CHAPTER 1

Costs of Layered U.S. Ballistic Missile Defense[1]

Ballistic missile defense missions are inherently difficult. Targeting and shooting down fast-flying ballistic missiles and their warheads takes prodigiously complex technologies. Interceptor systems developed and built to perform those missions generally entail huge budgetary costs. The more ambitious the mission — as would be the case for a highly effective, comprehensive defense of the United States, its allies, and forward-based forces against surprise attack by strategic and shorter-range ballistic and cruise missiles — the higher the costs will escalate. Even attempting to meet that goal imperfectly is bound to be enormously expensive.

Efforts to devise a missile shield have risen and fallen as a strategic defense priority several times since World War Two. The unfavorable cost-exchange ratio of interceptors against strategic missiles, coupled with the stimulus they imparted to the strategic arms buildup, led President Nixon to enter into the ABM Treaty with the Soviet Union in 1972, in the midst of the Cold War. The Treaty severely restricted the scale of U.S. and Soviet ABM deployment and thus reduced the influence of one type of strategic offensive arms competition.

Missile defense regained prominence in 1983 with President Reagan's Strategic Defense Initiative (SDI), due to excessive optimism that new, non-nuclear missile interceptor technologies could provide a virtually impenetrable shield against strategic nuclear attack. Interest in missile defense fell off after the weakening and subsequent demise of the Soviet Union and after the promoted new SDI technologies failed to materialize. But a goal of more limited missile defense objectives against unauthorized or accidental nuclear attack was pursued under the first President Bush from 1988-92. Missile defense goals initially receded further under President Clinton, but recovered to some degree when his administration pursued overseas theater missile defense (TMD) and then a limited, ground-based National Missile Defense (NMD).

[1] This chapter was written by Rodney W. Jones and Richard F. Kaufman.

Congress exerted a growing influence of its own in strategic missile defense, especially after 1994. New evidence of long-range missile capabilities in the hands of hostile developing countries resulting from broader missile proliferation struck a high note of concern with a North Korean missile test in early 1998. The current Bush administration came to office determined to pursue a more energetic, comprehensive approach to ballistic missile defense. President Bush made it clear that he intended to set the ABM Treaty aside, giving notice of US withdrawal in December 2001. Formal withdrawal took place six months later on June 13, 2002.

The Bush missile defense architecture is likely to consist of: the ground based, midcourse intercept system, a sea based, midcourse intercept system, boost-phase systems including space based, air based, ground based and sea based components, and terminal U.S. and theater defenses.

Since President George Bush has committed the administration to building a layered ballistic missile defense system with ambitious goals, it is important to have at least a rough idea of how attainable such a system is and, if technically attainable, how much it would cost. Public evaluation of such a system must weigh not only the affordability and cost-effectiveness of such a system against known and projected offensive missile threats, but also compare that figure with the costs of achieving the same objectives by other means.

Negating offensive missile threats against the United States and its allies is also pursued by various other means, including diplomatic negotiations, arms control agreements, threat reduction initiatives, export controls, sanctions against illicit exports and inducements to subscribe to restrictions on acquiring nuclear and missile capabilities. Moreover, neutralizing offensive missile threats has relied on deterrence based on retaliatory instruments, and on advanced conventional interdiction capabilities, and the credible threat of their use. While there is no shortage of US retaliatory and interdiction instruments today, improving those that exist — for example, by modernizing offensive capabilities — is likely to be far less costly than building reliable missile defenses, especially against long-range or strategic missiles. Finally, US military planning against rogue state threats generally includes the option of preemption of hostile strategic missiles before they can be launched.

How much it would cost to build a layered ballistic missile defense system cannot be projected precisely. This is due, in part, to lack of knowledge about which programs the Administration will decide to build. There is also uncertainty about the effectiveness of unproved missile defense technology against evolving threats, and restrictions on public access to information about developing military technology. Even where such technology has been developed, public information is limited by proprietary restrictions on the dissemination of industrial production costs. Rough order of magnitude estimates can nevertheless be pieced together. In some cases, estimates can be drawn from reporting information supplied to Congress and its research organizations regarding actual missile defense development programs. Assessments that rely on information supplied to Congress may also be refined, in some cases, by drawing on experience with past weapons program experience and inferring how they may apply to the architectural options that are being explored today.

Ballistic missile defense programs are not novelties. Research has been pursued in this area for at least half a century, and limited BMD systems have been deployed. The Soviet Union installed the Galosh nuclear-tipped strategic anti-ballistic missile (ABM) system surrounding Moscow in the 1960s. The Galosh system was subsequently improved in the 1980s, although its operational status became uncertain after the breakup of the Soviet Union. Under the Nixon administration, the US briefly deployed and then deactivated a similarly nuclear-tipped ABM system known as Safeguard in the early 1970s. Many fundamentals of physical analysis from that time remain relevant to more recent concepts of terrestrially based BMD.[2]

While technical capabilities of BMD have changed over time, and even since the Cold War when they were evaluated mainly in the framework of the stability of the US-Soviet strategic balance, many of the technical issues of achieving reliable interception in the face of offensive penetration measures still pertain. Since the end of the Cold War, the proliferation of long-range ballistic missile and mass destruction warhead capabilities has increased the number of actors capable of producing ballistic missiles and thus expanded the geographical scope of offensive missile threats. At the same time — as a consequence of successfully implementing the START Treaty and economic difficulties in Russia— the total magnitude of such threats has been reduced by deep reductions in former Soviet strategic offensive arms.

To estimate the cost of the layered BMD system that the Bush administration promises, some assumptions must be made about the planned architecture. The Bush administration has not clarified its approach to BMD architecture to date. It has affirmed, however, that it intends to provide a *layered* BMD system that protects the United States, US allies, and US and allied forces abroad. The Bush missile defense architecture is likely to consist, at a minimum, of the following components and features: The ground based, midcourse intercept system, a sea based, midcourse intercept system, boost-phase systems including space based, air based, ground based and sea based components, and terminal U.S. and theater defenses.[3]

In the summer of 2002, the Bush administration indicated that it intended to pursue boost-phase intercept technologies aggressively, both in the field of space-based lasers and in naval programs. In the latter, the intent is to modify or adapt the Navy Theater Wide (NTW) midcourse kinetic interceptor technology to have the option to perform boost-phase functions against certain classes of threat missile, possibly including contingency options before the middle of the decade.[4]

President Bush announced on December 13, 2001, his intention to withdraw the United States from the ABM Treaty, and formal US withdrawal from the treaty took place on June 13, 2002. Withdrawal from this treaty removes cer-

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[2] A key difference is that designs for both US and Soviet ABM systems in the 1960s and 1970s relied on nuclear warheads as the interceptors' kill vehicles. The Russian system from that era remains nuclear-tipped. Current US programs for missile defense interceptor kill vehicles generally rely on non-nuclear principles. During the Reagan administration, a Strategic Defense Initiative (SDI) concept advocated by Edward Teller would attempt to use a nuclear explosive-pumped laser as the kill mechanism of the interceptor. This remained a paper concept as successive administrations focused on non-nuclear explosive principles. Some interest in studying once again the utility of nuclear-tipped interceptors has emerged, however, in the current administration.

[3] See Robert Wall, "Missile Defense's New Look to Emerge this Summer," *Aviation Week and Space Technology*, March 25, 2002. Two industry panels were commissioned by the Missile Defense Agency (MDA) in 2002 to report by June 2002 on missile defense architecture options. One panel focused on system engineering and integration. The other dealt with battle management issues. The were set up to advise the Pentagon on a new "development road map" for missile defense, following US withdrawal from the ABM Treaty.

[4] Robert Wall, "Pentagon Eyes Additions To Anti-Missile Arsenal," *Aviation Week & Space Technology*, June 7, 2002.

tain negotiated restrictions on BMD deployment options and thus on choices of an overall architecture.[5] The Bush administration also favors strategic boost-phase interceptors on mobile platforms and space-based interceptor systems that the Clinton administration shied away from due to ABM Treaty restrictions.

US withdrawal from the ABM Treaty has made moot the demarcation initiative of the Clinton Administration — the purpose of which was to define a boundary between ABM Treaty-restricted *strategic* defense interceptors and less capable *tactical* or *theater* missile defense interceptors. Even as the strategic-theater missile defense distinction becomes irrelevant as a legal matter, theater level defenses will remain operationally relevant against shorter-range offensive missiles and their costs will continue to be a significant part of the overall cost of US missile defense.

Presumably, the technical factors that will shape Bush administration BMD architectural choices are projections of the offensive threat, formalization of missile defense requirements (to counter the postulated threat), development of interceptor technologies capable of satisfying the requirements, and the lead time needed to build and deploy key missile defense components, such as interceptors, sensor, and battle management systems, in each layer of an overall missile defense system.

The Bush administration's 2001 Nuclear Policy Review (NPR) conclusions[6] added a new conceptual wrinkle. This was the term "capability based" planning as a guide to future US defense programs, including BMD. In essence, this new "capability based" planning terminology decouples the *size and effectiveness of required US military forces* from the *size and effectiveness of an expected threat*. Traditionally, the size and effectiveness of threats postulated in official threat assessments has been crucial to defining the size and effectiveness of forces that would be procured under US defense programs. "Capability based" planning claims to focus broadly on the nature of emerging threats of various kinds — irrespective of their size or effectiveness. It is not clear from the NPR announcements what size or effectiveness standards "capability based" planning uses, or even if it uses any quantitative standards.

During the Cold War, decisions on the scale of defense procurement typically were driven by estimates of the projected size of Soviet/Warsaw Pact strategic and conventional forces and the need to counter the threat of a massive, surprise attack against Western Europe. The stated rationale for the new NPR's "capability based" planning concept is that the traditional Cold War threats have ended or greatly diminished in strategic importance. The argument is that the worldwide threat horizon now consists of emerging threats from multiple sources, and the character of these threats may be more important than their nominal force size. Insofar as "capability based" planning still con-

[5] As amended in 1974, the ABM Treaty restricted the United States and the Soviet Union each to the deployment of no more than 100 strategic missile interceptors, at one site, either the national capital or an ICBM deployment area, placed additional restrictions on the power and geographical orientation of radars, and prohibited full-scale testing and deployment of mobile (land-, sea-, or air-based) and space-based ABM interceptor systems. The Treaty's main purpose was to prohibit either side's deployment of nationwide strategic missile defenses that could stimulate a competitive build up of ever-larger strategic offensive forces.

[6] A classified version was delivered to Congress on January 8, 2002, and subsequently briefed to the press at an unclassified level. Subsequent newspaper accounts reportedly disclosed points that had appeared in the classified version. See, for example, Michael R. Gordon, "U.S. Nuclear Plan Sees New Weapons and New Targets," *New York Times*, March 10, 2002; John H. Cushman, Jr., "Rattling New Sabers," *New York Times*, March 10, 2002; Paul Richter, "U.S. Works Up Plan for Using Nuclear Arms," *Los Angeles Times*, March 9, 2002; William M. Arkin, "Secret Plan Outlines The Unthinkable," *Los Angeles Times*, March 10, 2002; David G. Savage, "Nuclear Plan Meant To Deter," *Los Angeles Times*, March 11, 2002.

siders force size, it apparently aims to build out suites of US weapons capabilities that can be adapted to respond to emerging threats, as and when those threats become operational. This concept assumes that emerging state threats are likely to be activated one or two at a time, rather than attacking or challenging the United States simultaneously. Thus the idea is that US forces and responses can be assembled flexibly and deployed as needed to counter threats as they materialize.

Apparently the NPR's "capability based" planning formula allows the administration to defer or minimize decisions on military requirements for BMD, leaving in limbo clear public explanations of BMD architecture. The same terminology could also be used to justify, in the interim, incomplete and ineffective responses to what the Administration itself assesses to be the threat. In short, "capability based" planning could be used politically to dodge legislative and public accountability over BMD programs, including meaningful evaluation of their scope, scale, and technical effectiveness. Those who are responsible for evaluating the effectiveness of US BMD programs may find that public criteria for this purpose have not been developed.

The Bush Administration has also reorganized the Defense Department's authority over missile defense by converting the former Ballistic Missile Defense Organization (BMDO) into the Missile Defense Agency (MDA). The MDA is supposed to have greater bureaucratic stature and presumably more autonomy in the Department of Defense family than BMDO enjoyed. This reorganization has been controversial and may continue to be troublesome in its own way by attenuating meaningful legislative and public accountability.[7]

I. BASIC APPROACH OF THIS REPORT

This report is an effort to project in realistic terms the likely costs of a layered BMD system — or "system of systems" — whose architecture corresponds to the reported aims of the Bush Administration. The cost estimates must reflect the development and testing of technologies and the deployment of systems that will meet technical effectiveness criteria. The systems must be sized and configured to be credibly capable of neutralizing the offensive ballistic missile threat as it evolves — from wherever it may appear, and to be ready to do so around the clock, irrespective of weather conditions. The systems must be designed to be highly resistant to rapid degradation, especially catastrophic collapse. While there is no assurance today that these technical criteria can be fully met — or even that the Bush Administration will actually insist that developers meet these criteria, cost analyses must take these criteria seriously. They will be at the forefront of legislative and public scrutiny of the missile defense programs that are selected at each important milestone.

In January 2002 in response to specific questions from Senator Daschle, the Congressional Budget Office (CBO) published a partial cost analysis of some of the possible components of layered defense entitled, *Estimated*

[7] See Philip E. Coyle, "Who Will Run Missile Defense?" *Washington Post*, Dec. 14, 2001, p. A-45.

Costs and Technical Characteristics of Selected National Missile Defense Systems.[8] Daschle's questions and hence this CBO report reflected the thrust of the Bush Administration's layered approach to BMD, insofar as it had been described to that point.[9] It drew on information provided by the Ballistic Missile Defense Organization (BMDO) and other Department of Defense sources since the inception of the Bush Administration. It also relied on earlier CBO analyses of BMDO plans and programs, particularly CBO's April 2000 report entitled *Budgetary and Technical Implications of the Administration's Plan for National Missile Defense*.[10]

CBO's January 2002 report offered explicit cost estimates only of certain candidate BMD technologies and basing modes in response to Daschle's questions, and omitted others, such as the airborne laser (ABL) system — even though it has been fairly well defined in recent years. CBO's report offered estimates for: (1) a ground-based system along lines planned by the Clinton Administration (with certain enhancements apparently planned by the Bush Administration), (2) a stand-alone naval midcourse system, and (3) a limited space-based laser (SBL) system. These reflect key areas of interest in Congress about the plans of the Bush Administration. Where CBO declined to offer explicit cost estimates — such as for the costs of other boost-phase, terminal and space-based interceptor systems in which the Bush Administration also has expressed interest but provided no architecture or requirements — it nevertheless considered the conditions that are likely to determine the costs of developing and deploying such systems. Thus CBO's latest report provided a useful starting point for several elements of this independent cost assessment.

Our report attempts to go beyond the inherently cautious estimates provided in CBO's latest report in four ways. First, we review the CBO estimates to determine whether there are additional issues or factors that are likely to lead to higher cost growth. Second, we consider the cost implications of larger defense configurations, in some cases, than the high end of the range CBO stipulated in its own necessarily cautious terms of reference. Third, we compile (and in some cases increase) expected life cycle costs estimated by CBO in the form of annual figures in memoranda but which were not spelled out in its bottom line numbers. Life cycle costs must be considered to provide a more realistic estimate of the total costs likely to be incurred to operate, maintain and support systems over the

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8 CBO prepared and forwarded the report under a cover letter dated January 31, 2002 responding to a request for information on BMD costs from Thomas A. Daschle, Majority Leader of the U.S. Senate. The document is available under "Letter to the Honorable Thomas Daschle regarding potential costs of national missile defense systems," at: <http://www.cbo.gov>.

9 CBO noted that the Bush Administration goes beyond the previous Clinton Administration's national missile defense (NMD) plans — which aimed for "only a limited ground-based midcourse system" — to pursue "a wide ranging research and development program for a variety of different missile defense systems. That program will explore systems that would intercept missiles in the boost and terminal phases of their flights as well as in the midcourse phase." CBO further noted that "Subsequent [Bush Administration] decisions regarding the architecture of missile defense or the mix of systems to be deployed will be based on the results of that research and development program." CBO, *Estimated Costs and Technical Characteristics of Selected National Missile Defense Systems*, January 2002, p. 1.

10 CBO's April 2000 report, it should be noted, set a standard for more realistic cost analysis of the Clinton ground-based, midcourse NMD program options than the figures issued previously by BMDO. Even without including the likely costs of SBIRS-low as a direct cost of NMD, CBO's April 2000 estimates for total program acquisition, construction and operations costs for an upgrade Capability 1 phase were approximately double BMDO estimates then in circulation, and CBO projected the likely costs for the Clinton Administration's NMD concepts for Capabilities 2 and 3 to the year 2015. This CBO report also set the stage for growing recognition that SBIRS-low, although it would have some other military and intelligence missions, will be indispensable to the effectiveness of any long-range midcourse or boost-phase missile defense scheme and ought to be treated, therefore, as a direct cost of developing, acquiring and operating NMD and upper tier or boost-phase TMD programs. CBO's January 2002 report therefore includes the costs of SBIRS-low in its projections of midcourse NMD systems. The CBO April 2000 report may be found at: <http://www.cbo.gov>.

life of the programs. Fourth, with respect to systems of interest to the Bush administration on which the CBO has not provided explicit cost estimates (e.g., airborne laser, naval boost-phase, and terminal defenses), this report seeks to provide independent cost estimates based on the information available.

Major variables for our estimates include: (1) higher cost growth assumptions than CBO's, based on historical experience with technical challenges and cost overruns in strategic weapons programs; (2) escalation of costs due to greater adversary challenges than previously anticipated (e.g., defense penetration or suppression countermeasures), and incorporation of additional sensors or more advanced BMD interceptor capabilities (by evolutionary steps in R&D and procurement) than those posited in the existing program; (3) additional costs due to inclusion of allies under US BMD umbrellas, beyond the present BMD systems' terms of reference; and (4) based on our understanding that operations and support (O&S) costs in official figures, when available, are typically understated, we seek to generate and spell out more realistic O&S estimates.

We examine BMD interceptor systems according to the phase of the trajectory of the target missile in the following order: (1) mid-course defenses; (2) boost-phase defenses; and (3) terminal defenses. Although another order could logically be followed, U.S. efforts to develop strategic missile defenses are furthest along in the mid-course and, to a lesser extent, in the boost phase areas. Under each category, the report also deals separately with the costs of BMD systems in the various basing modes that may be considered technically attractive — whether land-based, naval, airborne, or space-based.

Our report draws together the likely costs of BMD systems regardless of the bureaucratic jurisdiction for their development. While renaming the BMDO as the Missile Defense Agency (MDA) and elevating its status as an agency under the Department of Defense in January 2002, for example, the Bush Administration announced that it would transfer further development program responsibility for the lower-tier theater missile defense (TMD) program known as PAC-3 to the Army. The Air Force in recent years has had the primary responsibility for developing airborne missile interceptors and the airborne laser (ABL) interceptor, but the ABL program evidently will be assigned to the MDA. To get a complete picture of missile defense costs, analysis needs to be brought to bear on all of these programs.

II. MID-COURSE DEFENSES

Mid-course defenses are designed to intercept the weapons payload of attacking ballistic missiles during their travel in space, outside the atmosphere. The mid-course regime begins after the offensive missile's powered ascent has ended and after its weapons payload has separated from the missile boosters. After separation from the boosters, the payload travels in space at a constant velocity on a predetermined trajectory. Mid-course defense technologies have an advantage in being able to rely on the constant velocity and predictable path of the attacking missile payload.[11] At intercontinental ranges, the mid-course trajectory may last as long as 20 minutes, providing defense system sensors time to detect, track, and discriminate the warheads from other objects and missile debris traveling in a cluster (threat cloud), and to launch interceptors on tracks that would intersect the trajectory of incoming warheads.[12]

After they are boosted into space, mid-course interceptors under development in the US missile defense program are designed to dispense an exo-atmospheric kill vehicle (EKV) into the predicted track of an incoming missile payload. The EKV is instructed by ground sensors and communications on the general direction to look, but then uses on-board, cryogenically cooled, infrared, homing sensors to identify incoming warheads. The EKV also uses its own micro-thrusters to maneuver itself into the path of an incoming warhead and to destroy that warhead by direct collision. The collision of the EKV with the incoming warhead at the high closing velocities involved (roughly 15,000 miles per hour) unleashes large kinetic forces that would cause both the KV and incoming warhead to disintegrate instantly into small pieces.[13]

Often described as "hitting a bullet with a bullet," this kinetic destruction mechanism at high velocities in space is a technically formidable objective. The Defense Department believes that its generic feasibility has been demonstrated in recent field tests. More important in judging the effectiveness of such defenses, though, will be their performance against offensive threats that use "countermeasures" designed to fool or overload the interceptors. Governments who possess long-range offensive missile programs can easily obtain and deploy countermeasures against mid-course defenses.[14] Among the options are the use of chaff and

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[11] If an attacking missile's payload consists of more than one warhead, each separating warhead may have a slightly different ultimate trajectory and velocity, but each warhead after its separation will nonetheless have a constant velocity and predictable trajectory, making individual warhead detection and tracking possible.

[12] Current mid-course interceptor programs usually feature missile interceptors. Concepts also have been explored for the use of directed-energy interceptor platforms. Directed energy systems would have major difficulties, however, in destroying hard warheads in the mid-course regime. In principle, directed energy systems could be used to aid discrimination of warheads from other objects. But directed energy systems are usually considered more useful for boost-phase intercept, as in the case of laser interceptor technologies discussed later in this work.

