United States General Accounting Office

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Report to the Chairman, Committee on Governmental Affairs, U.S. Senate

July 1993

BALLISTIC MISSILE DEFENSE

Evolution and Current Issues

149620

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GAO United States
General Accounting Office
Washington, D.C. 20548

National Security and
International Affairs Division

B-223094

July 16, 1993

The Honorable John Glenn
Chairman, Committee on
Governmental Affairs
United States Senate

Dear Mr. Chairman:

This report responds to your request that we provide a summary of information on the evolution and progress of the Strategic Defense Initiative program and the current issues that the Congress faces in funding ballistic missile defense research and development. You asked that we trace the evolution of the program, the role of the Department of Defense oversight boards, the investments in major projects, and the progress relevant to systems proposed for theater missile defense and national missile defense. You also asked for information on technology spin-offs, suborbital and orbital launches to support testing, and nuclear power for space uses.

We plan no further distribution of this report until 10 days after its issue date, unless you publicly announce its contents earlier. At that time, we will send copies to the appropriate congressional committees; the Secretaries of Defense, the Army, the Navy, and the Air Force; and the Directors, Ballistic Missile Defense Organization and Office of Management and Budget. We will also make copies available to others upon request.

If you or your staff have any questions concerning this report, please contact me at (202) 512-4841. Major contributors are listed in appendix II.

Sincerely yours,

Louis J. Rodrigues
Director, Systems Development
and Production Issues

Executive Summary

Purpose

The United States has been concerned about having an adequate defense against intercontinental ballistic missiles since the Soviets successfully tested one in August 1957. The magnitude of the effort has risen and fallen several times over the intervening 36 years. On March 23, 1983, President Reagan announced his decision to investigate the possibility of rendering nuclear ballistic missiles impotent and obsolete. The effort undertaken was conducted under the official name "Strategic Defense Initiative" (SDI). Studies, projects, demonstrations, experiments, and tests have been conducted at a cost through fiscal year 1993 of over $30 billion.

In May 1993, the Secretary of Defense announced the "end of the Star Wars era" and changed the name of the SDI Organization (SDIO) to Ballistic Missile Defense Organization (BMDO). He also announced changes in priorities. Theater missile defense is first, and national missile defense is second. The total request for fiscal year 1994 is $3.8 billion. The Brilliant Pebbles space-based interceptor program has been recast from an acquisition to a technology base program and funding reduced significantly from previous plans.

The Chairman of the Senate Committee on Governmental Affairs requested that GAO prepare a summary of information that would be of benefit to individuals considering questions of future ballistic missile defense policy and funding. Specifically, GAO was asked to provide information on the evolution of SDI, its oversight by the Department of Defense (DOD), investments in major projects, technical progress and remaining challenges, commercial spin-offs of SDI technology, use of retired missiles as launch vehicles for SDI tests, and plans for using nuclear power in space.

Results in Brief

Ten years ago, President Reagan set DOD on a course to decide, in the early 1990s, whether to develop defenses against a massive Soviet ballistic missile attack. However, the former Soviet Union dissolved, and SDI was refocused. Today, the major funding and effort is on deployment of theater missile defenses. BMDO's proposed deployments have been subject to comprehensive reviews by the Under Secretary of Defense for Acquisition and the Defense Acquisition Board since 1987, when an initial system, called Phase I, was submitted for review and approval.

A total of $30.4 billion has been spent through fiscal year 1993 by BMDO and the Department of Energy for developing sensors to find the targets and interceptors and directed energy weapons to destroy them. The efficient pursuit of SDI programs has been hampered because the executive branch has frequently made plans and started projects on the basis of unrealistic and overly optimistic funding requests and schedules.

BMDO currently estimates that for theater missile defense it will cost $2.6 billion to develop and produce the Patriot Upgrade and another $9.5 billion for the Theater High Altitude Area Defense system. Technology to build these systems has not been fully demonstrated. Other systems under consideration, such as Brilliant Eyes, Corps Surface-to-Air Missile, and ship-based systems, could increase costs substantially.

Deployment of a treaty-compliant system at Grand Forks, North Dakota, to partially defend the 48 contiguous states will cost $21.8 billion. Five additional sites needed to fully protect those 48 states plus Alaska and Hawaii would cost another $12.5 billion and require modification of the Anti-Ballistic Missile (ABM) Treaty. Discussions on potential modifications to the ABM Treaty are in abeyance pending completion of the new administration's ongoing national security strategy review. Technology to build the system has not been fully demonstrated.

As required by law, BMDO has established a technology transfer program. BMDO has had some successes with this program, which includes an on-line data base, periodic reports, demonstration projects, and coordination with other technology transfer groups.

Between 1994 and 1999, BMDO proposes 175 suborbital and 19 orbital flights for conducting experiments and tests in the upper atmosphere and space. BMDO plans to use retired stages from intercontinental ballistic missiles and submarine-launched ballistic missiles to create the suborbital launch vehicles.

BMDO has no plans to use nuclear reactors to generate electricity for space-based systems. However, it has obtained two Russian Topaz II nuclear reactors and is conducting ground tests to evaluate them.

Principal Findings

Evolution and Oversight

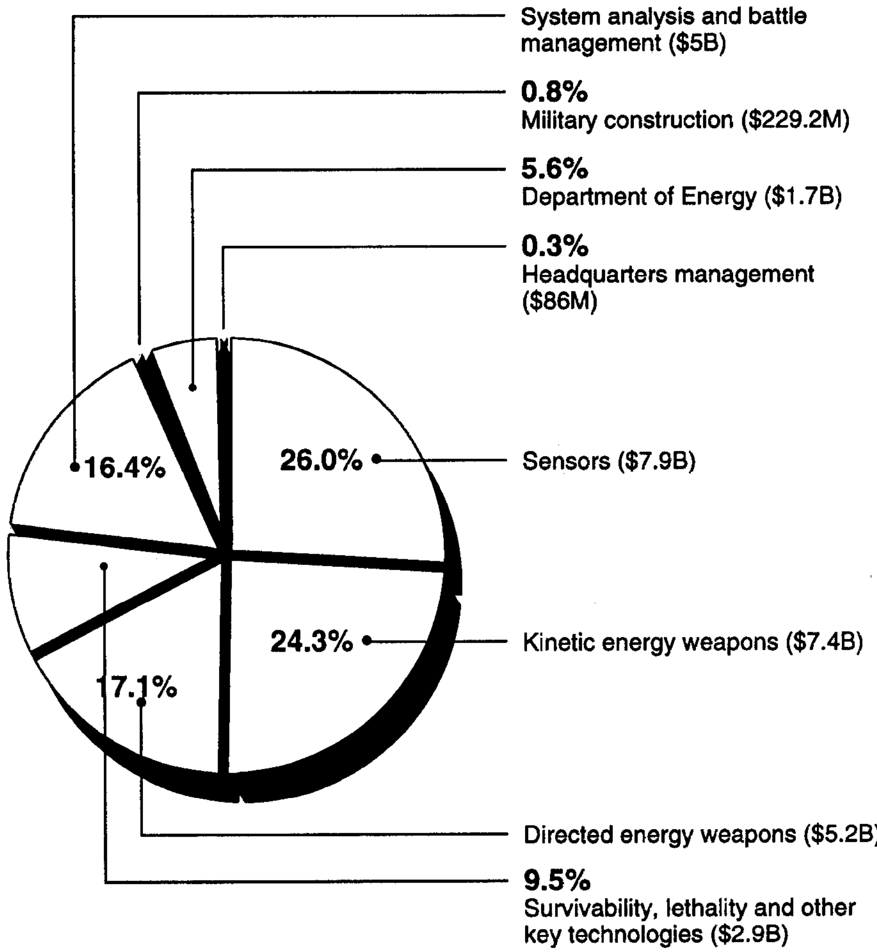
From 1983 to 1993, the SDI program has had two different missions. First, it was to help deter a massive attack by the former Soviet Union. SDIO developed an architecture for a Phase I Strategic Defense System in 1987, and DOD began making periodic reviews of it under DOD's major acquisition process. The Under Secretary of Defense for Acquisition and the Defense Acquisition Board and its committees have highlighted to decisionmakers key challenges in technical performance and program management. They also addressed cost and budget pressures on the program. In 1991 the program was refocused by President Bush. Its new mission was to provide protection from limited ballistic missile strikes from anywhere against the United States or its allies.

During each of these mission periods, there were significant changes to the program, based on policy reviews and decisions by the President, Secretary of Defense, and the Congress. Under the Clinton administration, the program priorities have changed, and the present development schedule of projects may change after DOD's bottom-up review is completed this summer. This review of defense needs and programs is to yield guidance for reshaping defense in the fiscal year 1995 budget.

Investments

A total of $30.4 billion has been spent on ballistic missile defense development since SDI was formed, including Department of Energy funding. Figure 1 shows a breakout of the total.

Figure 1: Funding for Ballistic Missile Development for Fiscal Years 1985 Through 1993



The initial SDIO investment strategy assumed that funds would be available to develop technologies on a schedule limited only by technology progress—not by funding. However, each year there were wide gaps between the funding needed for such a schedule and the appropriation. Between fiscal years 1985 and 1993, appropriations for SDIO have averaged 29 percent below requested budgets, ranging from 20 percent to 36 percent.

The efficient pursuit of research and development has been hampered by the executive branch making plans and starting projects on the basis of unrealistic and overly optimistic funding requests and schedules through fiscal year 1993. The administration's amended budget request for fiscal year 1994 is $3.8 billion, the same as the appropriation for fiscal year 1993. This represents a major change from optimistic requests in the past.

Theater Missile Defense

The mission of theater missile defense is to protect U.S. forces deployed overseas and allies and friends. The intelligence community estimates that there are a number of growing threats of theater ballistic missile attacks by third-world countries.

BMDO plans to upgrade the current Patriot system, the most important feature being a new interceptor that would provide short-range intercepts. There are two alternatives—the Multimode Interceptor and the Extended Range Interceptor—neither of which has completed flight testing. Selection is now expected in early 1994, after which engineering and manufacturing development will begin. Costs through production are estimated to be $2.6 billion. It would be initially fielded in 1998. The ability to destroy warheads containing submunitions, so as not to disperse their lethal contents over the forces being protected, has not been demonstrated.

BMDO also plans to build a new system, called Theater High Altitude Area Defense, that would intercept targets at longer ranges. BMDO estimates costs through production of $9.5 billion. Several years of development work remain to be done, and initial fielding would not occur until 2001. The major problems are demonstrating that (1) enough radar antenna modules can be produced, (2) the radar and interceptor will function together as needed, (3) the interceptor is effective against submunitions, and (4) the software needed to make the interceptor work can be developed within planned cost and schedule. BMDO must also satisfy the Under Secretary of Defense for Acquisition and Technology that the Theater High Altitude Area Defense system complies with the ABM Treaty, and current plans are to do this by November 1993.

Other theater missile defense systems under consideration include a space-based sensor called Brilliant Eyes, Corps Surface-to-Air Missile, and ship-based systems.

National Missile Defense

The mission of national missile defense is to protect the United States from limited ballistic missile attacks, whether deliberate, accidental, or unauthorized. BMDO projects a need for ground-based interceptors at six sites to provide full coverage of all 50 states. The Congress has restricted an initial deployment to a single site with 100 interceptors to comply with the ABM Treaty. BMDO said it will cost $21.8 billion to develop and produce a system for deployment at Grand Forks, North Dakota, in 2004. Five additional sites needed to fully protect all 50 states would cost another $12.5 billion. The four major elements that make up national missile defense are Brilliant Eyes; Ground-Based Interceptor; Ground-Based Radar; and battle management/command, control, and communications. Brilliant Eyes would also be useful to theater missile defense.

Currently, the intelligence community reports that there are seven countries possessing long-range ballistic missiles with the potential of reaching the United States—China, France, Great Britain, and the former Soviet Republics of Russia, Belarus, Kazakhstan, and Ukraine. More nations may have the capability after the turn of the century.

There are several factors decisionmakers should consider in deciding whether and how quickly to develop national missile defense. These issues include whether the administration will be successful in removing ABM Treaty restrictions on the number of sites and on space-based sensors, whether threats justify the costs and schedule, and when the technology will be demonstrated.

Technology Transfer

DOD's research and development goal is to advance the technology for national defense. However, the law also requires DOD to promote the transfer of its technology to the commercial sector where possible. Some of BMDO's technology is applicable to the commercial sector, and it has an active program to transfer the technology, including a data base containing over 2,000 ideas. By the end of 1993, 97 commercially available products will have evolved from BMDO technologies. Examples include multilevel-secure computers and networks, a magnetic bearing compressor, and software that aids in designing the cooling characteristics of computer chips.

Planned Use of Launch Vehicles

Many BMDO experiments and tests will be conducted in the upper atmosphere and space. BMDO has proposed 194 sub-orbital and orbital flights between 1994 and 1999. Most of these, 175, are suborbital and would use launch vehicles made up of a combination of stages from retired missiles, with at least one stage from a retired intercontinental ballistic missile or a submarine-launched ballistic missile. Air Force planning documents show that out of 102 orbital launches expected between fiscal years 1994 and 1999, 19 are for BMDO.

Planned Use of Nuclear Reactors in Space

BMDO has no plans to use nuclear reactors to generate electricity in proposed system deployments. However, it continues to study reactor technology for potential advanced ballistic missile defense concepts. BMDO has identified three potential areas where nuclear reactor power would be required for, or beneficial to, advanced ballistic missile defense concepts: midcourse discrimination, housekeeping, and electric propulsion. Requirements range from 5 to 100 kilowatts of power.

BMDO has obtained two Russian Topaz II nuclear reactors for $13 million and plans to purchase four more. The Topaz evaluation is a joint program by BMDO, which is the lead agency; the Air Force; and the Department of Energy. Topaz currently can produce about 6 kilowatts for 3 years, and BMDO estimates the design can be upgraded to produce 50 kilowatts and to operate longer. Non-nuclear ground tests are currently being conducted. Flight testing plans are uncertain.

Agency Comments

As requested, GAO did not obtain fully coordinated comments on this report from the Department of Defense. However, GAO discussed the information contained in the report with responsible officials from DOD, the Joint Chiefs of Staff, BMDO, and the Army and has made changes where appropriate. They agreed with the information in the report.

Contents

Abbreviations

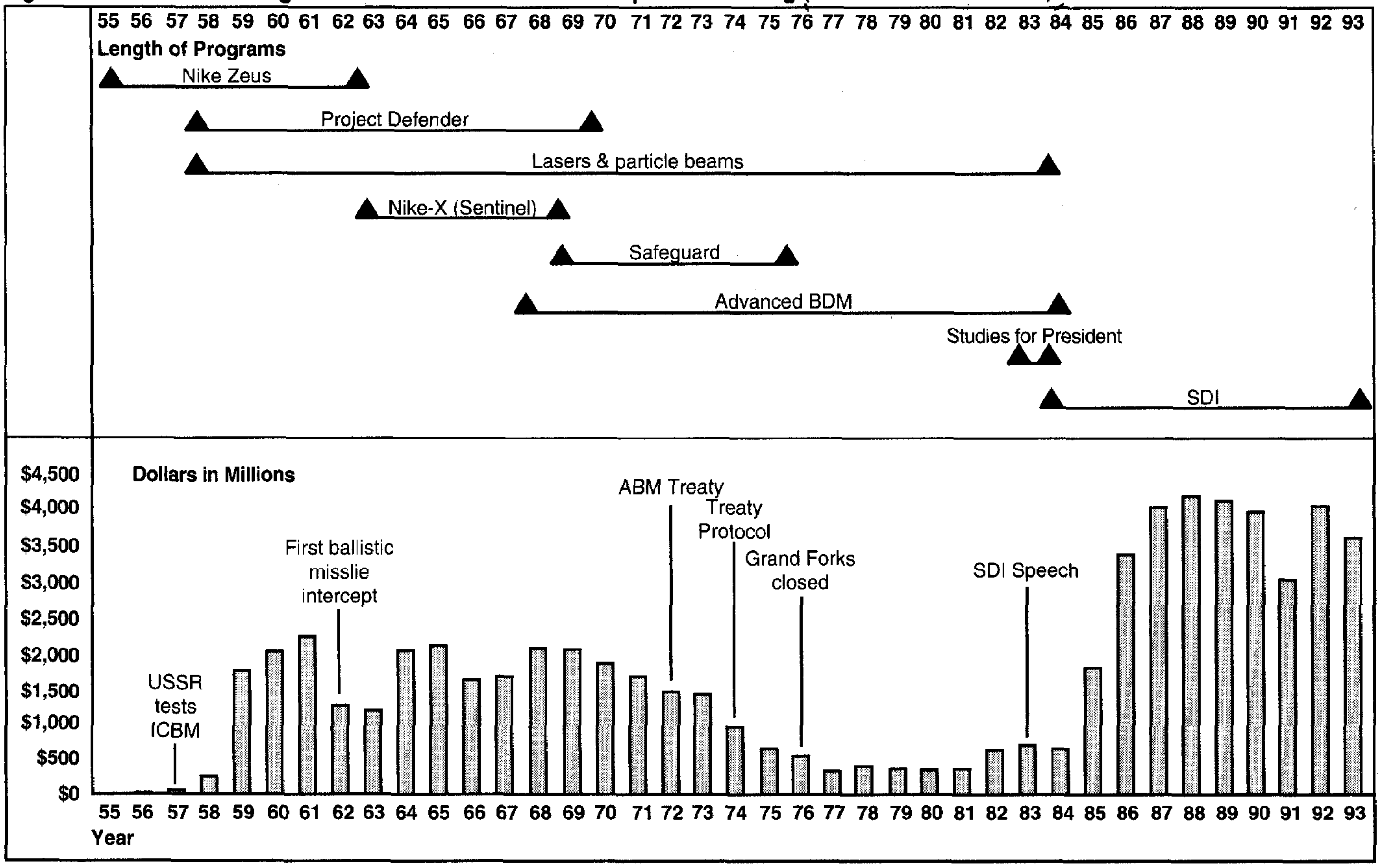
ABM	anti-ballistic missile
BE	Brilliant Eyes
BM/C3	battle management/command, control, and communication
BMD	ballistic missile defense
BMDO	Ballistic Missile Defense Organization
DAB	Defense Acquistion Board
DOD	Department of Defense
ERINT	Extended Range Interceptor
GAO	General Accounting Office
GBI	Ground-Based Interceptor
GBR	Ground-Based Radar
GPALS	Global Protection Against Limited Strikes
ICBM	intercontinental ballistic missile
NMD	national missile defense
PAC-2	Patriot Advance Capability-Two
PAC-3	Patriot Advance Capability-Three
SDI	Strategic Defense Initiative
SDIO	Strategic Defense Initiative Organization
SLBM	Submarine-Launched Ballistic Missile
THAAD	Theater High Altitude Area Defense
TMD	theater missile defense
TMD-GBR	Theater Missile Defense Ground-Based Radar

Introduction

History of Ballistic Missile Defense

The United States has been developing technologies to build ballistic missile defense (BMD) systems since World War II. Early studies concluded that available technology was insufficient for BMD. When in 1955 it appeared feasible to develop ground-based interceptor systems using nuclear warheads, BMD system development began. System development continued until the first deployed system, Safeguard, was judged too costly and was closed. However, advanced BMD technology research and development was continued by the Department of Defense (DOD). In 1983, the President announced a new BMD program that would capitalize on emerging technologies. In 1984, the Strategic Defense Initiative Organization (SDIO) was created to manage all BMD efforts throughout DOD. Figure 1.1 traces the evolution of BMD programs; it also traces the research and development funding for BMD, in fiscal year 1993 dollars.

