OFFICE OF TECHNOLOGY ASSESSMENT

Strategic Defense Initiative

Survivability and Software

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SDI

TECHNOLOGY, SURVIVABILITY, and SOFTWARE

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Foreword

In its 1985 report, *New Ballistic Missile Defense Technologies*, OTA attempted to place those technologies against a useful policy background for the Congress. While that report introduced the major subject areas of Strategic Defense Initiative research, the amount of detailed technical evaluation it could offer was limited. The chief limitations were the relative newness of the SDI program and the lack of specific BMD system architectures to examine. Since that report, the SDIO has conducted enough additional research and, in particular, identified a sufficiently specific system architecture that a more detailed OTA review of the relevant technologies should be helpful to Congress.

Public Law 99-190 (continuing appropriations for fiscal year 1986) called for the Office of Technology Assessment to conduct a "... comprehensive classified study ... together with an unclassified version ... to determine the technological feasibility and implications, and the ability to survive and function despite a preemptive attack by an aggressor possessing comparable technology, of the Strategic Defense Initiative Program." In addition, the accompanying Conference Report specified that ... "This study shall include an analysis of the feasibility of meeting SDI computer software requirements."

This unclassified report completes OTA's response to that mandate. It puts SDI technologies in context by reporting the kinds of ballistic missile defense (BMD) system architectures that the SDI organization has considered for "phased deployment." It reviews the status of the various SDI technologies and system components. It analyzes the feasibility of producing dependable software of the complexity that advanced BMD systems would require. Finally, it summarizes what is now known—and unknown—about the probable survivability of such systems against concerted enemy attacks of various kinds.

The study found that major uncertainties remain concerning the probable cost, effectiveness, and survivability of the kinds of BMD system (which rely on kinetic rather than directed-energy weapons) that might be deployable in the "phase-one" proposed for the mid to late 1990s. In addition, OTA believes several more years of SDI research would be needed to determine whether it is feasible to construct the kinds of directed-energy weapons contemplated as follow-ons to SDIO's "phase one" BMD system. The survivability of both short-term and longer-term BMD systems would depend heavily on the outcome of a continuing competition in weapons and countermeasures between the United States and the Soviet Union. Finally, developing dependable software for advanced BMD will be a formidable challenge because of the difficulty of testing that software realistically.

OTA gratefully thanks the hundreds of individuals whose contributions of time and effort helped make this report possible. OTA, of course, bears the final responsibility for the contents of the report.

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NOTE: OTA appreciates and is grateful for the valuable assistance and thoughtful critiques provided by the Advisory Panel members. The views expressed in this OTA report, however, are the sole responsibility of the Office of Technology Assessment. Participation on the Advisory Panel does not imply endorsement of the report.

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Office of Technology Assessment

The Office of Technology Assessment (OTA) was created in 1972 as an analytical arm of Congress. OTA's basic function is to help legislative policymakers anticipate and plan for the consequences of technological changes and to examine the many ways, expected and unexpected, in which technology affects people's lives. The assessment of technology calls for exploration of the physical, biological, economic, social, and political impacts that can result from applications of scientific knowledge. OTA provides Congress with independent and timely information about the potential effects—both beneficial and harmful—of technological applications.

Requests for studies are made by chairmen of standing committees of the House of Representatives or Senate; by the Technology Assessment Board, the governing body of OTA; or by the Director of OTA in consultation with the Board.

The Technology Assessment Board is composed of six members of the House, six members of the Senate, and the OTA Director, who is a non-voting member.

OTA has studies under way in nine program areas: energy and materials; industry, technology, and employment; international security and commerce; biological applications; food and renewable resources; health; communication and information technologies; oceans and environment; and science, education, and transportation.

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Preface

This report is the unclassified version of a classified document delivered to Congress at the end of August 1987. In attempting to reach agreement with the Department of Defense on what information could be included in an unclassified report, OTA found the wheels of bureaucracy to turn very slowly—when they turned at all. Only through the active intervention of the Strategic Defense Initiative Organization, beginning in late in November 1987, and extending to the end of March, 1988, was a partial resolution of the problem achieved.