[13] To cause the warhead to disintegrate totally depends on both the KV and the warhead having sufficient mass and compactness. Payloads with hardened submunitions, for instance, may pose special challenges to kinetic interceptors. The US has developed and is testing a larger exoatmospheric kill vehicle (EKV) weighing about 60 kg for the ground-based midcourse NMD system, and a smaller KV designated as LEAP (light exoatmospheric projectile) weighing about 25 kg for Navy TMD systems.

[14] The US National Intelligence Council, in its unclassified 1999 summary of a classified National Intelligence Estimate, used the following words: "We assess that countries developing ballistic missiles would also develop various responses to US theater and national defenses. Russia and China each have developed numerous countermeasures and probably are willing to sell the requisite technologies. • Many countries, such as North Korea, Iran, and Iraq probably would rely initially on readily available technology—including separating re-entry vehicles (RVs), spin-stabilized RVs, RV reorientation, radar absorbing material (RAM), booster fragmentation, low-power jammers, chaff, and simple (balloon) decoys—to develop penetration aids and countermeasures. • These countries could develop countermeasures based on these technologies by the time they flight test their missiles." *Foreign Missile Developments and the Ballistic Missile threat to the United States Through 2015*, September 1999, available at: <http://www.cia.gov/cia/publications/nic/nic99msl.html>.

decoys in the payload to conceal or mimic warheads. Decoys present a large number of possible targets to the defense sensors that could rapidly exhaust the inventory of mid-course interceptors. Developing and fielding interceptor systems that can neutralize the countermeasure challenges as the threat evolves will pose profound issues of missile defense system cost. They are likely to drive the "cost growth" factors and scale of deployed missile defense systems to higher levels than are presently assumed in official reports, and possibly by those assumed in this report, if the defenses are to be made reliable and effective.

1. Ground-based Mid-course Defense System

CBO's January 2002 report provided a cautious but rigorous overview of the foreseeable financial costs of completing, deploying, and augmenting the ground-based mid-course defense technologies that the Clinton Administration had planned as a *limited* National Missile Defense (NMD) of the territorial United States.[15] The development of the ground-based interceptor (GBI) system is by far the furthest along (most mature technologically) of the long-range interceptor systems conceived in US missile defense programs.[16] Moreover, its architectural options as a single system are better understood than other possible components of a layered strategic BMD system. As a result, the *minimum* costs of procuring and operating such a system, given an assumed timeline, can be stated more closely and with greater confidence than other components that may be under consideration. Even so, the *maximum* costs resulting from technical risk, program delays, previously unforeseen requirements, and cost overruns could be much higher than forecast.

The CBO report considered three ground-based BMD configurations of ascending size and capability, the first two of which are similar to the three phases of NMD expansion that the Clinton Administration had contemplated.[17] The third illustrates how the Bush Administration might further expand a ground-based NMD system to three sites to deal with long-range missile threats originating in both the Middle East and Far East, or threats that could be launched from both the Atlantic and Pacific oceans. CBO's three illustrative configurations are: (1) a single site with 100 deployed interceptors; (2) a two-site deployment with more radars and sensors,

[15] The Clinton Administration had intended to make a decision on whether to proceed with deployment of a limited, ground-based NMD system before the administration's term ended, but finally announced in September 2000 that it would not make a deployment decision, leaving this issue and the underlying R&D program to future decisions by the Bush Administration. The Clinton Administration had attempted in negotiations with Moscow, which failed, to win Russian assent to codifying amendments to the ABM Treaty that would have permitted deployment of the initial phases of its limited planned NMD system and thus made it possible both to deploy limited strategic defenses and preserve the ABM Treaty.

[16] See Philip E. Coyle, "National Missile Defense," prepared testimony before the Senate Committee on Armed Services, July 19, 2001.

[17] CBO's single-site configuration with 100 deployed interceptors resembles the Clinton Administration's NMD Expanded Capability 1 (C-1) phase, for deployment in Alaska. The original Clinton plan for C-1 was to deploy only 20 interceptors, but C-1 was modified and renamed as Expanded C-1 late in Clinton's second term as a plan to deploy 100 interceptors in Alaska. Expanded C-1 was intended to defend the entire United States against attack by "several tens" of *unsophisticated* strategic missiles that might have employed simple countermeasures. The Clinton Administration's Capability-2 (C-2) plan was to add more radars and sensors to Expanded C-1 to enable the system to defend against the launch of a small number of missiles with somewhat more sophisticated countermeasures. Clinton's Capability 3 (C-3) construct was to add a second site (probably at Grand Forks in North Dakota); with 150 more deployed interceptors, more radars, and better engagement software. C-3 was intended to defend the US against "several tens" of *sophisticated* strategic missiles with sophisticated countermeasures. After taking office, the Bush Administration decided to add a ground-based missile defense test bed to the testing infrastructure, by means of additional facilities at Kodiak Island, Alaska, and interceptor launch facilities at Fort Greely, Alaska, and to add an additional prototype X-band radar. The test bed and Fort Greely launch facilities could, according to the Defense Department, provide a small missile defense capability for contingencies as early as 2004.

TABLE 1

Estimates of U.S. Ground-based Midcourse National Missile Defense Systems

CBO's Estimate of Costs of Various Ground-Based National Missile Defense Systems, Fiscal Years 2002-2015 (in billions of 2003 dollars)

	Single-Site Systems		**Two-Site System + More Radars/Sensors**		**Three-Site Systems**	
Type of Cost	**Low Est.**	**High Est.**	**Low Est.**	**High Est.**	**Low Est.**	**High Est.**
Research and Development						
Ground-based system	6.3	7.3	9.4	9.4	9.4	9.4
SBIRS-Low	0.0	0.0	4.2	5.2	4.2	5.2
Subtotal	6.3	7.3	13.6	14.6	13.6	14.6
Production						
Ground-based system	8.3	10.4	16.7	18.8	19.8	22.9
SBIRS-Low	0.0	0.0	8.3	11.5	8.3	11.5
Subtotal	8.3	10.4	25.0	30.2	28.2	34.4
Military Construction	1.0	1.0	3.1	3.1	4.2	4.2
Total Acquisitions Costs	16.7	18.8	41.7	48.0	45.9	53.2
Operations Through 2015	7.3	7.3	12.5	12.5	12.5	12.5
Total Costs Through 2015	24.0	26.1	54.2	60.5	58.4	65.7
Prior Year Costs from 1996 to 2001	7.3	7.3	9.4	9.4	9.4	9.4
Annual Costs for Operations After 2015	0.6	0.6	1.3	1.3	1.5	1.5
Annual Costs to Replace	0.0	0.0	0.8	1.0	0.8	1.0
SBIRS-Low Satellites After 2015						
Estimates below not included in CBO totals:						
Operations and SBIRS-Low						
Costs, 2015 through 2035	12.0	12.0	42.0	46.0	46.0	50.0
Total Costs Through 2035	**43.3**	**45.4**	**105.6**	**115.9**	**113.8**	**125.1**

Numbers may not add up to totals due to rounding.

TABLE 1

Estimates of U.S. Ground-based Midcourse National Missile Defense Systems

Our Estimates of Same Systems, 2002-2035
(in billions of 2003 dollars)

	Single-Site Systems		**Two-Site System + More Radars/Sensors**		**Three-Site Systems**	
Type of Cost	**Low Est.**	**High Est.**	**Low Est.**	**High Est.**	**Low Est.**	**High Est.**
Research and Development						
Ground-based system	7.3	8.3	11.5	14.6	12.5	15.6
SBIRS-Low	2.1	4.2	6.3	9.4	7.3	9.4
Subtotal	9.4	12.5	17.7	24.0	19.8	25.0
Production						
Ground-based system	10.4	15.6	20.9	37.5	27.1	42.8
SBIRS-Low	2.1	5.2	9.4	15.6	9.4	15.6
Subtotal	12.5	20.9	30.2	53.2	36.5	58.4
Military Construction	1.0	3.1	4.2	5.2	6.3	8.3
Total Acquisition Costs	22.9	36.5	52.2	82.4	62.6	91.8
Operations Through 2015	7.3	9.4	14.6	18.8	17.7	21.9
Total Costs Through 2015	30.2	45.9	66.8	101.2	80.3	113.7
Prior Year Costs from 1996 to 2001	7.3	7.3	9.4	9.4	9.4	9.4
Annual Costs for Operations After 2015	0.6	0.6	1.4	1.5	1.8	1.9
Annual Costs to Replace	0.0	0.0	0.8	1.0	0.8	1.0
SBIRS-Low Satellites After 2015						
Estimates below not included in CBO totals:						
Operations and SBIRS-Low						
Costs, 2015 through 2035	12.5	12.5	43.8	50.1	52.2	58.4
Total Costs through 2035	**50.1**	**65.7**	**119.9**	**160.6**	**141.8**	**181.5**

Numbers may not add up to totals due to rounding. Sea-based system inludes the costs of sea-based interceptors and a ground-based infrastructure. SBIRS-Low in CBO figures assumes 24 satellites.

and an additional 150 deployed interceptors (for a total of 250 deployed interceptors); and (3) a three-site system with another 125 deployed interceptors (total of 375 deployed interceptors).[18]

CBO assumed the first of these configurations, the single site system with 100 deployed interceptors, could be completed by 2007, and that the second site with 150 additional deployed interceptors and additional radars and sensors could be completed by 2011. CBO further estimated that a third site could be built by 2012 and reach "full operational capability" following a post-deployment "period of robust operational testing" by the year 2015.[19] CBO used 2015 as the end point of its cumulative GBI cost illustrations, even though logistics, operational and replacement costs might continue for more years.

The CBO report offered "low" and "high" figures as a range of estimates for each GBI configuration, in Table 1 (Estimates of U.S. Ground-Based Midcourse National Missile Defense Systems) below.[20] According to CBO, the low end of this range includes increased costs "already realized in the costs of developing and manufacturing flight-test interceptors" while the high end of the range seeks to "account for potential additional cost growth" — as may be expected from "uncertainties and technical difficulties in making the systems fully operational."[21]

For a single site with 100 deployed interceptors, CBO estimated that the total costs from 2002 through 2015 (in 2001 dollars, and *not counting prior year costs*) would range from $23 to $25 billion. For the two-site configuration with 250 deployed interceptors and additional radars and SBIRS-low sensors, CBO estimated the total costs from 2002 through 2015 would range from $51 to $58 billion, more than double the costs of the single site configuration. The additional costs of a three-site configuration with 375 deployed interceptors would consist mainly of the construction and operating costs of a third site and the procurement costs of additional interceptors, for a low and high range of between $56 and $64 billion from 2002 through 2015. Table 1 displays CBO's estimates converted into 2003 dollars.

CBO's high end estimate in the range for each configuration assumed that the US would be able to build each configuration, cumulatively, for at least the higher cost figure in each cost estimate range, provided that the planned system's technical objectives actually will prove to be feasible. CBO's high-end figures include a projection of potential "cost growth." CBO notes that the low earth orbit Space Based Infra-Red System (SBIRS-low) tracking satellites[22] have the highest technical risk of the com-

[18] Along with deployed interceptors, CBO stipulated certain numbers of spare interceptor missiles for testing and replacement in operating each configuration. CBO stipulated 82 spares for a single site, 42 additional spares for the two-site configuration, and 25 more for the three-site configuration.

[19] CBO, *Estimated Costs*, January 2002, *op. cit.*, p. 2.

[20] The columns in Table 1 attributed to CBO combine the constant 2001-dollar information in Table 1 of the CBO Report with CBO figures on prior year costs (1996-2001) given in Appendix Table A-1 of the CBO report. CBO, *Estimated Costs*, pp. 9, 31.

[21] CBO, *Estimated Costs*, p. 4.

[22] The overall SBIRS constellation will include four satellites, two in very high geosynchronous orbits and two in high elliptical orbits, for early warning of missile launches and certain other detection functions. These SBIRS-high satellites will replace the current Defense Support Program (DSP) early warning satellites, which have already exceeded their expected lifetime. The SBIRS-low satellites will orbit closer to the earth's surface and are being designed to use high-resolution sensors that can track objects moving through space. The schedules for both SBIRS-high and SBIRS-low have slipped. The SBIRS-high program is further along but its estimated cost in the SAR provided to Congress recently rose by $1.5 billion. The SBIRS-high program is indispensable for strategic purposes quite apart from BMD and its cost, therefore, usually is not allocated to missile defense. Although SBIRS-low may also have other military intelligence functions, its availability will be indispensable to currently planned BMD programs, and its cost can legitimately be assigned to missile defense.

ponents projected for the ground-based midcourse NMD.[23] SBIRS-low potential cost growth alone represents about two-thirds of the total cost growth that CBO includes in its high estimate for the two-site configuration illustrated in Table 1.[24] The cost growth estimates for the high technical risk components are, albeit probably conservative, relevant benchmarks for other high-risk components in less technologically mature segments of a prospective layered missile defense system.

Moreover, the figures for the two-site system in Table 1 show that CBO estimates that the cost growth for SBIRS-low *research and development* (R & D) by itself could be a differential of approximately 20 per cent. Similarly, CBO estimates the cost growth for SBIRS-low *procurement* alone could be approximately 37 per cent. The cost growth estimates for these high technical risk components are, albeit probably conservative, relevant benchmarks for other high-risk components in less technologically mature segments of a prospective layered missile defense system.

While CBO's estimate of cost growth of the SBIRS-low system is based on reasonable, albeit cautious, judgments, we believe CBO's overall cost growth estimates for the three configurations are too conservative, underestimating the probability of delays and the likely overall cost of bringing the GBI system to maturity. We believe that the challenge of sophisticated countermeasures will require further development of the EKV, that difficulties already encountered with the GBI boosters are likely to increase booster development and procurement costs, and that the development and procurement of battle management software and communications systems will present challenges that have not yet been reflected adequately in financial estimates.

Although it is not possible at this time to predict that the Bush Administration will seek to commit the United States to the three-site GBI configuration illustrated by CBO, we believe the administration will seek to implement at least the two-site goal with its augmented radars and sensors. Based on CBO's results, including operations and support (O&S) and replacement estimates to 2025, and our best estimates on unrecognized but likely cost growth, and projecting life cycle costs out to 2035, we believe that the likely costs for the GBI configurations will be: (1) $50 billion and $65.7 billion respectively for the low and high ends of the estimate range for the single-site configuration; (2) similarly, $119.9 to $160.6 billion as the range for the two-site configuration; and (3) $141.8 to $181.5 billion as the range for the three-site configuration.

We further believe that the Bush Administration will attempt to bolster the effectiveness of this ground-based architecture with some form of terminal defenses both of the GBI system and of key infrastructure near the US coastlines. This could be pursued by either a ground-based or sea based terminal defense system, or some combination of both. Related estimates appear below in the section on Terminal Defenses. In addition, boost-phase defenses deployed close to enemy launch sites will also add to the overall cost and are discussed in the sections below on ground-based, sea-based and airborne boost-phase defenses.

[23] CBO notes that SBIRS-low involves considerable technical uncertainty because it is at a relatively early stage in its development, is on a high-risk schedule for testing and deployment, its deployment will begin before testing that could otherwise influence its design has been completed, the software to operate the system to perform all of its missions will not be available until three years after the first satellite has been launched, the design weight of the satellites has grown significantly, and the number of satellites needed (27 had been assumed) is still an open question. CBO, *Estimated Costs*, p. 11. An Air Force program, SBIRS-low had already suffered significant delays and cost overruns before the latest CBO report, due to disagreements over its requirements.

[24] CBO's estimated cost growth, in 2003 Dollars, for acquisition of the two-site system is $6.3 billion (from $41.7 to $48 billion). The SBIRS-low portion of this cost growth estimate for the two-site system is $4.2 billion.

2. Stand-Alone Sea based Mid-Course NMD System

Sea based missile defenses potentially can have three advantages over an exclusively ground-based missile defense based in the territory of the United States. One advantage is that sea based defenses can roam the seas and engage missiles aimed at the United States from other locations, earlier in their trajectory, and from different geographic angles. Another is that sea based defenses can provide local protection to forward based US forces and the territory and forces of allies — missions that the US Navy is either eager or amenable to performing. A third is that sea based defenses are inherently mobile and as such can be more difficult to attack successfully in a concerted strike than fixed ground-based defenses.

The stand-alone sea based system, would cost from $65.9 billion to $87.8 billion.

Proponents of sea based missile defenses have coupled these theoretically appealing global protection arguments with another related to cost that does not stand up well to scrutiny. They have argued that sea based missile defenses can be installed easily and cheaply in the US Navy's more than 60 AEGIS cruisers and destroyers. These multi-mission AEGIS ships have sophisticated sensors and fire control systems, enabling them to detect, track and fire at multiple short-range targets simultaneously. Most of the AEGIS ships are designed to carry from 90 to 120 ready-to-fire missiles apiece in their magazines — known as Vertical Launch Systems (VLS). These ships already carry an assortment of different types of missiles for land-attack, fleet air defense, and anti-submarine warfare missions. In the minds of some proponents, the AEGIS ships, which typically cost more than a billion dollars apiece is a sunk cost, so that the cost of incorporating missile defense interceptors is mainly that of the new interceptors and upgraded software and communications systems for the ships.

This cost savings argument does not hold up, however, because missile defense missions against strategic (long-range) attacking missiles usually require the defending ships to be in locations different from those they would normally occupy for the defense of their assigned naval battle group, the local defense of US ground or air forces in overseas bases, or the defense of allies and their coastal facilities. Missile defense against longer-range missiles competes directly with other US naval missions. Logically, therefore, building capabilities for missile defense missions generally requires dedicated assets that have to be funded separately. Short-range theater missile defense (TMD), such as the Navy's recently cancelled "lower tier" NAD program, would not necessarily compete so directly with the other AEGIS missions. However, operating the longer range ("upper tier") TMD systems and strategic interceptors from ships — the NMD mission of protecting the United States — would require dedicated ships and compete directly with the normal AEGIS fleet defense and other forward based missions.

Moreover, AEGIS ships as currently designed are not suitable for housing long-range missile defense interceptors. As a result, installing NMD interceptors on ships would either require radical redesign of AEGIS ships or the procurement of other ships especially fitted out for and dedicated to strategic missile defense. Generally speaking, these would not be low cost solutions. Nevertheless, bipartisan interest in sea

TABLE 2

Estimates of Stand-Alone Sea-Based Midcourse National Missile Defense System

	CBO's Estimate of Costs of a Stand-Alone Sea-Based Midcourse National Missile Defense System, Fiscal Years 2002-2015 (in billions of 2003 dollars)		Our Estimates of Same Systems, 2002-2035 (in billions of 2003 dollars)	
	Total Costs		**Total Costs**	
Type of Cost	**Low Estimate**	**High Estimate**	**Low Estimate**	**High Estimate**
Research and Development				
Sea-based system	6.3	9.4	9.2	13.2
SBIRS-Low	4.2	5.2	6.3	9.4
Ships	0.5	0.5	0.7	0.8
Subtotal	11.0	15.1	16.2	23.5
Production				
Sea-based system	10.4	13.6	19.5	22.6
SBIRS-Low	8.3	11.5	9.4	15.6
Ships	7.3	10.4	12.5	15.6
Subtotal	27.1	35.5	41.4	53.9
Military Construction	1.0	1.0	2.1	3.1
Total Acquisition Costs	39.6	52.2	59.7	80.5
Operations Through 2015	5.2	5.2	6.3	7.3
Total Costs Through 2015	44.8	57.4	65.9	87.8
Prior Year Costs from 1996 to 2001	9.4	9.4	9.4	9.4
Annual Costs for Operations after 2015	0.9	1.0	1.1	1.5
Annual Costs for Replacing SBIRS-Low	0.8	1.0	0.8	1.0
Satellites After 2015				
We Add Estimates Below:				
Operations & SBIRS-Low Costs	35.5	41.7	39.6	50.1
Total CostsThrough 2035	**89.7**	**108.5**	**114.9**	**147.3**

Numbers may not add up to totals due to rounding. Sea-based system inludes the costs of sea-based interceptors and a ground-based infrastructure. SBIRS-Low in CBO figures assumes 24 satellites.

based missile defense options against long-range missiles has increased over the last few years and has to be taken seriously.

CBO's January 2002 report was directed by Congressional request to estimate the cost of a *stand-alone*, sea based NMD system. CBO was asked to base its analysis on the constructs used by the BMDO report to Congress of June 1999. The 1999 document is a stripped down unclassified summary (without architectural details) of the classified report on the *Utility of Sea based Assets to National Missile Defense* that BMDO had prepared in 1998.[25] CBO therefore assumed for its stand-alone, sea based NMD analysis, as BMDO had done, that it should estimate the cost of a sea based, midcourse NMD system equivalent in capability to the single-site, ground-based NMD configuration known towards the end of the Clinton Administration as Expanded Capability 1. This configuration called for 100 deployed interceptors together with an expanded suite of ground-based sensors. The stand-alone sea based NMD system envisaged in BMDO's 1999 Summary also would require SBIRS-high and SBIRS-low for full defense coverage of the United States. As CBO noted: "Effectively, this [BMDO] architecture would take the single-site ground-based system and put the interceptors to sea." [26]

CBO pointed out that it would be improper to consider the costs of this stand-alone sea based system as simply additive to the ground-based NMD. Conceptually, they are alternative NMD systems. Either would have a land-based sensor and communications infrastructure, as well as SBIRS-low. The main difference in cost between the systems would be in the sea-based system's distinctive costs for ships, sea based communications, and naval operations. In this light, it still turns out that a stand-alone sea based system would be more expensive than a stand-alone ground-based system of equivalent capability. We estimate that a single-site ground-based system would have a projected cost range to 2015 of from $37.5 billion to $53.2 billion. (see Table 1). The stand-alone sea based system, would cost from $65.9 billion to $87.8 billion (see Table 2).