Figure 1.1: **DOD BMD Programs and Research and Development Funding** (1993 Dollars in millions)



Notes: Fiscal year 1993 dollars determined by using DOD Budget Authority Deflators for RDT&E.

Funding figures were drawn from a variety of sources. The rise associated with SDI funding should not be directly compared with pre-SDI figures. SDI assumed responsibility for a number of programs that were not funded as part of BMD RDT&E.

The United States first became interested in BMD during World War II in response to German V-2 ballistic missile attacks. Studies done shortly after the war concluded that radar, missile, and data-processing technologies were insufficient to develop a missile defense system. With no near-term ballistic missile threat, the United States focused on strategic defenses against intercontinental bombers.

As technology improved, the ability to intercept intercontinental ballistic missiles (ICBM) became technically possible. In 1955, both the Army and the Air Force reassessed the feasibility of BMD. From this research, the Nike-Zeus program emerged. It was given top priority after the Soviets announced that they had successfully tested an intercontinental ballistic missile in August 1957. The Nike-Zeus system consisted of four different radars, the three-stage Zeus missile, and a set of computers that operated at what was then considered high speed.

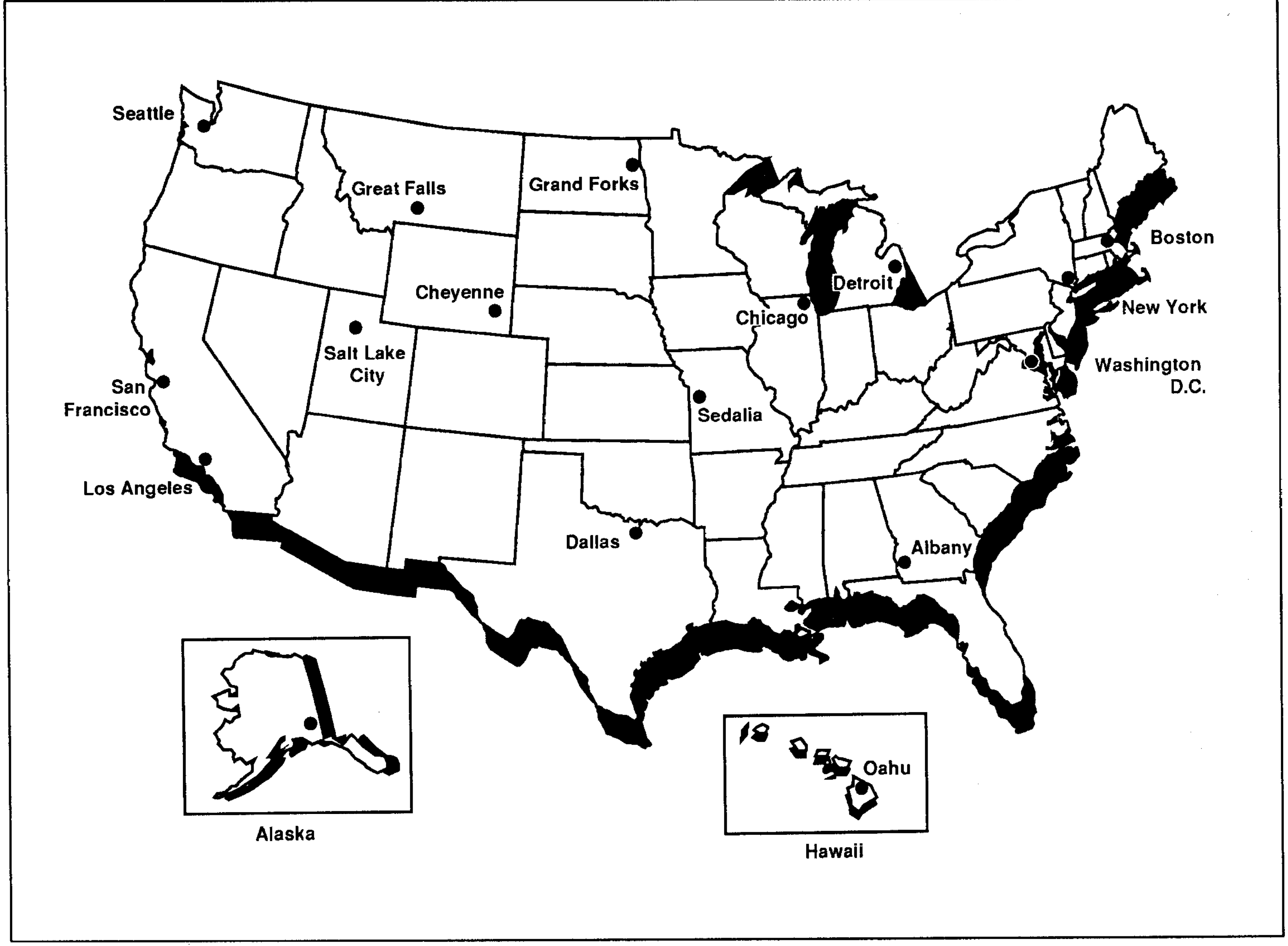
In 1958, the Secretary of Defense initiated an advanced BMD research and development program, sponsored by DOD's Advanced Research Projects Agency. The Agency's BMD task, which became Project Defender, was to study and develop advanced technologies and systems. A large part of Project Defender was devoted to reentry physics and discrimination, which is the task of distinguishing reentry vehicles with nuclear warheads from non-threatening objects. This project accelerated the development and use of new radar technologies. It also explored potential space-based systems that could attack ICBMs in the boost-phase. The Agency also initiated research into directed energy weapons: lasers, particle beams, microwaves, X-rays, and gamma rays. Breakthroughs in chemical lasers led it to continue developing several types of high-energy lasers for BMD.

In the early 1960s, a prototype Nike-Zeus system was installed at the Kwajalein Atoll. In July 1962, a Zeus missile launched from the Kwajalein Test Site made the first intercept of an ICBM by coming within killing range of a target ICBM warhead launched from Vandenberg Air Force Base in California, 4,300 nautical miles away. Eleven more successful intercept tests were conducted through 1963. DOD decided not to deploy the Nike-Zeus system because of its questionable effectiveness against a growing Soviet missile threat.

In 1963, DOD directed that work begin on a project to improve the performance of the Nike-Zeus radars and interceptors. This high-priority program, called Nike-X, studied a number of systems and component designs and included some of the near-term advanced technologies developed by Project Defender. The Nike-X program developed new phased-array radars for acquisition, discrimination, tracking, and interceptor guidance. It also developed two interceptors: the short-range, high acceleration Sprint; and the long-range Spartan, an improved Zeus that could intercept warheads above the atmosphere. Both missiles carried nuclear warheads. The Nike-X program also developed a parallel data processing system to integrate functions of the systems. In 1967, the

Johnson administration announced plans to deploy a 17-site BMD system to protect U.S. urban-industrial areas from a potential future attack by the Peoples' Republic of China or an accidental Soviet launch (see fig. 1.2). The system, based on Nike-X components, was given the name Sentinel.

Figure 1.2: Projected Site Locations for Sentinel (1967)



In 1969, President Nixon reviewed the Sentinel program and announced his decision to move away from urban defense and to employ BMD to defend U.S. land-based missiles. The system's components remained the same but to reflect the shift in emphasis, the name was changed to Safeguard. Initially, the Safeguard plan called for up to 12 sites, deployed in several phases. The first phase, for which authorization was granted, provided for defense for U.S. Minuteman ICBMS at Grand Forks Air Force Base, N.D., and at Malmstrom Air Force Base, Montana, together with a BMD Center at Cheyenne Mountain, Colorado. The second phase, which would defend additional sites, was to proceed as a measured response to Soviet and Chinese developments and actions. In 1971, the Hardsite program (later called Site Defense) was initiated to improve Safeguard's ability to defend hardened military assets against future Soviet threats.

In 1972, the United States and the Soviet Union signed the Treaty on the Limitation of Anti-Ballistic Missile (ABM) Systems, restricting each country to only two sites. In 1974, the countries signed a protocol to the treaty limiting each side to one site. The United States chose to continue deployment at Grand Forks. This site became fully operational in October 1975. Four months later it was de-activated because it was deemed too costly to justify operation in face of a new Soviet threat from ICBMS carrying multiple independently targetable reentry vehicles.

In 1968, a new organization was created to conduct advanced research and development on BMD, the Army Advanced BMD Agency, made up of portions of Project Defender and the Nike-X development office. It assumed responsibility for continuing the development of new BMD technologies and systems and for improving the performance and cost of existing technologies and systems.

In the 1970s and early 1980s, much of the BMD effort was focused on defense of the Air Force's new ICBM, the MX, later renamed Peacekeeper. As the basing mode for Peacekeeper changed from one configuration to the next in an effort to increase the missile's survivability, the configuration of the proposed BMD systems (first called Low Altitude Defense and later Sentry) had to change continually to meet each new basing requirement. After several years of debate, the decision was made in 1983 to deploy the Peacekeeper missiles in existing, hardened silos, and the Sentry BMD option was dropped.

From the mid-1970s to early-1980s, DOD continued BMD research programs on a treaty compliant basis with no plans for development of a deployable system. Progress was made in technologies for several BMD areas. Missile guidance was improved through advances in optical sensors and data-processing technology. This made it possible for interceptors to attack warheads beyond the range of ground-based radars. Improvements in laser technology and tracking systems made directed energy weapons potentially feasible.

Much of the work in directed energy weapons was conducted by the Defense Advanced Research Projects Agency. The Agency's technology development was directed mostly to spaced-based lasers, with an initial focus on defending U.S. satellites. Concepts for BMD were also studied. A major effort was the Triad program, which sought to develop high-powered chemical lasers, large-diameter mirrors, and tracking and pointing systems suitable for use in space. It also became the manager of neutral particle-beam and charged particle-beam programs.

On March 23, 1983, President Reagan called for the start of "a comprehensive and intensive effort to define a long-term research and development program to begin to achieve our ultimate goal of eliminating the threat posed by strategic nuclear missiles." He directed DOD to conduct two studies. The first, entitled Report of the Study on Eliminating the Threat Posed by Nuclear Ballistic Missiles and known as the Fletcher study, assessed the status of missile defense technologies throughout DOD and the feasibility of the President's goal. The second, entitled Future Security Strategy Study, assessed the role of defensive systems options and their implications for defense policy, strategy, and arms control.

In April 1984, Secretary of Defense Weinberger chartered SDIO to manage the new missile defense program developed in response to the President's directions. SDIO assumed responsibility for most of the Army's advanced BMD programs, much of the Defense Advanced Research Projects Agency's programs in high-energy lasers and particle beam weapons, and parts of the Air Force's space surveillance program, redirecting them towards BMD applications.

In May 1993, Secretary of Defense Aspin changed the title of the organization to the BMD Organization (BMDO) and confirmed his directions that the organization's top priority will be development of defenses against theater ballistic missile threats. The Secretary also has a bottom-up review of defense needs and programs ongoing. The evolution of the Strategic Defense Initiative (SDI) program since 1984 is discussed in chapter 2.

Objectives, Scope, and Methodology

The Chairman of the Senate Committee on Governmental Affairs asked that we provide the Congress a summary of the SDI program. Specifically, our objectives were to (1) describe the evolution of the program, (2) describe the oversight of the program by DOD, (3) provide the investment history of the program, (4) describe the technical progress made in the national missile defense and theater missile defense programs and the additional progress necessary for both of them to enter engineering and manufacturing development, (5) examine BMDO's efforts in spinning off technology to commercial users, (6) provide BMDO's planned use of retired strategic offensive missiles as launch vehicles for conducting tests in space, and (7) provide information on BMDO's plans for using nuclear power in orbit. A list of related GAO reports and testimonies is included at the end of this report. In addition, a number of classified and For Official Use Only reports were issued, which are not listed.

We examined records and interviewed officials in the Office of the Secretary of Defense, the Secretary of the Air Force, BMDO, the U.S. Army Strategic Defense Command, and the U.S. Navy's Strategic Systems Program Office. We also used information from publications by BMDO, the Congressional Research Service, and the U.S. Army Strategic Defense Command, which are listed in the bibliography. We conducted our review from December 1992 to June 1993 in accordance with generally accepted government auditing standards.

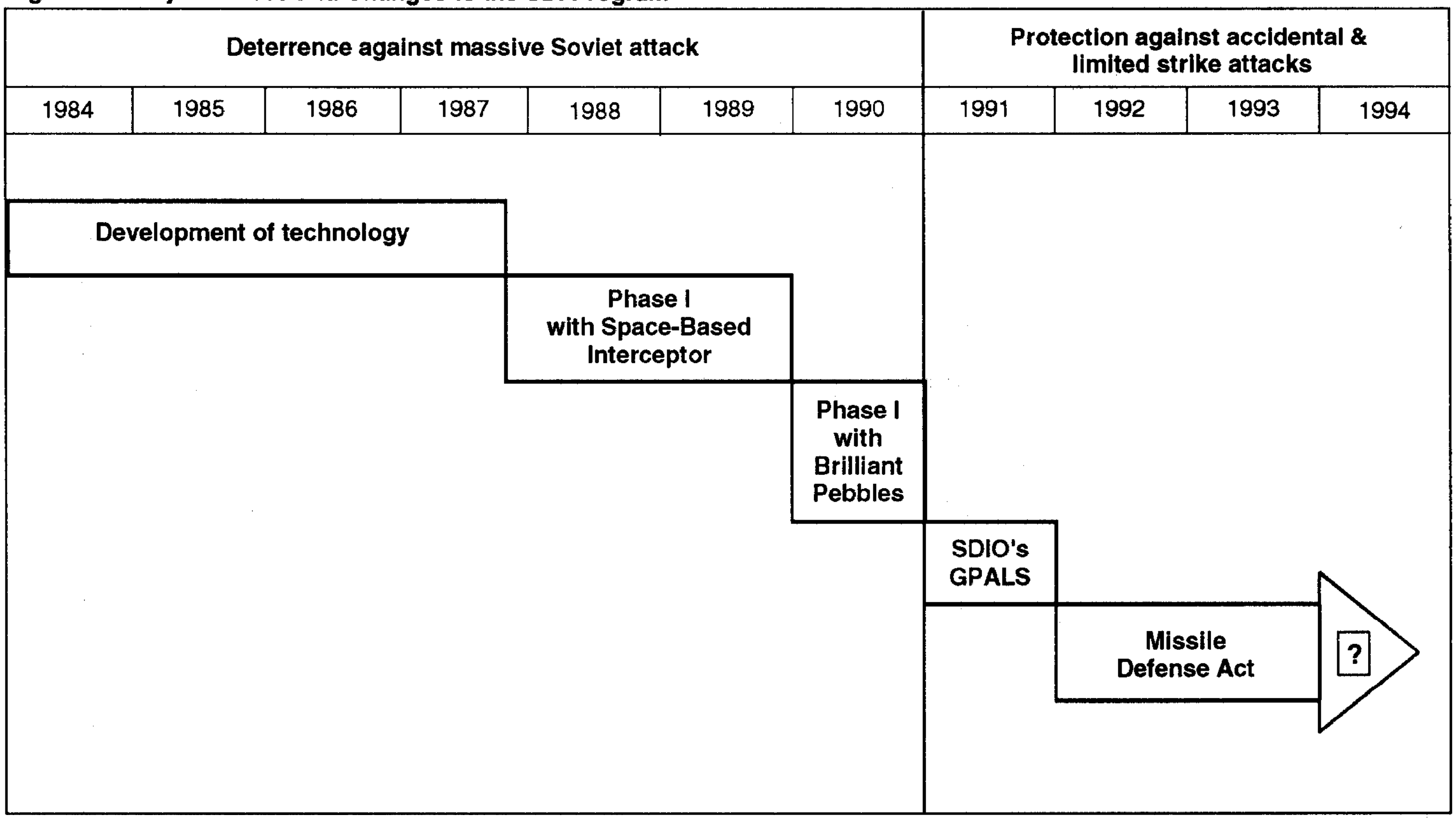
As requested, we did not obtain fully coordinated DOD comments on this report. However, we discussed the results of our review with officials from DOD, the Joint Chiefs of Staff, BMDO, and the Army and have made changes where appropriate. They agreed with the information in this report.

Evolution and Oversight of Strategic Defense Initiative Program

From 1983 to 1993, the SDI program has had two different missions. The first mission period, which lasted from 1983 through 1990, was focused on the threat of a massive Soviet attack on the United States. The second, current mission period began in 1991 when President Bush changed the focus to "providing protection from limited ballistic missile strikes, whatever their source...to the United States, to our forces overseas, and to our allies." During each of these mission periods, there were significant changes to the program, based on policy reviews and decisions by the President, the Secretary of Defense, and the Congress. These changes are shown in figure 2.1 and are explained below.

Beginning with the entry of the Phase I Strategic Defense System into DOD's formal acquisition process, the Under Secretary of Defense for Acquisition has been responsible for SDI program oversight. Of the advisory boards and committees he can call on in this role, the Defense Acquisition Board (DAB) is the most significant and includes senior DOD officials. The Under Secretary also requested advice from the Defense Science Board. DAB and Defense Science Board advice has highlighted to decisionmakers key challenges in technical performance and program management. It also addressed cost and budget pressures on the program.