OTA, with assistance from SDIO staff, revised the entire report to produce a complete version that both agreed should not be considered classified. The Department of Defense concurred on all but the final three chapters. These latter chapters deal—in a general way and without the kind of specific detail that might be useful to an adversary—with a variety of potential countermeasures to BMD systems. In particular, chapters 11 and 12 deal with defining and countering threats to the survivability of space-based BMD systems.

Chapter 1 offers a brief review of the "bottom lines" of chapters 10 through 12. But apparently some in the Defense Department wish to assert that it is *impossible* to present an unclassified analytical discussion that would enable the reader to understand the issues and form his own judgments. In OTA's judgment, this position does not deprive potential adversaries of any information they do not already have: rather, it stifles rational public debate in the United States over the pros and cons of proceeding with ballistic missile defense. To give the reader at least some appreciation of the scope of the deleted material, the tables of contents of chapters 10 through 12 appear at the end of this volume. In addition, the major conclusions of these chapters (without, of course, the supporting analysis) are summarized in chapter 1.

OTA thanks the SDIO for the additional substantive comments and information it provided on the final drafts of the report. Thus, despite the many months of delay since original completion of the report, this unclassified version is reasonably up to date. OTA, not SDIO, is responsible for the contents and conclusions of the report.

A further note on the subject of classified information is in order. Any report which attempts to analyze the feasibility and survivability of prospective ballistic missile defense systems must refer to possible measures an adversary could take to counter the system. OTA sought the views of a variety of experts on Soviet military research, development, and deployment about potential responses to the SDI. It also sought to understand the technical feasibility of various countermeasures. It did not seek out or report on the official judgments of the U.S. intelligence community on what countermeasures the Soviet Union would or could take against SDI-derived systems. *Therefore, nothing said in this report should be construed as an "intelligence" judgment of Soviet intentions or capabilities.*

SDI

TECHNOLOGY, SURVIVABILITY, and SOFTWARE

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Chapter 1
Summary

PRINCIPAL FINDINGS

The Strategic Defense Initiative Organization (SDIO) currently advocates planning for a three-part "phased deployment" of ballistic missile defense (BMD) systems, with each phase providing an increment of strategic benefits while preparing the way for the next phase. The first phase would be intended to "... compel Soviet operational adjustments and compromises by reducing the confidence of Soviet planners in predicting the outcome of a ballistic missile attack." The second phase would be intended to negate Soviet abilities to destroy many strategic targets, and the third to "eliminate the threat posed by nuclear ballistic missiles." The exact composition and timing of each phase are still under study, but some tentative system "architectures" have undergone preliminary analysis.

Finding 1: After 30 years of BMD research, including the first few years of the Strategic Defense Initiative (SDI), defense scientists and engineers have produced impressive technical achievements, but questions remain about the feasibility of meeting the goals of the SDI. The SDIO has identified most of the gaps between today's technology and that needed for highly effective ballistic missile defenses; it has initiated programs to address those gaps. It should surprise no one that many technical issues remain unresolved, especially when one considers that the SDI has so far had time and authorization to spend only a fraction of the money that the Fletcher Commission estimated would be necessary to assess BMD feasibility. The SDIO argues that application of sufficient resources will resolve the outstanding issues.

Finding 2: Given optimistic assumptions (e.g., extraordinarily fast rates of research, development, and production), the kind of first-phase system that SDIO is considering might be technically deployable in the 1995-2000 period. Such a system might include:

- space-based hit-to-kill vehicles for attacking missile boosters and post-boost vehicles (PBVs) and
- ground-based rockets for attacking warheads before reentry into the atmosphere.

Depending on whether U.S. deployment schedules could be met, the effectiveness of countermeasures that should be available to the Soviets in that period, the numbers of offensive weapons they had deployed, and the nature of the attack, such a system might destroy anywhere from a few up to a modest fraction of attacking Soviet intercontinental ballistic missile (ICBM) warheads.

Again depending on the effectiveness of Soviet countermeasures, the BMD system might be able to carry out a strategy of "adaptive preferential defense," allowing it to protect successfully a useful fraction of certain sets of U.S. military targets.[1]

Additional defense capabilities would soon be needed to sustain this level of defense against either increased or more advanced, but clearly feasible, Soviet offenses.