Following BMDO's 1998 and 1999 reports, CBO assumed that the sea based midcourse interceptor would use the EKV designed for the GBI (the EKV's mass is more than twice that of the Navy's light KV, dubbed LEAP),[27] yet be based on AEGIS ship platforms. CBO recognized that the sea based midcourse interceptor missile would have to be larger and faster — to operate at longer range with a heavier throw weight — than the currently planned TMD versions of the Navy's Standard Missile interceptor. These planned TMD versions of the Standard Missile are intended to be compatible either with the existing AEGIS ships' Vertical Launch System (VLS) modules or with a modified VLS module that would have somewhat larger launch tubes able to accommodate

[25] See BMDO, *Summary of Report to Congress on Utility of Sea based Assets to National Missile Defense*, June 1999 (unclassified), available at <http://www.acq.osd.mil/bmdo/bmdolink/pdf/seanmd.pdf>; and BMDO, *Utility of Sea based Assets to National Missile Defense*, June 1998.

[26] CBO, *Estimated Costs*, p. 13.

[27] To have a mid-course intercept kill vehicle that fits within the dimensions of the Standard Missile/AEGIS VLS systems, the Navy developed the Light Exo-Atmospheric Projectile (LEAP) for its upper tier TMD. There are serious doubts, however, about the effectiveness of LEAP as a mid-course kinetic-kill interceptor. For a recent discussion of problems in the Navy's testing of LEAP, see David Wright, "An Analysis of the 25 January 2002 Test of the Aegis-LEAP Interceptor for Navy Theater Wide," Union of Concerned Scientists Working Paper, March 3, 2002.

midcourse-capable interceptor missiles.[28] CBO did not examine the feasibility, or estimate the cost, of placing the EKV on a ship-based missile but noted that "there could be significant challenges in making such a kill vehicle compatible with shipboard operations."[29]

Again following BMDO's sea based reports, CBO included in its own estimates the cost of constructing either seven or nine new AEGIS (Arleigh Burke class) destroyers (the cost is about $1.25 billion per ship) that would be dedicated to the NMD mission. But CBO has some misgivings about whether these ship numbers should not be higher, for two reasons. First, CBO doubts that the overall number of ships needed to cover distant oceanic launch sites (from which intercept of the attacking missiles would be most efficient) could be so low, once their transit times to shore-basing locations and rotation for maintenance are taken into account. Indeed, even BMDO noted in its 1999 Summary that as many as 13 ships might be required to maintain enough ships on station to cover simultaneous offensive missile threats. Second, CBO assumed a 3:1 ratio between the pool of ships needed and those on station, and may doubt the adequacy of this ratio. The ratio is lower than the 4:1 (or even more conservative 5:1) ratio that the Navy would prefer to rely on for planning the optimum fleet size for sea-shore rotation and maintenance during a normal tempo of operations.[30]

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[28] Until very recently, the Navy had two TMD programs, the "lower tier" Navy Area Defense (NAD) and the "upper tier" Navy Theater Wide (NTW) program. The Bush Administration canceled NAD in December 2001 (although the Navy may seek to revive this program in restructured form). The cancellation of the NAD program after spending $2.4 billion over nearly ten years, was a surprise to the Navy and its contractors. Despite a history of delays and cost overruns, this program was based on upgrading the Standard Missile — versions have been in use for decades — and had Navy and Congressional support. NAD was to begin full-scale sea based testing in February 2002, and had the potential for near time deployment as a sea based means of defending ships and coastal areas against short-range ballistic missiles. Using AEGIS-equipped cruisers and destroyers, it was also a stepping stone toward developing the Navy Theater Wide (NTW) mid-course interceptor system against longer-range missiles. The decision to terminate NAD cited the Nunn-McCurdy Act, which obligates the Defense Department to re-certify and plan to restructure a weapons program once it exceeds its expected cost by more than 25 per cent. In early 1999, NAD was already $420 million over budget. By the fall of 2001, the Navy acknowledged it was 32 per cent over budget, and at least a year and a half behind the original 2001 start of production schedule. DOD and the Navy are studying alternatives, but may restart this program under modified guidance and with a new name. See Bradley Graham, "Rise and Fall of a Navy Missile: Interceptor, Hit by Delay and Cost Overruns, Was Grounded," *Washington Post*, March 28, 2002, p. A-3.

NAD was a "lower tier" (point defense, or small-area defense) TMD interceptor system designed to operate from AEGIS ships and the Vertical Launch System (VLS), against attacks by shorter-range ballistic missiles. The NAD two-stage Standard Missile (SM-2) interceptor can reach high altitude but within the atmosphere, using a high-explosive fragmentation warhead as the KV.

The Navy's "upper tier" program, NTW, also planned for AEGIS ships and the VLS, is intended to defend bigger areas and to reach beyond the atmosphere using a light exoatmospheric KV (designated LEAP) against attacking missiles in their midcourse phase. For NTW, the Navy has been developing three-stage Standard Missiles (SM-3); the first generation (Block I) is planned for deployment between 2006 and 2010. A more capable, VLS-compatible, follow-on NTW interceptor (SM-3, Block II) is in development, for planned deployment after 2010.

A stand-alone, sea based, midcourse NMD system would depend upon an even larger and faster interceptor missile than NTW's planned Block II, a missile that has not been designed and exists only as a paper concept. It is not clear that an EKV-equipped interceptor that is sufficiently capable in speed and range for NMD midcourse missions could be incorporated in a redesigned VLS or in a traditional AEGIS ship, short of a radical redesign of the ship itself. For a more detailed discussion of the technical and Navy operational issues related to sea based NMD capabilities, and an earlier effort to anticipate probable system costs, see Rodney W. Jones, *Taking National Missile Defense to Sea: A Critique of Sea based and Boost-Phase Proposals*, Washington, D.C.: Council for a Livable World Education Fund, October 2000.

[29] CBO, *Estimated Costs*, p. 14, fn 10. CBO evidently alludes here to the fact that the Navy strongly prefers that the interceptors used in its AEGIS VLS be equipped with *solid-fuel* thrusters for their divert and attitude-control maneuvers — as reflected in the design of LEAP. The THAAD KV and EKV for GBI, by contrast, use *liquid-fuel* thrusters. Leakage of this fuel into the VLS apparently could create serious hazards.

[30] CBO properly recognized that AEGIS ships assigned to or equipped for the NMD mission would not necessarily be able to perform their current missions of TMD, and battle group command, control, and communications. This mission tradeoff cost would, if taken seriously, require that other ships be built to replace ships that are assigned or dedicated to NMD missions. See CBO, *Estimated Costs*, p. 17, Box 2.

CBO also pointed out that its own cautious estimates could be greatly exceeded by actual requirements in two other areas. First, while CBO includes in its estimates some costs related to improving the Navy's communications systems to permit the integration of ground-based command and control and information from land-based and satellite sensors, CBO notes that the technical challenges and the overall infrastructure that will be needed here may prove to be more expensive than it had assumed.[31]

Second, CBO assumed in its estimate, relying on BMDO's judgment in its 1999 Summary, that an adequate booster for the sea based midcourse NMD mission could be developed by upgrading the NTW SM-3, Block II missile to produce a more powerful follow-on interceptor missile — but still compatible with the VLS missile tube's constraints on missile cross-section and length. But CBO clearly had misgivings about this assumption, as reflected in the following paragraph:

The Department of Defense has faced a number of challenges in developing the ground-based interceptor—both with the booster and the kill vehicle. The development of a sea-based interceptor could present a new and different set of technical hurdles. The interceptor for national missile defense could be much larger than the missiles currently launched from the vertical launch system (VLS) on surface ships. The department believes that the VLS can be altered to accommodate a larger missile. However, it is possible that alternatives to that system may need to be explored, which could lead to greater costs. Moreover, whether the current ground-based kill vehicle could simply be placed on sea-based interceptors is unclear. A unique maritime variant may need to be developed.[32]

As a result, we believe the CBO estimates for a stand-alone, sea based NMD considerably understate the actual cost that would be incurred by such a system. We would, therefore, add to CBO's R&D and production (full acquisition) estimates the following figures as a more realistic portrayal of the likely costs:

1. For a strategically-capable (and therefore distinct) naval midcourse interceptor missile that greatly exceeds the capability of the SM-3, Block II yet remains compatible with AEGIS VLS, if compatibility actually proves feasible: (a) R&D — $1.8 billion additional; and (b) $7.3 billion additional to support the total of $13 billion, for production and procurement of 600 upgraded missiles — to outfit up to 13 ships, each with 36 missiles on board, and 132 additional spares for testing and research.[33]

2. For an improved marine KV or EKV adapted to marine use: (a) R&D — $1.1 billion additional; and (b) production and procurement — $1.7 additional.[34]

3. Four additional ships (total of 11 to 13 ships), for additional acquisition cost of $5.2 billion. This would allow for 3 to be on station at all times. With 36 missiles per ship, this would mean 108 missiles on station at all times. This corresponds to 100 GBI that would not be built if the stand-alone sea based NMD system were chosen.

[31] CBO, *Estimated Costs*, p. 17.

[32] CBO, *Estimated Costs*, pp. 17-18.

[33] For our "low estimate" in Table 2, we assume a unit acquisition cost for each missile of $25 million (not counting the KV and R&D costs), plus $6 million per missile for the EKV-type warhead. Our "high estimate assumes a 30 per cent increment in R&D costs.

[34] These figures are for the "low estimate"; the "high estimate" adds a 30 per cent cost growth increment.

4. Ship launch system modifications: $44 million per ship, total: $569 million.
5. Communications infrastructure: $16.7 million per ship: $217 million.
6. For SBIRS-low, the adjustments made in Table 1 for our estimates, are carried into Table 2.

In summary, based on the additional figures reflected in our estimates in Table 2, we believe that acquisition of a stand-alone, sea based NMD system would cost, at the low end $65.9 billion; and at the high end $87.8 billion through 2015. Including life cycle costs through 2035, these costs would rise to $114.9 billion at the low end, and $147.3 billion at the high end. Keep in mind that this stand-alone sea based system is equivalent in capability to the single site, 100-interceptor deployment, and the smallest of CBO's three hypothetical ground-based configurations — although with enhanced sensors, including SBIRS-low.

Partly because this illustrative stand-alone sea based system is much further from real world implementation, and partly because the costs would be so much higher than for an equivalent, stand-alone, ground based, midcourse NMD system, we doubt that a stand-alone sea based midcourse NMD system will be pursued to conclusion by the Bush Administration or its successor.

There are still two good reasons for paying close attention to these illustrative costs for a stand-alone sea based NMD. One is that some research organizations have publicized misleading reports that sea based NMD systems could be done very quickly for very low cost. These misleading notions need to be countered by more objective analyses. The other reason is that considerable interest remains in the NMD-potential of sea based missile defense components either as forward deployed defenses of US forces and allies or as adjuncts to a ground-based NMD system that might reinforce its effectiveness. It is easier to visualize and discuss the costs of alternate sea based systems or components after reviewing a sea based system that might, conceptually speaking, perform the midcourse NMD function by itself.

3. Adjunct Sea based Missile Defense Systems

We believe that the Bush Administration will push naval missile defense technology forward as components of a more comprehensive, layered missile defense system. Naval systems have several geographical advantages. They can respond flexibly to conflicts as they arise in various parts of the globe. Unlike ground-based systems within US territory, they can offer defense coverage to forward based US forces and allies. Unlike mobile ground-based TMD systems (PAC-3, THAAD), naval systems do not need the permission of host states to patrol nearby in international waters. They can, in principle, extend the timeline for engagement by attempting intercepts early in the threat missile's trajectory, and from different angles than systems based on US territory. Insofar as long-range interceptors might use AEGIS platforms, AEGIS assets exist and naval TMD interceptor development could be considered as further along than space-based missile defense constructs. Sea based platforms also could, if redesigned, support boost-phase interceptors close in to those rogue states that are accessible from the sea.

We do not believe that the Bush Administration would jettison the ground-based system to rely primarily on a stand-alone naval NMD system. Rather, we judge it highly likely that the Bush Administration will seek to build naval missile defense components as one or more supporting layers of a broader missile defense system, reinforcing a ground-based system in US territory and also providing local defense to US forces and allies overseas. We believe the Bush Administration's naval missile defense choices are most likely to be designed as adjuncts to, and built to complement or support, a core ground-based system based in US territory. Of the options that have been considered in the naval TMD program technology base, we assume that the terminal (and even boost-phase) sea based defenses are likely to be the easiest to develop and deploy.

The main architectural issue for naval missile defense, therefore, would be whether to choose between sea based midcourse and boost-phase technologies, or instead to develop and deploy both midcourse and boost-phase systems from naval platforms. If only midcourse is chosen, this would complement the ground-based system by providing a longer engagement timeline and more shoot-look-shoot opportunities. If the choice is to develop both boost phase and midcourse, the boost-phase segment could reinforce the ground-based system even more by deploying the capacity to disable or destroy some fraction of attacking missiles before they reach full velocity and deploy their payloads. Our forecast is that the Bush Administration is likely to pursue both types of naval interceptor technologies.

A subsidiary but related architectural issue is whether to rely primarily on AEGIS assets or, instead, to build newly designed ships and sensors for naval interceptors. For naval adjunct missile defense systems, we believe the Administration is likely to pursue both paths, seeking to develop midcourse interceptors compatible with AEGIS technology, on one hand, while acquiring newly designed or reconfigured ships for large boost-phase interceptors as well as for more powerful shipborne X-band radars. Since this section has been devoted to midcourse interceptor systems, we consider the cost of naval midcourse adjunct components here. We will take up the costs of a naval boost-phase adjunct in the next section on boost-phase defenses.

Assuming the Bush Administration pursues *naval adjuncts* to a ground-based midcourse NMD, *the acquisition costs of the naval adjuncts generally would be additive to those of the ground-based system*. Care needs to be taken, in this case, not to count twice the cost of: (a) land-based sensors and battle management functions that are already being developed for the GBI and upon which the naval systems would rely for integrated command, especially interceptor allocation and tracking and discrimination functions against target missiles; and (b) the R&D cost of any component that has been developed for the GBI system but is also used by the naval system, as would be the case, for instance, if the naval midcourse interceptors use the EKV rather than the LEAP KV being developed currently in the Navy's NTW (TMD) program.[35]

[35] Naval adjuncts may complement but probably would not substitute for the baseline components or sensors needed by the basic GBI NMD system, and therefore probably would not reduce GBI costs. Conceivably, success in developing highly capable naval adjuncts could lead to a decision downstream that only the first phases of the planned GBI NMD (i.e., a one-site system instead of a two-site system, or a two-site system instead of a three-site system) need be deployed. But if such a decision were made it probably would presume that the Administration had scaled back its threat assessment of the level of sophistication or size of the anticipated offensive missile threat from that postulated in GBI NMD planning earlier. We believe major savings from GBI-naval tradeoffs would not come from substituting naval for GBI components, but rather from deploying fewer GBI (and perhaps naval) assets due to a revised estimate of the threat. On the other hand, insofar as additional GBI sensor assets might be built abroad in consenting countries, this could allow tradeoffs against naval sensor components — with possible savings in the naval adjunct systems.

BMDO and the Navy outlined three possible naval adjunct roles in complementing a ground-based missile defense in its report to Congress at the end of 2000. Only the unclassified Summary of this December 2000 classified report is available for the analysis here.[36] The Summary provided certain rudimentary, and highly qualified, estimates of acquisition costs of strictly illustrative naval components and adjunct configurations, and noted that ongoing studies were being conducted to attempt to refine cost estimates so that they may "become more relevant to the decision process."[37]

CBO reviewed this BMDO/NAVY December 2000 study but decided not to attempt itself to define a complementary sea based architecture or to estimate sea based adjunct system costs, noting that:

Sea based [strategic missile defense] options remain largely conceptual [in contrast to naval TMD], so additional research and development are necessary before an operational system can be defined. The eventual cost of any given sea based option will depend on many factors, including what the threats are that the system will defend against; what territory it will defend; whether the ships will be on patrol continuously or used only in the event of a crisis; and whether the ships will be dedicated solely to the mission of national missile defense or will be multimission.[38]

The BMDO/Navy December 2000 summary outlined three possible naval adjunct roles as complements to the then planned land-based NMD architecture: (1) *Strategic Radar Picket*; (2) *Strategic Missile Trap*; and (3) *Strategic Defense*. The three roles are in order of enhanced sea based NMD support capability. Each sea based element would be integrated with the land-based NMD sensor and battle management architecture and be provided with high data rate communications, but only (2) and (3) would actually add a distinctly sea based "layer" of missile defense *interceptors*. The Strategic Radar Picket (1) essentially involves deploying X-Band radars on ships in forward locations to extend the tracking and discrimination timeline for ground-based interceptors.

For our layered defense cost assessment purposes, it is the second and third of the configurations above that are of interest. The BMDO/Navy Summary makes clear that the earliest any of these adjuncts could be developed and deployed would be in the post-2010 timeframe, but does not specify how soon after 2010 the more ambitious systems (2) and (3) could be initially deployed or completed.[39] We follow the CBO report in assuming 2015 as a notional date for full deployment, and about $1 billion per year in annual operating costs after 2015 — for a system of 7-10 ships and 100 in-

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[36] BMDO and US Navy, *Naval National Missile Defense: A Potential Expansion of the Land-Based NMD Architecture to Extend Protection - Executive Summary (U)*, December 8, 2000, pp. 1-1 to 1-12 (hereafter referred to as BMDO/Navy, December 2000 report). The Navy's underlying Concept Definition Study focused on "evaluating how a Naval NMD system could enhance, not replace, the planned land-based NMD architecture. Some of the major goals of a postulated Naval NMD system are to expand the battlespace of the land-based NMD architecture, add flexibility and robustness, and extend the defensive coverage beyond the 50 U.S. states. ... Navy ships equipped with NMD-capable sensors and/or weapons could complement the planned land-based NMD architecture by providing earlier radar tracking of threats and additional engagement opportunities when integrated into the NMD architecture. Within the context of the NMD mission, the National Command Authority (NCA) could take advantage of the Navy's inherent mobility, sovereignty, freedom of movement, survivability, and operational reach. ... The mobile nature of Naval NMD forces could confront a potential adversary with a higher level of defense and add uncertainty to his knowledge of the deployment of NMD forces. A Naval NMD system could also provide the NCA a hedge against unanticipated threat tactics that an adversary might employ." *Ibid*., p. 1-3.

[37] BMDO/Navy, December 2000 report, p. 1-11.

[38] CBO, *Estimated Costs*, pp. 18-19.

[39] BMDO/Navy, December 2000 report, p. 1-3.

TABLE 3

Navy Estimates of Seabased Adjuncts to NMD Fiscal Years 2002-2035

(in billions of 2003 dollars)

	BMDO/Navy Adjunct Cost Estimates			
	Missile Trap		**Strategic Defense**	
	Low Estimate	**High Estimate**	**Low Estimate**	**High Estimate**
System Size				
AEGIS Ships	6	6	6	6
SPY-1 Upgrade			6	6
Radar Ships				
Interceptors	100	100	100	100
Type of Cost				
Research and Development				
AEGIS Ships				
Interceptors				
X-Band Ship Radars				
Spy-1 Upgrade				
BMC4I				
Subtotal				
Production				
AEGIS Ships			6.3	6.3
Interceptors				
X-Band Radar Ships				
Spy-1 Upgrades				
BMC4I				
Subtotal				
Total Acquisition Costs	4.2	7.3	14.6	18.6
Operations through 2030			3.8	3.8
Total Costs through 2030			18.4	22.5
Operations Costs Through 2015				
Annual Operations Costs After 2015				
Operations Costs 2015 Through 2035				
Total Costs Through 2035				

Numbers may not add up to totals due to rounding.

TABLE 3

Estimates of Seabased Adjuncts to NMD
Fiscal Years 2002-2035

(in billions of 2003 dollars)

	Our Adjunct Cost Estimates			
	Missile Trap		**Strategic Defense**	
	Low Estimate	**High Estimate**	**Low Estimate**	**High Estimate**
System Size				
AEGIS Ships	9	9	12	15
SPY-1 Upgrade	0	9	12	15
Radar Ships			6	10
Interceptors	282	282	336	390
Type of Cost				
Research and Development				
AEGIS Ships	0.4	0.5	0.4	0.5
Interceptors	2.9	3.9	2.9	3.9
X-Band Ship Radars	0.2	0.3	0.2	0.3
Spy-1 Upgrade	0.3	0.4	0.3	0.4
BMC4I	0.1	0.2	0.1	0.2
Subtotal	4.0	5.3	4.0	5.3
Production				
AEGIS Ships	11.3	11.3	15.0	18.8
Interceptors	5.8	7.4	7.0	10.2
X-Band Radar Ships			2.8	4.7
Spy-1 Upgrades				
BMC4I				
Subtotal	17.1	18.7	24.8	33.7
Total Acquisition Costs	21.1	24.0	28.8	39.0
Operations Costs Through 2015	6.3	7.3	8.3	10.4
Annual Operations Costs After 2015	1.3	1.4	1.7	2.3
Operations Costs 2015 Through 2035	25.0	27.1	33.4	45.9
Total Costs Through 2035	**52.4**	**58.4**	**70.5**	**95.3**

Numbers may not add up to totals due to rounding.

terceptors.[40] ECAAR's postulated larger system size (11-13 ships, 282 to 390 interceptors, and, in the Strategic Defense configuration only, 6-10 dedicated radar ships) points to correspondingly higher operations costs as depicted in Table 3.

The Strategic Missile Trap concept is to equip Navy surface ships with NMD-capable midcourse interceptors and to deploy them in locations at sea where the land-based NMD sensor architecture could support engagements. Generally the Missile Trap locations would not be in distant regional conflict locations[41] but rather closer to the coastlines of the United States. The sea-based interceptors would provide additional angles of intercept to those of GBI and a denser overall defense system, and could enable the "integrated land and sea architecture to counter larger raids and defense suppression tactics."[42] If the interceptor platforms chosen were multimission AEGIS ships, as the BMDO/Navy Summary assumes, the patrol locations would be well away from the forward locations to which battle groups and AEGIS ships are usually assigned. The BMDO/Navy Summary suggests that the Missile Trap sea based assets would provide a crisis-response, "surge" force that could reach patrol areas in 24 to 48 hours, depending on warning. As described, the Missile Trap sea based NMD component would not be always ready for immediate action. It could be on duty at all times only if dedicated NMD interceptor platforms were built and kept continuously in logical patrol locations — albeit at higher cost.