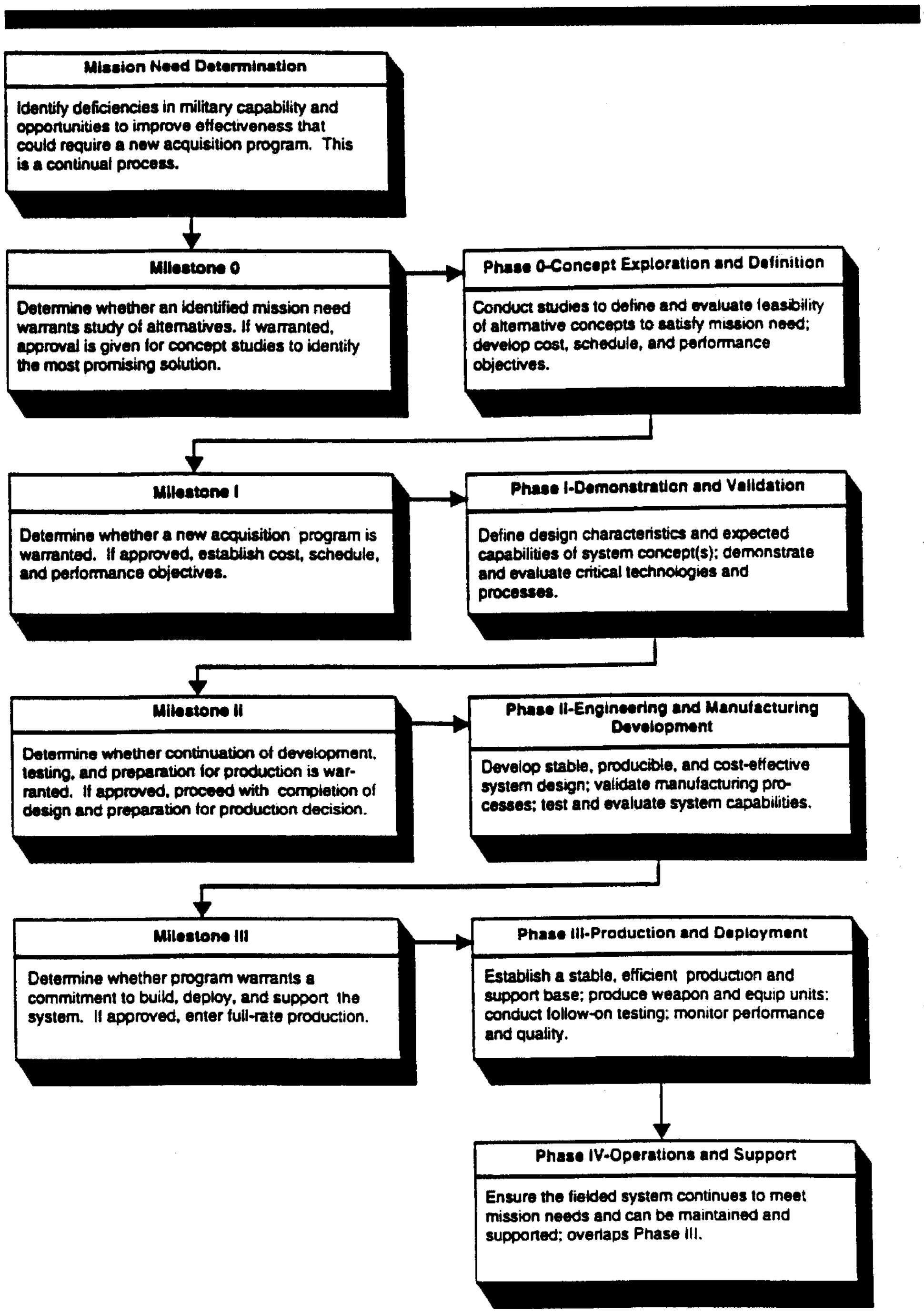
Figure 2.1: Major Phases and Changes to the SDI Program



Background

DOD's major systems acquisition process is a sequence of activities, beginning with concept exploration and definition, and ending with operations and support, as diagrammed in figure 2.2 below.

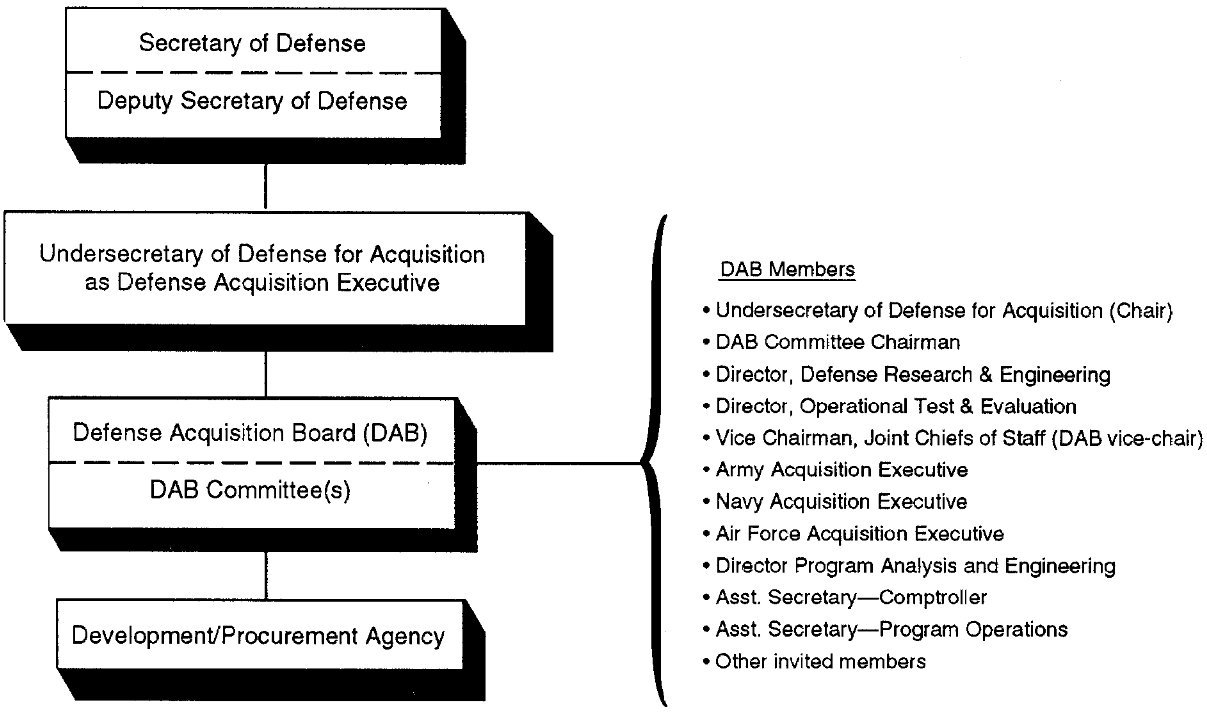
Figure 2.2: DOD's Major Systems Acquisition Process



Note: A fourth milestone may be necessary to determine whether significant upgrades are needed for the weapon in production.

SDIO's proposed deployments have been subject to formal DAB reviews since 1987, when an initial system was submitted for review and approval. The DAB is the forum through which the DOD staff and component acquisition executives resolve issues, provide and obtain guidance, and make recommendations to the Under Secretary of Defense for Acquisition in his role as Defense Acquisition Executive. The DAB review activity for a major system is coordinated by a designated DAB committee, which brings together the various DOD staff offices involved in the reviews. Formal DAB reviews are preceded by months of staff review and coordination to identify issues to be presented to DAB members. The DAB advisory structure and various DOD offices whose inputs are coordinated by the DAB committee structure are shown in figure 2.3.

Figure 2.3: DAB Operating Structure and Permanent Members



Deterrence Against a Massive Soviet Attack: 1983-90

This phase began in 1983 with the creation of the program and lasted through 1990, when the unbridled competition with the Soviet Union in strategic forces ceased. In accordance with directives from the President, the Secretary of Defense chartered SDIO in 1984 to research and develop a comprehensive set of technologies supporting concepts for BMD. SDI research was to support an early 1990s decision on whether to begin developing BMD for deployment. Initial deployments were to contribute to strategic deterrence and move the United States toward an ultimate goal of eliminating the threat posed by strategic nuclear missiles. SDI also was to protect options for near-term deployment in case of a Soviet deployment in violation of the ABM Treaty.

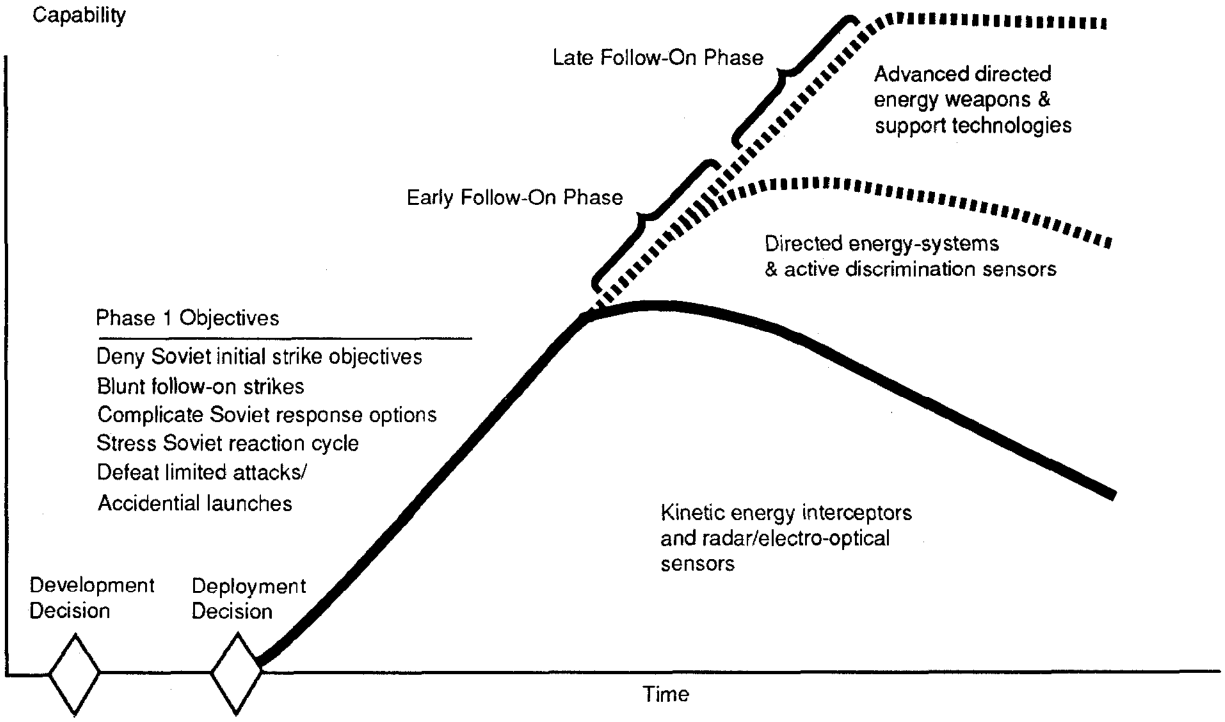
Development of Key Technologies

SDIO's early plan was to treat the SDI program as a research program until the early 1990s, when a decision would be made on whether to develop an initial capability. SDIO was developing a broad range of key technologies for sensors, kinetic kill weapons, and directed energy weapons. According to President Reagan, the SDI program was to provide to a future president and a future Congress the technical knowledge required to support a decision on whether to develop and later deploy advanced defensive systems. This research phase lasted from 1984 through early 1987, when the Phase I system became subject to the oversight of DOD's formal acquisition process.

Phase I Strategic Defense System

In the fall of 1986, a Phase I design was conceived in a series of meetings between the Secretary of Defense and top advisors. The concept of evolutionary, incremental, or phased deployment was to develop and deploy militarily useful increments of capability that would also add to arms control negotiating leverage for reductions in offensive weapons. The phased deployment plans could be modified if the Soviets responded favorably to arms reduction proposals. The three phases envisioned appear in figure 2.4. Follow-on phases would include directed energy systems and would lead to highly effective, multi-layered defenses, which could enhance the prospects for negotiated reductions, or even the elimination, of offensive ballistic missiles.

Figure 2.4: Concept of Phased Deployments



In December 1986, President Reagan approved the general outlines of the Phase I and follow-on deployment concepts. SDIO prepared program plans and documentation and submitted them for DAB review. Phase I emphasized space-based elements as critical to countering Soviet proliferation of offensive missiles and countermeasures. The White House, in this period, called SDI "a main inducement for the Soviets to negotiate for deep cuts in offensive arsenals."[1] In October 1986, the President declined Soviet demands that he confine the SDI to laboratory research.

Following the DAB's September 1987 review, the Under Secretary of Defense for Acquisition recommended that selected Phase I system elements pass milestone I. The selected Phase I elements were:

[1]Casper W. Weinberger, Fighting for Peace: Seven Critical Years in the Pentagon (New York, NY: Warner Books, 1990), p. 324.

- Boost Surveillance and Tracking System;
- Ground-Based Surveillance and Tracking System;
- Space-Based Surveillance and Tracking System;
- Spaced-Based Interceptor;
- Exoatmospheric Reentry Vehicle Interceptor System;
- Ground-Based Radar;
- battle management/command, control, and communications;
- system engineering and integration; and
- launch.

The DAB review raised a list of technical and management concerns to be addressed in subsequent months. The Under Secretary noted that "the scope and complexity of the program required an extensive evaluation complemented by independent review." A key staff person for the DAB committee explained that it required several months after this memo for DAB staff and SDIO to agree on an implementing memo to guide continued oversight. The DAB, based on information provided by the SDIO, raised key technical performance, cost, and management issues. These were addressed in subsequent revisions to the program.

The Under Secretary requested a Defense Science Board review concurrent with the DAB's review. The Board raised several technical and management concerns with Phase I proposals. It noted that the system design was still in an early stage and subject to substantial modification, and made clear that a number of significant technology problems remained to be solved. Technology problems noted included survivability and sensor discrimination—issues addressed by subsequent revisions to the system design. It further noted weaknesses in SDIO's management and technical support for system design and integration.

In September 1987, Secretary Weinberger approved the recommendation of the DAB, that Phase I concepts and technologies, called the Phase I Strategic Defense System, enter the demonstration and validation portion of the acquisition process. Advanced technologies for follow-on phases, such as directed energy, were to be pursued as concept definition and technology development efforts and were to enter demonstration and validation prior to full-scale development of Phase I.

The elements comprising the Phase I architecture were the subject of continuing design review and revision. This was driven by the need to lower costs and to resolve effectiveness issues of survivability, vulnerability, and sensor performance—particularly the challenge of discriminating targets in the midst of countermeasures designed to confuse SDI sensors. The cost estimates for Phase I were reduced from the original, June 1987 DAB milestone I estimate of $145.7 billion, to $115.4 billion in June 1988, then $69.1 billion in September 1988, and to $55.3 billion by November 1989. This reduction was accomplished through successive redesign of the system elements, reducing quantities, reducing support costs, and changing cost estimating models.

Design changes addressed issues raised by SDIO and DAB during their review process. DAB recommendations on design changes to the initial Phase I element designs came as late as June 1990. Key changes included extending the capabilities of the Ground-Based Radar to midcourse tracking and discrimination; redesign of the Space Surveillance and Tracking System satellites; and redesign of the Space-Based Interceptor's sensors, communications, and missiles. The DAB requested that SDIO look into alternatives to the Phase I architecture as first deployment steps, including limited protection options.

A second Defense Science Board study group, in the spring of 1988, recommended that DOD do Phase I in steps. The Board suggested that, for example, a first deployment might be a limited defense with 100 interceptors, complying with the ABM Treaty. It noted that ABM Treaty issues would be confronted to meet Phase I goals. Finally, it reiterated the SDIO's need for long-term engineering support for this large and complex program.

Phase I "Brilliant" Architecture

After Phase I was proposed, the SDIO began investigation of a new space-based interceptor that became known as "Brilliant Pebbles." The concept was to develop a constellation of thousands of individual interceptors, each with its own surveillance capability and enough computing power to operate autonomously, if necessary, within its field of vision. Brilliant Pebbles became a competitor to the Space-Based Interceptor design concept, which was to house several interceptors together in a large "garage" or carrier vehicle. BMDO officials noted that Brilliant Pebbles directly responded to DAB concerns regarding the anticipated high cost of the Space-Based Interceptor "garage" or carrier vehicle; it also addressed DAB concerns over survivability of the Space-Based Interceptor garage. BMDO subjected Brilliant Pebbles to several technical feasibility reviews in 1989, including a review by independent experts, by Lincoln Laboratories, as well as an SDIO-managed study that included the Army and Air Force and SDIO's Phase One Engineering Team.

President Bush directed a National Security Review upon entering office in 1989. He directed an independent review of SDI, which was led by former arms control negotiator Ambassador Henry F. Cooper.[2] Completed in the spring of 1990, the independent review endorsed the Brilliant Pebbles concept and recommended its innovative approaches be applied to the remainder of the SDI's Phase I architecture. In testimony before the Congress in April 1990, SDIO's Director announced that Brilliant Pebbles had replaced both the Space-Based Interceptor and the Boost Surveillance and Tracking System in the Phase I architecture.

The DAB committee staff were briefed on SDIO's study of Brilliant Pebbles and assisted the independent study. The Under Secretary of Defense for Acquisition, in June 1990, endorsed the change to Brilliant Pebbles. The Defense Science Board, at his request, had also studied the proposed Brilliant Pebbles. The Board's advice was similar to the independent study, but the report was not issued for general release to the public.

SDIO reviewed potential innovations to the remainder of the Phase I architecture and proposed revisions in November 1990. Recommended revisions included replacement of the Space Surveillance and Tracking System satellites with the smaller, highly distributed Brilliant Eyes satellites; introduction of the Endo-Exoatmospheric Interceptor as a competitor to the exoatmospheric Ground-Based Interceptor; and design changes to the Ground-Based Radar, redesignating it the Ground-Based Radar-Terminal. Two months after these recommendations, President Bush refocused the SDI to the Global Protection Against Limited Strikes (GPALS) mission and threat as explained below. This began another set of architectural concept studies.

Protection Against Limited Attacks: 1991-93

During most of 1989 and 1990, DOD and SDIO were reacting to two new forces affecting SDI—the innovations in the Brilliant Pebbles concept and the changes in Soviet and third-world threats. Unfolding world events led to a reexamination of the policy and technical goals of the SDI during 1990. The independent study had recommended that SDI give closer attention to the threat posed by the proliferation of ballistic missiles. This led to an Office of the Secretary of Defense study of the strategy and technical

[2]Ambassador Cooper subsequently served as Director, SDIO, from July 1990 to January 1993.

feasibility of global protection against limited strikes, in the spring and summer of 1990.

In January 1991, President Bush refocused the SDI to deal with accidental or unauthorized launches of ballistic missiles and with deliberate attacks of limited scope. The new deployment concept was called GPALS. While the threat for GPALS is less technically stressing in some ways, the mission of near-perfect protection also put additional stresses on designs. High levels of protection require near perfect system performance in detecting, discriminating, and tracking targets; in battle management, command, control, and communications functions; and in intercepting and destroying targets. SDIO commissioned a new architectural integration study to assess designs and design trade-offs against the new threats and new mission.

In 1991 and 1992, congressional deliberations placed distinct congressional policy imprints on the program. The emphasis on theater defenses, begun by the Congress in 1990, was formalized in a Theater Missile Defense Initiative and by markedly increased funding and a mandate to seek deployable prototypes. In the environment of reduced threat to the United States, the Congress barred deployment of space-based weapons in an initial limited defense system.

GPALS Architecture

The administration's GPALS emphasis included a Brilliant Pebbles space-based weapon. Secretary of Defense Cheney made it clear in reporting to the Congress that space-based weapons were critical to threatening Soviet missiles in the boost and post-boost phases and that planned defenses would complement arms control negotiation objectives. He stressed that space-based weapons were important to threaten Soviet multiple-reentry vehicle payloads, a "key objective of U.S. arms reduction policy."

