimately, these Multi-Object Kill Vehicles will revolutionize our missile defense architecture, substantially reducing the interceptor inventory required to defeat an evolving and more capable threat to the Homeland."[36]

The MOKV program also involves developing strategies and technologies, such as communication architectures, guidance technologies, and command and control strategies, that might be used in future MOKVs. In August 2015, the MDA awarded three roughly $10 million contracts to Boeing, Raytheon and Lockheed Martin to define a MOKV concept, assess and mitigate risks, and develop a proof of concept demonstration program for MOKVs. In parallel, the MDA will invest in developing several key MOKV technologies. However, even if the MOKV program is successful, MOKVs may not be deployable until 2025-2030.

Deployments of GBIs

The first GBI was deployed into a silo at Fort Greely Alaska in July 2004. By the end of 2004, eight GBIs were deployed, six in the six-silo Missile Field One at Fort Greely and two in silos at Vandenberg Air Force Base in California. The 24th GBI, and the last one equipped with the Capability Enhancement-1 (CE-I) kill vehicle, was deployed in September 2007. Deployment of GBIs, now equipped with the new CE-II kill vehicle, resumed in late 2008.

As of the end of the George W. Bush administration, plans called for a total of 44 GBIs, 40 at Fort Greely and four at Vandenberg Air Force Base. In April 2009, citing the lack of a threat justifying larger numbers, the Obama administration announced that the planned total number of deployed GBIs had been reduced to 30. The 30th GBI was deployed in September 2010. Thereafter, four additional CE-II GBIs were deployed, replacing older CE-I GBIs.

In March 2013, the Obama administration announced plans to deploy an additional 14 GBIs by 2017, bringing the planned total back to 44.[37] Further deployment of GBIs, however, was suspended following the FTG-06a intercept test failure in December 2010, at which point 10 CE-II GBIs had been deployed. Deliveries and deployments of GBIs resumed after the successful CE-II intercept test FTG-06b in June 2014. The final eight interceptors needed to bring the total to 44 by the end of 2017 are to be equipped with the CE-II Block 1 version of the EKV still under development (two more CE-II Block 1s will also be deployed in early 2018, replacing older missiles.)

The Two/Three-Stage Selectable GBI Configuration

As part of the European Missile Defense plan announced by President George W. Bush in 2006, the United States planned to deploy a two stage-version of the GBI in 10 silos at a new facility to be built in Poland. By omitting the third stage of the GBI, the interceptor's burn time was reduced by about one-third, giving a faster response at the price of a somewhat lower burnout speed (the velocity at the end of powered flight). Although the three-stage GBIs based in Alaska and California were already capable of reaching ICBMs launched from Iran at U.S. territory, the Europe-based two-stage GBIs were intended to improve the performance of the GMD system by providing additional intercept opportunities

missile after its boost phase but before it can deploy its warhead(s) and countermeasures.

[35] Department of Defense. 2009. DoD news briefing with Secretary Gates from the Pentagon. News transcript. April 6. Online at ***http://archive.defense.gov/Transcripts/Transcript.aspx?TranscriptID=4396***.

[36] Syring 2015.

[37] The 40 GBIs planned for Fort Greely corresponds to the number of missile silos at the base. There are six silos in the original Missile Field One, which had been deactivated but is being refurbished and reopened after the March 2013 announcement, 20 in Missile Field Three, and 14 in Missile Field Two (which was built after Missile Field Three).

against Iranian ICBMs. Russia strongly objected to the proposed European Missile Defense system, and in particular to the plans to deploy two-stage GBIs in Poland, arguing that they might be able to attempt to intercept some Russian ICBMs.

Although President Obama cancelled the European Missile Defense System in 2009, the MDA continued to develop a two-stage version of the GBI as part of its GMD hedging strategy.[38] The shorter burn time of the two-stage interceptor hedges against an increased threat by expanding the defense's battlespace (the amount of time during target missiles' flight that the GMD system can engage the enemy missiles), enabling later interceptor launches and intercepts. A reportedly successful flight test (BVT-01, a non-intercept test) of a two-stage GBI was conducted in June 2010. A planned intercept test using a two-stage GBI, at one time scheduled for 2010, was cancelled after the FTG-06 test failure in January 2010 in order to conduct FTG-06a later that year.[39]

The 2012 National Academy of Sciences (NAS) study recommended that the current GBIs be replaced with a new two-stage interceptor based on the cancelled Kinetic Energy Interceptor, to provide a shorter booster burn time in order to expand the defense's battlespace. The NAS's proposed interceptor would have a burn time of about 60 seconds, compared to about 138 seconds for the two-stage GBI and about 206 seconds for the three-stage GBI.[40]