The Strategic Defense concept comes closer to providing a robust and flexible sea based midcourse NMD support system by equipping naval platforms with both NMD-capable X-band radars and NMD-capable interceptors. These ships could then be distributed either close to hostile missile states, or further away — to provide longer trajectory tracking and discrimination as well as multiple engagement opportunities before the GBI interceptors engage. At higher cost, dedicated ships rotated so that several are continuously on station, could significantly enhance an NMD system as well as provide long-range defense coverage of allies and US forces in forward theaters.

Table 3 shows the BMDO/Navy Summary's illustrative capabilities, and low and high cost estimates, side by side with our adjusted estimates. Our adjusted estimates assume, in contrast to the BMDO/Navy summary, that the sea based adjunct systems must be on NMD duty around the clock. The AEGIS Ticonderoga class cruisers required therefore must be more numerous. The X-Band radar for the Strategic Defense concept will require dedicated sensor ships (even upgraded Spy-1 radars on AEGIS cruisers could not discriminate small objects at long range as X-Band radars can). The development costs of the interceptor components will be higher (in line with those estimated above for a stand-alone sea based system), and other cost growth factors will have an impact on procurement and maintenance in the post-2010 timeframe.

We assume that AEGIS cruiser ship rotation for NMD dedicated platforms must be on average at least 3:1. For 3 cruisers on station in patrol locations continuously, therefore, 9 dedicated cruisers would be required; for 4 cruisers on station, 12 cruisers would be required, and so on, as reflected in our low and high estimates for the Missile Trap and Strategic Defense configurations in Table 3. We assume a minimum of

[40] CBO, *Estimated Costs*, Table 2, p. 16.

[41] Unless, in contrast to current plans, X-Band radars were built in or near Japan in the western Pacific and in Europe in the north Atlantic.

[42] BMDO/Navy, December 2000 report, p. 1-3, and Finding #8, p. 1-5.

3 patrol locations would be required for the Missile Trap function. Realistic planning for the Strategic Defense configuration would require at least 4 to 5 patrol locations: two at some distance from threat locations in the north Atlantic and north Pacific oceans, two closer in to threat locations (e.g., north of Japan and west of Scandinavia), plus a fifth in the Mediterranean or the Arabian Sea.

If dedicated AEGIS cruisers are drawn from the existing fleet and modified for TMD roles (modified VLS, upgraded Spy-1 radars, and upgraded wide-band communication systems), the per ship modification cost would be $156 million. For NMD roles, however, we assume new AEGIS cruisers would be built with modified VLS magazines, upgraded Spy-1 radars, and wide-band communication systems, at a per ship cost of about $1.25 billion. Each dedicated X-Band radar ship would cost about $469 million.[43]

The AEGIS cruiser load-out of NMD-capable interceptor missiles normally would average at least 18 (housed in three "six-pack" VLS modules). The total acquisition would include at least 120 spare interceptors, and the unit acquisition cost of sea based NMD-capable missiles would be in the range of $21 to $26 million. While we assume that dedicated X-band radar ships would not be required for the Missile Trap mission, they would be required for the sea based Strategic Defense role. The Strategic Defense mission could not be performed only with the upgraded Spy-1 radar that may be retrofitted on AEGIS ships, although these upgraded AEGIS radars will be required for Navy Theater Wide (TMD) missions anyway. NMD-capable interceptor ships will still require companion sensor ships carrying larger X-Band radars (even so, these X-Band radars will be smaller than fixed-site X-band radars on land). We assume the rotation of dedicated radar ships would have a more relaxed 2:1 ratio, and that between 3 and 5 such ships on station continuously would support the Strategic Defense sea-based adjunct role.

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[43] CBO estimated in 2000 that three ship-based X-band radars would cost about $1.3 billion. See Table 2 in CBO, *Budgetary and Technical Implications of the Administration's Plan for National Missile Defense*," April 2000; available at: <http://www.cbo.gov>.

III. BOOST-PHASE DEFENSES

Boost-phase interceptors would interdict missiles early in their trajectory, after the launch but before the termination of the missiles' rocket-powered flight into the upper atmosphere and space. This boost-phase period is usually very brief, between three and five minutes (180 to 300 seconds) for strategic missiles, and shorter (from 60 seconds or less to 120 seconds) for short-, medium-, and intermediate-range missiles. Conceptually, a boost-phase interceptor would be designed to detect and home in, initially, on the hot rocket plume of the target missile as it accelerates toward its burnout velocity. This heat-seeking homing mechanism is often described as easier to engineer from existing interceptor sensor and guidance technologies than the mid-course, hit-to-kill mechanism. The latter must find and home into smaller objects — cold warheads that may be concealed by decoys traveling at maximum velocity in dark space. A key advantage of boost-phase intercept is that it calls for destruction of the attacking missile before it dispenses its payload of warhead(s) and any decoys, and before it has reached its peak velocity.[44]

This avoids the decoy problem that faces mid-course interceptors. It also has the advantage of preventing the missile remnants (and any warhead that survives) from reaching peak velocity, thus causing them to fall short of the intended target.

However, successful boost-phase intercept does not totally eliminate all danger from the missile debris or warheads that may not specifically have been destroyed or disabled, unless they fall into open ocean waters. While the intended target may have been protected, some damage to inhabited areas that are closer in the missile's intended flight path could still occur.

Even so, boost-phase intercept is difficult to accomplish because of the very brief time for effective engagement (three to five minutes at most, even for long-range missiles) during the target missile's powered flight. Some time must elapse before remote sensors detect the launch of a hostile missile, and more before it is characterized as a threat and the command to fire an interceptor can be given. Given this compressed response time, the boost-phase defense reaction must be virtually automatic, taking decision-makers out of the loop. Moreover, research and development on boost-phase interceptors has not yet been pursued intensively. As a result, boost-phase technology development for strategic missile defense arguably is less mature than that for mid-course and terminal interceptors.

Boost-phase interceptor systems could be based on rocket-powered interceptor missiles or on directed energy principles, such as lasers. The interceptors in either case could be based on ground-launched missiles, ships at sea, airborne platforms, or orbiting satellites. In the case of rocket-powered interceptors, the interceptors themselves must also cover some distance from their launch platforms to the intercept point, so that additional time elapses. A boost-phase rocket-powered interceptor must be very powerful and accelerate at an extremely high rate to catch and engage a threat missile — which has had a head start — within those few critical minutes. As a result, the launch points of rocket-

[44] Velocity imparted by the booster increases exponentially in the last seconds of a ballistic missile's powered flight. Hence, the speed of the target missile 10-20 seconds before missile burnout is much less than the peak velocity that mid-course intercept must cope with, making interceptor engagement theoretically easier in the boost-phase than in the mid-course regime. However, the ease of boost-phase intercept is often overstated. This is partly due to the fact that the missile is still accelerating; a process that may not be entirely smooth or predictable, and thus its actual trajectory may not be extrapolated accurately.

powered boost-phase interceptors must be relatively close to launch points of hostile missiles.

Furthermore, the sensor and guidance mechanism of a rocket-powered interceptor must also accomplish the non-trivial task not only of catching up to the target missile but of attacking an aim point on the structure of the missile (the so-called “plume to hardbody handover” problem) that ensures the destruction of the missile warhead(s). If the interceptor merely followed the rocket plume, it could miss the missile or fail to destroy both the missile booster and the payload it carries.

Boost-phase interception could also be based on directed energy principles, of which the most plausible today is the energy beam that can be produced by chemical lasers.[45] A laser beam travels at the speed of light and might require only a brief interval to engage a target missile in its line of sight. But focusing a laser beam coherently to minimize the angular dissipation of its energy, and keeping the beam fixed on a single vulnerable point on a target missile hundreds of kilometers away represent exquisitely difficult engineering problems. Moreover, time must still elapse as the laser beam builds up lethal energy to burn through the structure of a given target missile, and again as it slews around to focus on another target, limiting the number of target missiles in a salvo that any single laser interceptor could engage. The lethality of a laser against even a liquid-fueled target missile depends on a number of factors, including distance to the target, any intervening atmosphere, the brightness (power output) of the laser, and the quality of the optics needed to achieve coherence of the laser beam itself.

Even if well within the range of the directed energy source, the properties of the target missile — such as whether it has been deliberately hardened to reflect or withstand heat — makes a big difference to whether or how rapidly a directed energy intercept system can deposit energy with decisive effect. A long-range missile designed to accelerate to peak velocity in 180 seconds or less also limits the length of time available to a boost-phase interceptor system, whether rocket-powered or based on lasers, to engage and destroy the target. A number of other missile design and launch options can also be used to defeat or limit laser lethality. Among the most common such countermeasures are thickening or layering the skin of the missile to enable it to absorb and survive directed energy, applying reflective coatings on the missile to dissipate a directed energy beam, or spinning the missile on its longitudinal axis impeding a laser’s ability to burn through the surface of the missile.

The operational infrastructure and costs of ground-based and sea based, airborne, and space-based boost-phase systems may vary significantly, and the system costs can only be estimated realistically when the architecture of any given choice is specified in some detail. Terrestrial and airborne systems require proximity to the countries and missile launch locations that are identified as threats. Space-based boost-phase concepts have had special appeal to many missile defense proponents since the 1970s because low-earth orbital constellations of interceptor satellites could be configured, theoretically, to bring offensive ballistic missile threats, irrespective of their location, within the

[45] Ashton Carter’s 1984 report for the Office of Technology Assessment remains one of the best public sources for an overview of the physical principles and technical analysis of the basic operational issues of directed-energy weapons, including space-based chemical lasers. See U.S. Congress, Office of Technology Assessment, *Directed Energy Missile Defense in Space – A Background Paper*, OTA-BP-ISC-26 (Washington, DC, U.S. Government Printing Office, April 1984). For a broader, policy-oriented analysis of the missile defense concepts and technologies in vogue after President Reagan announced the Strategic Defense Initiative in 1983, see U.S. Congress, Office of Technology Assessment, *Ballistic Missile Defense Technologies*, OTA-ISC-254 (Washington, DC: US Government Printing Office, September 1985).

operating range of one or several orbiting interceptor satellites at all times.

Two kinds of space-based interceptor systems have received the most attention in US missile defense program research. One concept known as Brilliant Pebbles is based on a fairly large constellation of self-powered satellites each of which would be capable of maneuvering into the path of an offensive missile within its range, to destroy the missile kinetically.[46] The other concept consists of laser-equipped interceptor satellites.

Judging by its FY 2002 budget request to spend $170 million towards the MDA's planned Integrated Flight Experiment (IFX), the Bush Administration appears to consider the space-based laser (SBL) type of system the more attractive of these space-based missile defense options for current R&D emphasis.[47] Under the Bush Administration, the Missile Defense Agency plans to restructure the SBL program and also to explore space-based kinetic boost-phase options — the latter in parallel with naval kinetic boost-phase options, as critical components of a comprehensive, layered missile defense.[48] While one might surmise that the Bush Administration, or any US administration, would choose between, rather than deploy both SBL and space-based kinetic missile defense systems in parallel, the Bush Administration seems to be exploring both aggressively.[49] This may be in part due to this administration's emphasis on seizing the initiative in space warfare, space countermeasure weapons, and military dominance of space that go well beyond missile defense. Thus costs may be incurred in R&D and even on at least partial deployment of both types of space-based missile defense technology.

1. Space-Based Laser (SBL) Interceptor System

The Congressional Budget Office's January 2002 cost estimate of a space-based laser (SBL) system assumes deployment in orbit of a relatively thin constellation of only 24 laser-equipped satellites for boost-phase intercept of strategic missiles.

The technical basis for the CBO estimate was a 1995 Defense Department Cost Analysis Requirements Document (CARD) that described specific space-based laser interceptor system component concepts, the launch requirements for placing those components in orbit, and a slightly smaller constellation of just 20 satellites. This DoD document did not cover, and CBO did not attempt to estimate, the cost of other SBL configurations with such options as ground-based or space-based relay mirrors. The document assumed a constellation of SBLs would be launched to rotate in an orbit about 1,300 km above the earth with an inclination of 40^{o} (i.e., traversing 40^{o} latitude, north of the equator) —

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[46] Less familiar than Brilliant Pebbles but sometimes discussed is another space-based concept with larger satellites stocked with small rocket interceptors designed to operate as kinetic projectiles. These satellites would remain in their orbits but launch the rocket interceptors at offensive missiles or warheads that were predicted to come within their operating range.

[47] Under earlier plans, the IFX project to investigate the feasibility of a space-based laser was to launch a less than full-size high-energy laser in orbit for boost-phase interceptor testing around 2012. CBO, *Estimated Costs*, p 21. The Bush administration recently announced a more aggressive schedule of space-based laser development activities that could put a rudimentary SBL boost-phase capability into orbit between 2008 and 2010, while developing more powerful SBL capabilities later. In addition, the revised program would consider other architectural options and missions for lasers, including ground-based lasers that might use space-based reflector mirrors, and SBLs that would be used for midcourse discrimination of threat missile warheads, decoys, and missile debris (following boost-phase) to improve the effectiveness of ground-based midcourse interceptors. See Robert Wall, "Pentagon Eyes Additions To Anti-Missile Arsenal," *Aviation Week & Space Technology*, June 7, 2002.

[48] Missile Defense Agency, "Unclassified Statement of Lt. Gen. Ronald T. Kadish, USAF, Director, before the Senate Appropriations Committee, Defense Subcommittee, Regarding the FY 03 Missile Defense Budget, April 17, 2012. (Available at: <http://www.acq.osd.mil/bmdo/bmdolink/html/statements.html/Kadish17apr02.pdf>)

[49] *Ibid*., see pp. 22-25.

well-positioned to interdict "third world" missile threats ascending in boost-phase on northeast or northwest trajectories from North Korea, South Asia, Iran, Iraq, and northern Africa. The CARD documented the elements of an option that BMDO evidently considered logical for a *theater missile defense* SBL system overlooking regions where DoD had planned in the 1990s to be able to fight two major regional conflicts (MRCs).[50] This orbit probably would also imply some potential to intercept Chinese ICBMs launched northward over the Pacific.

The cost estimate CBO prepared on the basis of the technology assumed in this CARD, CBO acknowledges, is highly conjectural:

> "CBO has used that [DoD] documentation as the basis for developing its estimate, which applies only to the system described by the department. Because of the technical uncertainties and early stage of the system's development, CBO has provided a range estimate for the costs of that system. CBO has also provided a discussion of the uncertainties associated with developing and deploying an operational SBL system. Those uncertainties could have a significant effect on the ultimate costs. For example, if the system ultimately deployed had more lasers or the system was composed of different elements (such as a combination of space-based lasers and space-based mirrors) than the ones in the system described by DoD in 1995, then the costs could be very different — in some cases lower, and in a number of other cases higher.[51] "

The unclassified 1995 CARD does not explicitly state but evidently assumes each operational laser satellite in orbit would have a power output of at least 12 Megawatts. Even from our standpoint seven years later, it is clear that this 12 MW power output goal actually poses a formidable technical challenge and with envisaged technology would require massive equipment to produce.[52] The power output goal in the CARD may be inferred from its reference to the laser interceptor's "range" of 4,000 kilometers against a *No-Dong* (North Korean) tactical ballistic missile, and a "kill time" of 10 seconds at that range (or a kill time of less than 1 second if the target is much closer at a distance of 1,290 km).[53] The inference is made by comparison with the figures of merit in the 1984 Office of Technology Assessment study which judged that a perfectly tuned 12 MW hydrogen-fluoride laser theoretically could deposit one kilojoule of energy per square centimeter (1 kj/cm^2) in 10 seconds at a range of 4,000 km, and that this might be sufficient to burn through the unhardened skin of a liquid-fueled ballistic missile in boost-phase, disabling or destroying it.[54] Thus the CARD and OTA study reference numbers for lethality in this case are approximately the same. The OTA study also noted that the laser's lethal fluence needed to disable or destroy a modern solid-fuel ICBM probably would be a tenfold increase over that for a liquid-fuel missile, i.e., 10 kj/cm^2 in ten seconds, requiring

[50] Ballistic Missile Defense Organization, *Space-Based Laser (SBL) For Theater Missile Defense*, Cost Analysis Requirements Document (CARD) Unclassified (U) (Washington, D.C.: Department of Defense, July 6, 1995), and hereafter referred to as 1995 CARD. A simplified description of the theater SBL system in the CARD may be found at the Federation of American Scientists website: <http://www.fas.org/spp/starwars/program/sbl.htm>

[51] CBO, *Estimated Costs*, p. 21.

[52] The assumed laser-equipped satellites are large objects, each about 32 meters (104.4 feet) long and 8.4 meters (27.5 feet) in diameter, weighing just over 39 tons with chemical fuel— much bigger than most tractor-trailer trucks — and present formidable, and costly, space-launch technical issues. 1995 CARD, *op. cit*., p. 14.

[53] "Summary of SBL System Characteristics," attached to "Foreword," 1995 CARD, *op. cit*.

[54] See Figure 3.2, and surrounding discussion, pp. 17-18, in U.S. Congress, Office of Technology Assessment, *Directed Energy Missile Defense in Space – A Background Paper*, OTA-BP-ISC-26 (Washington, DC, U.S. Government Printing Office, April 1984).

TABLE 4

Estimates of a Space-based Laser (SBL) National Missile Defense System, Fiscal Years 2002-2045

(in billions of 2003 dollars)

Type of Cost	CBO's Cost Estimate for Minimal SBL **Total Costs** **Low Estimate** 24 satellites	**High Estimate** 24 satellites	Our Estimates for Larger SBL Systems **Total Costs** 48 satellites	72 satellites
Research and Development				
IFX Laser	3.1	5.2	3.1	5.2
Operational Laser	7.3	11.5	7.3	11.5
Launch Vehicle	3.1	5.2	3.1	5.2
Subtotal	14.6	20.9	13.6	21.9
Production				
Operational Laser	28.2	34.4	82.4	124.1
Launch Vehicle	13.6	13.6	32.3	49.0
Subtotal	41.7	48.0	114.7	173.1
Total Acquisition Costs	56.3	69.9	128.3	195.0
Operations Through 2025	2.1	2.1	6.3	9.4
Total Costs Through 2025	58.4	70.9	134.5	204.4
Annual Costs for Operations After 2025	0.3	0.3	0.4	0.5
Annual Costs to Replace				
Space-Based Lasers after 2025	4.2	5.2	10.4	15.6
We Add Estimates Below:				
Operations Through 2045	6.3	6.3	8.3	10.4
Replacement of SBLs through 2045	83.4	104.3	166.9	208.6
Total Costs Through 2045	**148.1**	**181.5**	**309.8**	**423.5**

Numbers may not add up to totals due to rounding. IFX = Integrated Flight Experiment. CBO assumes constellation size is 24 satellites in system. We assume constellation size is 48 satellites for low estimate and 72 satellites for high estimate.

either a much more powerful laser or engagement at a much closer range.[55] Shorter missile burn times and other countermeasures would require even brighter lasers or more of them (larger constellations) to handle a salvo attack.[56]

CBO's "low" and "high" estimates for developing, acquiring, and operating an SBL system with 24 operational satellites through 2025, in constant 2001 dollars, are $56 and $68 billion.[57] These figures assumed launch of the initial three operational SBLs in 2018 and three more each year to full operational capability in 2025. CBO also estimated annual costs for operations after 2025 would be at least $300 million in 2001 dollars, and that the annual costs to replace SBLs after 2025 would be $4 to $5 billion. We convert CBO figures to 2003 dollars in Table 4.

We believe that constraints in the CBO analysis led CBO to underestimate the true costs of deploying and operating an effective SBL missile defense system. CBO acknowledged that this might be the case by pointing out the limitations in the DoD program documentation it had to work with, and in the uncertainties involved — not only due to the nature of the threat that could present itself, but also because of the formidable problems in launching massive laser platforms and large quantities of fuel into orbit, and the technical risks that would be faced in developing the various SBL technologies themselves. CBO noted doubts expressed by defense analysts that the constellation size that BMDO assumed (12 to 20 satellites for third world theater threats, with another 4 to reinforce capability to intercept long-range missile threats to the United States) would prove sufficient in reality. CBO points out "other analysts argue that these [BMDO] constellation sizes are based on optimistic assumptions about the vulnerability of potential threats [i.e., the vulnerability to interceptors of hostile missiles]. *Defending against one or more hardened missiles could require significantly larger constellations than the 24-satellite one that CBO assumes for its estimate. System costs would increase in direct proportion to the larger number of lasers composing the constellations* (emphasis added)." [58]

More realistic estimates of the costs of a future SBL missile defense system would be based on larger constellations, at least 48 operational satellites on the low side, and 72 operational satellites on the high side. (See Table 4.) Putting aside similar misgivings about the technical reliability and potentially insufficient power output of the system described in the CARD, and since the "Production" cost (for SBL platforms, and their launch costs) could rise in direct proportion to the number of satellites, we have augmented CBO's Production (and Operations) figures proportionally. We have also incorporated a 20 per cent cost growth factor beyond the CBO estimates, in both our low and high estimates. By this reckoning, we estimate that the overall cost of a more plausible SBL system through 2025 would be $134.5 and $204.4 billion dollars — for 48 and 72 SBL satellite configurations respectively. If one extended

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55 *Ibid*., pp. 19ff.