Subsequent to the President's direction to focus on GPALS, the DAB, in September 1991, approved a management oversight approach dividing GPALS into six major defense acquisition programs (see fig. 2.5).

Figure 2.5: DAB Program Review Structure for GPALS

GPALS System							
Segments	**Theater Missile Defense (TMD)**				**National Missile Defense (NMD)**	**Global Missile Defense (GMD)**
Major Defense Acquisition Programs (MDAP)	GPALS System & BM/C3	Patriot	Corps SAM	Upper Tier System	NMD System	GMD System
Weapons, Sensors, & BM/C3 Systems in each MDAP	Architectural Integration System Engineering & Integration Command Center Element	Patriot	Corps Surface-to-Air Missile	THAAD & TMD-GBR	Ground-Based Interceptor Ground-Based Radar Space-Based Sensor (BE)	Space-Based Interceptor (Brilliant Pebbles)

Missile Defense Acts

The Missile Defense Act of 1991, passed in December 1991, changed the shape and priorities of the President's GPALS. It represented the first agreement between the Congress and the executive branch to prepare to deploy a BMD system. The act set goals for early deployment of advanced theater missile defenses and the initial site for defense of the United States against limited attacks. The Congress gave DOD 180 days to develop a plan to meet its mandate for early deployment. It also mandated that Brilliant Pebbles space-based interceptors not be part of initial planned deployments, but be pursued in "robust" research and development.

In November 1991, SDIO briefed the DAB's coordinating committee that the Theater High Altitude Area Defense program, including the Theater Missile Defense Ground-Based Radar, had high cost and schedule risks. The committee requested SDIO to develop acquisition strategy options to reduce risk. SDIO and the Army modified the program to reduce risks. The DAB approved a milestone I entry into demonstration and validation and agreed on key program performance parameters that must be satisfied.

DOD reviewers identified concurrency risks in meeting the Congress' early fielding goals for an initial, single-site national missile defense system. After considering DOD's assessment, the Congress amended the Missile Defense Act in 1992, delaying the proposed fielding date. The 1992 Act continued the restrictions on deployment of space-based interceptors.

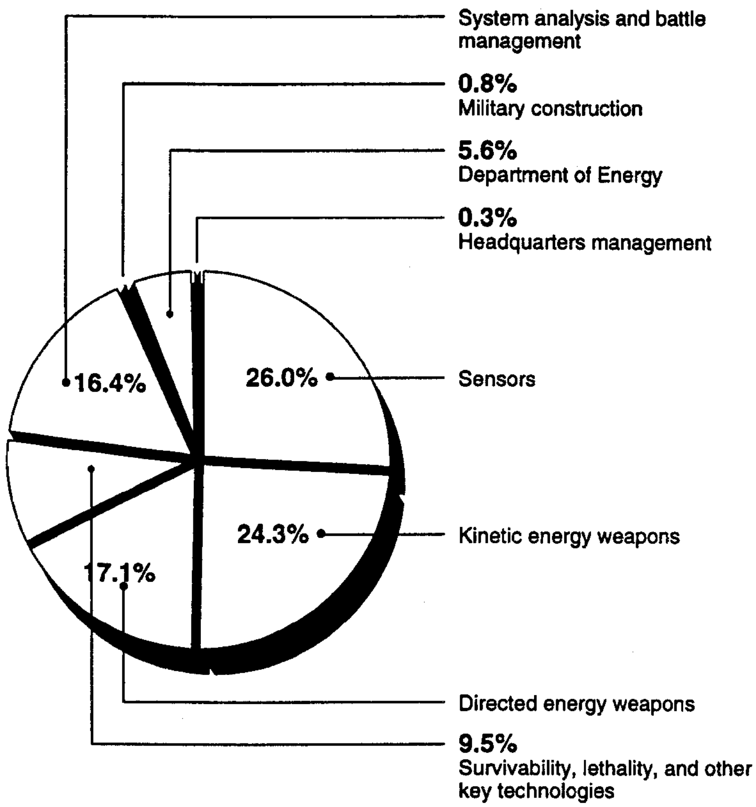
BMD Program Under Clinton Administration

Under the Clinton administration, the program priorities have changed and are still under review. A bottom-up review of defense needs and programs is to be completed this summer and will yield guidance for reshaping defense. It is to be reflected in the fiscal year 1995 budget. Secretary of Defense Aspin reduced the budget request for fiscal year 1994 from $6.4 billion that the Bush administration had submitted to the Congress, to $3.8 billion—the amount that the Congress had approved for fiscal year 1993. The Secretary made theater missile defense the top priority, national missile defense second priority, and follow-on systems third priority. On May 13, 1993, Secretary of Defense Aspin changed the SDIO's name to the Ballistic Missile Defense Organization and directed that it now report through the Under Secretary of Defense for Acquisition and Technology rather than directly to the Secretary. He noted that "these changes represent a shift away from a crash program for deployment of space-based defenses designed to meet a threat that has receded..." and pronounced "the end of the Star Wars era."

BMDO's Use of Funds for Fiscal Years 1985 Through 1993

A total of $30.4 billion has been spent on BMD development since 1985—$28.4 billion by BMDO and $1.7 billion by the Department of Energy. Through fiscal year 1993, BMDO has received $28.4 billion for research and development on BMD. About $7.9 billion was for sensors; $7.4 billion for kinetic energy weapons; $5.2 billion for directed energy weapons; $5.0 billion for systems analysis and battle management; and $2.9 billion for survivability, lethality, and other key technologies. In addition, BMDO received $86 million for headquarters management and $229.2 million for military construction. The Department of Energy received $1.7 billion for research on space-based nuclear power sources for SDI weapons, X-ray laser research, and other SDI research. (See fig. 3.1.)

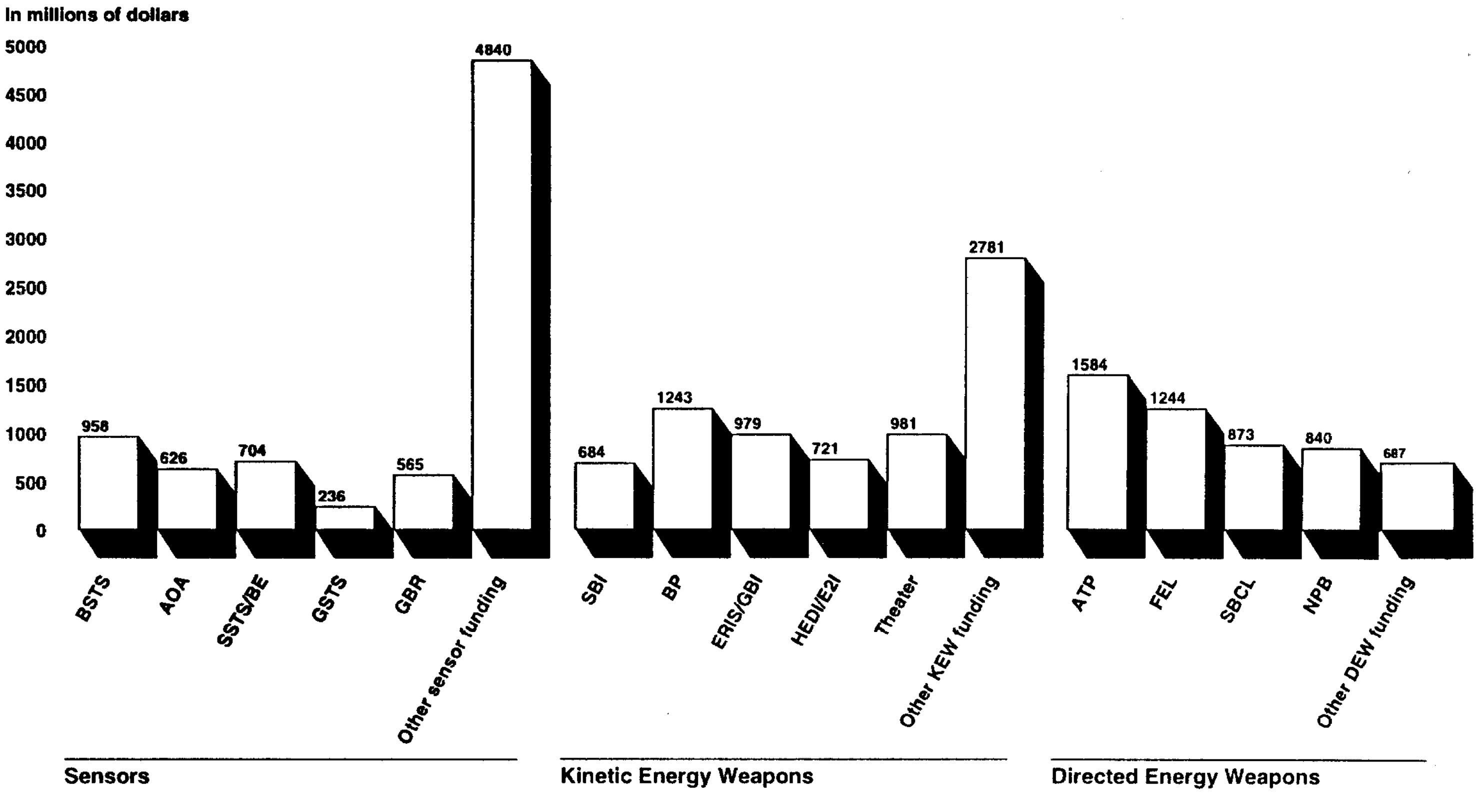
Figure 3.1: Funding for Fiscal Years 1985 Through 1993

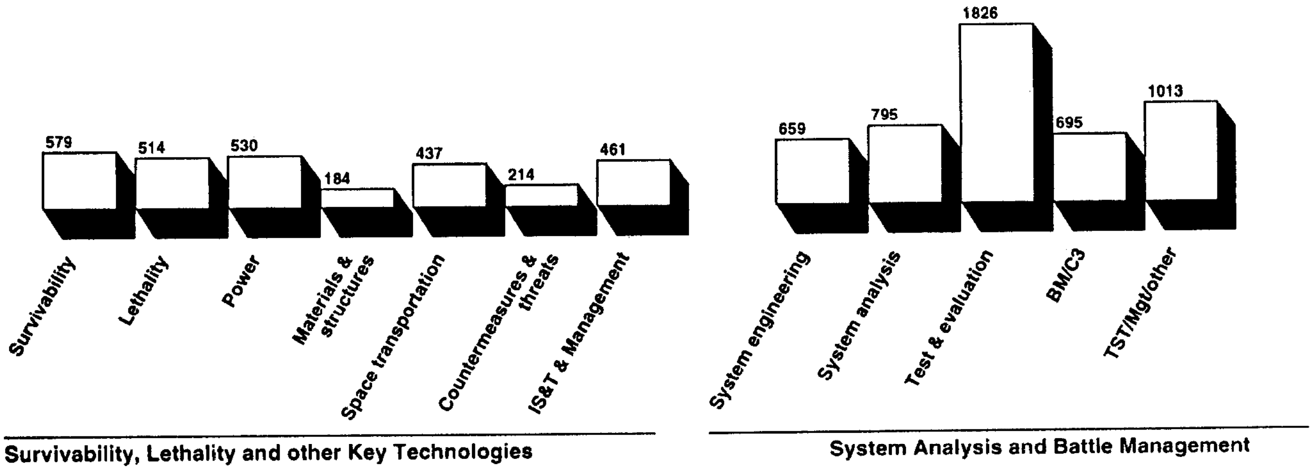


Past Uses of Funds

Additional details about how BMDO used the money are discussed in the following sections. Figure 3.2 shows the funding for each of the major projects.

Figure 3.2: Funding for Major Projects for Fiscal Years 1985 Through 1993





Sensors

BMDO allocated $7.9 billion, 26 percent of its total funding, for developing sensors. About $3.1 billion was used for developing sensors able to detect boosters, warheads traveling through space, and warheads after they have reentered the earth's atmosphere. Most of the money, $4.8 billion, was used for several supporting technology base projects, data-gathering projects, and space experiments. Data gathering was necessary to determine what typical targets, clutter, and space or atmospheric backgrounds look like to different types of sensors.

Table 3.1: Sensors Funding

Dollars in millions

	Amount
Boost Surveillance and Tracking System	$958
Airborne Optical Adjunct	626
Space Surveillance and Tracking System	389
Brilliant Eyes	315
Ground-Based Surveillance and Tracking System	236
Ground-Based Radar	565
Technology base & phenomenology	4,840
Total	**$7,929**

BMDO stopped funding of the Boost Surveillance and Tracking System and transferred it to the Air Force in fiscal year 1991. The Space Surveillance and Tracking System was replaced by Brilliant Eyes in the GPALS architecture. BMDO dropped Ground-Based Surveillance and Tracking System this year, since funding was not sufficient to carry it as an alternative to Brilliant Eyes.

Kinetic Energy Weapons

BMDO allocated $7.4 billion, 24.3 percent of its total funding, for developing kinetic energy interceptors. About $4.6 billion, or 62 percent, was for five major demonstration projects.

Table 3.2: Kinetic Energy Weapon Funding

Dollars in millions

	Amount
Space-Based Interceptor	$684
Brilliant Pebbles	1,243
Exoatmospheric Reentry Vehicle Interceptor Subsystem, now called Ground-Based Interceptor	979
High Endoatmospheric Defense Interceptor, replaced by Endo-Exoatmospheric Interceptor	721
Theater	981
Other	2,781
Total	**$7,389**

BMDO replaced the Space-Based Interceptor design with Brilliant Pebbles in 1990. The Ground-Based Interceptor was selected for potential deployment at six sites to defend the U.S. mainland, Alaska, and Hawaii under GPALS. Work was stopped in fiscal year 1992 on the

Endo-Exoatmospheric Interceptor. BMDO concluded that funding was not sufficient to carry two interceptors and now envisions this terminal intercept capability would be a potential product improvement to the Ground-Based Interceptor.

The other $2.8 billion was used to fund advanced interceptor technologies, test facilities, test missile integration, simulation test beds, and hyper-velocity gun technologies.

Directed Energy Weapons

BMDO allocated $5.2 billion, 17.1 percent of its total funding, for research and technology development to determine the feasibility of directed energy weapons. Four large technical feasibility demonstrations cost $4.5 billion.

Table 3.3: Directed Energy Funding

Dollars in millions

	Amount
Free Electron Laser	$1,244
Space-Based Chemical Laser	873
Neutral Particle Beam	840
Acquisition, tracking, and pointing	1,584
Other	687
Total	**$5,228**

Based on reduced funding for fiscal year 1991, the remaining ground-based laser effort, the Free Electron Laser project, was reduced to a technology base program; and the Starlab acquisition, tracking, and pointing experiment was canceled after spending $600 million in order to keep alive other directed energy work. These are instances where optimistic planning resulted in starting projects and making significant investments, which then became unaffordable. In fiscal year 1994, the Free Electron Laser will be transferred to the Army, which does not plan to provide any additional funding. Additional information on directed energy programs is summarized in appendix I and in a recent GAO report.[3]

Systems Analysis and Battle Management

BMDO allocated $5.0 billion for systems analysis and battle management activities such as the National Test Bed; architecture studies; engineering support from the DOD federally funded contract research centers; a

[3]Ballistic Missile Defense: Information on Directed Energy Programs for Fiscal Years 1985 Through 1993 (GAO/NSIAD-93-182, June 25, 1993).

systems engineering and integration contractor; battle management, command, control and communications experiments; and theater defense test beds.

Survivability, Lethality, and Other Key Technologies

This $2.9 billion funded research and development for (1) survivability of the system elements; (2) lethality, or target kill, technology; (3) advanced solar and nuclear power sources for sensors and weapons; (4) launch capabilities; (5) innovative science and technology, and BMDO management; (6) advanced materials research for application to sensors, interceptors, and directed energy system elements; and (7) threat and countermeasures research.

Five technology areas—survivability, lethality, power sources, space transportation, and innovative science and management were the largest users of funds, with about $500 million expended in each category (see fig. 3.2).

Persistent Optimism in Budget Requests and Plans

The efficient pursuit of BMD research and development has been unnecessarily hampered by the executive branch's persistence in making plans and starting projects on the basis of unrealistic and overly optimistic funding requests and schedules through fiscal year 1993. This optimistic planning, followed by cutting back program plans to fit actual appropriations, has resulted in lost effort and higher risks. We have previously testified on the need for the administration and the Congress to agree on program goals and budget amounts for each program element, as well as target dates for full-scale development for the major elements of theater or national missile defense systems before committing major investments toward their acquisition.[4]

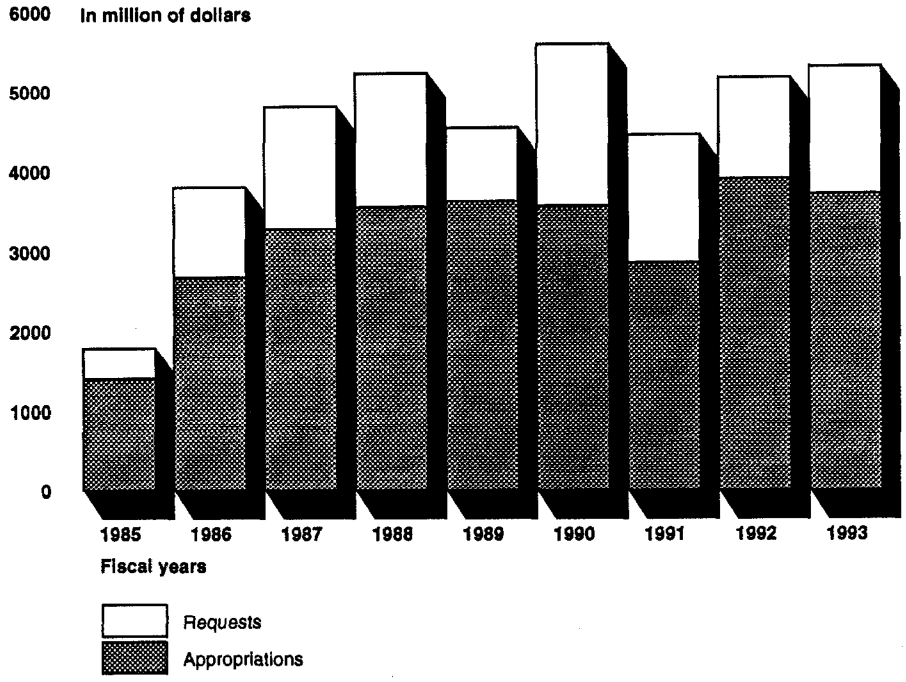
For example, the initial investment strategy assumed that funds would be available to develop technologies on a schedule limited only by the rate at which they could efficiently be developed—not by funding. However, administration and congressional differences on policy, program goals, and affordability have culminated each year in a wide gap between DOD's budget requests and actual appropriations for SDI.

Between fiscal years 1985 and 1993, appropriations for BMDO have averaged 29 percent below requested budgets, ranging from 20 percent to

[4]Strategic Defense Initiative Program: A Look at Lessons Learned During SDIO's First 7 Years (GAO/T-NSIAD-91-33, May 16, 1991).