One key to sustaining and improving defense capabilities in the 2000-10 period would be development of technologies to discriminate between missile warheads and decoys so that ground- and satellite-based rockets could effectively attack warheads in space. **Assuring functional survivability of space-based systems would also be essential (see Finding 4).**

Note: Complete definitions of acronyms and initialisms are listed in Appendix B of this report.

[1]SDIO officials argue that denial to the Soviets of high confidence of destroying as many of these targets they would like (as estimated by U.S. planners) would enhance deterrence of an aggressive nuclear attack.

As the Soviets phased in faster burning, faster weapon-dispensing ballistic missiles, it would probably be necessary to develop and deploy directed-energy weapons to intercept missiles in the boost phase and post-boost phases.

Given higher annual funding levels than so far appropriated, the SDI research and technology program might establish in the mid-to-late 1990s whether the components needed for warhead/decoy discrimination in a second-phase system would be feasible for deployment in the 2000-10 period. Also assuming higher funding levels than in the past, by the mid-to-late 1990s the SDI may determine the technical feasibility of deploying BMD directed-energy weapons in the 2005-15 period. The cost and survivability of such weapons will be among the key issues.

Finding 3: A rational commitment to a "phase-one" development and deployment of BMD before the second and third phases had been proven feasible, affordable, and survivable would imply: a) belief that the outstanding technical issues will be favorably resolved later; b) willingness to settle for interim BMD capabilities that would decline as Soviet offenses improved; or, c) belief that U.S. efforts will persuade the Soviets to join in reducing offensive forces and moving toward a defense-dominated world.

Finding 4: The precise degree of BMD system survivability is hard to anticipate, because it would depend on the details of measures for offensive attack on the BMD system and defensive countermeasures, on the tactics employed by each side, and on the inevitable uncertainties of battle. **It appears that direct-ascent nuclear anti-satellite weapons (DANASATs) would pose a significant threat to all three defense system phases, but particularly to the first two.** Numerous DANASATs could be available to the Soviets in the mid-1990s (e.g., ballistic missiles relying on mature technology, could probably be adapted to this role.) **Such weapons deployed in quantity, especially with multiple decoys, would threaten to degrade severely the performance of a first- or second-phase BMD system.** SDIO officials say, however, that adequate survivability measures could meet this threat. If the Soviets chose to attack the U.S. BMD satellites during emplacement, they might prevent full system deployment and operation altogether.

Finding 5: There has been little analysis of any kind of space-based threats to BMD system survivability. SDIO analyses assume that U.S. BMD technologies will remain superior to Soviet technologies (although such superiority would not necessarily guarantee U.S. BMD system survivability). **In particular, SDIO and its contractors have conducted no serious study of the situation in which the United States and the Soviet Union both occupy space with comparable BMD systems.** Such a situation could place a high premium on striking first at the other side's defenses. The technical (as well as political) feasibility of an arms control agreement to avoid such mutual vulnerability remains uncertain.

Finding 6: The survivability of BMD systems now under consideration implies unilateral U.S. control of certain sectors of space. Such control would be necessary to enforce "keep-out" zones against Soviet anti-satellite weapons or space mines during and after U.S. BMD deployment. Most BMD weapon technologies would be useful in an anti-satellite role before they reached the levels of power and precision needed for BMD. **Thus, the Soviets would not need to achieve BMD capabilities to begin to challenge U.S. control of, or even access to, space.**

Finding 7: The nature of software and experience with large, complex software systems indicate that there may always be irresolvable questions about how dependable BMD software would be and about the confidence the United States could place in dependability estimates. Existing large software systems, such as the long-distance telephone system, have become highly dependable only after extensive operational use and modification. In OTA's judgment, there would be a significant probability (i.e., one large enough to take seriously) that the first (and presumably only) time the BMD system were used in a real war, it would suffer a catastrophic failure.[1] The complexity of BMD software, the changing nature of system requirements, and the novelty of the technology to be controlled raise the possibility that the system may not even be able to pass the more realistic of the peacetime tests that could be devised for it. **The relatively slow rate of improvement in software engineering technology makes it appear unlikely to OTA that this situation will be substantially alleviated in the foreseeable future.** SDIO officials assert, however, that SDI software problems will be manageable, that adequate testing will be possible, and that previous military systems have been deployed without complete system testing (e.g., the Minuteman missile system, the Navy's AEGIS ship defense system.)