56 Note that calculating the missile defense capabilities of orbital interceptors and the notional size of constellations required for threats of a given size involves what is known as the satellite "absentee ratio." Only a fraction of the satellites in a given orbital plane will be in position to view, engage, and attempt to intercept during its boost phase any particular missile that has been launched nearby that orbital plane; the earth at any given time will mask the view of other satellites in that orbital plane.

57 CBO, *Estimated Costs*, Table 3, p. 17.

58 CBO, *Estimated Costs*, p. 25. CBO also notes that other SBL architectures which rely on autonomous relay mirrors for ground-based and airborne as well as space-based lasers are under serious study, entail high technical risk, and could impose greater complexity and higher costs. As did CBO, this study also declines to attempt to estimate SBL system costs that involve autonomous relay mirrors, or system concepts that integrate ground-based and airborne lasers with relay mirrors.

this out to a 20 year life cycle period, which is to 2045, we estimate the cumulative costs for satellite systems of these same configurations easily could be $309.8 and $423.5 billion respectively.

2. Brilliant Pebbles type Space-Based Interceptor System

Space-based kinetic interceptor system concepts for boost-phase have been discussed actively at least since the Reagan administration, and the best known such concept has come to be known as Brilliant Pebbles. The High Frontier organization formerly led by Gen. Daniel Graham claimed that Brilliant Pebbles with a suitable number of platforms could be deployed for very low costs, on the order of $4-$5 billion. Brilliant Pebbles is usually associated with small satellites. In one variant, the small satellites contain on-board propulsion and sensors, and maneuver out of orbit and operate as kinetic interceptors themselves. In another variant, the small satellites shelter a smaller rocket-powered kinetic interceptor that leaves its shelter to home in on a missile in boost-phase.[59]

Once interceptors with their own propulsion systems are based in space orbits, they can be quite small and still achieve significant velocity, traveling to considerable ranges — because they do not have to overcome gravitational forces. A substantial part of the cost of deploying such systems is the launch cost of putting them into orbit with their space-based support equipment, including autonomous sensors, communications, shielding, and power supplies. As space-based systems, however, these Brilliant Pebbles satellites and interceptors would be tiny by comparison with the space-based platforms required to support laser weapons capable of attacking missiles, and far easier to launch into orbit.

Because of the paucity of realistic data about Brilliant Pebbles constructs, the authors of this report have decided not to attempt an independent cost analysis. But since the Bush administration is believed to be promoting classified research on this type of system and may soon initiate a development and testing program, we include in this report a brief discussion and an update of the CBO estimates published in 1996.

The cost estimate for brilliant pebbles was made by CBO as part of its overall estimate of the costs of the national missile defense program mandated by Congress in the Defend America Act of 1996. The legislation contemplated a program that would include interceptors that could be ground-based, sea-based, or space-based, with ground-based radar, space-based sensors, and a battle management and command and control system. The legislation anticipated "a highly effective defense" of all 50 states that would be "augmented over time to provide a layered defense against larger and more sophisticated ballistic missile threats as they emerge."[60] But the legislation did not specify the size of possible missile attacks.

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[59] A third space-based kinetic interceptor concept would deploy somewhat larger satellites as "battle stations," each containing a magazine of small rocket vehicles that could be fired sequentially to operate as kinetic interceptors against several targets. This type of system is not labeled Brilliant Pebbles.

[60] CBO, *Budgetary Implications of H.R. 3144, The Defend America Act of 1996*, p.1. This report was supplemented by CBO's responses to questions by members of Congress requesting information about the cost estimates. See CBO letters to Representative Floyd Spence , May 15, 1996, and to Senators J.James Exxon and Byron L. Dorgan, and attachments, July 26, 1996. An earlier CBO report stated, "Based in space Brilliant Pebbles are hit-to-kill interceptors that can intercept attacking missiles and warheads shortly after they leave the atmosphere over the attacker's country. That provides an opportunity to destroy the missiles before they have released the multiple warheads and decoys they often carry." CBO, *Costs of Alternative Approaches to SDI*, May 1992, p.9.

Relying on BMDO inputs, CBO's brief report provided figures for a ground-based system and separately estimated the acquisition cost of the space-based components of an "initial defense" to comply with the Act. CBO estimated that the space based sensors (Space and Missile Tracking System, or SMTS, the earlier name for the program now designated SBIRS) would cost about $5 billion. CBO further estimated that a space-based interceptor system of 500 interceptors similar to Brilliant Pebbles would cost an additional $14 billion. CBO assumed this Brilliant Pebbles layer might be added sometime after 2006. It could give the layered defense, according to BMDO, the capability to protect the United States "against a more sophisticated attack of up to 60 warheads."[61]

The CBO figures above were presented in "then year" dollars (taking inflation projections into account), but do not include O&S costs and therefore are not life cycle cost figures. In addition, CBO made clear that its May 15, 1996 estimates did *not* contain adjustments "to reflect cost increases that typically occur in developing systems that advance the state of the art."[62] CBO also noted that its estimates were based on BMDO's refocused requirements for the "smaller and less capable threat" from Third World missiles, and therefore presupposed a much less demanding development and testing program, in contrast to the earlier requirements[63] which assumed an unauthorized launch of much more sophisticated Soviet missiles. CBO indicated that if the requirements of the overall missile defense evolved into protecting against larger and more sophisticated threats, its estimate of the costs of the same ground- and space-based system would at least double from the low end figure of about $31 billion to about $60 billion, and that new technical challenges or delays could drive the net cost well above $60 billion by 2010.[64]

CBO produced a subsequent memo on July 26, 1996, based on follow-up questions from Senators Exon and Dorgan concerning the potential O&S costs for the layered system which CBO had estimated in its May 15 paper, two months earlier.[65] For the Brilliant Pebbles space-based interceptor system after 2010, CBO estimated that the annual O&S costs probably would include $250 million annually (in 1997 dollars) for personnel and infrastructure to manage the satellite constellation, or $5 billion over 20 years. CBO estimated satellite average service life would be 10 years and therefore that about 50 Brilliant Pebbles would have to be launched each year, but that 10 Brilliant Pebbles could be launched by each space launcher, thus requiring 5 launches each costing $60 million, or $300 million a year. CBO estimated that producing each Brilliant Pebble would cost about $4 million, with total replacement production each year costing $200 million.[66] Replacements would therefore cost $500 million per year, or $10 bil-

[61] *Ibid*., p. 2. In CBO's paper, based on BMDO inputs, it is assumed that the ground-based system by itself (100 interceptors) would be capable of intercepting an unsophisticated attack of up to 20 warheads. The space-based augmentation, therefore, is assumed to triple the number of unsophisticated warheads that could be inercepted by the layered defense.

[62] *Ibid.*, p. 1.

[63] BMDO's earlier system requirements had been based on the first Bush administration's concept known as Global Protection Against Limited Strikes (GPALS), which was to be designed to protect against limited or unauthorized Soviet attacks.

[64] *Ibid*., p. 2.

[65] Congressional Budget Office, "Answers to Questions Posed by Senators Exon and Dorgan" (On the potential costs of operating and supporting the defenses included in its estimate of the Defend America Act of 1996), under cover letter of July 26, 1996 from June E. O'Neil of CBO to Congressman Byron L. Dorgan, pages 1-7.

[66] *Ibid*.

lion over 20 years. In CBO's July, 1996 estimate, therefore, total O&S costs for Brilliant Pebbles over 20 years would add up to roughly $15 billion.

From the vantage point of 2002 and without technical data on Brilliant Pebbles to work with, but with retrospective knowledge of how BMD estimates have climbed since 1996, we conclude the following: First, the number of interceptors in the final requirements probably would have to be doubled to at least 1,000, roughly doubling the 1996 CBO estimated acquisition cost from $14 to $28 billion, irrespective of cost growth.[67] Second, the technical challenges would delay deployment past 2010 and push cost growth, we believe, above 50 per cent, raising acquisition cost to $42 billion. Third, operational and support (including satellite replacement) costs over 20 years, we believe, would be at least 60 per cent of the acquisition cost, adding another $25 billion, for a total of $67 billion in 1997 dollars, or about $76 billion in 2003 dollars. Clearly this space-based kinetic system would be less expensive than the space-based laser system we estimate separately, but it would not be a small cost.

3. Ground-Based Boost-Phase System

Private sector defense experts Richard L. Garwin and Theodore Postol have long advocated ground-based and sea based boost-phase missile defense as technologically easier, more effective, less costly, and more congenial internationally than inherently global space-based boost-phase systems of any kind, even the once fashionable kinetic concept among missile defense proponents of Brilliant Pebbles.[68] They have also argued that terrestrially-based boost-phase missile defense systems would be much cheaper and probably more effective than the ground-based, mid-course NMD system planned by the Clinton Administration against the emerging missile threats from so-called "rogue states" such as North Korea, Iran, Iraq, or Libya. In a similar vein, they have argued against sea based mid-course systems using the AEGIS fleet on the grounds that converted cargo ships could be used more cheaply as platforms for boost-phase interceptors.

Garwin and Postol have asserted that the heat-seeking sensors, kill vehicles and boosters they envisage for their boost-phase concepts could be fashioned from existing (and therefore familiar off-the-shelf) technologies and thus would not require so lengthy or costly R&D and testing programs as the more exotic mid-course and space-based missile defense concepts. They have assumed that tailored, geographically localized boost-phase systems could be built and deployed at considerably lower cost than systems that might provide global coverage. They also have argued that "rogue states" could easily develop countermeasures that would defeat mid-course interceptors, but not countermeasures that would easily defeat terrestrial boost-phase interceptors.[69]

Part of the appeal of the Garwin-Postol arguments is that their boost-phase missile defense ideas are geographically localized and focus only on the threat from "rogue states." Their constructs therefore would not threaten Russian or Chinese strategic missiles where they are de-

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[67] Richard L. Garwin came to the same conclusion about the number of interceptors that would be required. See Space News, March 11-17, 1991.

[68] Garwin and Postol also advanced their missile defense proposals (long before President Bush announced US intent to withdraw from the ABM Treaty) as ways to sidestep a break with the ABM Treaty, arguing that terrestrially based, localized boost-phase defenses could be accommodated by a protocol amending the ABM Treaty.

[69] Postol, Theodore A., "Boost-Phase Missile Defense Concepts for Protecting the US from *Postulated* Rogue-State ICBMs: An Assessment of Military, Engineering Design, and Policy Issues" (Briefing Slides), Cambridge, MA: MIT Security Studies Program, circa spring, 2002. Garwin, Richard L., National Missile Defense, Testimony to Senate Foreign Relations Committee, May 4, 1999.

ployed. Another part of the appeal of the Garwin-Postol ideas is the notion that missile defense could be acquired on a "pay as you go" (i.e., modular or incremental) basis — adding boost-phase missile defense interceptors and radars in new sites if and when new threats emerge in the future.

Pentagon (BMDO or MDA) estimates for terrestrial boost-phase systems have not been developed, or if they have, have not been made public. Nor has Congress requested them. CBO has not been asked to estimate the costs of such systems. This leaves us without public boost-phase missile defense system benchmarks to review or critique.

The alternative is to devise possible architectures and to attempt to provide cost estimates of plausible configurations of our own. In doing so, it must be clear that even if boost-phase technologies could draw on existing technologies and thereby simplify the development and testing stages before acquisition, US regulations and Congressional procedures still would require program accountability, with demonstrated milestones to support budgetary appropriations.

Past experience suggests that the expense of developing a dedicated boost-phase system with methodically stipulated requirements would not be small and that the time frame for such development could not be less than five or six years — unless a war or acute emergency drove the development steps onto an unusually foreshortened schedule. The most advanced current program the US has for developing boost-phase missile defense is the Air Force development program for an airborne laser. No US program to develop ground or sea based boost-phase interceptors had been authorized through 2001. Any such program, legislatively speaking, would have to begin from scratch. Indications have emerged just this year, however, that the Bush Administration may attempt to develop naval boost-phase interceptor capabilities. Plans may now be underway to modify the design objectives of the still undeveloped Navy Theater Wide (NTW) interceptor technologies — including modifications to the LEAP KV and requirements to develop higher velocity interceptor missiles needed to achieve boost-phase performance. Whether such performance can be achieved with AEGIS-VLS-compatible interceptor missiles remains to be seen, but this appears to be the focus of the new, naval boost-phase efforts.[70]

In Table 5, we show high and low estimates for two ground-based, boost-phase configurations. The first contains four sites based on the current threats from rogue states (North Korea, Iran, Iraq, and Libya), and the second offers eight sites based on the potential emergence of future challengers. Our architecture for these systems assumes that the current program for US-based, mid-course missile interceptors will continue and that the basic infrastructure for that system would integrate and support boost-phase modular interceptor units as elements of the infrastructure (e.g., SBIRS-low) become available. These infrastructure costs are not counted twice in this report. However, we assume each modular boost-phase unit will also require at least one co-located acquisition and tracking radar that would be comparable in acquisition cost to an intermediate-size X-band (e.g., THAAD) radar. We further assume that each site would have 15 alert interceptors and 15 reloads, or spares, for a total of 30 interceptor missiles.

Ground- or sea based boost-phase interceptors must be located fairly close to the launch sites of hostile missiles and preferably downrange along their logical flyout corridors. They must be very powerful and capable of accelerating rapidly to velocities of as much as 8.5

[70] Robert Wall, "Pentagon Eyes Additions To Anti-Missile Arsenal," *Aviation Week & Space Technology*, June 7, 2002.

TABLE 5

Estimates of Ground Based Boost-Phase Systems Deployed Overseas, Fiscal Years 2002-2003

(in billions of 2003 dollars)

Type of Cost	Four-Site Configuration 120 interceptors	Eight-Site Configuration 240 interceptors
Research and Development		
BP Interceptor Missile	9.4	9.4
BP Kill Vehicle	1.9	1.9
BP Radar	0.5	0.5
Subtotal	11.8	11.8
Production		
BP Interceptors with KV	7.5	12.5
BP Radars	1.0	2.1
Site Construction	1.3	2.5
Subtotal	9.8	17.1
Total Acquisition Costs	21.6	28.9
Operations Through 2015	0.9	1.3
Total Costs Through 2015	22.5	30.1
Operations From 2015 Through 2035	5.4	11.7
Total Costs Through 2035	**28.0**	**41.8**

Numbers may not add up to totals due to rounding.

km/sec within the 3 to 5 minutes burn time of the hostile long-range missiles. Postol's work indicates that a large Spartan-type missile (i.e., like the long-range interceptor used for the 1972 Safeguard system), inherently a "strategic missile," will be needed. No current production of such a missile exists. A converted ICBM (e.g., the Peacekeeper) would not have the optimal acceleration for boost-phase intercept. Thus a new missile will have to be designed and produced. We believe the $9.4 billion historical development cost of the Trident D-5 submarine-launched ballistic missile (SLBM) is a reasonable benchmark for projecting the likely development cost of a ground-based boost-phase interceptor, including testing, but not including the KV. We believe the development cost of the KV would be about $1.9 billion, and that the development of a dedicated site radar for boost-phase interceptors would cost about $520,000.

The per unit acquisition cost for such a strategic, high-acceleration missile and its kill vehicle is unlikely to be less than $50 to $60 million, and for small production runs it could be higher. We assume construction of each site with 15 silo launchers (not hardened against nuclear effects), together with command, control, and communications facilities, and personnel support buildings, would cost about $313 million, and the co-located acquisition and tracking radar another $250 million.

We assume about 150 US military personnel would be required to man and operate each site, at an annual cost of about $31 million, per site. Provisions and utilities would add about $5 million annually, per site. Host countries presumably would insist on providing basic perimeter security, and basing agreements, if such cooperation is actually attainable, might cost $10 million annually, per site. Other system operations and maintenance costs we estimate would be about $21 million annually per site. Thus, about $68 million per site would be incurred annually for O&S, or $271 million a year for four sites. An eight-site system would incur savings only in supporting a longer production run and a lower unit cost of interceptor missiles. We assume that the missiles for four sites would be acquired at $63 million apiece, but that the average unit cost of missiles for eight sites would drop to $52 million. The O&S costs for eight sites would be $542 million a year.

In our judgment, the R&D and testing for a ground-based boost-phase system would take at least 5 years from the decision to develop such a system, and that procurement for four sites along with actual construction of those sites would take at least 3 more years. Thus the earliest date for the full operation of such a system would be 2011. This would be an optimistic schedule, however, since negotiations with host countries and other delays probably would cause the schedule to slip by several years. We therefore assume, more realistically, that a fully operational four-site system could be in place in 2015, with O&S costs phased in beginning in 2012 and rising to a normal level in 2015. Augmentation by adding sites could occur incrementally and presumably would only rise as threats emerge, but once the system has been established, it could be expanded to eight sites over the next 3 years, by 2018, with correspondingly higher O&S costs as each site is added.

Our acquisition estimate for four sites by 2015, comes to $21.6 billion, and for eight sites by 2018 $28.9 billion. The total cost for the four-site configuration of this system operating to 2025, would be at least $22.5 billion, and with eight sites would be $30.1 billion. Projected with O&S costs through 2035, the life cycle costs would rise to $28 and $41.8 billion for the four and eight site configurations respectively. By that time, missile and equipment replacement costs could become significant, but we have not tried to estimate those costs.

While these figures for localized, ground-based boost-phase defenses are certainly lower than those estimated for a ground-based mid-course NMD or for a space-based laser system, they are not inconsiderable. Moreover, the willingness of suitably located countries to host such systems is not a foregone conclusion, and negotiated arrangements might preclude full US control over interceptor launch. In weighing the relative appeal of ground-based boost-phase systems, then, there are several points of comparison to bear in mind. The localized boost-phase systems presumably would be focused exclusively on rogue states or emerging adversaries with long-range missile capability, and would not have any utility against an accidental launch or unauthorized strikes by Russian or Chinese strategic forces. The ground-based boost-phase systems would also be positioned to deal with northeast, north, and northwest strategic flyout trajectories against the United States, Europe and Russia from states in a zone between 30 and 40 degrees latitude north of the equator. They would not necessarily be well located to protect other allies against threats from other geographic locations, long-range or short-range, launched along plausible trajectories.

If the primary objective is to complement and reinforce ground-based midcourse US defenses against rogue state long-range missile threats, however, ground-based boost-phase defenses would be a more economical way to go than space-based interceptor systems — as long as host countries cannot veto US launch decisions and both systems' technical effectiveness against such threats are otherwise roughly comparable.

4. Sea based Boost-Phase System

It was demonstrated in an earlier cost study of sea based NMD concepts that the high acceleration and burn-out velocity required of boost-phase interceptors in plausible maritime scenarios would require more powerful and probably much larger boosters than those employed or planned by the Navy in its missile defense programs. The larger boosters and interceptors probably would be incompatible with the AEGIS Standard Missile platform — particularly with the current, eight-pack Vertical Launch System (VLS) modules, and even with the larger launch tubes in the six-pack module modification that is being considered for the Navy Theater Wide (NTW) mid-course interceptors (SM-3, Block II).[71] A sea based boost-phase interceptor missile probably could be derived from the same R&D envelope (and cost) as that postulated in Section 3 above for a ground-based boost-phase interceptor missile, producing a "common missile" for both deployment modes.[72] This also means that the unit acquisition costs for the sea based boost-phase system interceptor missiles would be akin to that assumed of the ground-based boost-phased interceptor missiles discussed above.

Some experts have argued that such a naval boost-phase interceptor missile could be based on reconstructed cargo ships. In contrast to AEGIS ships, a reconstructed cargo ship may have sufficient deck space to install a more powerful radar, such as a mid-sized X-band radar. This approach almost certainly would be less

[71] See Rodney W. Jones, *Taking National Missile Defense to Sea: A Critique of Sea based and Boost-Phase Proposals*, Washington, D.C.: Center for Arms Control and Non-Proliferation (Council for a Livable World Education Fund), October 2000, Section IV. Compare, for instance, the size of historical missile defense interceptor missile in Figure 2 on page 15, where the Spartan represents the mass (mostly fuel volume) that a newly designed boost-phase interceptor probably would require.

[72] Note that since AEGIS platforms are unlikely to support boost-phase interceptors, the acquisition of AEGIS ships by allies and the current profile of Japanese TMD cooperation probably would not reduce the US cost burden of deployment of naval boost-phase missile defense assets.

expensive than designing a new surface ship specifically for sea based, boost-phase missile defense purposes, and probably less expensive and much quicker than building a series of missile defense variants of new US Navy surface warships.[73] Modified cargo ships probably would be far less survivable under attack, however, than the Navy's current cruisers. Surface ships dedicated to missile defense that are located near countries that pose offensive missile threats would require that other ships and aircraft be assigned for their protection, with naval and perhaps air force mission tradeoff costs.[74]

Our cost estimate of a sea based boost-phase system assumes the choice of reconstructed cargo ships, which we believe would be the least costly of the ship platform alternatives, at least in direct budgetary costs. But each ship would require an on-board fire control and launch system, probably a mid-size X-band radar, and integrated communications with the larger missile defense battle management system. We assume that converted cargo ships would cost about $200 million each, plus about $250 million each for the fire control, sensor, and launch systems, for a total of about $450 million per ship. This would be only 40 per cent of the cost, however, of building a state of the art AEGIS cruiser today.

Boost-phase interceptor ships must patrol very close to those threat countries that have maritime exposure. We assume five patrol areas, two in northeast Asia, two in the Persian Gulf, [75] and one in the Mediterranean covering Libya. Since we are dealing with dedicated missile defense ships, we assume that if two interceptor ships are stationed in each patrol area, another two should be sufficient to support rotation for each patrol area, giving a total of 20 ships for the sea based system.[76] We assume each interceptor ship would carry 24 interceptor missiles in vertical launch magazines, and that 12 spares would be acquired and stored in home port for each ship.[77] We conservatively estimate Operation and Support (O&S) costs (not counting missile acquisition and ship replacement) at $13.6 million per ship annually, or $271.2 million annual O&S for the entire complement of 20 missile defense ships.[78]

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73 Now cancelled, the DD-21 Zumwalt destroyer is an example of a ship program that might have been adapted, before construction began, to incorporate new, missile defense mission objectives. On the Zumwalt program, see Richard Scott, "DD-21 Teams Show Rival Designs," at: <http://www.janes.com/defence/naval_forces/news/jni/jni010529_1_n.shtml>, and "DD-21 Zumwalt Class Multimission Destroyer," at: <http://www.naval-technology.com/projects/dd21/index.html#dd211>.