36 percent. Despite a history of congressional decisions that not all planned investments would be funded, the difference between program plans and available funding has increased from 21 percent in 1985 to about 30 percent in 1993. Figure 3.3 shows the annual requests and the appropriations for BMDO.

Figure 3.3: Budget Requests Versus Appropriations



The effects of this optimistic initial planning followed by replanning were described in our early reports and in BMDO's annual reports to the Congress. In 1986 and 1987, for example, we issued nine reports, covering nine major SDI projects, which documented the effects created by the differences between expectations and appropriations: disproportionate cuts to advanced technologies, increased program risks, and canceled contracts. We also reported that for fiscal year 1987 nearly one-half of the difference between the budget request and the amount appropriated was in the directed energy weapons account. Negative effects of funding reductions include deleting technology alternatives; reducing the scope of experiments and demonstrations; increasing technical risks; and adding costs due to stretching schedules and canceling, renegotiating, or terminating contracts, according to BMDO.

Because funds were not provided in planned amounts in 1991, BMDO either canceled or cut back major directed energy technology demonstrations after it had made large investments, in order to hold to an early 1990s schedule for a development and deployment decision on other systems. The Starlab experiment—to demonstrate precision target tracking and weapon pointing technologies generic to many directed energy weapons—was canceled after $600 million had been invested. The Free Electron Laser work was reduced to a technology base program after a major demonstration facility costing $72.4 million was constructed.

In 1990, BMDO structured its program to support a 1993 deployment decision by the President, even though the addition of Brilliant Pebbles fundamentally changed the architecture and integrated system tests would not be conducted prior to the decision. By providing important system performance information, such tests help ensure that critical decisions are event—not time—driven. The 1993 decision date was postponed.

DOD's budget request for fiscal year 1994 is $3.8 billion, the same as the amount actually appropriated for fiscal year 1993. This represents a major change from optimistic requests in the past. In addition, DOD is doing a bottom-up review of the BMD program to determine the planned funding for future years and what kind of program should be conducted with the planned funding. The results are expected to be available this summer.

Theater Missile Defense

The mission of theater missile defense (TMD) is to protect U.S. forces deployed overseas and U.S. allies and friends from theater ballistic missile attacks. According to BMDO, improved TMD capability is urgently needed because of the increasing proliferation of ballistic missile weapon systems and technology to countries with the potential to threaten U.S. and allied theaters of operation.

BMDO estimates that the initial elements of TMD will cost about $12.1 billion in then-year dollars to develop and produce—$2.6 billion for the Patriot Upgrade and $9.5 billion for the Theater High Altitude Area Defense (THAAD) system. Other TMD elements under consideration, such as Brilliant Eyes, Corps Surface-to-Air Missile, and ship-based TMD systems, could increase costs substantially.

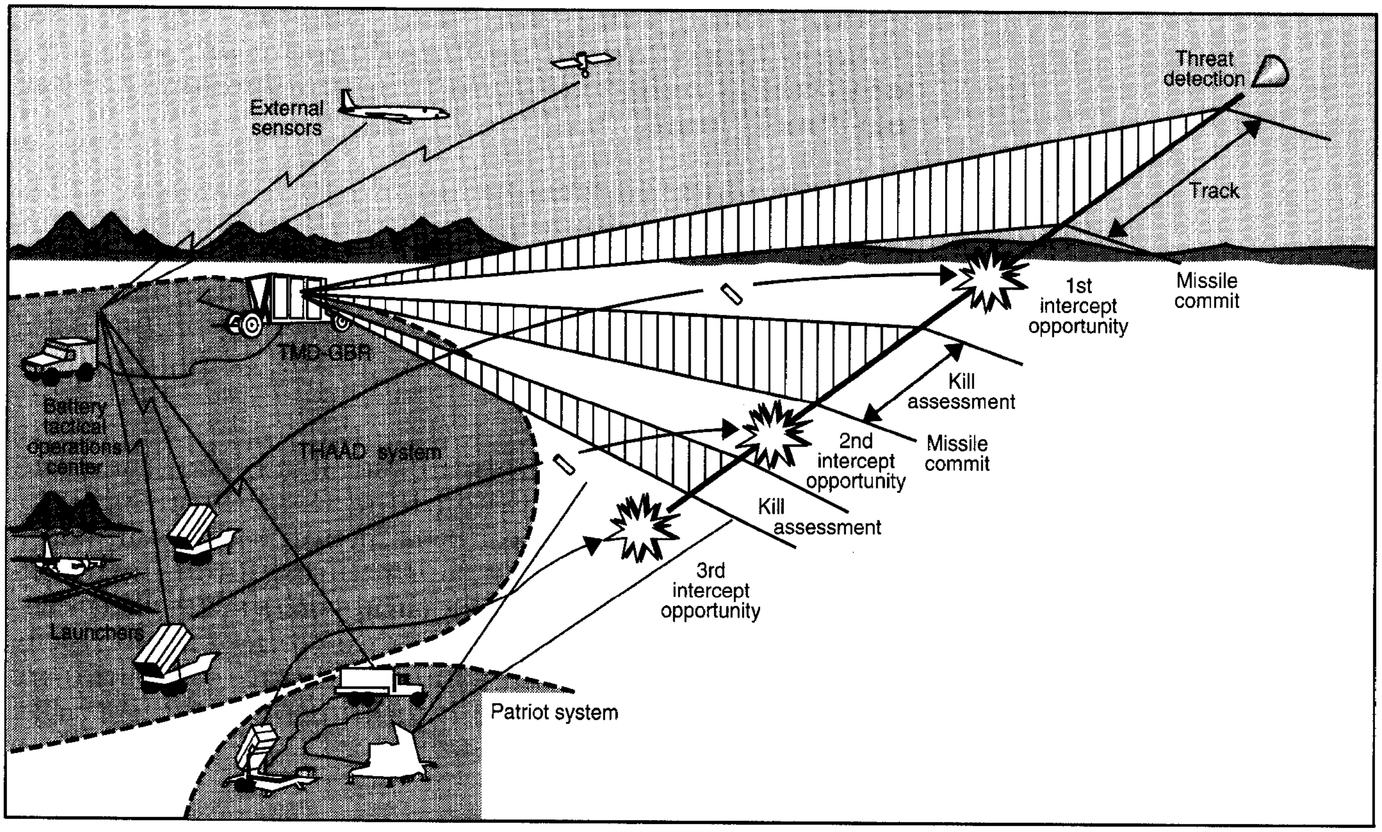
Description of TMD Architecture

BMDO plans a two-tier TMD architecture. The THAAD system comprises the upper tier and provides a wide area defense, to include coverage of dispersed assets and population centers. Intercepts will occur either outside the atmosphere or high in the atmosphere. Patriot comprises the lower tier, with intercepts inside the atmosphere, and will provide defense of critical assets. This two-tier architecture is designed to intercept threat missiles as far away from protected areas as possible, maximize the number of intercept opportunities, and minimize the number of ballistic missiles that "leak" through the defense.

Figure 4.1 shows the initial TMD elements in a potential sequence of operations. First, an external early warning sensor, if available, would detect the target and cue the THAAD system for an interceptor launch before the Theater Missile Defense-Ground Based Radar (TMD-GBR) could acquire the target. With or without an external sensor, the TMD-GBR would eventually acquire and track the target.

After receiving target identification and guidance information from the radar, the THAAD interceptor would engage the target, and a kill assessment would be conducted by the radar and tactical operations center. Then, if necessary, a second THAAD interceptor would be launched. If the radar and operations center again assesses that the target was not destroyed, the TMD-GBR would cue the Patriot system to engage the missiles that got by THAAD.

Figure 4.1: TMD Operating Concept



Patriot Upgrade

Beginning about 1998, the Patriot Advanced Capability-Three (PAC-3) Upgrade of the current Patriot (PAC-2) interceptor is scheduled for fielding. To fill this role, BMDO plans to select either (1) the Extended Range Interceptor (ERINT), which is designed to destroy missiles by colliding with them; or (2) the Patriot Multimode Interceptor, which incorporates a multimode seeker and an improved explosive warhead. BMDO plans to make its selection before the PAC-3 program enters engineering and manufacturing development in early 1994.

Either of the PAC-3 interceptors offers advantages in range and lethality over the Patriot's current interceptor, which was used during Operation Desert Storm. However, PAC-3 comprises only the lower tier portion of the defense. It cannot, by itself, fulfill the total TMD requirement, which includes defense of dispersed assets and population centers. According to

TMD program documents, both a lower and upper tier, such as PAC-3 and THAAD, are needed for high effectiveness.

THAAD System

The THAAD system—consisting of missiles, launchers, TMD-GBRS, and tactical operational centers—is scheduled for initial fielding in the year 2001. It will defend dispersed assets and population centers within a large area. The system is being designed as a transportable, ground-based system to intercept theater missiles fired at U.S.-defended territories worldwide. THAAD will destroy targets by colliding with them (hit-to-kill) rather than using an explosive warhead like the existing Patriot.

The THAAD program plans to build a prototype system for early operational testing before THAAD enters the engineering and manufacturing development phase of development in late fiscal year 1996. The production design would include changes resulting from this prototype testing and from engineering and manufacturing development testing. The production design also will undergo flight and simulation testing to demonstrate performance, including all-weather tests and integration with the Patriot. Additional prototype missiles will be put in storage and will then be available for deployment in a national emergency.

Estimated Acquisition Cost and Schedule

The Patriot Upgrade and THAAD TMD elements must complete two development phases and enter the production phase before the United States will have the promised capability. These phases and their related costs and schedules are shown in table 4.1.

Table 4.1: Acquisition of Theater Missile Defense Elements

Dollars in billions

Defense systems acquisition management phase	Estimated cost	Begin phase (fiscal year)
Demonstration and validation		
Patriot Upgrade	$.7	1991
THAAD	2.1	1992
Engineering and manufacturing development		
Patriot Upgrade	.4	1994
THAAD	2.1	1996
Production		
Patriot Upgrade	1.5	1996
THAAD	5.3	1999
Total		
Patriot Upgrade	**$2.6**	
THAAD	**9.5**	

Presently, the Congress is deciding whether to approve fiscal year 1994 funding for (1) the Patriot Upgrade to begin the engineering and manufacturing development phase and (2) the THAAD to continue the demonstration and validation phase. If these programs progress as scheduled, DOD would request funding in 1995 to begin Patriot Upgrade production and THAAD engineering and manufacturing development beginning in fiscal year 1996.

Major Issues Relevant to Future TMD Funding

A number of issues bear on decisions for future TMD funding. These include THAAD compliance with the ABM Treaty, threat uncertainty, and technical challenges.

ABM Treaty

In November 1992, the Under Secretary of Defense for Acquisition—who is responsible for BMDO treaty compliance—expressed concern over whether the THAAD program's design and flight tests were in compliance with the ABM Treaty. Accordingly, the Under Secretary amended authorization for the demonstration and validation phase. He directed that BMDO not proceed with the current development contract beyond the final design review that is scheduled for November 1993, unless the program's design and flight tests are certified as treaty compliant.

BMDO presented the THAAD design and flight test program to DOD's Treaty Compliance Review Group in May 1993. As of June 8, 1993, the Under Secretary had not made a decision. However, a decision to limit required capability or testing to comply with the ABM Treaty could result in less TMD capability.

Threat

The mission of TMD is to protect U.S. forces deployed overseas and U.S. allies and friends from theater ballistic missile attacks. BMDO notes that the intelligence community estimates there are a number of growing threats of theater ballistic missile attacks by third-world countries. For example, there is concern that the North Koreans will develop a missile that could have a 1,000-kilometer range and could carry a nuclear warhead and sell it to nations that could use it to strike U.S. allies.

A July 1993 decision is pending on whether TMD elements need to be designed to operate in a nuclear environment. If so, development costs and risks could increase. In early 1993, DOD formed a working group to determine appropriate levels of nuclear hardening for the ground-based elements of TMD. The group is to examine the nuclear threats and requirement for operating in a nuclear environment. In addition, it is supposed to define the costs and technical and programmatic risks associated with incremental levels of nuclear hardening.

Another key question related to threat is the ability of defenses to destroy threat warheads that contain chemical or biological submunitions. Lethality against these threats is a challenge to ongoing developments.

Technical Challenges

The Patriot Upgrade and THAAD TMD elements face a number of technical challenges over the next several years of development. Project officials do not believe any of the problems are insurmountable and they assess overall risk of both programs as low to moderate, based in part on using technologies developed during earlier programs. The progress and challenges of the Patriot Upgrade and THAAD are discussed below.

Progress and Challenges of Patriot Upgrade and THAAD

Both the Patriot Upgrade and THAAD development programs take advantage of technologies developed during earlier BMD programs. However, both face challenges during the remaining development time in critical areas such as lethality, integration of complex components, and testing.

Patriot Upgrade

As discussed earlier, the new Patriot PAC-3 interceptor will consist of either the ERINT or the Multimode Interceptor. BMDO reports that both use proven technology that was demonstrated during earlier programs. The Flexible Lightweight Agile Guided Experiment program is credited by BMDO for laying the foundation for key PAC-3 interceptor technologies. Like the proposed PAC-3 interceptors, the experimental missile contained a radar system for guidance when in close proximity to the target and operated at a relatively low altitude. Three guided flight tests were conducted during 1987, and all were claimed to have hit the target.

Concerning testing of the two PAC-3 interceptors, three of four scheduled flight tests of the Patriot Multimode Interceptor have been conducted. Test reports show that two missiles intercepted targets. The other self-destructed because of the failure of the missile's clock. For the ERINT, two preliminary flight tests, which did not attempt to intercept targets, successfully met objectives. A third test failed to hit a ballistic missile target as planned but did achieve other objectives, according to project representatives. The remaining five ERINT tests, which will attempt to intercept targets, are to be completed by early 1994. Additionally, ground tests and simulations are planned for both PAC-3 interceptors.

Destruction of warheads containing submunitions is a major challenge facing the PAC-3 program. A warhead that contains chemical or biological submunitions may be difficult to fully destroy because all of the submunitions would have to be destroyed at a sufficient range to prevent harm from them. Merely fragmenting the warhead in flight could (1) leave multiple submunitions traveling on a ballistic course that would allow them to fall in the area the system is supposed to protect or (2) release chemical or biological agents in a cloud that would disperse the agents in the area to be protected. Meeting this challenge will require high performance levels for aiming and maneuvering. The remaining PAC-3 interceptor tests are critical to demonstrating that the lethality challenge is being overcome.

THAAD

Earlier BMD efforts, such as the Army's Patriot PAC-2 and BMDO's High Endoatmospheric Defense Interceptor program, have contributed to THAAD development. Technology improvements resulting from these programs include (1) improved data and signal processors, (2) better ground-to-missile communications, and (3) enhanced infrared sensors. In addition, hit-to-kill interceptors, which destroy missile warheads through collision, have been demonstrated.

However, successful development of THAAD will require overcoming a number of program challenges. In September 1992, the THAAD program awarded a 4-year contract for the demonstration and validation phase of development. The challenges include (1) producibility of TMD-GBR solid state radar antenna modules, (2) integration of the missile and radar, (3) lethality against warheads with submunitions, (4) THAAD kill vehicle integration, and (5) THAAD kill vehicle software development.

Producibility of TMD-GBR Solid State Transmit and Receive Modules

BMDO is using solid state transmit and receive radar modules for the radar antenna of the mobile TMD-GBR. The non-mobile Ground-Based Radar for national missile defense is using traveling wave tube technology. BMDO chose different technologies because (1) the lighter, solid-state modules facilitate meeting THAAD's mobility requirement and (2) the production of solid-state modules for both the theater and national radars would overwhelm the production base.

Even so, officials in the TMD-GBR Technology Division assess the production of the more than 68,000 modules required for three radars and spares as among the most challenging areas during the TMD-GBR's demonstration and validation phase. According to these officials, manufacturers have never demonstrated the production rate required to meet the demonstration and validation schedule. In addition, the TMD-GBR Deputy Project Manager told us that the TMD-GBR contractor anticipates an initial 40- to 50-percent defect rate. While a reduced defect rate is likely as the contractor gains experience, a 40-percent rate would require producing and testing over 110,000 of the modules to produce 68,000 acceptable units.

Integration of the THAAD Missile and Radar

The THAAD system contractor is responsible for developing all THAAD ground elements except the TMD-GBR, which is being developed by another contractor. The radar is critical for successful operations. Separately developing and then successfully integrating the missile and radar software, data and signal processors, and communication links will be a major challenge. Until initial radars and missiles are available for testing as a system, success in this effort will be difficult to assess.

Lethality

Destruction of warheads containing certain submunitions is a critical challenge for the THAAD program. The problem is similar to that faced by the PAC-3 program. A warhead containing chemical or biological submunitions may be difficult to fully destroy at a sufficient range to prevent damage from them. Ongoing analyses and ground testing, together with flight tests beginning in late 1994, will demonstrate whether they have been successful.

THAAD Kill Vehicle Integration

According to the THAAD Project Manager, building a THAAD kill vehicle for testing is a challenge because of the limited time available to develop an integrated design for such vehicle components as the (1) seeker, (2) sapphire seeker window, (3) protective window shroud, and (4) avionics hardware. The kill vehicle integration schedule is further compressed because the components must be produced and assembled before flight tests begin in late 1994. The THAAD project manager stated that parallel designs and dual sources for these components are intended to lessen kill vehicle integration risk.

THAAD Kill Vehicle Software

BMDO also assesses development of the THAAD kill vehicle software as a challenge because of the short time before the first flight test in late 1994. The THAAD missile will have 70,000 to 100,000 lines of computer code. The areas of concern are the (1) integration of available code from earlier programs for reuse with THAAD; (2) development of new software algorithms for target selection, aim point selection, and battle management; and (3) integration and testing of the software prior to flight tests. BMDO reports that the innovative nature of the new algorithms makes it difficult to accurately predict the time and cost needed to develop them.

Other TMD Development Programs

Other programs are under consideration to supplement PAC-3 and THAAD capabilities. These include Brilliant Eyes, Corps Surface-to-Air Missile, and ship-based TMD systems. The U.S.-Israeli Arrow program has been funded by SDI but is not part of DOD's deployment plans.

Brilliant Eyes is a space-based surveillance sensor that could be used to support TMD weapon systems. Brilliant Eyes would carry a suite of sensors intended to acquire small targets, track the incoming targets, and discriminate real targets from debris and decoys. Because the spaced-based Brilliant Eyes could see beyond the horizon, it could cue the TMD interceptors to a precise location in the battle space, well before attacking missiles could be detected by the TMD-GBR. However, relief from the ABM Treaty may be required for the United States to deploy Brilliant Eyes. (Brilliant Eyes is discussed in the next chapter.)

The Corps Surface-to-Air Missile is to be an air transportable, rapidly deployable, highly mobile air defense system. Its mission is to destroy both aircraft and tactical missiles. Its employment is to range from a relatively stationary role in rear areas to a highly mobile role when defending a moving force. Corps Surface-to-Air Missile also will replace the Hawk air defense system. However, because the proposed system is in a very early phase of development (concept definition), requirements have not been defined. DOD does not plan to approve a program cost estimate until after a concept has been selected.