The MDA now plans to make the new C3 GBI booster selectable between two and three stages. At launch, if the three-stage option is chosen, all three booster stages will be used, as is currently done. If the two-stage option is chosen, one of the stages (either the second or third) will not be used, and will simply be dropped off without ever being ignited.[41] The 2/3 stage selectable booster will likely be first flight tested in the CTV-03 non-intercept flight test of the RKV scheduled for 2018, followed by intercept tests in 2019 and 2020. Assuming the 2019 intercept test is successful, the 2/3 stage selectable booster could begin deployment as RKV-equipped C3 GBIs in 2020.

SM-3 Alternatives to GBIs

The European Phased Adaptive Approach (EPAA) system announced by President Obama in 2009 envisioned the deployment of four phases of increasingly capable defenses built around versions of the U.S. Navy's SM-3 interceptor missile. While the first three phases were focused solely on defending European territory, the fourth phase was essentially a replacement for President Bush's now-cancelled European Missile Defense System, although with more interceptors. The EPAA Phase IV, originally scheduled for deployment beginning about 2020, would have deployed high-speed SM-3 Block IIB interceptors in land sites in Poland and Romania and on U.S. Navy ships in the Mediterranean and adjoining seas. Although no official figure for the planned speed of these SM-3 Block IIB interceptors has been made public, they would have been fast enough (likely 5 to 6 kilometers per second) to intercept Iranian ICBMs launched towards U.S. territory. The deployment of the high speed Block IIB interceptors was a primary focus of Russian objections to the EPAA. In March 2013, the Obama administration cancelled the SM-3 Block-IIB program, citing delays in the program. Despite the cancellation of its fourth phase, Russia continues to object to the EPAA.

Instead of deploying the SM-3 Block IIB interceptor in Europe, the United States has significantly increased the number of SM-3 Block IIA interceptors it plans to

[38] Department of Defense. 2010. Ballistic missile defense review report. Washington, DC. February, 17. Online at ***www.defense.gov/Portals/1/features/defenseReviews/BMDR/BMDR_as_of_26JAN10_0630_for_web.pdf***.

[39] GAO 2011, 27.

[40] National Research Council (NRC). 2012. ***Making sense of ballistic missile defense***. 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 Sciences. Washington, DC: National Academies Press, 146. Online at ***www.nap.edu/catalog/13189/making-sense-of-ballistic-missile-defense-an-assessment-of-concepts.***

[41] According to Admiral Syring, the two-stage booster 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 in terms of does it—does it—fly the two-stage or does it—second stage—or does it just drop." Syring, J.D. 2016. Ballistic missile defense system update. Presented at the Center for Strategic and International Studies. January 19. Videos online at ***http://csis.org/event/ballistic-missile-defense-system-update-0*** and at ***http://www.c-span.org/video/?403405-1/discussion-ballistic-missile-defense***. (The two videos differ somewhat in their coverage of the Admiral's slides.)

deploy as part of the EPAA. Current plans call for buying 182 SM-3 Block IIA interceptors to support the EPAA through 2040, with deployment beginning in Phase III of the EPAA in about 2018.[42] The SM-3 Block IIA interceptor is somewhat slower than the cancelled Block IIB missile with a speed likely about 4.0–4.5 km/s. From a purely kinematic perspective, the SM-3 Block IIA would not be able to intercept ICBMs from Iran or Russia if based in Europe. However, if it were deployed on U.S. territory or offshore, it could intercept ICBMs launched from those two countries (or from North Korea or China), although with a smaller defensive footprint than the GBIs.[43] U.S. officials have indicated that SM-3 interceptors will be examined as possible alternatives to deploying additional GBIs at a third site in the United States.[44]

The Exo-Atmospheric Kill Vehicle Sensor

The EKV homes in on its target using infrared sensors that detect the infrared (heat) energy emitted by the approximately room-temperature warhead target. The EKV sensor uses two beam splitters to simultaneously illuminate three 256 x 256 pixel charge-coupled device focal plane arrays.[45] The first array is an uncooled silicon array used for visible light detection. The second and third arrays are mercury-cadmium-telluride (HgCdTe) arrays that detect in two different sections of the long-wave infrared (LWIR) band, possibly extending into the very long-wave (VLWIR) infrared band as well. According a 1998 technical paper on the testing of the infrared arrays, the shorter wavelength array had its cutoff (maximum) wavelength "targeted in the lower range of the LWIR band" and the cutoff for the longer-wavelength array was targeted in the upper end of the LWIR band.[46] There is no single definition of the wavelength extent of these bands, but typically the LWIR band extends from six to eight micrometers (μm) up to 12–16 μm and the VLWIR band from 12–16 μm up to about 30 μm.