74 A potential alternative would be modifying surplus strategic missile submarines (SSBNs) as launch platforms for boost-phase interceptors. Concealed submarine launch platforms need not tie up surface ships in protective missions. But modifying submarines for this purpose would be technically quite complicated and still would pose tradeoffs with current US Navy mission planning for covert insertion or intelligence missions.

75 There is some doubt that sea based boost-phase interceptors located in the Persian Gulf could catch strategic missile launched northward from the interior of Iran or even of Iraq in a "tail chase." Thus the Black Sea and the landlocked Caspian Sea may be better locations than the Persian Gulf for sea based boost-phase interceptors protecting the northern hemisphere against strategic missiles launched from Iran and Iraq. Using such ships in the Caspian Sea would depend on the cooperation of litoral states.

76 Hypothetically, dedicated boost-phase interceptor ships could also intercept sea-launched offensive missiles close to the United States coastal areas, but since this threat could emanate from almost anywhere along the coasts, it would require a very large number of boost-phase interceptor ships to provide coverage. Hence, we assume that sea based and land-based midcourse and terminal defenses would be considered more suitable architectural responses to close-in sea based offensive missile threats.

77 Reloading of such missiles at sea is technically conceivable but would require special cranes, storage either in the cargo ships or in replenishment ships (the latter would enlarge the flotilla and surface fleet protection requirements), and would be time-consuming. We believe the Navy would consider this impractical and inconsistent with its planning for active defense operations against a threatening missile state. Thus we assume that reloading would follow rotation and be done in homeport.

It should be kept in mind that R&D costs for the ground-based and the naval boost-phase interceptors, assuming they use a common missile, could be nearly the same. If they did involve a common missile and both systems were developed and deployed, then most of the missile R&D would be a one-time cost for both, and not additive. In practice, however, there are likely to be significant Navy R&D requirements that do add development costs to the Navy's version. We assume the Naval R&D add-ons would add 25 per cent more to the R&D cost of the ground-based version as a distinct cost for the sea based version. If both ground-based and naval systems were built and deployed, the 25 per cent margin would simply be counted against the Naval system. If only one system were developed and deployed, the entire R&D cost would be counted against that system.

Other things being equal, we believe that any future U.S. administration would prefer investing in a naval boost-phase system to a ground-based one hosted by a foreign power. This is partly because negotiating the use of sites on the territory of Russia or other well-located states would be problematic,[79] and partly because US defense planners would be strongly inclined to take advantage of maritime freedom of movement as long as a naval boost-phase system proves feasible and affordable. It is possible, however, that both systems would be developed and built incrementally, one filling gaps that the other leaves uncovered.[80] It is also possible but in our view unlikely that the US would rely on the existing or slightly improved Russian S-300 (a successor to the SA-10) high-altitude surface to air missiles for missile defense against Third World missiles to the south of Russia.[81] It is most unlikely that this class of missiles could be improved sufficiently to provide a true boost-phase capability. It is possible, however, that Russia could produce a boost-phase-capable booster with US technical cooperation more cheaply than the US could relying on domestic defense firms.

We estimate the acquisition of a naval boost-phase system manning five maritime pa-

[78] The Navy assumed the following O&S costs in constant 1996 Dollars would be achievable for the once-planned (subsequently canceled) DD-21 Zumwalt destroyer, a ship whose crew was to be smaller than is assigned to AEGIS destroyers today, but that might be comparable to a dedicated missile interceptor ship operating in pre-assigned locations: (a) $2,500.00 per hour for 3,274 hours of steaming hours (136 days) each year, $1,700 per hour for 1,886 hours of steaming hours in port (78 days) each year, with the balance being considered "hotel hours" (151 days) each year. See the "DD-21 Zumwalt" analysis by the Federation of American Scientists at: <http://www.fas.org/man/dod-101/sys/ship/dd-21.htm>. We assume a similar profile in round numbers of steaming and hotel hours (or days) but somewhat lower costs for the converted cargo-missile interceptor ship: $2,200.00 per hour for steaming hours over 140 days per year; $1,400 per hour for steaming hours in port over 75 days each year, and $450 per hour for hotel hours in port for 150 days per year. This adds up to about $11.5 million operating costs per ship per year in 1996 dollars, and $13 million per ship per year in 2003 dollars.

[79] The US National Command Authority would want absolute US control over decisions to launch interceptors whereas a host country almost certainly would want concurrent consultation if not joint firing control with an outright veto. The operational time frame for boost phase interceptors after a hostile missile is launched, realistically speaking, would not allow time for consultation with the top political authority of a host state. Negotiating an acceptable solution to this issue may be well nigh impossible.

[80] Even a Spartan-like boost-phase interceptor based on ships in the Persian Gulf or Arabian Sea would have difficulty catching up with and intercepting long-range missiles in northward flyout corridors from launch sites deep in Iran or northern Iraq — the most commonly analyzed case. One might think large boost-phase interceptors in that region would have somewhat greater effectiveness against offensive missiles launched southwest against Israel or south against Saudi Arabia, but the short burn of missiles launched against those targets would make it difficult for US boost-phase interceptors to reach them. Suitably located in the Indian Ocean, they could also influence the nuclear balance between India and Pakistan.

[81] Russian manufacturers claim that variants of the S-300 are comparable in capabilities to the US PAC-2/3 TMD. Deployed to the south in the Persian Gulf or adjacent states, the PAC-3 and even the more powerful THAAD TMD interceptors would not be boost-phase capable against longer-range offensive missiles launched to the north from such states as Iraq or Iran.

TABLE 6

Estimates of Forward Deployed Sea Based Boost-Phase Interceptor System, Fiscal Years 2002-2035

(in billions of 2003 dollars)

Type of Cost	Five Patrol Area Configuration	Seven Patrol Area Configuration
Research and Development		
BP Interceptor Missile	9.4	9.4
BP Kill Vehicle	2.4	2.4
BP Ship	1.0	1.0
BP Ship Radar	0.8	0.8
Subtotal	13.6	13.7
Production		
BP Interceptors with KV	37.5	45.1
BP Ships & Radar	9.4	11.3
Subtotal	46.9	56.3
Total Acquisition Costs	60.5	70.0
Operations Through 2015	0.8	1.0
Total Costs Through 2015	61.4	71.0
Operations Through 2035	5.4	6.5
Total Costs Through 2035	**66.8**	**77.5**

Numbers may not add up to totals due to rounding.

trol locations, each with two ships on station and two more for rotation, around the clock would cost about $60.5 billion. In the event that the sea based system uses the same missile as a ground-based boost-phase system, the sea based boost-phase system would cost less, about $53.6 billion. Given an aggressive development and ship modification program, deployment of a five patrol area system could begin by 2008, possibly reaching full deployment between 2013 and 2015. Including O&S costs, the total cost of this system through 2035 would be at least $66.8 billion (or $59.9 billion if a common naval and ground-based missile is used).

The second column of Table 6 contains estimates of an expanded sea based boost-phase system with 7 patrol areas that probably could be fully deployed by 2018. In this case the acquisition costs would be about $70 billion (or about $63.6 billion if a common missile is used), while life cycle costs would be about $77.5 billion.

5. Airborne Boost-Phase System

Airborne boost-phase intercept concepts and technology have been developed along two lines: (1) directed energy (laser) interceptor mechanisms; and (2) rocket-powered (kinetic or terminal explosive KV) interceptor mechanisms. Most of the conceptual and development work to date on rocket-powered interceptors has featured *manned* aircraft platforms, but as a further wrinkle, *unmanned* aerial vehicles (UAVs) have also been in view as alternative platforms for rocket-powered missile defense interceptors.[82] Among these airborne boost-phase technical options, only the airborne laser (ABL) has been in formal development since 1994, with an acquisition program launched in 1996.[83] The ABL was then conceived of as a boost-phase “theater missile defense” (TMD) program of the US Air Force. Because of 25 years of earlier scientific development at the laboratory level, the ABL technology had gained a reputation for greater maturity than the other boost-phase missile defense options. Nevertheless, upon recent examination the General Accounting Office concluded that several of the ABL program’s critical technologies at this time are less than technically mature.[84]

The Bush Administration recently transferred responsibility for the ABL program from the Air Force to the Missile Defense Agency and gave it stronger impetus. Program objectives were upgraded to include *strategic* missile defense capability, and a goal was set for the deployment of an operational prototype ABL with limited capability that could see emergency use

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[82] See the treatment of these options in Dean A. Wilkening, *Ballistic-Missile Defence and Strategic Stability*, London: International Institute of Strategic Studies, Adelphi Paper No. 334, May 2000, especially chapter 4 on “Boost-Phase Ballistic Missile Defence.”

[83] The ABL program entered the Program Definition and Risk Reduction (PDRR) phase in November 1996 when the Air Force selected a single team from two competing concept teams and awarded the contract to a team led by Boeing, and including TRW and Lockheed-Martin. “Boeing, Lockheed Martin, TRW Win Airborne Laser Contract,” news release, Washington D.C., November 12, 1996 <http://www.fas.org/spp/starwars/program/abl/pr961112.htm>. For background through 2000, see Director, Operational Test & Evaluation, *Annual Report, FY 2000*, Washington, DC: Department of Defense, February 2001, pp. V-15 to V-20.

[84] Asked by a Congressional committee to explain the Air Force’s August 2001 acknowledgement of 50% development cost overruns (up from $2.5 to $3.7 billion) and an estimated schedule for initial fielding of the system that had slipped from 2006 to 2010, the GAO said: “In 1996, at program launch, the Air Force did not have enough knowledge about the technology challenges facing the program. As a result, the Air Force underestimated the complexity of the engineering task at hand and misjudged the amount of time and money that the program would need. Some critical technologies that the system’s design depends upon remain immature, making it very difficult, even today, for analysts to establish realistic cost and schedule goals.” General Accounting Office, *Missile Defense: Knowledge-Based Decision Making Needed to Reduce Risks in Developing Airborne Laser* (Report to the Chairman, Subcommittee on National Security, Veterans’ Affairs and International Relations, Committee on Government Reform, House of Representatives) GAO-02-631 (Washington, D.C. July 2002), p. 2.

in contingencies by 2004 or 2005.[85] In this regard, the prototype ABL may become the United States' first operationally deployed boost-phase BMD system.

Depending on what is learned from operational testing and choices from technology evolution by 2005, a fleet of seven ABL aircraft conceivably could be fully deployed by 2010. Because of the advanced status of this airborne program and no apparent interest in the unmanned alternatives for airborne missile defense purposes at this point in time, we focus in this report upon the ABL program for our cost analysis of an airborne component of a layered missile defense system.

The Air Force program requirements since 1996 have called for the acquisition and modification of seven Boeing 747-400F (wide-bodied cargo) aircraft. Each was to be equipped with a three-megawatt weapons laser[86] capable of destroying enemy missiles from a distance of "several hundred kilometers". The aircraft are to be equipped with pointing and tracking lasers as well as high-energy weapon lasers, and command post electronics. They are to be based in the United States, but available within 24 hours anywhere a threat emerges.[87]

The "megawatt class" laser developed in the mid-1990s for the ABL program was a Chemical Oxygen-Iodine Laser (COIL). COIL reportedly was demonstrated in August 1996 by TRW with sufficient efficiency (to make carrying the reactants feasible on an aircraft like the 747) at a power output of several hundred kilowatts.[88] To achieve airborne laser power in the megawatt range, it has now been determined (after what were described as successful tests of the first "flight laser module" in early 2002) that six COIL modules will be ganged together in the prototype ABL aircraft.[89] The high-energy laser to be scaled up for production would consist of 14 connected COIL modules.[90]

Under the Air Force concept of operations, the ABL aircraft would fly from its US base upon order to the vicinity of the threat and then fly in patterns at 40-50,000 feet altitude above the clouds, over friendly territory or open ocean areas.[91] There it would be ready to detect, track, and fire laser beams at ascending threat missiles after they have cleared any cloud cover.[92] Experts estimate the ABL's maximum lethal range to be over 200 miles (usually described only as "several hundred kilometers") — and that this range is applicable only against the more

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85 Missile Defense Agency, "Unclassified Statement of Lt. Gen. Ronald T. Kadish, USAF, Director, before the Senate Appropriations Committee, Defense Subcommittee, Regarding the FY 03 Missile Defense Budget, April 17, 2002, op. cit., p. 24.

86 Wilkening, op. cit., pp. 65ff.

87 The first Boeing-747-400F aircraft for the ABL program had already been modified and made ready to receive the pointing, tracking and high-energy laser equipment by the spring of 2002, and was expected to begin ground and flight testing in late 2002. "Boeing Completes Major Modifications to First Airborne Laser Aircraft," Boeing press release, Seal Beach, Calif., May 30, 2002.

88 See "Boeing, TRW, and Lockheed-Martin form the team doing ABL," ABL Team news release, Redondo Beach, CA, March 29, 2002, available at: <http://www.airbornelaser.com/special/abl/news/>.

89 *Ibid.*

90 GAO, *Missile Defense: Knowledge-Based Decision Making Needed to Reduce Risks in Developing Airborne Laser*, *op.cit.,* p. 14, note 8: "One of the major technical challenges is accommodating the laser's weight. Engineers determined that the six-module system would weigh 180,000 pounds, but the original system requirement was that the system must weigh no more than 175,000 pounds with 14 laser modules. Because each additional module weighs about 6,000 pounds, the agency intends to redesign some components to reduce their mass and redistribute the weigh using a passenger version of the Boeing 747 as the block 2008 [a second prototype] aircraft. The passenger version of the 747 can accommodate the crew on an upper deck, thereby allowing the laser's weight to be moved forward where it places less stress on the aircraft frame." See also Tony Capaccio, "Boeing's Aircraft Laser Faces Redesign To Cut Weight, GAO Said," *Bloomberg.com*, July 15, 2002.

91 The ABL aircraft are highly vulnerable to hostile anti-aircraft fire or fighter aircraft and thus must either stay inside a friendly territory or be accompanied by fighter aircraft, with significant refueling requirements.

vulnerable early generation, liquid fueled missiles (e.g., Scud-B/C, No Dong, Taepo-Dong).[93]

The ABL system has the advantages of being sheltered on stand-by out of harms way, yet available for rapid response upon warning almost anywhere in the world. Arguably, it provides a lateral boost-phase capability against short- and intermediate-range liquid-fueled missiles as well as additional real-time surveillance in the theater of operations, and it could offer cueing assistance to other layers of missile defense. But the ABL system itself would not, as planned, provide a round the clock, continuous missile defense capability. The technical limitations of the system are that its range would be rather limited against more sophisticated missiles and the ABL aircraft are highly vulnerable to attack by a hostile air force or long-range surface-to-air missiles. The effectiveness of the ABL laser system has yet to be demonstrated in an airborne environment where atmospheric turbulence buffets the aircraft, causes jitter in the laser beam and therefore makes it extremely difficult to fix the beam continuously on a vulnerable point on an accelerating target.

The cost of the seven-airplane ABL system has been advertised since 1996 as $5 billion for total acquisition, with $11 billion life cycle costs over 20 years, presumably in constant 1996 dollars.[94] According to Wilkening, the Air Force had already devoted $1.6 billion by 1999 to development of a prototype ABL system, to be tested between 2003 and 2005.[95] Table 7 contains the fragmentary official data that we have for the ABL program in column one, and shows our conservative estimate with cost growth assumptions in column two. As reflected in the GAO 2002 report, we display in column one of the table the recent Air Force estimate of $3.9 billion (vs. the earlier estimate of $2.5 billion) for development, and add the increase to the official estimate of the total acquisition cost as well as to the official estimate of the life cycle cost, deriving an official estimate of $6.3 billion for O&S costs through 2035. The figures in the second column are based on our estimate that R&D and O&S cost growth will be at least 30 per cent above the revised official figures, that production cost will be roughly twice the $2.6 billion production cost inferred from official figures, and that total acquisition cost will be nearly 60% higher than official figures suggest.[96]

Thus, while the recently adjusted and fragmentary official figures suggest this ABL system could be acquired and operated for 20 years for about $12.7 billion, our estimate is that total life cycle cost will be at least $19.3 billion. In addition, the technical challenges in this program

92 A military professional's analysis of the TMD capability of the system is in Maj Gerald W. Wirsig, "The Airborne Laser and the Future of Theater Missile Defense," Air Command and Staff College, March, 1997.

93 See Wilkening, op. cit., pp. 66-67, and references to calculations by Geoffrey Forden, *The Airborne Laser: Shooting Down What's Going Up*, CISAC Working Paper (Stanford, CA: Center for International Security and Arms Control), September 1997.

94 These figures are given in Wilkening, op. cit., p. 67, evidently dating back to 1997 or 1996. Even today the USAF Directorate of Requirements website says: " ABL is an $11B USAF and Missile Defense Agency (MDA) weapon system designed to destroy enemy ballistic missiles (BMs) in their boost phase. ABL utilizes a multi-megawatt laser and a precision tracking and pointing system, mounted on a 747-400 aircraft. ABL became a formal program in 1996." The website is available at: <http://xr.acc.af.mil/worldaccess/Staff/abl/abl.htm>. The Congressional Research Service evidently refers to this same estimate as the "most recent estimate" in a May 2002 report: See Hildreth, Steven A. and Amy F. Woolf, Missile Defense: The Current Debate, Report for Congress, Library of Congress, Congressional Research Service, No. RL31111, updated May 6, 2002, p. 39.

95 Wilkening, op. cit., p. 65.

96 We have found neither official production figures nor a breakdown among components. Our own estimate of $5 billion production costs includes seven converted 747 aircraft at $240 million apiece, $60 million per aircraft for fire control and beam stabilization, pointing and tracking equipment, and $400 million for each laser weapon. We believe these productions cost estimates may prove low, however, given the technology challenges and high technical risk that remains in this program. The production and O&S costs of a larger fleet, of course, would rise in nearly direct proportion to the additional numbers of ABL aircraft.

TABLE 7

Cost Estimates of Airborne Laser, 2002-2035 (ABL) Boost-Phase Program

(in billions of 2003 dollars)

Type of Cost	Official Figures	Our Estimate
Research and Development	3.9	5.0
Production		
Aircraft	n/a	1.8
Laser Weapon	n/a	2.9
Additional Equipment	n/a	0.5
Subtotal	2.6	5.2
Total Acquisition Cost	6.5	10.2
Operations Through 2015	n/a	0.9
Total Acquisition Costs Through 2015	n/a	11.2
Operations From 2015 Through 2035	6.3	8.1
Total Costs Through 2035	**12.7**	**19.3**

Numbers may not add up to totals due to rounding.

could drive up the development and production costs further, and any expansion from a seven aircraft fleet to a larger one would entail additional costs (about $746 million per unit) and proportionately higher O&S costs. Neither the official nor our estimates take account of the trade-off costs of using fighter and airborne warning and control system (AWACS) aircraft for the protection of ABL missions overseas.

IV. TERMINAL DEFENSES: U.S. TERMINAL AND THEATER MISSILE DEFENSES

Terminal defenses intercept ballistic missiles upon their reentry to the atmosphere following mid-course travel through space. Terminal defenses can be likened to a baseball "catcher's mitt," catching missile warheads before they reach targets on the ground. Terminal defenses by their nature must be located nearby the targets that hostile missiles would be aimed at, and therefore are inherently limited in their geographical reach. For similar reasons, terminal defenses normally launch within tightly restricted time frames, often allowing just a few seconds, or at most a few tens of seconds, between interceptor launch and the intercept itself. The accuracy and range of the terminal interceptor may be enhanced by early detection and tracking of the incoming warhead by long-range sensors and data communication systems, including those in a layered missile defense system that support boost-phase or mid-course defense components. But terminal defense systems usually need their own terminal radars and homing sensors to fine-tune interceptor launches and engagements close in to the targets they defend.

Terminal defense interceptor systems have one big advantage over mid-course systems in that lighter decoys and chaff (which may conceal or imitate warheads in cold space, to overload or penetrate mid-course defenses) are stripped away from the actual incoming warheads once they encounter air resistance in descent through the atmosphere. This also allows the homing sensors of terminal interceptors to rely on simpler technologies than the cryogenically cooled infrared sensors required by mid-course interceptors. However, terminal defense interceptors may still face extraordinary technical challenges in the event incoming warheads have been designed to maneuver aerodynamically once they reach the atmosphere.