DOD's Joint Requirements Oversight Council validated the mission need for a sea-based TMD capability in December 1992. According to BMDO, deploying the capability on ships offers the potential advantage of getting a capability in theater faster than if transporting ground-based systems from the United States or other locations. The National Defense Authorization Act for Fiscal Year 1993 specified that not less than $90 million should be made available for exploring promising concepts for naval TMD. The Navy is exploring a near-term, lower tier defense that would modify its existing Aegis weapon system and Standard Missile. It is also looking at varied options for a more advanced, upper tier defense. Navy has proposed plans to DOD for sea-based TMD that could require up to $3.6 billion in fiscal years 1994 through 1999.

Arrow is a U.S. and Israeli missile development program intended to meet Israeli requirements for anti-tactical ballistic missile defense. DOD does not have an operational requirement for this missile and has no plans to buy it. The SDI program has funded the Arrow development.

National Missile Defense

The mission of the national missile defense (NMD) system is to protect the United States from limited ballistic missile attacks—whether deliberate, accidental, or unauthorized. BMDO projects a need for Ground-Based Interceptors at six sites to give full, confident coverage of the United States. The Congress has restricted an initial deployment to a single site with 100 interceptors to comply with existing terms of the ABM Treaty.

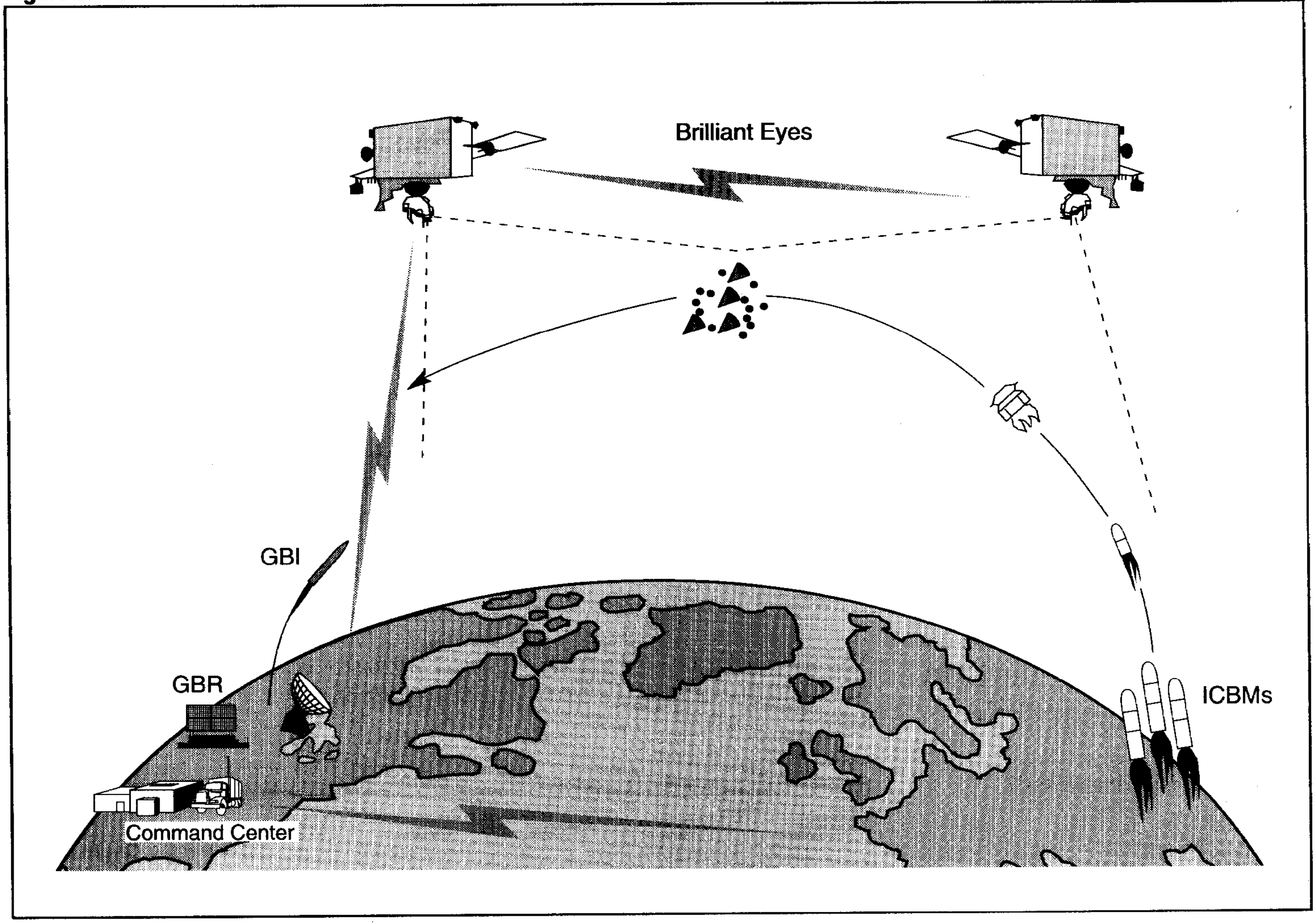
BMDO said it will cost $21.8 billion in then-year dollars to develop and produce a treaty-compliant BMD system, to be deployed at Grand Forks, North Dakota, in 2004. This estimate includes $4.3 billion for the Brilliant Eyes satellites. However, an official determination on whether Brilliant Eyes is treaty-compliant has not yet been made. Five additional sites needed to fully protect all 50 states would cost another $12.5 billion, with costs ranging from $1.1 to $4.8 billion per site.

Description of NMD Architecture

Figure 5.1 shows the architecture for the NMD system. NMD currently includes the following four elements:

- Brilliant Eyes (BE);
- Ground-Based Radar (GBR);
- Ground-Based Interceptor (GBI); and
- battle management/command, control, and communications (BM/C3).

Figure 5.1: NMD Architecture



These elements perform three primary functions—sensing, battle management, and intercept. Sensing involves detecting a launch, tracking the thrusting booster, discriminating actual warheads from decoys and other objects, and passing this information to the battle manager. Battle management coordinates the launching of interceptors to destroy the nuclear warheads. Intercept involves launching the interceptor, directing it to a point in space, and maneuvering to collide with the warhead.

A typical intercept would occur as follows. An early warning satellite would alert BE of booster launches. BE would acquire the boosters and continue tracking throughout the missile trajectory. During the midcourse phase, BE would cue GBR to acquire and track threat clusters containing reentry vehicles and decoys. BE and GBR would track the threat cluster, generate track information, and provide the information to the BM/C3 center. The sensor or BM/C3 center would also determine which objects in the threat cluster are targets and which are decoys. The tracking and discrimination information would then be passed to the interceptor through the BM/C3 center. The sensor would continue tracking the cluster and pass updates through the BM/C3 center to the interceptor during its flight toward the threat cluster.

The BM/C3 center would launch an interceptor toward a predicted intercept point based on the information it had received from the sensors. When the interceptor nears the threat cluster, the infrared seeker in the nose of the interceptor collects information about the relative positions and infrared signatures of the cluster objects. The interceptor then selects the target that matches the description provided by the sensor. The interceptor then maneuvers into the path of the target and the collision destroys the target.

Estimated Acquisition Costs and Schedule

The NMD program still has three broad phases to go through before the site at Grand Forks is operational. These phases and their details are shown in table 5.1.

Table 5.1: Acquisition of NMD

Dollars in billions

Defense systems acquisition management phase	Estimated cost	Begin phase (fiscal year)
Demonstration and validation	$6.5	1991
Engineering and manufacturing development	7.0	1998
Production	8.3	2002
Total	**$21.8**	

BMDO plans to spend $6.5 billion and 5 more years to demonstrate that the system elements and their component technologies are ready to enter engineering and manufacturing development. If successful, a decision would be made in 1998 on approving and funding this next phase.

Major Issues Relevant to Approving and Funding Demonstration and Validation Phase

There are several factors decisionmakers should weigh in deciding whether and how quickly to develop NMD. These issues are ABM Treaty restrictions; whether threats justify the costs and schedule; and remaining uncertainties in the program's cost, schedule, and performance.

ABM Treaty Restrictions

An impediment to building a system that will defend all 50 states is the ABM Treaty. It limits each country to 100 interceptors at a single site, located at either the country's capital or one of its intercontinental ballistic missile (ICBM) fields. The United States selected the ICBM field at Grand Forks, North Dakota, as its site. This initial site is only the first step toward deployment of the full NMD system. One site of 100 interceptors cannot protect against some of the more stressing threats projected.

Since the NMD system is being designed to protect the United States from limited numbers of nuclear ballistic missiles, it must destroy all nuclear warheads launched against the United States, not just some of them. Threats DOD is designing against currently include up to 200 nuclear warheads, launched from either sea or land, and from various distances and locations. Threats are being reevaluated by the Joint Chiefs of Staff, and maximum design threat numbers from 20 to 200 warheads are being considered. After the turn of the century, the threat could include intentional attacks from third-world countries.

According to BMDO, the BE satellites are needed to improve the projected effectiveness of the NMD system. They provide interceptors the maximum time to fly out from a given site and thus provide the maximum defended area possible from a given deployment of GBIs. Five additional sites would also be needed to provide confident, complete coverage of the United States against all limited ballistic missile threats, including ballistic missiles launched from submarines operating in places other than close to Russian borders or in waters north of the United States.

However, relief from the ABM Treaty may be required to deploy BE satellites and will be required for additional sites. The Congress urged the executive branch to approach Russia and other countries of the former Soviet Union on changing the treaty to permit deployment at other sites. While talks were started, they are currently in abeyance while the administration reviews its national security strategy, according to DOD representatives.

The timing and content of any potential agreements cannot be reliably predicted.

Threat

The NMD program is being designed to protect the United States from limited ballistic missile attacks—whether accidental, unauthorized, or deliberate. The countries currently possessing long-range ballistic missiles with the potential of reaching the United States are China, France, Great Britain, and the former Soviet Republics of Russia, Belarus, Kazakhstan, and Ukraine, according to the intelligence community. More nations could have the capability after the turn of the century.

Accidental launches are unintentional. They could be a result of human error or technical malfunctions. Scenarios considered by BMDO would likely involve a single ICBM or submarine-launched ballistic missile (SLBM) carrying 1 to 10 warheads.

Unauthorized launches are deliberate launches initiated outside the normal command structure. They could result from political instability or unreliable launch control personnel. The estimated number of missiles that could be launched from an unauthorized launch is bounded by the number of missiles under the command of a single individual. Such scenarios could consist of a group of 10 ICBMs carrying about 100 warheads or a submarine load of SLBMs carrying up to 200 warheads.

Deliberate limited attacks would contain a small number of warheads. The intelligence community estimates that over the next 10 years several third-world nations could develop the technical knowledge and establish the infrastructure required to develop ICBMs.

Program Uncertainty

The NMD program is currently being reviewed. A new program plan is not yet defined due to the changes expected from the ongoing bottom-up review in DOD. Results of the DOD review should provide the basis for preparing a new program plan for submission to the DAB and the Congress.

Past program changes—which were responses to technical, funding, mission, and policy changes—have led to frequent revisions of program plans. Remaining technical uncertainties in the NMD elements may cause significant future architecture changes as the demonstration and validation phase proceeds. Estimates of costs, performance, schedule, and risk will not be available until after DOD's bottom-up review and likely will not be sufficiently defined for a DAB system review until next year, according to schedule information DOD has provided.

Technical Progress and Remaining Technical Issues for Each Element

BMDO has made progress in developing the technology for each of the four NMD elements—BE, GBI, GBR, and BM/C3. However, additional progress must be demonstrated during the ongoing demonstration and validation phase before these elements are ready to enter engineering and manufacturing development in 1998.

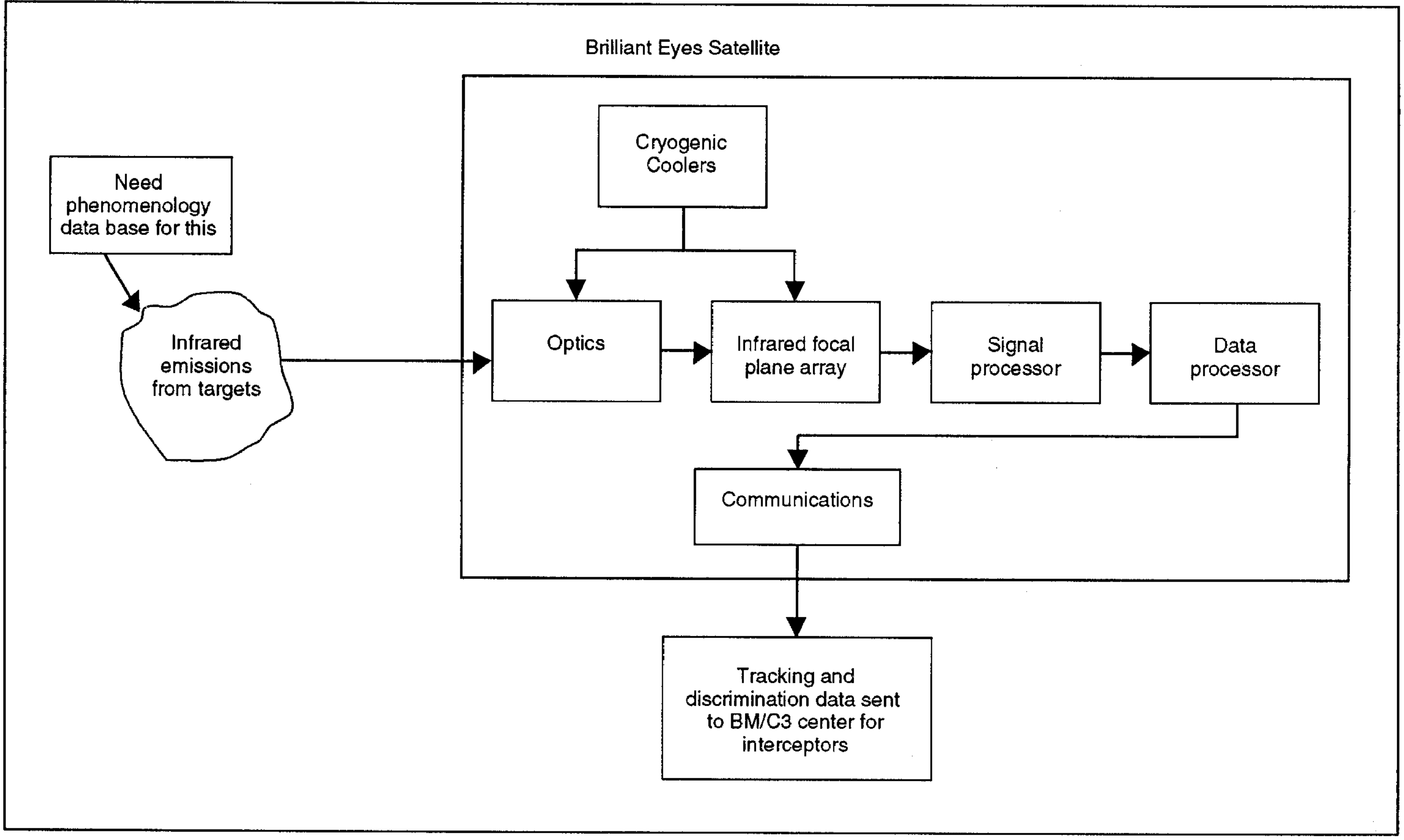
Demonstrating that these elements will work will not be easy. There are a number of difficult problems that must be solved during this 5-year period, including producibility of some hardware components, development of software needed to discriminate reentry vehicles from other objects, and integration of the various elements into a single system.

BE Technical Progress and Remaining Problems

BMDO is developing component technologies needed to build BE. The current plan is to spend $1.08 billion over the next several years to demonstrate key component technology in ground tests and space experiments. Prototype satellites built with more readily available technologies will also test critical functions such as "stereo" tracking, which uses two satellites to provide three-dimensional track information. BE is needed to extend the reach of GBIs and to cue the GBR.

The toughest remaining problems in developing and building operational satellites, according to DOD assessments, include the cryogenically cooled focal planes and space-to-space communications components. The system integration, assembly, and test of components to perform critical functions is also in the top risk grouping for BE development tasks. A simplified view of the BE's components is shown in figure 5.2. Component progress and remaining risks are described below.

Figure 5.2: BE Components



BMDO has demonstrated progress in fabricating and polishing radiation-hardened mirrors made of beryllium, but all performance goals have not been met. Lesser threats may permit use of a different material, but its suitability must still be proven. Additional work is required on radiation-hardened filters and coatings and on the means to clean the cryogenically cooled mirrors.

Focal planes that can detect long-wave infrared emissions from reentry vehicles have been the subject of a progression of projects to develop needed performance, manufacturing quality, and lower cost. The 1990 design change to BE altered focal planes sufficiently to require additional technology development. Focal plane technology remains a top risk.

The long-life cryogenic coolers needed to keep BE's focal planes and mirrors at operating temperatures as low as minus 441 degrees Fahrenheit (10 degrees Kelvin) remain a top risk. The baseline BE design requires focal plane cooling to minus 387 degrees Fahrenheit (40 degrees Kelvin); the alternate, back-up focal plane design requires minus 441 degrees Fahrenheit (10 degrees Kelvin). Initial Phase I system plans called for a performance test and the first 3 years of an extended life test to have been completed by now. Demonstrated performance has not met requirements, and life tests still must be run.

Progress has been made in the development of radiation hardened signal and data processor components. However, additional work is needed to get to the required performance. The reduced radiation threat for GPALS may permit BMDO to adapt commercial data processor components, if sufficient fault tolerance can be added. This could yield savings in hardware and software.

Communications between BE satellites requires smaller, lighter weight components than were planned in earlier, larger satellite concepts. Manufacturing process technology to provide a low cost, reliable transmitter/receiver remains a top program risk.

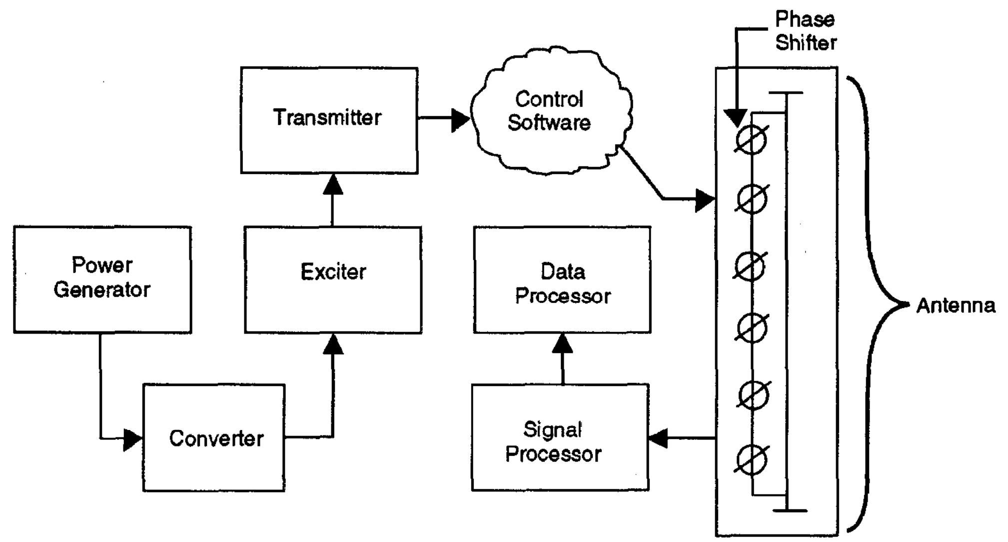
Other significant technology tasks include (1) a large reliable phenomenology data base on the targets and backgrounds the BE is likely to see and (2) the algorithms and software to enable automated target discrimination and tracking. Two major space experiments are scheduled over the next few years to provide better and more comprehensive data and a design basis for reliable algorithms.