The visible detector array on the EKV is used for star sighting measurements to more accurately determine the EKV's position and orientation; it is also used in some initial homing operations. However, at least in early versions of the EKV, the EKV could not achieve an intercept using only the visible light array.[47] The limited role of the visible array was evident in the failed IFT-4 intercept attempt in January 2000. According to the Ballistic Missile Defense Organization (the predecessor to the MDA):

> ***The visible light sensor acquired the target complex and directed the EKV thrusters to adjust the trajectory toward the calculated intercept point. The EKV requires an operative infrared sensor in order to transition into its terminal guidance mode prior to intercept. In effect the***

[42] Doubleday, J. 2015. Pentagon will buy extra Block IIA interceptors for European missile shield. ***Inside Defense SITREP***. August 4. Not all of the interceptors would be deployed at the same time, as the Block IIA interceptor has a lifetime of only 12 years (compared to the planned 20 years for the Block IIB).

[43] See, for example, figures three through eight in Butt, Y. and T. Postol. 2011. ***Upsetting the reset: The technical basis of Russian concerns over NATO missile defense***. FAS Special Report No. 1. Washington, DC: Federation of American Scientists. September. Online at ***www.fas.org/pubs/_docs/2011%20Missile%20Defense%20Report.pdf***.

[44] In April 2013, Joint Chiefs of Staff Chairman General Martin Dempsey told the Defense Subcommittee of the House Appropriations Committee that a final decision on deploying an East Coast interceptor site had not yet been made and that there were "other options, to include sea-based" that were possible. He went on to say, "But we want to do the work to understand where we could conceivably place an East Coast missile field in the event that the threat continues to increase or if we decide that the sea-based capability would be inadequate." Springer, S. 2013. Dempsey noncommittal on east coast site, cites "other options." ***Inside the Pentagon,*** April 18.

In July 2013, MDA Director Vice Admiral James Syring similarly told the Senate Appropriations Committee that a sea-based option was under consideration for East Coast defense. Syring, J. 2013. Testimony before the Defense Subcommittee of the Senate Committee on Appropriations. July 17. Online at ***www.gpo.gov/fdsys/pkg/CHRG-113shrg39104550/html/CHRG-113shrg39104550.htm***.

[45] Kandebo, S. 1997. EKV contractor selection targeted for Fiscal 1999. ***Aviation Week and Space Technology***, March 3.

[46] Herring, J., L. Bollengier, D. Madajian, C. Magoun, L. Pham, S. Price, W. Ritchie, E. Schulte, R. Wyles, H. Howarth, W. Burk, D. Oleson, K. Pflibsen, and S. Wald. 1998. Staring 256 x 256 LWIR focal plane array performance of the Raytheon exoatmospheric kill vehicle. ADA400061. January. Online at ***www.dtic.mil/dtic/tr/fulltext/u2/a400061.pdf.***

[47] Lopez, R. 2000. BMDO blames infrared sensors for NMD missile test failure. ***Flight International***, January 25.

visible light sensor steered the EKV into the general vicinity of the target—the infrared sensor should have then taken control to complete the intercept. Apparently, a malfunction occurred during IFT-4 that prevented the infrared sensors from cooling properly. As a result, the infrared guidance needed to complete the intercept was not available.[48]

The infrared detector arrays are cooled to about 70 K using a krypton gas cooling system. Each of the infrared detector arrays has separate electronic equipment and signal processing channels that ultimately feed into a single data processor. Thus, the EKV can continue to home in on a target even if one of the two arrays fails, although in a "degraded fashion."[49]

The EKV has a 20-centimeter optical aperture.[50] It can detect room-temperature warhead-sized objects at a range of roughly 1,000 km, giving of order 100 seconds of observation time depending on the closing speed. In an early EKV prototype flight test, IFT-2, the EKV was able to acquire the nine dispensed targets (a mock warhead and balloon decoys) at a range of about 700–800 km as they spread out over an area four to five km across.[51] In the IFT-06 test in July 2001, the EKV began to acquire the target complex at a range of just over 725 km and had identified the warhead within the target complex at a range of about 480 km.[52] Sunlit objects might be detectable by the optical sensor at significantly longer ranges than by the infrared sensor[53] For comparison, the new design kill vehicle recommended in the 2012 NAS Report had a 30 cm aperture and was expected to be able to detect room-temperature "threat objects" at a range of 2,000 km.[54]