In the distant past, terminal missile defenses were quite similar to high altitude anti-aircraft missiles and usually were nuclear-tipped. Since the Reagan Administration in the 1980s, US missile defense programs have tended to rely on non-nuclear intercept principles. Current US terminal missile defense programs (whether land-based or sea based) depend on interceptor missiles designed to use either the kinetic (hit-to-kill) principle (collision with the incoming warhead) or conventional fragmentation warheads (detonating in proximity to the incoming missile warhead). Theoretically, terminal defenses could also use directed energy principles, such as ground-based lasers. Directed energy terminal defense systems would be phenomenally expensive, however, and not cost-effective for small areas or the population defense of large countries like the United States.[97]

Although there are signs that the Bush Administration intends to study nuclear intercept principles again, particularly for terminal defenses, detonating nuclear warheads in the atmosphere above the United States or allied territories would present such politically unpalat-

[97] A ground-based, mobile defense laser developed and tested in Israel has been demonstrated to have utility against Katyusha rockets (by heating and preemptively detonating explosives in their warheads), but this system is not thought to be effective against even short-range ballistic missiles, such as the Scud-A/B/C. Whatever the viability of the ground-based laser concept for defense against *theater* missiles of a tiny country with just three major urban concentrations, such as Israel, it should not be confused with the use of ground-based lasers for the terminal defense of big countries where some individual metropolitan areas are comparable in size to the entire, main settled area of Israel. Similarly, although some missile defense advocates may claim that space-based lasers or space-based kinetic rocket systems could intercept offensive warheads after atmospheric reentry, missile defense system designers with real world experience do not consider these serious options for the foreseeable future.

able or technically disruptive consequences that we view it as unlikely and do not consider it further. But while the public backlash that would result from pursuing the basing of nuclear-tipped terminal interceptors within the continental United States, Europe or Japan probably precludes this option in those areas, it is not so clear at this juncture that the current administration necessarily would rule out such concepts for the terminal defense of US forces and other allies overseas, particularly in maritime locations.[98] Our cost assessment of terminal defense of the US against ballistic missiles is restricted, therefore, to non-nuclear interceptors that use kinetic or fragmentation warheads as kill mechanisms.

Depending on their slant range, acceleration, and altitude capability (the reach) of their interceptors against various types of ballistic missile threat, terminal defenses may be used for either *point defense* or *area defense*. The velocity and angle of approach of the incoming missile warhead and the relative location and capabilities of the defending interceptors and sensors define the geographical extent of a circular or oval-shaped protected area, otherwise known as a *defense footprint*.[99] In the case of early-generation interceptors designed for point defense, that footprint often was quite small (dozens of square kilometers), but could cover an airfield, naval base, or even ships clustered in a battle group. Modern, long-range terminal defense interceptors can defend much larger footprints encompassing thousands of square kilometers against theater-range ballistic missiles.[100] To defend contemporary metropolitan areas or overseas military theaters that encompass tens to hundreds of thousands of square kilometers, terminal defense interceptor launch sites (or launch platforms) would not only each need multiple, ready-to-fire interceptors but would also have to be positioned to provide overlapping footprints.

The number of interceptors needed at each launch site (or platform), and as an aggregate, for the defense of a metropolitan area, military base, or military theater would be based not only on the defense footprint of the defense system but on assumptions concerning the potential attack size, effectiveness of preceding missile defense layers, residual size of the attack that might be expected to penetrate to within reach of the terminal defenses at that area, and

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[98] The Soviet (now Russian) Galosh system is essentially a terminal defense system for Moscow that uses nuclear warheads as the kill mechanism. But as the US learned in the course of building and briefly deploying the Safeguard (Sentinel) ABM system to defend an ICBM base in the early 1970s, while some of the first salvo of nuclear-tipped interceptors might achieve intercept, the nuclear explosions would effectively blind terminal missile defense radars opening a path for subsequent salvos of a sequenced missile attack. Moreover, the electro-magnetic pulse (EMP) from nuclear explosions in the atmosphere could cripple sensitive military and commercial electronics on the ground and in the air, while other effects of the detonations could cripple low-orbit communication satellites in the vicinity.

[99] A useful discussion of the theoretical issues involved in calculating footprints for TMD, applied with illustrations for the national capital region, can be found in Congressional Budget Office, *The Future of Theater Missile Defense*, June 1994, chp. II, pp. 10-14, and chp. IV, pp. 53-61. The theoretical reach (and footprint diameter) of a local missile defense installation is not only a function of the range and velocity of the interceptors (dependent on the range and resolution of its sensors) but also of the range and velocity (as well as angle of approach) of the attacking missile or its warhead. The defensible area or footprint of a terminal defense system is much smaller against strategic missiles, which travel at much higher velocities, than the footprint against slower medium- or short-range ballistic missiles. Moreover, the theoretical reach of a terminal defense interceptor is no guarantee that it will successfully intercept a warhead that falls within the footprint area.

[100] Wilkening, *Ballistic Missile Defense, op. cit.,* pp. 46-47, gives the *diameters* of defense footprints advertised for TMD systems during the Clinton era, presumably defending against short- and medium-range attack missiles. The corresponding size of the footprints in square kilometers, would be as follows: (1) PAC-3, between 40 and 60 km (footprint about 1,250 square km); (2) NAD, also approximately 40 to 60 km (footprint about 1,250 square km); (3) THAAD, several hundred km (assume 300 km, footprint about 70,000 square km); and (4) NTW, several hundred to 1,000 km (assume 300-1,000 km, footprint ranges from 70,000 to 785,000 square km).

As mentioned in the previous note, the size of these defense footprints as estimated for defense against relatively low velocity, short-range missiles shrinks dramatically, as much as tenfold, when facing progressively higher velocity, intermediate-range and strategic missiles.

the objectives of the defense (e.g., how many casualties or losses of major equipment or infrastructure is acceptable in the defended area), in whatever attack scenarios are considered plausible. A terminal defense of the entire United States against strategic missiles would be prohibitively expensive.

As indicated earlier in this report, the Bush administration has reclassified US missile defense programs into boost-phase, mid-course, and terminal categories (ballistic trajectory phases), and away from the *strategic* versus *theater* missile defense distinction previously favored by the Clinton administration.[101] As a result, most of the theater missile defense (TMD) systems pursued by the Clinton administration — particularly the ground-based and naval TMD programs, plus certain related programs that have been conducted in cooperation with allies — now fall under the Bush Administration's rubric of terminal defense.[102] These programs were the Army's Patriot Advanced Capability (PAC)-3, the Army's Theater High Altitude Area Defense (THAAD) system, the Navy's Area Defense (NAD) system (until it was cancelled in December 2001), the Navy Theater Wide (NTW) system, the Medium Extended Air Defense System (MEADS) intended for Western Europe,[103] and the U.S.-subsidized Arrow system in Israel. In effect, therefore, we assume for cost estimating purposes that the US terminal defense layers will be more or less synonymous technologically with the Bush Administration's revised vision of the TMD programs that the Clinton Administration initiated. These TMD programs were intended then mainly for US and allied force protection overseas, but also offered specific types of bilateral TMD technology cooperation with

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[101] The limits that were codified in the ABM Treaty were understood to apply to ABM, i.e., *strategic,* interceptors and their components, and did not cover tactical or theater missile defense interceptors. As tactical and theater range technologies increased in their capabilities, a once obvious gap between strategic and lesser capabilities (based on the relative velocities and range of offensive ballistic missiles, and the capabilities to intercept them) became blurred. Despite the *demarcation* negotiations conducted by the US with Russia during the Clinton Administration to clarify what ballistic missile capabilities were and were not covered by ABM Treaty provisions, a technically defined distinction was never successfully codified.

[102] The Clinton Administration offered cooperation with allies on what were deemed non-strategic missile defense systems under the US interpretation of the ABM Treaty. The non-transfer provisions of the ABM Treaty legally prohibited the parties from cooperating with other countries in *strategic* missile defense systems or capabilities. While the Clinton Administration considered the Air Force development program for airborne laser (ABL) boost-phase capability as TMD, the Bush Administration has shifted that program responsibility to the MDA and apparently intends to restructure the program to achieve strategic as well as TMD capabilities and functions (the upgrade would require a laser that can deliver more power against harder missiles).

During the Clinton Administration, Congress required BMDO to evaluate the conceptual options for deploying strategic (mid-course) missile defense capability on the US Navy's AEGIS ships, but these strategic options were not accepted or programmed by the Clinton Administration, and cooperation with Japan was promoted under the TMD rubric with Navy systems, including the planned Navy Area Defense (NAD) and Navy Theater Wide (NTW) TMD systems. The Bush Administration later canceled but plans to restructure NAD, possibly as a close in, boost-phase (strategic and theater) missile defense system.

Having shed the ABM Treaty, the Bush Administration may pursue an upgraded, strategically-capable, mid-course missile defense capability through the NTW program, and will not necessarily be inhibited in drawing AEGIS ship buyers Britain, Spain, and Japan (and perhaps Taiwan, for whom AEGIS has been considered but not yet approved) into strategic missile defense cooperation. The primary obstacles to actually developing strategic capability under the NAD and NTW programs, however, are the limitations of the AEGIS VLS platform.

As currently configured, AEGIS is not compatible with strategic missile defense interceptors and sensors, and the modification of the AEGIS combat system to make it strategically capable may not be feasible, or even if determined to be feasible still may not be cost-effective, and almost certainly will not be cost-competitive with building alternative ships that can be dedicated to strategic missile defense missions. The Bush Administration may seek to overcome these limitations by deploying strategic missile defense sensors on land in overseas locations. Whether overseas partners will agree to host such facilities remains to be seen.

[103] MEADS is an air defense upgrade program that enlists the cooperation of our European allies to acquire (and therefore defray part of the US cost of PAC-3 acquisition) as a NATO system dedicated to the defense of Western Europe against theater missiles. France originally participated, but has distanced itself from MEADS. Arrow is an Israeli ground-based TMD interceptor system, using an Israeli-developed interceptor, for which the US has paid the lion's share.

NATO, Japan and Israel. The Bush Administration's altered vision of these programs apparently would also provide for terminal missile defenses in the United States against long-range or strategic missiles.

The Bush Administration's altered vision of these formerly TMD programs presumes not only that some of the systems can be upgraded to serve as strategically capable missile defenses, but that allies will offset significant portions of the US acquisition cost for any shared systems. It is possible that upgrading some of these programs to the strategic level might serve as an incentive in Europe and Japan to contribute more, financially, to the US development of missile defense technology.

But we doubt that this will greatly reduce the net cost to the United States of developing and deploying naval and ground-based components of a layered missile defense system. The financial contributions allied states have made to these systems so far have been marginal, and burden sharing in missile defense will remain politically difficult.

The Clinton Administration concluded that the US needed TMD systems that could be deployed to distant theaters to protect US and allied forces and certain allied territories. But it did not consider deploying dedicated terminal missile defenses capabilities within the fifty United States or along US coastlines. Such defenses would have come up against ABM Treaty limits as long as the treaty was in force, and sea based missiles launched from nearby US coastlines was not viewed as an imminently operational and therefore serious threat. The Bush Administration, however, has not ruled out, and thus may be moved by its own missile defense philosophy, to plan terminal missile defense systems that could defend coastal areas of the United States against potential ballistic and cruise missile threats from the sea.

1. Terminal Defenses of the United States Coastal Regions:

To date, the Bush Administration has discussed terminal missile defenses only in vague terms and has not specified anything resembling an architecture for such defenses in the United States. Our effort to project the possible costs of terminal defense in a layered missile defense of the United States itself must therefore specify elements of a geographically plausible architecture using currently programmed or actually developed US defense technologies, without prejudice to the actual effectiveness of such technologies in performing the terminal defense missions.

A hypothetically plausible terminal defense architecture against sea based and long-range missile threats would consist of a combination of naval TMD positioned off-shore and land-based TMD positioned locally near cities to maximize protection of heavily populated, coastal metropolitan areas and strategic installations, such as ports and airfields, key early warning and defense engagement radar systems, and communication nodes. If a coastal terminal missile defense layer is built for the fifty United States, it would be based, we believe, primarily on the "upper tier" TMD programs — THAAD on land, and NTW offshore — or on follow-on versions of these still developing programs.[104] We assume that a terminal defense architecture of this kind would not be designed to defend ICBM fields or strategic air bases directly, nor the interior of the United States as a whole, but rather only cities and key military installations along the coastlines. Our illustrative missile defense architecture would not be a thick

[104] We have not seriously considered the technical potential and therefore do not evaluate for cost analysis the recently floated concept of using stratospheric airships, or dirigibles, as terminal missile defense platforms or auxiliaries. MDA reportedly asked for white papers and is evidently exploring concepts to use stratospheric airships for BMD surveillance, tracking, discrimination, and possible weapon basing. See *Inside Missile Defense*, May 15, 2002, p. 4.

missile defense of the coastal areas let alone a complete terminal defense, even a thin one, of the entire United States.

We also assume that such a terminal defense would be of very limited effectiveness against a dedicated first strike by Russian strategic missiles (ICBMs or SLBMs), bearing in mind that this type of scenario seems to be ever more remote politically and correspondingly recessed in military planning. A terminal defense architecture of the coastlines would be built in stages. We assume the current administration's capabilities based planning (and corresponding military requirements) would focus primarily on sea based ballistic and cruise missile threats, and on potential long-range ballistic missile threats from China and rogue states in the Middle East and Asia. Against such threats, the theoretical system effectiveness might appear to be quite significant.

For low and higher cost estimate purposes (see Table 8), we hypothesize two levels of capability: (1) an initial, thin or *light,* terminal defense, and (2) later, a somewhat thicker or *medium* system — with roughly double the numerical interceptor capacity. The medium system probably would yield somewhat wider area coverage and more than double the overall effectiveness against sea based attacks of any plausible size. From a military planner's standpoint, the terminal defense "upper tier" systems logically would be reinforced by "lower tier" (or point defense) systems such as PAC-3 and NAD. We assume therefore that the postulated light and medium terminal defense levels would have both upper and lower tiers (area, and point defense). We do not specifically enumerate point defense systems nor locate them geographically in this hypothetical architecture, and therefore do not directly estimate the cost of "lower tier" systems. Rather, we assume that installing point defense would represent an add-on or surcharge procurement cost to coastal terminal defenses of 15 per cent (and a 12 per cent O&S surcharge) to the sum of the cost of the TMD systems that we do postulate here explicitly.

The *light* terminal defense level would provide at least one dedicated, NTW-configured missile defense ship always on station offshore (and another in retrofit or reprovisioning in port) for each key metropolitan area.[105] The *light* terminal defense level would also have from one to two THAAD bases or installations for each coastal metropolitan area, depending on the overall size of that metropolitan area.[106] Each THAAD unit would have one mobile X-band radar. We assume that 10 fixed X-band radars would suffice to support the missile defense ships, one in Hawaii, 4 on Atlantic and Pacific coasts, and one on the Gulf coast. The *medium* terminal defense level would, in many cases, double the numbers of ships offshore and the

[105] Naval rotation with forward based combat ships typically requires from 3 to 4 ships to maintain one unencumbered on station at great distance. Because the ships postulated here would be dedicated to the terminal defense mission (not covering forward based missions) and would be operating close to the United States and to reprovisioning ports, the number of ships for rotation could be less, and we assume 2 per station would suffice.

[106] Technically, terminal defenses operate against the missile warhead in the terminal stage of the trajectory, and this is usually understood to mean the last part of the trajectory after the warhead has entered the atmosphere. Interceptor kill vehicles that operate above and within the atmosphere generally use different physical principles and thus usually are designed differently. However, there has been some overlap between exoatmospheric (late-midcourse) and endoatmospheric (terminal) technical objectives in US TMD programs. THAAD's hit-to-kill interceptors were designed, for example, to operate both in the thin upper atmosphere and above the atmosphere. The Navy's NAD program was clearly only endoatmospheric in capability, but the objectives of the NTW development programs (Block I and Block II) have been ambivalent and are still subject to evolution. Our assumption here is that both exo- and endoatmospheric interceptor principles have been employed in US TMD planning to function as terminal defenses (i.e., to be used in a "terminal defense mode" for local area and point defense of US and allied military forces). Viewed thus in terms of objectives, rather than exclusively in terms of interception at one or another physical stage of offensive missile trajectories, local US terminal defenses of the homeland against ballistic missile threats probably would be derived from US TMD programs or their technologies, and thus would operate in both late midcourse and endoatmospheric domains. It follows that such terminal defenses would be inherently layered.

TABLE 8

Cost Estimates of U.S. Coastline Terminal Defenses Fiscal Years 2002-2035

(in billions of 2003 dollars)

Type of Cost	Light	Medium
Research and Development		
THAAD interceptors - counted in Table 9		
NTW interceptors - counted in Table 9		
Coastline defense ships	1.0	1.0
X-band radars - not material		
Subtotal	1.0	1.0
Production		
THAAD combat units	22.5	45.1
NTW ships	15.0	23.5
NTW interceptors	37.2	55.3
X-band radars	3.7	3.7
BMC3I	1.0	1.0
Subtotal	79.5	128.5
Surcharge for Point Defense (15%)	12.1	19.6
Total Acquisition Costs	91.6	148.1
THAAD Operations through 2035	8.3	16.7
Ship Operations through 2035		
Surcharge for Point Defense (12%)	1.0	2.1
Total Costs Through 2035	**101.0**	**166.9**

Numbers may not add up to totals due to rounding.

THAAD installations on land, but the number of new coastal X-band radars would remain constant at ten.

To facilitate cost calculations, we postulate in Table 8 A, below, what terminal defenses based on current US TMD programs might consist of for stipulated metropolitan areas along US coastlines. This table provides a basis for estimates of numbers of ships (including rotation) and of THAAD installations required as follows, for *light* and *medium* levels of terminal defense, respectively:

AEGIS ships are expensive, multi-mission platforms for naval power projection. They can accommodate short- and medium-range missile defense interceptors. But diverting AEGIS ships to coastal terminal defense of the US homeland would be a costly approach that undermines their forward power projection and regional security missions. We assume the US would instead develop and procure dedicated missile defense ships with their own version of a VLS system for about half the unit cost of AEGIS ships, particularly if the dedicated coastline missile defense ships rely on land-based X-band radars, and on SBIRS-low once it is available.

Our illustration of cost in Table 8 therefore assumes 32 (low level) or 50 (medium level) dedicated missile defense ships for this coastal mission, and assumes a cost of $469 million each, not counting the cost of the interceptors. While these ships could surely be built to house a larger number of interceptors, we assume for cost purposes that each ship on station carries 48 NTW Block II, midcourse-capable, ready-to-fire missiles, and that 240 spares would be acquired. The production cost per NTW interceptor is assumed to be about $21 million — the cost per interceptor for a large order. Each ship could and probably would also carry a complement of lower tier interceptors. As discussed earlier, the acquisition and support costs are estimated indirectly as a surcharge.

Plans for each mobile THAAD combat unit (a battery) currently call for 9 truck-mounted launchers,[107] 72 interceptor missiles, 1 mobile X-band radar, and 3 BM/C4I (command and control) trucks.[108] In April 2001, BMDO estimated THAAD acquisition costs to be $16.8 billion, and the life cycle costs to be $23 billion.[109] These official estimates are for a planned 14 THAAD combat units with about 1,250 interceptor missiles that could be rapidly deployed overseas in emergencies.[110] The official estimate suggests an acquisition cost per THAAD combat unit of about $1.2 billion in FY 2001. We assume the current unit cost of land-based X-band radars to support the missile defense ships will be about $365 million[111] We also assume that at least $1 billion would be required to build, test and integrate terminal defense battle management, command and control and communications (BMC3I) with the strategic US missile defense BMC3I system.

Table 8 provides our cost estimate for the light and medium levels of the coastal terminal defense layer. R&D costs in the existing THAAD and NTW programs are counted as part of their regular overseas programs (see next section, and Table 9), and not counted in this

[107] Each launcher carries 4 interceptor missiles in canisters that also serve as launch tubes.

[108] GAO, Ballistic Missile Defense: Improvements Need in THAAD Acquisition Planning, GAO/NSIAD-97-188 (Washington, DC, September 1997), p. 5.

[109] Hildreth, Steven A. and Amy F. Woolf, *Missile Defense: The Current Debate*, Report for Congress, Library of Congress, Congressional Research Service, No. RL31111, updated May 6, 2002, p. 46.

[110] Director, Operational Test & Evaluation, *Annual Report, FY 2000*, Washington, DC: U.S. Department of Defense, February 2001, p. IV-41ff.

[111] CBO estimated in 2000 that three ship-based X-band radars would cost about $1.3 billion. See Table 2 in CBO, *Budgetary and Technical Implications of the Administration's Plan for National Missile Defense*," April 2000; available at: <http://www.cbo.gov>.

TABLE 8A

Terminal Defenses — US Coastal Areas

	Light		Medium	
Metropolitan Area	**Ships**	**THAAD**	**Ships**	**THAAD**
Honolulu-Pearl Harbor, HI	2	1	2	2
Anchorage, AL	2	—	2	—
Seattle, WA	2	1	4	2
San Francisco, CA	2	2	4	4
Santa Barbara, Los Angeles, CA	4	3	6	6
San Diego, CA	2	1	4	2
Houston, TX	2	1	4	2
Tampa, FL	2	1	2	2
Jacksonville, FL-Kings Bay, GA	2	1	2	1
Charleston, SC	2	1	2	1
Norfolk, VA	2	1	2	2
Philadelphia, PA	2	2	4	4
New York, NY	4	2	8	6
Boston, MA	2	1	4	2
Totals	**32**	**18**	**50**	**36**

coastline terminal defense construct. However, we estimate about $1 billion R&D costs for the development of dedicated missile defense ships for US coastline defense. The estimated costs in this construct are based primarily on the production and installation of the dedicated missile defense ships and hardware items, procurement of 18 (low level) or 36 (medium level) additional THAAD combat units, and operation and support costs. The schedule assumed for initial deployment of the light system is 2010 for THAAD, and 2012 for the NTW platforms, with full deployment in 2015. Deployment of the medium system is assumed to begin in 2015 and be completed in 2020. The cost of operations and support is projected through 2035.

Our estimates suggest a light coastline terminal defense would cost $79.5 billion to acquire; and a medium level would cost about $128.5 billion, before taking point defense into account. Including the point defense surcharge, the estimated acquisition costs would be about $91.6 billion and $148.1 billion for the light and medium levels respectively. Adding O&S costs to derive life cycle costs indicates that for the period through 2035 the costs of the light and medium levels of terminal coastline defense would total about $101 billion and $166.9 billion respectively.

These hypothetical terminal defense capabilities are relatively thin and limited, and would not protect the interior of the U.S. Thicker coastline and nationwide terminal defenses could cost several times the figures indicated here.