GBR Technical Progress and Remaining Problems

BMDO is developing the component hardware and software technologies needed to build the GBR. The current plan is to build and test two radars: one at Kwajalein Missile Test Range in the Central Pacific and a second at Grand Forks, North Dakota. Production of the second radar is contingent on exercising an option in the current contract. The GBR is to perform target tracking, discrimination, and kill assessment functions for the NMD system.

According to BMDO assessments, the toughest remaining problems are to (1) demonstrate that certain radar components can be manufactured in large quantities at reasonable cost, (2) develop the software algorithms needed to perform discrimination and kill assessment, and (3) overcome radar systems engineering problems. A simplified illustration of the GBR components is shown in figure 5.3. Component progress and remaining risks are explained below.

Figure 5.3: GBR Components



BMDO has demonstrated progress in fabricating the radar's direct current "step down" converters and phase shifter assemblies. These converters reduce or "step down" the power from the main generator to a more usable level, which is then sent to the various radar components. Phase shifters electronically steer the radar beam in a particular direction and can be oriented to listen for the returning signal.

The production of large quantities of components remains a challenge. To mitigate this risk, the prime contractor is evaluating alternative vendors and building and testing pilot arrays. The contractor is taking steps to maximize design producibility and maintain close control of the factors driving cost and yield.

Discrimination and kill assessment with a phased array, X-band radar has long been a technology hurdle for BMDO—in particular, development of the algorithms. Current algorithms are designed to meet the original kill assessment requirements, which were based on determination of a hit or a miss. However, the radar is now required to determine the probability of kill for intercepts that do not result in total destruction of the target. The radar must also determine the next object to shoot at. Both of these functions require more complex algorithms.

The GBR project office is primarily using the prime contractor, another contractor, and a research laboratory at a major university to address the discrimination problem. BMDO officials state that progress has been made in developing these algorithms.

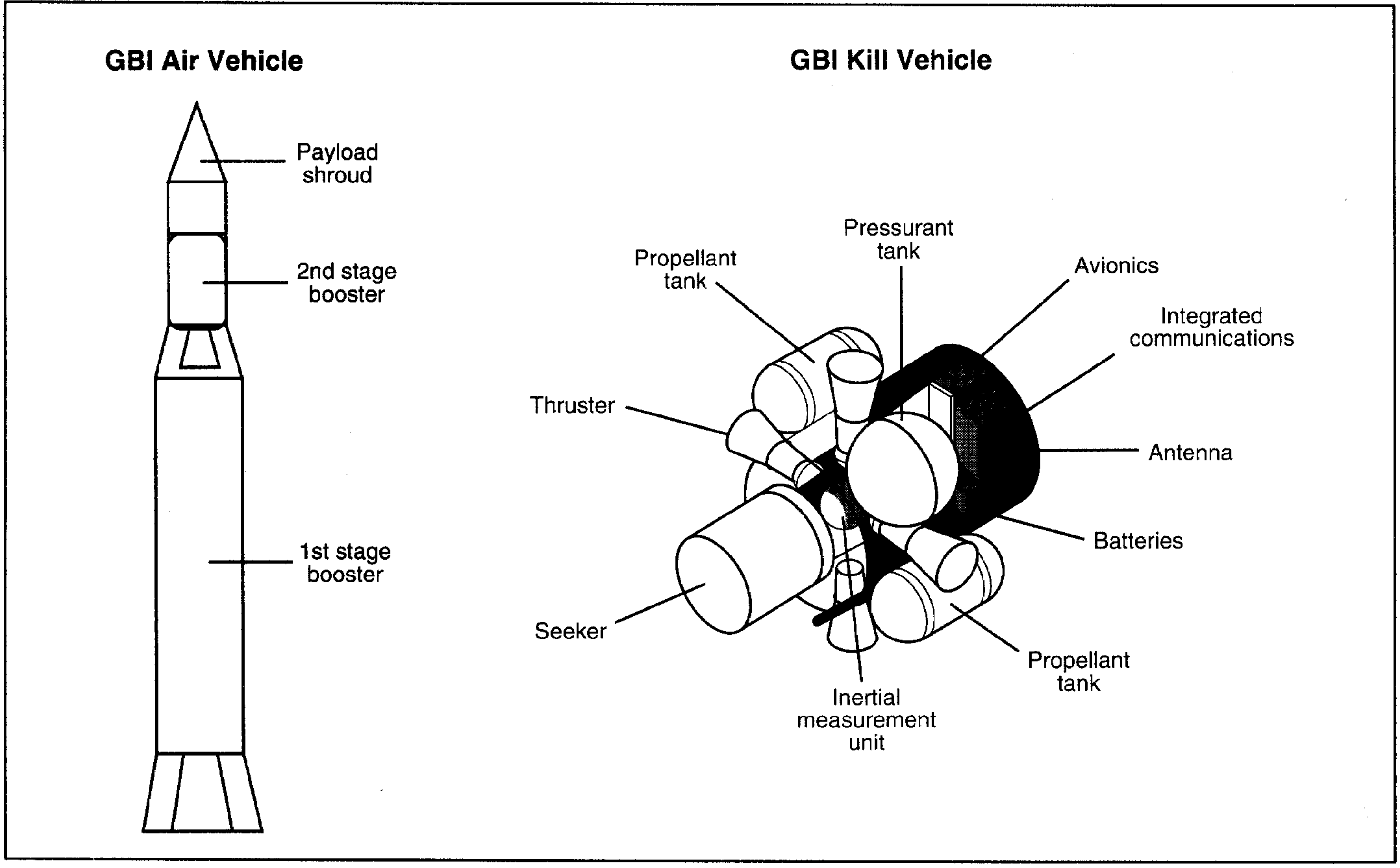
Systems engineering also presents a major challenge for the GBR program. All radar components must be integrated, assembled, and tested. Once assembled, the radar has to be properly aligned and calibrated. The project office intends to make maximum use of systems engineering work performed for the TMD-GBR. In addition, the research laboratory mentioned earlier is to independently assess and review the prime contractor's efforts, providing alternative solutions and approaches if needed.

GBI Technical Progress and Remaining Problems

BMDO is developing the hardware and software technologies needed to build an operational GBI, which is the weapon to be used for destroying incoming enemy warheads in the NMD system. These interceptor technologies have progressed further than other NMD elements because the GBI program has built on the technology advances of earlier BMD research, technology base programs, and the Exoatmospheric Reentry Vehicle Interceptor Subsystem program. Two prototype interceptors were flight tested during the program, with one resulting in a direct hit of a reentry vehicle in space and the other resulting in a near miss. The demonstration and validation program to ready GBI for engineering and manufacturing development is estimated to cost about $1.6 billion.

The key technical issues remaining to be resolved before entering the next phase are (1) readiness for quick launch after long-term dormancy, (2) producing the seeker focal plane arrays, (3) improving techniques for selecting reentry vehicles from decoys in the last few seconds of flight, and (4) most importantly, integrating the GBI with the GBR and BM/C3 system. A simple illustration of key interceptor components is shown in figure 5.4.

Figure 5.4: GBI Components



BMDO demonstrated interceptor dormancy for over 1 year during the program. However, the operational concept is for the GBI to remain dormant, yet constantly ready for a quick launch, for a period of up to 10 years. The remaining technical challenge is to keep the interceptor's liquid fuel and coolant tanks continuously full or "topped off." The liquid in these tanks tends to evaporate and periodically has to be replaced. The interceptor would not be available for launch during refueling operations.

In the manufacturing area, BMDO has identified producibility risks for the interceptor's seeker. Two alternate infrared seeker detector technologies are being pursued: mercury cadmium telluride and enhanced silicon. Although production yields of mercury cadmium telluride detectors has improved from less than 10 percent to over 50 percent, yields and uniformity have not been validated with integrated seekers to the point that cost and performance goals can be met. The primary remaining challenge for enhanced silicon detectors is the need to cool them to extremely low temperatures.

Improving techniques for discriminating reentry vehicles from decoys has long been a challenge for BMD. Although discrimination is to be done primarily by an external sensor, the interceptor demonstrated basic techniques for choosing targets among decoys, using information that would be supplied from a BM/C3 center, during two flight tests in the Exoatmospheric Reentry Vehicle Interceptor Subsystem program. The technical issue to be resolved in the demonstration and validation phase is to expand the frequency range at which the GBI's seeker operates so that it can assist the external sensor in selecting the reentry vehicle from among decoys in the last few seconds of flight. Producing the modified seeker is difficult due to the precise control and purity of materials required during the manufacturing process.

Finally, the most important goal to be accomplished before entering engineering and manufacturing development is to integrate the GBI with the GBR and BM/C3 and operate them as a system. The GBI, GBR, and BM/C3 are to be integrated for a system test during demonstration and validation that includes intercepting simulated enemy reentry vehicles over the Central Pacific.

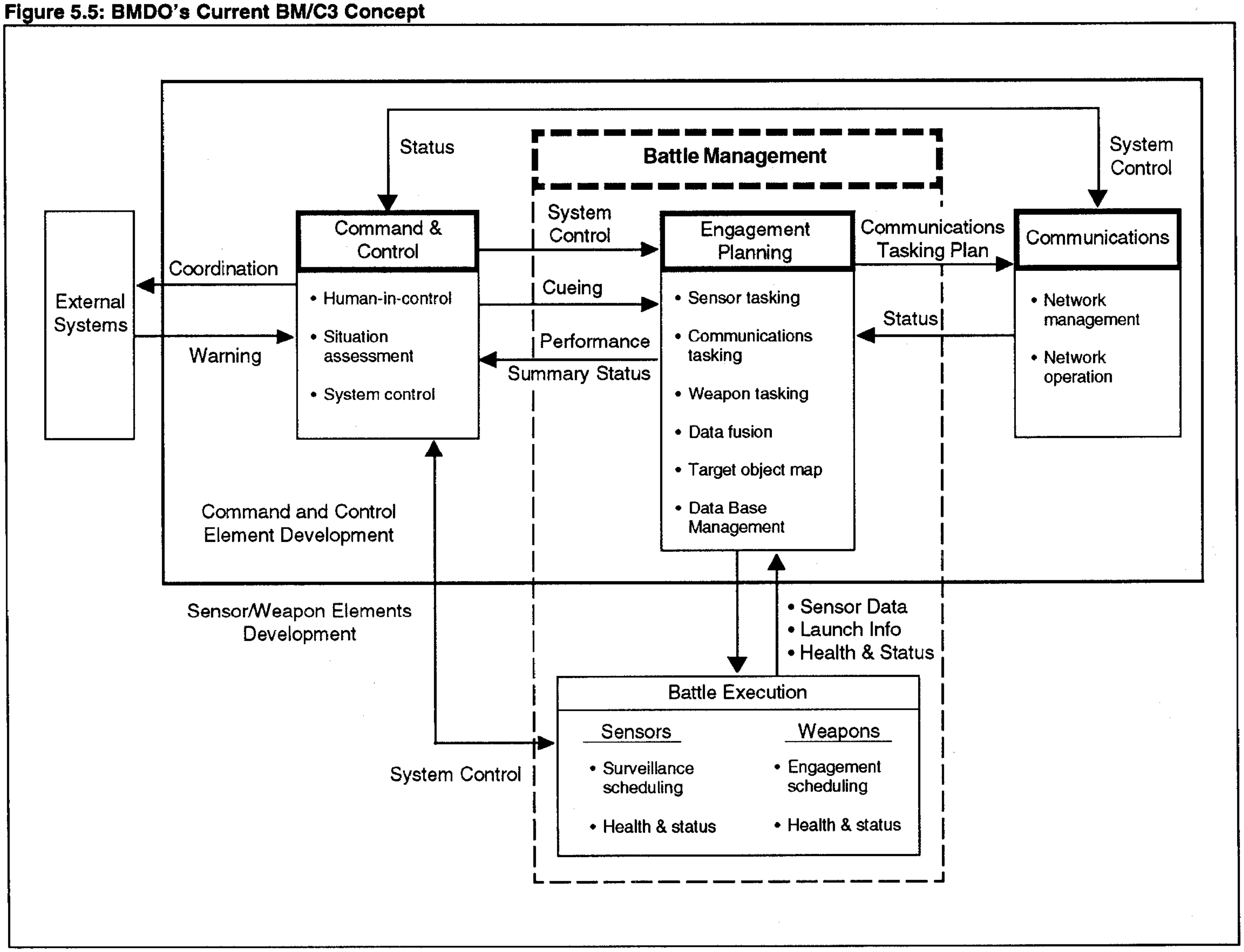
Progress and Issues Involving BM/C3

BM/C3 commands, controls, and coordinates the NMD's Command Center, GBI, GBR, and BE. Historically, it has been characterized as the "long pole in the tent." BM/C3 is what makes sensors and interceptors behave in the way they are intended to fulfill missions and achieve desired performance. BM/C3 consists of the flow and processing of information by computers, displays, and various communications links and is primarily implemented through software.

Until the Missile Defense Act of 1991, BMDO's approach to BM/C3 was a broad-based research effort in six areas: processors, algorithms, communications, networks, system engineering, and security. Since the passage of the act, BMDO has been focusing on BM/C3 efforts that directly support the acquisition of the NMD system—it is no longer a broad-based research effort.

BMDO's BM/C3 concept is "centralized control and distributed execution." The commander, with automated assistance, will decide on courses of action, but the actual functions—sensing, tracking, target assignment, and etc.—will be executed by operations centers. Figure 5.5 depicts BMDO's current BM/C3 concept.

Figure 5.5: BMDO's Current BM/C3 Concept



BMDO has not yet finalized the BM/C3 architecture. BMDO has awarded three contracts to provide an innovative approach and process for the development of BM/C3.

Progress

BM/C3 strategies and technologies for NMD have progressed because of (1) major program changes that have mitigated some BM/C3 technical risks, (2) change in BM/C3 management, (3) the development of an information architecture, (4) BM/C3 technology advances, and (5) other defense and commercial advances in the six research areas mentioned above.

Major program changes, such as the move from the Phase I mission of deterring a massive Soviet attack to protection against limited attacks, mitigated some BM/C3 development risk. These changes reduced the amount of data needed to be processed and, consequently, reduced the dependence on massive parallel processing. Therefore, success no longer hinges on advances in parallel processing and the development of complex parallel algorithms.

Risks have also been mitigated in the development of BM/C3 because BMDO has redirected its BM/C3 strategy. For example, we reported in February of 1992[5] that management of BM/C3 activities was distributed among elements. Subsequently, BMDO set up a separate office to centrally manage BM/C3 architecture and technology issues rather than distributing the responsibility.

Further, BMDO is developing a generic information architecture—the heart of a well-defined system architecture—to ensure understanding of information flow among subsystems. An information architecture provides an informational view of a system, i.e., it describes the information needed by functions—sensing, intercepting, battle managing, commanding, and controlling—to perform processes at the various NMD locations. This information architecture will be a major driver, according to BMDO officials, in finalizing BM/C3 and system architectural definitions.

Technology advances include BMDO specific advances and generic advances in system and software engineering. One of BMDO's more notable advances in BM/C3 software and security technology is its completion and implementation of its Trusted Software Development Methodology. Initiated in 1988 and developed in concert with the National Security Agency, the Trusted Software Development Methodology defines a

[5]Strategic Defense Initiative: Changing Design and Technological Uncertainties Create Significant Risk (GAO/IMTEC-92-18, Feb. 19, 1992).

standard process for developing secure and high-quality software. Additionally, BMDO is also making progress in the development of software engineering environments. BMDO is currently developing a highly sophisticated framework called the Strategic Defense Development System, which is expected to integrate software developed by multiple vendors using various automated tools.

Generic advances include technologies needed for software engineering environments, advanced programming languages, and the availability of high-quality commercial-off-the-shelf products.

Remaining Challenges

Although BMDO has made progress developing BM/C3 technologies and concepts, it still has formidable challenges. First, BMDO goals call for the design and development of an open, flexible, BM/C3 architecture that can be modified to include new technologies and new requirements as needed. However, this is no easy task; BM/C3 is dependent on many different technologies. Prematurely committing to inadequate existing technologies or depending on the future success of immature or unavailable technologies increases the risk that the system will not work as intended or will not be able to easily evolve. Second, as systems become increasingly complex, successful software development becomes more difficult. The demand for software has outstripped the available engineering processes, procedures, and tools needed to effectively develop and test such complex software—especially trusted software.

Finally, individual technologies alone cannot support the system. If and when BM/C3 technologies are proven, BMDO has to integrate them to provide the data-processing and communications capabilities needed; this is a technically demanding endeavor especially since technologies are progressing at different rates. Therefore, the immaturity of some critical technologies and the necessity of integrating these technical solutions early in the program provide a challenge for BMDO. It must manage the development of a system dependent upon technologies of various maturity levels while planning for technology insertion as each becomes available. Far simpler, better understood real-time systems have failed.

BMDO's Role in Defense and Commercial Technology Transfer

DOD's research and development goal is to advance the technology base for U.S. national defense missions—one of which is BMD. As requested by the Congress in 1988, DOD describes its research and development strategy through yearly critical technology plans. In addition, DOD research and development can be applicable to the commercial sector. The Congress requires BMDO and other research and development programs to facilitate the technology transfer process. BMDO does this through its BMD Technology Applications Program.

Defense Critical Technology Plans and Technology Transfer Legislation

To ensure the continuing military superiority of the United States and to maximize results from DOD's research and development investment, the Congress in Public Law 100-456 required that DOD submit a Critical Technologies Plan on an annual basis. Other laws provide for technology transfer.

Public Law 100-456, the National Defense Authorization Act for Fiscal Year 1989, required the annual plan to identify "the technologies most essential to develop in order to ensure the long term qualitative superiority of United States weapon systems." For 3 years, DOD submitted a Critical Technologies Plan, which included 21 technologies. In 1992, in part to respond to the end of the Cold War, DOD consolidated some of these into 11 key technology areas and presented them in the Key Technologies Plan.