The field-of view of the EKV is generally assumed about one degree.[55] The new kill vehicle proposed by the NAS report (which also uses 256 X 256 arrays) has an "almost-1-degree sensor field-of-view."[56] A one-degree field of view corresponds to a total cross-range extent of about 17.5 km at 1,000 km range or about 68 m per pixel. The pixel size does not fall below the size of a warhead (roughly two meters) until a range of about 25 km, or two to three seconds before intercept. Prior to this time, the warhead and similarly-sized objects will appear as only as single pixels, so that the EKV cannot obtain information about the shapes of these objects, only about their brightness and temperature (and area-emissivity product using range information provided to it by external sensors) and how those quantities vary in time.

The pixel size in each of the 256 x 256 arrays is 30 μm.[57] Each detector array has two readout arrays that operate at a frequency of two megahertz (MHz). Radiometric test measurements on early arrays were made with an integration time of eight milliseconds at a frequency of 30 Hz. This integration time and readout rate indicate a minimum readout time of $8 + (256)^2/4\text{x}10^6 = 24.4$ ms, which is consistent with operation at a 30 Hz frame rate. The noise equivalent irradiance for each type of array was between about 0.8 to 1.2 $\text{x}10^{11}$ photons/cm^2-s for the shorter wavelength arrays and 1.0 to 2.0 x 10^{11} photons/cm^2- s for the longer wavelength arrays when tested at a wavelength of 8.6 μm.

The EKV seeker descriptions above apply to the prototype (CE-0) and likely to the first operational

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[48] Ballistic Missile Defense Organization (BMDO). 2000. National Missile Defense integrated flight test four (IFT-4). ***BMDO Fact Sheet***. 124-00-11. November. Online at ***www.bits.de/NRANEU/BMD/documents/IFT4.pdf***.

[49] Kandebo 1997.

[50] NRC 2012, 151.

[51] Scott, W. 1998. Data boosts confidence in kill vehicle performance. ***Aviation Week & Space Technology***, June 8, 57.

[52] Department of Defense (DOD). 2001. MG Nance provides update on missile test. News transcript. August 9. Online at ***http://archive.defense.gov/Transcripts/Transcript.aspx?TranscriptID=1568***.

[53] The Space-Based Visible (SBV) on the Midcourse Space Experiment (MSX) satellite (launched 1996) had a design specification detection range of 6,000 km for a warhead-sized target (area-reflectivity product = 0. 35 m^2) at a 100 km altitude tangent height with a 0.4 second exposure time. (Harrison, D. and J. Chow. 1996. The space-based visible sensor. ***Johns Hopkins APL Technical Digest*** 17(2):226–236. Online at ***www.jhuapl.edu/techdigest/TD/td1702/harrison.pdf***.) Scaling for the SBV's smaller aperture (15 cm) and using the 8-millisecond exposure time at which the EKV's infrared sensor was tested (Herring, et al. 1998) gives a visible detection range of 1,100 km, similar to that of the infrared sensor. In actual practice, however, the visible detection range could be much larger since the EKV's visible sensor could use a lower frame rate than its infrared detector because the visible sensor is not used for terminal homing. Moreover, the SBV was able to detect targets more than nine times dimmer than its design specification.

[54] NRC 2012, 148. Assuming the same detector and telescope technology, the detection range will be directly proportional to the aperture, giving an approximate range for the EKV of about 1,300 km.

[55] Gronlund et al. 2004, note 22.

[56] NRC 2012, 148.

[57] Details in this paragraph are from Herring, et al 1998.

version of the EKV (CE-I). The second version of the operational kill vehicle (CE-II) has been described as having greater sensitivity. However, the increases in sensitivity and range may be relatively minor, as improving these characteristics was not the primary motivation for producing the new version of the EKV and arrays in the earlier versions have been described as having "near-theoretical performance characteristics."[58]

TABLE 1. GBI Booster Stages

Booster	**Stage 1** **Orion 50S XLG**	**Stage 2** **Orion 50 XL**	**Stage 3** **Orion 38**
Diameter (meters)	1.27 (50 inches)	1.27 (50 inches)	96.5 (38 inches)
Length (meters)	9.45	3.10	1.35
Fully loaded mass (kilograms)	16,203	4,318	894
Propellant (kilograms)	15,024	3,924	771
Burn time (seconds)	68.4	69.7	67.7
Total impulse (newton-seconds)	40,265,100	11,200,600	2,184,100
Average thrust (newtons)	588,021	160,560	32,230
Average specific impulse (seconds)	273	291	289

[58] Herring, et al. 1998.