2. US Terminal Missile Defenses Overseas: PAC-3, THAAD, and NTW

The Bush Administration under the rubric of terminal defense programs is sustaining US TMD programs focused on overseas missions that were initiated by the Clinton Administration, with one exception. The Bush Administration canceled the US Navy's Area Defense (NAD) in December 2001 because of cost overruns. But this program may be reconstituted with a new name. The U.S. Army's PAC-3 and THAAD programs and the U.S. Navy's NTW program, are moving ahead. The Missile Defense Agency has been looking at ways to increase the capability of these TMD programs now that the ABM Treaty has been set aside, so some of them may be upgraded to offer some degree of strategic intercept capacity.

Table 9 includes the officially reported cost estimates of these US TMD programs in columns one and two — the figures in column two being derived — and seeks to project their deployment schedules and full acquisition costs, together with projected O&S costs. Tinkering continues with the planned number of interceptors under some of these programs, as technical challenges become clearer and as they rise in cost.

Official estimates for PAC-3 acquisition, for example, have been rising steadily, from a then projected $2.9 billion in 1994, for a planned buy of 1,200 missiles, to $6.9 billion for just 1,012 missiles in previous plans. In April 2001, BMDO estimated that PAC-3 acquisition costs had escalated to $10.1 billion — a threefold increase in the seven years since 1994. The Defense Department's Systems Acquisition Reports (SAR) Summary Tables of December 31, 2001 indicated that PAC-3 costs had risen further in 2001 to $10.7 billion. The SAR announced a further increase to $11.8 billion — due partly to an increase of 103 in the number of missiles planned (from 1,056 to 1,159), at a unit cost of just under $3.8 million, and partly to increased testing requirements, several upgrades, and revised inflation estimates.[112] We use $11.8 billion

[112] Department of Defense, OUSD (AT&L) AR&A/AM, "Selected Acquisition Report (SAR) Summary Tables, as of Date: December 31, 2001, April 2002, p. 5.

as the current official acquisition estimate in column one of Table 9.

After NAD was canceled in December 2001, the Army increased its request for PAC-3 to 2,200 missiles or more, no longer being able to count on the complementary overseas land-based missile defense contribution of 1,500 to 2,000 NAD missiles.[113] If this Army wish were granted, based on the SAR unit cost of $4 million per missile, it would add more than $4 billion to the system acquisition cost. In this case, the figures in Table 9 would have to be increased accordingly.

As mentioned earlier, in April 2001 BMDO projected THAAD acquisition to cost $16.8 billion, and lifecycle costs to reach $23 billion.[114] But these official figures (converted to 2003 dollars), which we include in column one of Table 9, appear to have remained almost unchanged at least since 1997,[115] and need to be updated for inflation and cost growth. The estimate in column two, accordingly, is higher.

BMDO reportedly had spent $2.5 billion on the NAD program before it was cancelled in December 2001, after it had overrun its budget by 32 per cent and missile procurement expense had risen 57 per cent — triggering the provisions of the Nunn-McCurdy Act. [116] This expenditure can be added to the terminal defense category as a sunk cost for the Navy Area TMD program and any successor program.

The NTW Block I program was officially projected to cost $5.7 billion for just 80 SM-3 missiles (at $11.3 million per missile) on 4 ships.[117] But the NTW Block I program was really just an appetizer for the second phase NTW program, using still undeveloped longer-range, mid-course (exoatmospheric) SM-3 Block II interceptors, which probably would cost another $26 billion just for acquisition, excluding the direct costs of new, already upgraded AEGIS platforms, or the indirect costs of upgrading the AEGIS weapon system and SPY-1 radars on existing AEGIS ships for the more capable SM-3 Block II interceptors.[118]

Table 9 assembles the official cost estimates for TMD programs so as to allow one to visualize their aggregate projected costs as terminal defense programs. The acquisition estimates in the upper section of column one are official estimates, except for NAD follow-on (where the figure of $4.7 billion is the unexpended balance of the official projected cost of the canceled NAD program) and the NTW Block II program, where the acquisition cost subsumes a high development cost and assumes a buy of 500 missiles at about $20 million each. The THAAD operations cost figure of $6.5 billion in the lower section of column one is inferred from the difference between BMDO's April 2001 estimated life cycle cost of $23 billion and acquisition cost of $16.8 billion. The PAC 3 Operations

[113] See *Inside Missile Defense*, May 1, 2002, p. 6.

[114] Steven A. Hildreth and Amy Woolf, *Missile Defense: The Current Debate*, Report for Congress, Library of Congress, Congressional Research Service, No. RL31111, updated May 6, 2002, p. 46.

[115] Wilkening, citing early 1997 articles in the missile defense trade press, gives $17.9 billion as the total program cost for THAAD (assuming acquisition of 14 radars and 1,233 missiles). See *Ballistic Missile Defense, op. cit.,* p. 47. The DOT&E Report for 2000, *op. cit*., p. VI-41, gives a TY$ total program cost for THAAD with 1,250 missiles (including Operation & Support costs) of $23 billion. This assumed a FY2000 cost per missile of $1.8 million, which seems implausibly low (e.g., less than half of the endoatmospheric PAC-3 FY 2001missile cost of $3.8 million).

[116] See Bradley Graham, "Rise And Fall Of A Navy Missile," *Washington Post*, March 28, 2002; and, on speculation that the program will be revived, Sharon Weinberger, "Pentagon To Consider Resurrecting Navy Area Missile Defense Program," *Aerospace Daily*, December 20, 2001.

[117] Director, Operational Test & Evaluation, *Annual Report, FY 2000*, Washington, DC: U.S. Department of Defense, February 2001, p. VI-19.

[118] See NTW analysis in Rodney W. Jones, *Taking National Missile Defense to Sea: A Critique of Sea based and Boost-Phase Proposals*, Washington, D.C.: Center for Arms Control and Non-Proliferation (Council for a Livable World Education fund), October 2000.

TABLE 9

Estimates of U.S. Theater Missile Defense (TMD) Programs Deployed Overseas, Fiscal Years 2002-2035

(in billions of 2003 dollars)

	Official	Derived	Our Cost
Program and Type of Cost			
PAC-3 acquisition	11.8		13.1
THAAD acquisition	17.5		21.9
NAD R&D sunk cost	2.5		2.5
NAD “follow-on” acquisition	4.7		9.4
NTW - Block I acquisition	5.7		7.2
NTW - Block II acquisition	10.4		26.1
Subtotal acquisitions	52.6		80.2
Operations Through 2035			
PAC-3 O&S	n/a	3.9	4.8
THAAD O&S	6.5	6.5	8.0
NAD follow-on O&S	n/a	5.2	6.6
NTW Block I O&S	n/a	1.0	1.4
NTW Block II O&S	n/a	5.7	7.2
Subtotal O&S		22.3	28.0
Total Operations Through 2035	22.3		28.0
Total Costs Through 2035	**74.9**		**108.2**

Numbers may not add up to totals because of rounding.

cost of $3.9 billion assumes that the THAAD ratio of operations to acquisition cost, just under 40 per cent, would be roughly comparable for both Army programs. The operations costs of the naval programs are derived from the number of ships projected for each program, the estimated annual cost of $22 million to operate an AEGIS ship,[119] and whether multimission or dedicated missile defense ships are expected to be employed.[120]

Our estimates in column two of Table 9 assume a 25 per cent cost growth factor over the official figures in column one, for the acquisition of three of the forward deployed TMD programs — PAC-3 and THAAD, and NTW Block I. The sunk cost of NAD, which has been cancelled, remains the same. However, the cost growth reflected in column two of the acquisition cost of a NAD follow-on is assumed to be 100 per cent, because the likely multimission objectives would include maritime boost-phase defense interceptor capabilities (e.g., for the North Korean threat, where offensive missile launch locations might be in reach from the sea) that have not yet been developed. In the case of NTW Block II, the acquisition estimate of $26 billion in column two assumes, in contrast to former Navy planning, the cost of 12 dedicated AEGIS cruisers at $1.2 billion apiece. We believe the operating areas for NTW Block II midcourse interceptors normally would be incompatible, even in terminal defense mode, with the multimission assignments, such as providing fleet defense for battle groups that are typical of AEGIS ships today.

In our judgment, the acquisition cost in official figures for the overseas TMD systems would be $52.6 billion, and the implied life cycle costs would bring the total figure to $74.9 billion. We believe that the adjustments in column two of Table 9 are closer to realistic projected costs for these systems. Our estimate of total acquisition for these terminal defense systems overseas is $80.2 billion, and of the life cycle costs, about $108 billion.

3. US Terminal Missile Defense Cooperation with Allies: Europe, Mediterranean, and Pacific

Most of what the United States has spent and expects to spend on ballistic missile defense is on systems deployed and operated by the US military forces. At the same time, the US has had cooperative programs on TMD with allies. With the removal of the constraints of the ABM Treaty, it is now possible that the US will pursue strategically capable BMD projects with allies. These programs involve technology and cost sharing through cooperation. In the cases of cooperative programs with Japan and Israel, the US has expected not only to provide its technology but also to benefit from technology developed by the partner. Where these programs involve partners adopting US technologies, as in the case of the Patriot-based MEADS in Western Europe, sharing in development costs and acquisition of the systems can reduce the unit cost of the same system to the United States. It remains to be seen, however, whether the net

[119] Citing US Navy sources, the Federation of American Scientists noted that AEGIS cruisers cost about $20 million a year to operate in 2000, and we have increased this figure to $21 million. See US Navy Visibility and Management of Operating and Support Costs (VAMOSC), a report, available at: <www.fas.org/man/dod-101/sys/ship/vamosc.htm>

[120] For example, we assume the NAD follow-on system would use up to 60 existing AEGIS ships within the multimission profile so that only a proportion of their annual operations and support costs, perhaps 20 per cent, would be attributed to this NAD missile defense role. Thus, the formula for operations costs for NAD follow-on in Table 9 is: 60 ships X $21 million X 20 years X 0.2, yielding just over $5 billion. We assume NTW Block I would also use multimission AEGIS ships, 12 ships in this case, for an estimated operations cost of $1 billion. We assume NTW Block II would use at least 13 dedicated AEGIS-type ships, so that the entire operations cost of these ships, about $5.5 billion, would be attributed to the missile defense mission.

benefit to the United States of any of these co-operative programs will actually reduce US costs of layered missile defense.

MEADS is intended to provide protection of maneuver forces in Western Europe, with area and point defense against tactical ballistic missiles, aircraft, and cruise missiles. Enabling MEADS to track friendly forces as well as threat targets cooperatively, and to deal with multiple targets (air breathing as well as tactical missile threats), places greater technical demands on MEADS and entails greater costs than is expected for other TMD systems. Planning for MEADS restructured the program with German and Italian agreement in 1999 to incorporate the PAC-3 as the initial interceptor.

As France has withdrawn, Germany and Italy are the primary, active partners in MEADS today. The German and Italian shares of the estimated $23 billion program cost are roughly 25 per cent and 15 per cent respectively, so that the US is likely to absorb 50 per cent or more of the overall cost. Development schedules have slipped. The definition phase of development was extended by three years, from 2006 to 2009, and initial deployment therefore probably could not begin before 2009 or 2010.[121] Based on the official figures above, we assume the expenditure of the United States on MEADS will be about $12 billion.

Dating back to 1986 and spurred by the Gulf War of 1990, US cooperation with Israel on the Arrow missile defense system involves US co-funding of an indigenous Israeli system. The US reportedly benefits from gains in technology and technical data that will reduce risks in U.S. TMD developmental programs, and from intelligence on the characteristics of regional ballistic missile threats. Israeli Arrow 2 components reportedly can track missile threats as far away as 500 km, and engage them between 16 and 50 km with a fragmentation warhead. Israel deployed two Arrow 2 batteries in early 2000 and had plans for a third. The development cost of the joint US-Israeli Arrow project reportedly had reached $1.3 billion, and one estimate of the total program cost is that it will reach or exceed $2.6 billion.[122]

Discussion of US-Japanese BMD cooperation goes back to the 1980s but Japan agreed to concrete bilateral cooperation on TMD only in 1999, allocating $300 million over six years to a bilateral project that focused on the US NAD and NTW systems or concepts. Japan has been a very cautious partner in this area and seems unlikely to participate in BMD in a manner that significantly lowers US BMD costs.[123]

Much the same can be said about burden sharing of overseas missile defense costs with our other allies. At the present time, it is not possible to predict the outcome of arrangements about costs with our potential missile defense partners. In any event, we do not expect substantial reductions in what the US spends.

[121] Hildreth and Woolf, *Missile Defense: The Current Debate*, updated May 6, 2002, op. cit., pp. 47-48.

[122] Federation of American Scientists, "Arrow TMD," available at: <http://www.fas.org/spp/starwars/program/arrow.htm>

[123] See Michael Swaine, Rachel Swanger, and Takashi Kawakami, *Japan and Ballistic Missile Defense*, Santa Monica, CA: RAND, 2001, chp. 2, p. 23.

V. SUMMING UP

This analysis is an effort to estimate in reasonable terms the likely costs of a layered missile defense, layer by layer. We have used the current frame of reference of boost-phase, midcourse, and terminal defense segments of missile trajectory and related intercept technologies. We have also examined programs and constructs under each of these intercept principle categories, examining specific systems or components in terms of whether they would be ground-, sea- or space-based, or airborne, and whether they would be deployed in or near the United States or in distant locations abroad. The interceptor and sensor technologies assessed in each layer are either development and prospective deployment goals of existing US missile defense programs or have been hinted at by the present administration as likely goals of its future missile defense programs. The architectures we have employed either reflect approaches that are already under policy consideration or are plausible representations of approaches that spokesmen of the present administration have alluded to.

We are now in a position to bring together the components, layers, and projected costs. Table 10 provides full cost estimates of total acquisition and operations of a layered missile defense through 2015. Table 11 shows the results of our life cycle cost analyses in earlier sections, through 2035, and a summation of "low" and "high" estimates for a comprehensive missile defense system. To be more precise, Table 11 offers a range of estimates to reflect the results of choices that an administration might make.

No choice on the number of sites (and interceptors per site) for a ground-based midcourse NMD, for example, has been officially announced. At the same time, the renunciation of the ABM Treaty means that there are no longer any specific limits on the number of sites (and interceptors) that could be constructed. We show, therefore, incremental cost estimates of both a two-site and three-site system in separate columns under both Low Estimate and High Estimate headings in the table.

Similarly, the illustrative "Missile Trap" and "Strategic Defense" constructs among a number of possible naval adjunct missile defense options — two constructs that the US Navy has analyzed for Congress — are different in cost and could be assembled from different specific components. These two approaches may also be thought of as lesser and more capable naval adjunct missile defense systems, respectively. We have represented both, but again in separate columns, under both Low Estimate and High Estimate headings in the table. This approach to the figures in the table avoids double counting of system components in our summations.

Once one adds together the layers and components for a "system of systems" following our illustration in Table 11, the Low Estimates including life cycle costs total between $798.5 billion and $838.5 billion dollars. Similarly, the total under our High Estimates for life cycle costs of this layered defense missile system ranges between $1.1 trillion and $1.2 trillion dollars.

TABLE 10

Estimates of Total Acquisition and Operations Costs Through 2015 of Layered Missile Defense

(In billions of 2003 dollars)

System Layers	Low Estimates		High Estimates	
Ground Based Mid-Course				
Two-Site Configuration	76.1	0.0	110.6	0.0
Three-Site Configuration	0.0	89.7	0.0	123.1
Sea Based Adjuncts to NMD				
Missile Trap	27.3	0.0	31.3	0.0
Strategic Defense	0.0	37.1	0.0	49.4
Space Based Laser	129.3	129.3	194.0	194.0
Space Based Kinetic	14.6	14.6	69.9	69.9
Ground Based Boost-Phase	22.5	22.5	30.1	30.1
Sea Based Boost-Phase	61.4	61.4	71.0	71.0
Airborne Laser Boost-Phase	11.2	11.2	11.2	11.2
Coastal Terminal Defense	92.6	92.6	150.2	150.2
Overseas Terminal Defenses	75.0	75.0	108.2	108.2
TOTALS	**510.1**	**533.5**	**776.4**	**807.1**

Numbers may not add up to totals because of rounding.

TABLE 11

Estimates of "Life Cycle" Costs of Layered Missile Defense

(In billions of 2003 dollars)

System Layers	Low Estimates		High Estimates	
Ground Based Mid-Course				
Two-Site Configuration	119.9	0.0	160.6	0.0
Three-Site Configuration	0.0	141.8	0.0	181.5
Sea Based Adjuncts to NMD				
Missile Trap	52.4	0.0	58.4	0.0
Strategic Defense	0.0	70.5	0.0	95.3
Space Based Laser	309.8	309.8	423.5	423.5
Space Based Kinetic	27.6	27.6	76.0	76.0
Ground Based Boost-Phase	28.0	28.0	41.8	41.8
Sea Based Boost-Phase	66.9	66.9	77.5	77.5
Airborne Laser Boost-Phase	19.3	19.3	19.3	19.3
Coastal Terminal Defense	101.0	101.0	166.9	166.9
Overseas Terminal Defenses	75.0	75.0	108.2	108.2
TOTALS	**799.7**	**839.8**	**1132.2**	**1189.9**

Life cycle costs to 2035, except for SBL, which is projected to 2045. Note: Numbers may not add up to totals because of rounding.

CONCLUSIONS

Missile defense has always been expensive, and relatively speaking, usually far more expensive than building offensive missiles and defense countermeasures. This remains no less true today. The full price tag for a layered missile defense that seriously aims to protect industry, urban areas, and the population at large, as well as military forces, against geographically diversified long-range missile threats is bound to be extraordinarily costly. Our estimates that the cost of such a defense could easily be in the neighborhood of a trillion dollars must give pause even to the most ardent proponents.

To those who speak of missile defense in terms of "insurance policies," the cost of the premiums looms large. If for others the issue is to demonstrate "political resolve," the question of technical effectiveness and alternate avenues of delivering weapons of mass destruction must also be faced — as graphically underscored by the terrorist attacks of September 11, 2001. Political resolve cannot long withstand evidence either that the systems might not rise to the tasks expected of them or that they do not protect against other threats to which our nation and allies are more acutely vulnerable. For the hard-nosed realist, technical effectiveness assessments must finally be translated into cost-effectiveness evaluations, and even less dramatic cost projections than those presented here are likely to drain that analysis of gratifying conclusions.

While the administration's approach to missile defense is still not well defined, those choices that are beginning to be made suggest an awareness both that the technical challenges actually are daunting and that the price tag will not be easy to manage. In looking for ways to demonstrate early results by building pieces of a system before it is fully proved, and continuing to test to advance the technology for other procurement later — as we see in pouring funds into an NMD "test bed" at Fort Greely and Kodiak Island, Alaska, to create a very limited standby or emergency NMD capability against two or three hostile missiles — the administration is masking both the true system requirements and the full system costs over the long term. By attempting to speed up and upgrade ABL development, and reconfiguring NTW in pursuit of an early naval boost-phase capability, the administration, if not exactly cherry picking, is pursuing leverage in the boost-phase layers that arguably may lower the bar of technical requirements, and expected cost, in other layers. This could be another way of moving the goal posts to mitigate full awareness of the ultimate costs. It could also presage scaling back elements of one or another BMD layer in favor of others, altering the degree to which the system of systems is really comprehensive operationally or geographically.

Clearly the administration also has a political strategy underway to try to ensure that construction of certain tangible system features is well underway before its first term ends. Similarly, the administration undoubtedly hopes to have some BMD elements operational before the end of a second term. In that regard, however, the cancellation of the NAD TMD system at the end of 2001 seems anomalous. To the extent that ballistic missile defense is relatively straightforward and has significant near term promise, it is in the protection of military forces against the low end of the threat — that of short- and medium-range ballistic missiles. Military effectiveness criteria by their nature are less demanding than those for effective protection of cities and population in the homeland. The Navy's Area Defense program, despite delays and cost-overruns, was closer to realistic deployment of a meaningful TMD system than other programs, with the exception of the Army's PAC-3. As a stepping stone in defending ships abroad against cruise as well as short-range ballistic missiles before taking on more difficult interceptor challenges — including those of protecting allied forces and allied coastal areas — the NAD program was militarily justifiable and proving it operationally would have been an appropriate milestone.[124]

Even if the administration picks and chooses from the array of BMD technologies and concepts in development or under consideration, it is clear that the intent is to move forward on a layered defense. At a minimum, the administration appears to have in mind the following components of a layered system: (1) some form of ground-based NMD as initially pursued by the Clinton administration; (2) an ABL boost-phase component that can be flown rapidly upon warning into distant theaters of operation; (3) a naval boost-phase system, probably building on a more versatile NTW system, operating in forward locations; (4) space-based elements with both laser and kinetic intercept principles for boost-phase purposes, as well as tracking and discrimination sensors with broader applications; and (5) overseas Army TMD, specifically PAC-3 and THAAD. Systems deployed with allied cooperation may also play a supplementary role. Adding up the price tags of these layers, even if some of them are truncated, will pose formidable total acquisition and life cycle costs. Their affordability and cost-effectiveness — as the threat evolves or recedes — will be evaluated one way or the other.

This report is an effort to anticipate how those costs may be described and accumulate over time. The results of this analysis are necessarily limited by the mixed quality and incomplete nature of publicly available information and the inevitable technical and political uncertainties any analyst must cope with in forecasting BMD technology, architecture, and broader policy choices. We believe our bottom line results provide a reasonable understanding of the magnitude of the costs that are likely to be incurred by methodically building and maintaining a layered missile defense with the technologies and operational constructs that have been under consideration. The report will have provided a valuable service if it does no more than encourage practitioners to ask the bottom line questions and help them think through how the answers must be derived.

[124] Since the provisions of the Nunn-McCurdy Act had been triggered, some action on NAD was unavoidable, but cancellation was not the only alternative.

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