Throughout the 1980s, legislation and executive orders have encouraged technology transfer by providing incentives to researchers as well as by having agencies track and report on their transfer activities. For example, the Federal Technology Transfer Act of 1986 directed that each government laboratory director promote technology transfer in various ways such as including them in laboratory descriptions and employee promotion policies. It also provided financial incentives to encourage federal scientists and engineers to patent, license, and commercialize their research. Taking this process a step further, the National Defense Authorization Act of 1986 stated that the Secretary of Defense shall "encourage to the extent consistent with national security objectives, the transfer of technology between laboratories and research centers of the Department of Defense and other Federal agencies, State and local governments, colleges and universities, and private persons."

BMDO's Role in DOD's Key Technologies

DOD's Key Technologies Plan presents its Science and Technology Strategy, which is based upon the following seven thrusts:

- global surveillance and communications,
- precision strike,
- air superiority and defense,
- sea control and undersea superiority,
- advanced land combat,
- synthetic environments, and
- technology for affordability.

DOD identified the following 11 key technology areas critical to these seven thrusts:

- computers,
- software,
- sensors,
- communications networking,
- electronic devices,
- environmental effects,
- materials and processes,
- energy storage,
- propulsion and energy conversion,
- design automation, and
- human-system interfaces.

For each technology area, top-level technology goals reflecting the needs of the thrusts are presented for the next 12 years. BMDO directly funds activities in all areas except design automation and human-system interfaces.

BMDO Commercial Technology Spin-Off Program

BMDO's research applicability reaches beyond DOD. Much may be applicable to the commercial sector as well. BMDO's technology transfer effort—the BMD Technology Applications Program—responds to congressional direction to maximize research investments by facilitating technology exchange. Its stated purposes are to (1) stimulate innovative research; (2) provide information about BMD-developed technologies to U.S. corporations, small businesses, universities, entrepreneurs, and other government agencies; and (3) facilitate the exchange of information among the developers of the technologies and those interested in using them. BMDO has had some successes in the less than 6 years of its technology transfer program.

Key Elements of the Program

The Technology Applications Program sponsors a variety of activities. These include an on-line data base, quarterly and annual reports, expert panels, demonstration projects, and coordination with other government technology transfer groups.

BMDO's program administers an on-line data base that can match technology providers with those who have the need for certain technologies or the resources to commercialize. The data-base currently contains about 2000 spin-off ideas. The ideas are categorized as research in-progress, developing technology, or maturing technology. Over 20,000 individuals have been certified to access the data-base abstracts on ongoing research. When a user expresses an interest in obtaining more information on an ongoing research effort, the program staff serve as the intermediary and provide the appropriate contact, usually the principal investigator. The Technology Applications Program staff follow up to see if the information was useful.

Publications serve as another outreach method. The Technology Applications Report is published annually and reports on successful commercialization efforts as well as those on the horizon. The High Technology Update is produced quarterly. This publication features articles on successful ventures, technologies that are being pursued by more than one company, and other program activities such as expert panel meetings and demonstration projects.

The Technology Applications Program works with panels of volunteer experts from academia, government, and the business community who confer with those BMD researchers wishing to commercialize a technology or let the research community know what is needed. For example, a panel on the technology requirements for biomedical imaging was held at Georgetown University in 1991. This event provided an opportunity for researchers to express what they needed and hoped to see coming out of the labs. Ongoing technology application review panels include power, electronics, optics, biomedical, and materials. Ad hoc panels have been put together on other technology areas such as superconductivity and sensors, with environmental monitoring and remediation in planning.

Several demonstration projects are underway. For example, in New Mexico, federal labs, state organizations, and the University of New Mexico have been working together to commercialize federal technologies at BMD-supported laboratories with significant potential to enhance the state economy. Several promising BMD technologies were selected from a larger group and commercialization strategies are currently being implemented.

Staff from the Technology Applications Program participate in a variety of activities that include the Department of Commerce's Interagency Technology Transfer Committee, the National Technology Transfer Center, the Federal Laboratory Consortium, and others. They also coordinate with other military components and share their techniques and lessons learned throughout the technology transfer community.

Commercial Applications

The 2,000 ideas currently in BMDO's data base are in various stages of maturity. Some are just emerging while 97 have already or will within the next year result in commercial products. Others have come to fruition and have been made part of the public domain, i.e., for use without charge. In addition to commercial products, BMD research has contributed to the formation of 22 spin-off companies, 112 patents, and 8 cooperative research and development agreements as of April 1, 1993.

BMDO's Technology Applications Program office publishes a report annually that highlights the activities of companies, universities, and national labs that have undertaken efforts to commercialize breakthroughs made while doing BMD-funded research. We identified instances where BMDO asserted that products were either on the market or were about to be marketed. We contacted the identified company official or researcher to confirm the status of the commercialization efforts and that the BMDO effort in some way advanced the commercialization effort. In all cases, the officials confirmed the claims. We also discussed the connection between BMDO-funded research and commercial spin-offs with individuals involved in other commercialization efforts. In general, they said that BMDO's outreach efforts have been effective. However, because technology is fungible, quantifying BMDO's—or any agency's—contribution to a given technology area, versus that of other research endeavors, is difficult.

Several commercially available products have evolved from BMDO technologies. For example, silicon-on-insulator wafers have been manufactured for several U.S. semiconductor and automotive companies for high performance electronics for industrial, computer, automotive, and consumer applications. Multilevel-secure computers and networks have been developed that provide protection of highly sensitive commercial data or classified defense and intelligence information with various levels of security, e.g., top secret, confidential, etc. A microprofile metrology system has been developed that measures the surface roughness of optical elements and the surface finish of computer hard disks that is critical to their performance. A magnetic bearing compressor, used in refrigerant recovery systems such as in automobiles, has been developed that increases power and efficiency and eases maintenance.

In addition, several commercial products or processes could emerge from BMDO technologies within the next few years. For example, the Railplug could replace sparkplugs for conventional engines and could be used to develop lean-burn engines. High-power, bipolar batteries could provide power for electric and hybrid vehicles and be used in battery packs for soldiers, laptop computers, and other continuous energy needs. High-power, short-pulse microwave generators could be used to remove hazardous chemicals from the atmosphere. The Sullivan Liquid Ceramic Process could be applied to ceramic rollers for manufacturing automobile engines, stamping beverage cans, and manufacturing surgical gloves.

BMDO technologies have also resulted in some commercially available, public domain software. For example, software for improving cooling capacity helps computer chip designers to model how to increase the cooling capacity of any semiconductor, especially heat producing high-power transistors used to amplify signals for communications. Also, "View" image processing software has a variety of applications in image and signal processing, including using View to enhance the images of cells and chromosomes in molecular biology research.

In addition to these examples, some research has led to products that can be used in more than one area. For example, work done at Los Alamos National Laboratory on directed energy weapons resulted in a linear accelerator design that is being used to treat cancer patients and detect bombs. An insulator material developed for rocket nozzles has uses in the aerospace and construction industries as well as in pollution control devices and hip implants.

Planned Use of Launch Vehicles

Many BMDO experiments and tests are conducted in the upper atmosphere and space, which is the intended operating environment for many of its sensors and interceptors. BMDO has proposed 194 sub-orbital and orbital flights between 1994 and 1999. Most of these, 175, will be sub-orbital flights that use one or more stages from retired ICBMS or SLBMS. BMDO has proposed 19 orbital missions.

Missile stages from the retired Minuteman ICBMS are the most often used stages in BMDO's plans. BMDO is the predominant user in DOD of retired ICBMS and SLBMS, with about 95 percent of planned DOD sub-orbital launches.

Planned Use of ICBMs and SLBMs for Sub-Orbital Launches

BMDO plans to use retired air defense missiles, short-range ballistic missiles, ICBMS, and SLBMS to build sub-orbital launch vehicles. Each launch vehicle is made up of a combination of stages from these missiles, with at least one stage from a retired ICBM or SLBM.

BMDO requests most of the sub-orbital launch vehicles it needs from the Air Force's Reentry System Launch Program, which is designated as the DOD source for all DOD deactivated weapons system missile stages. This program refurbishes, modifies, and combines a variety of missile stages and provides them to government customers such as DOD and the National Aeronautics and Space Administration. The resulting launch vehicles range from one to four stages. Examples of resulting launch vehicles include the Aries and Starbird. Since its formation in 1972, the program's mission has been to supply launch vehicles for research and development programs. Most program activity involved Air Force and Navy reentry vehicle testing. However, reentry vehicle development has slowed and BMDO is currently its primary customer.

In 1986, BMDO initiated the Strategic Target System program to provide launch vehicles for testing BMD projects. This program was initiated to develop a launch vehicle to augment diminishing quantities of retired Minuteman I systems. It utilizes decommissioned Polaris SLBMS. The first launch was made in February 1993 from the Pacific Missile Range, on Kauai, Hawaii.

Sub-orbital flights attain altitude to reach into space, generally above 100 kilometers, but do not attain earth orbit. DOD sub-orbital research and development missions include exoatmospheric experiments and reentry vehicle testing. BMDO sub-orbital missions include sensor and intercept system tests.

BMDO primarily uses launch vehicles that use Minuteman I and Minuteman II stages. It plans to begin using a small number of modified Polaris A-3 SLBMs developed by its Strategic Target System program. Other DOD services plan to use Minuteman II stages for test launch missions.

BMDO sub-orbital launches are about 95 percent of all planned DOD sub-orbital launches using retired ICBMs or SLBMs between fiscal years 1994 and 1999. BMDO planning figures show that 352 retired ICBM stages and 14 SLBM stages are to be used for 175 launches during this period. Other DOD users plan 9 launches using up to 12 stages for the same time period. Both BMDO and Air Force launch planners cautioned that these early planning figures may exceed actual launches.

Most of the planned BMDO launch activity is allocated for TMD-related missions. The remainder is for technology base experiments and NMD. BMDO planning data shows 124 launches for TMD, 31 launches for technology base experiments, and 20 launches for NMD.

The Air Force plans to use two entire Minuteman II ICBMs for two reentry vehicle tests as part of the Guidance Replacement Program. The Air Force is also considering using launch vehicles made from Minuteman II stages for seven launches to test engines and advanced materials in support of the National Aero-Space Plane program.[6] According to DOD officials, these launches are in the early planning stages and payload and booster requirements have not been determined.

Planned Use of Space Launch Vehicles for Orbital Launches

BMDO has few planned orbital launches between fiscal years 1994 and 1999. Orbital flights are designed to place payloads into earth orbit. BMDO orbital flights are primarily used for space-based sensor and interceptor experiments.

BMDO uses both commercial and Air Force space-launch vehicles for orbital flights. Launch support is provided by the Air Force. Launches planned between fiscal years 1994 and 1999 use Pegasus, Taurus, Titan II, and Delta II expendable launch vehicles. BMDO also has plans for one Space Shuttle flight in this period to conduct sensor experiments in space.

BMDO's planned orbital launch activity represents around 19 percent of all DOD orbital launches between fiscal years 1994 and 1999. Air Force launch

[6]GAO report entitled National Aero-Space Plane: A Need for Program Direction and Funding Decisions (GAO/NSIAD-93-207, June 18, 1993) discusses the status of the National Aero-Space Plane program.

planning documents for this period show BMDO scheduled 19 orbital missions and other DOD users scheduled around 83 orbital missions. Nine of the BMDO orbital launches are in support of the Brilliant Pebbles program, which has been reduced from an acquisition to technology program.

Planned Use of Nuclear Reactors in Space

BMDO has no plans to use nuclear reactors to generate electricity in proposed system deployments. However, it continues to study reactor technology for potential advanced BMD concepts. Nuclear reactors have advantages for several advanced BMD concepts, as well as for other DOD and the National Aeronautics and Space Administration missions. BMDO has obtained two Russian Topaz II nuclear reactors for $13 million and is conducting ground tests and examining the possibility of one space test.

Utility of Nuclear Power in Space

Space nuclear power reactors have the potential to be an effective power source for certain tasks. The potential advantages of using nuclear power in space include

- long operational lifetime,
- compact size,
- light weight,
- reliability,
- high power, and
- independence from the sun.

The June 1992 Joint National Aeronautics and Space Administration/DOD Space Nuclear Reactor Power System Application Study, prepared for the Office of Management and Budget, states that potential future civil and military space missions, such as planetary science, space exploration, and orbital satellite support will require more power than available systems can provide.

Flight Approval Process

Before space nuclear reactors can be used in a space mission, they must undergo a safety review process. The safety review is prescribed by a 1977 presidential directive that establishes basic procedures for launching space nuclear systems. It also establishes the Interagency Nuclear Safety Review Panel to determine the risk posed by a nuclear power system in space. The Panel consists of representatives from the Department of Energy, the National Aeronautics and Space Administration, and DOD. It conducts a safety review of each nuclear-powered space mission prior to launch. This Panel is conducting a preliminary evaluation of BMDO's plans for possible testing of Topaz II in space.

Application to BMD

BMDO has identified three potential areas where nuclear reactor power would be required for, or beneficial to, advanced BMD concepts: midcourse discrimination, housekeeping, and electric propulsion.

Midcourse discrimination is the task of tracking and segregating ballistic missile reentry vehicles carrying warheads from debris and "penetration aids" such as decoys. This is a major technical challenge to BMD. Midcourse discrimination can be made more effective through the use of (1) active sensors such as laser radars or (2) interactive sensors, such as high-energy lasers and neutral particle beams. Active sensors that emit electromagnetic power have the capability to more accurately develop track files and also to better discriminate reentry vehicles from penetration aids. The current technology for active sensors would require around 5 to 40 kilowatts of power.

Housekeeping is a collection of functions that maintain the on-board systems of a space platform. Some directed energy weapons platforms concepts, for example, would require cryogenic refrigeration systems to capture and reliquify chemical boil-off. The effectiveness of these refrigeration systems to recycle the boil-off could be increased with the higher energy output provided by nuclear power.

Housekeeping power requirements for some directed energy concepts are estimated to be between 10 to 30 kilowatts. However, current designs for an initial deployment of the space-based chemical laser show an orbital average power requirement of 3 kilowatts under peacetime conditions. This power is readily provided by solar cells charging batteries that would provide peak power requirements of 19 kilowatts. Increased power would allow enhanced space-based data processing systems that would transmit information directly to users on the ground. DOD says that this could allow information to be transmitted to smaller and more mobile ground receiver units that could be deployed in a TMD system. Space-based processing systems power requirements are estimated to be between 10 and 100 kilowatts.

Electric propulsion is a result of using electricity to insert energy into a gaseous flow, which increases the thrust. Nuclear electric propulsion has the potential to provide greater long-term spacecraft mobility and orbit transfer capability than conventional combustion propulsion. Electric propulsion can also save payload size and weight over chemical combustion propulsion systems. The power requirements for proposed electrical propulsion systems are estimated to be between 5 and 50 kilowatts.

BMDO has no plans to use nuclear power for systems currently proposed for deployment. Formerly, when BMDO was working toward defense against a massive Soviet ballistic missile threat, it saw potential applications for nuclear power systems in follow-on phases. With the threat and mission now redefined, BMDO plans to evaluate reactor technology for electric propulsion, support systems, and laser radars.

Topaz

BMDO is the lead agency in a space nuclear power system design and technology program. Other participants are the Department of Energy and the Air Force. As part of this program, BMDO is studying the Russian-made Topaz II nuclear reactor for potential space applications. BMDO has purchased two reactors for $13 million and has plans to buy four more. Non-nuclear ground tests have started. One space test of a nuclear reactor is planned. The Topaz flight testing program is still in the early design stage.

The Topaz II reactor is designed to produce around 6 kilowatts of electricity and has an estimated life of 3 years. BMDO estimates that the Topaz II technology can be upgraded to produce up to 50 kilowatts. BMDO and the Air Force are funding a preliminary design of a 40-kilowatt reactor for technology evaluation. The Department of Energy provides project management for the design and potential future development. Design goals are for both higher power and longer life than the current design.

Former Programs

BMDO participated in the SP-100 Space Reactor and the Multimegawatt Space Nuclear Power programs. The SP-100 program was initiated by the Department of Energy, the National Aeronautics and Space Administration, and DOD in February 1983. The goal was to develop technology for space nuclear reactor power systems capable of providing up to 1 megawatt (1,000 kilowatts) of electricity for future civil and military space missions. The selected SP-100 system concept used a thermoelectric conversion process. By the mid-1980s, the primary near-term mission considered for use of a SP-100 was the BMD program. BMDO expected that SP-100 technology would be sufficiently proven by fiscal year 1991 to satisfy mid-1990s missions. However, the projected costs increased, and the program's completion was delayed. In addition, BMDO missions and deployments changed, and power requirements were reduced. BMDO concluded that the SP-100 program was too expensive, the schedule was too long, and power output exceeded requirements. DOD discontinued support of the SP-100 in fiscal year 1992. Up to that time, DOD had contributed about $132 million of the $467 million spent on the program to that date.

The Multimegawatt Space Nuclear Power Program was initiated by BMDO in 1985. It focused on defining and designing a multimegawatt power system concept that, alone or in combination with a nonnuclear power system, could meet BMDO power requirements for future deployments. Electrical power output in the tens to hundreds of megawatts was considered necessary for directed energy weapons that were envisioned in early SDI plans. The program was canceled in fiscal year 1991 when BMDO reduced the role of directed energy weapons in proposed deployments. Up to that time, around $21 million was spent on the nuclear portion of the program.

Planned Funding for Directed Energy Activities

In 1984, SDIO developed a plan for development of directed energy weapon technologies. The plan envisioned the expenditure of $5.6 billion over a 6-year period. Through fiscal year 1993, SDIO will have spent about $4.9 billion on these activities over 9 years and, as table I.1 shows, SDIO estimates that $777 million and 4 more years would be needed to complete the work required for decisions on whether to fund system level demonstrations for the space-based chemical laser; space-based neutral particle beam; and acquisition, tracking, and pointing subsystems. We reported on these efforts in Ballistic Missile Defense: Information on Directed Energy Programs for Fiscal Years 1985 Through 1993 (GAO/NSIAD-93-182, June 25, 1993).

Table I.1: Directed Energy Activities

Dollars in millions

				SDIO estimate of	
Program	**Purpose**	**SDIO's 1984 funding plan**	**Allocated through FY 1993**	**Additional funding needed**	**Additional years needed**
Space-based chemical laser	Disable boosters and interactive discrimination	$1,121	$873	$176	2
Ground-based free electron and excimer lasers	Disable boosters and interactive discrimination	1,721	1,244	Program and funding transferred to Army	N/A
Particle beams	Disable reentry vehicles and interactive discrimination	747	840	421	4
Acquisition, tracking, and pointing	Track targets and aim weapons	1,298	1,584	180	3
Nuclear directed energy	Disable boosters and reentry vehicles	136	138	0	0
Other activities, part of 1984 plan (airborne laser)	Concept definition and and support	(for concept definition only) 630	206	0	0
Total (1984 plan)		**$5,653**	**$4,885**	**$777**	**4**
Other activities, not part of 1984 plan	SDI-wide technology	0	343	N/A	N/A
Total (with non-plan activities)		**$5,653**	**$5,228**		

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