Finding 8: No adequate models for the development, production, test, and maintenance of software for full-scale BMD systems exist. Systems such as long-distance telephone networks, early missile defense systems such as SAFEGUARD, the AEGIS ship defense system, and air traffic control all differ significantly from full-scale BMD.

The only kind of BMD system for which the United States has software development experience is a terminal defense system. Incorporating a boost-phase defense would add complexity to the software and require the inclusion of technologies hitherto untried in battle. Adding a mid-course defense would probably increase the software complexity beyond that of any existing systems.

[1]In ch. 9 catastrophic failure is arbitrarily defined as a decline of 90 percent or more in system performance, and there is a discussion of alternative approaches to the concept.

Experts agree that new methods for producing and safely testing the system would be needed. Evolution would be key to system development, requiring new methods of controlling and disseminating software changes and assuring that each change would not increase the potential for catastrophic failure. OTA has found little evidence of significant progress in these areas.

Finding 9: There is broad agreement in the technical community that significant parts of the research being carried out under the SDI are in the national interest. There is disagreement about whether or not this research is best carried out within a program that is strongly oriented toward supporting an early 1990s BMD deployment decision, and that includes system development as well as research elements. This question was outside the scope of OTA's mandate and is not addressed in this report.

INTRODUCTION

Origin of This Study

The appropriations continuing resolution for fiscal year 1986 (Public Law 99-190) called for the Office of Technology Assessment to produce a "comprehensive classified study . . . together with an unclassified version . . . to determine the technological feasibility and implications, and the ability to survive and function despite a preemptive attack by an aggressor possessing comparable technology, of the Strategic Defense Initiative Program." In addition, the conference report accompanying this legislation specified that "this study shall include an analysis of the feasibility of meeting SDI computer software requirements." This report responds to that legislation.

After 30 years of BMD research, including the first few years of the Strategic Defense Initiative, the dedication and ingenuity of thousands of U.S. scientists and engineers have produced many impressive technical achievements. Such achievements may someday cumulate to form the basis for a highly effective BMD system. For now, however, many questions remain about the feasibility of meeting SDI goals.

Goals of the SDI

According to SDIO's annual report to Congress:

> From the very beginning, the SDIO has maintained the same goal—to conduct a vig-

orous research and technology development program that could help to eliminate the threat of ballistic missiles and provide increased U.S. and allied security. Within this goal, the SDIO's task is to demonstrate SDI technology and to provide the widest range of defense options possible to support a decision on whether to develop and deploy strategic defenses.[2]

Such defenses might, to a greater or lesser degree, protect the American population from nuclear weapons. **But, contrary to the perceptions of many, SDIO has never embraced the goal of developing a leakproof shield against an unconstrained Soviet nuclear weapon threat.** It is the position of SDIO that President Reagan has not embraced that goal either.[3]

Rather, the organization, in its first 4 years, worked out a scenario that it argues could lead to President Reagan's stated "ultimate goal of eliminating the threat posed by strategic nuclear missiles . . . [which could] . . . pave the way for arms control measures to eliminate the weapons themselves."[4] The scenario, paraphrased from the SDIO report, is as follows:

1. a research and development program continues until the early 1990s, when a decision could be made by a future President and Congress on whether to enter into full-scale BMD engineering development;
2. the Defense Department begins full-scale development of a "first-phase" system while continuing advanced technology work;
3. the United States begins "phased deployment" of defensive systems, "designed so that each added increment of defense would enhance deterrence and reduce the risk of nuclear war"; although this "transition period" would preferably be jointly managed by the United States and the Soviet Union, U.S. deployments would proceed anyway; then
4. the United States completes deployment of "highly effective, multilayered defensive systems," which "could enhance significantly the prospects for negotiated reductions, or even the elimination, of offensive ballistic missiles."

Figures 1-1 and 1-2 are SDIO graphic representations of its development and deployment policies. Figure 1-1 illustrates that, as time goes on, newer, more capable BMD systems would be necessary to respond to advanced Soviet missile threats. Alternatively, it is argued, the *prospect* of such new systems might persuade the Soviets to accept U.S. proposals for joint reductions of offensive forces which might, in turn, obviate the need for new systems.

Figure 1-2 lists the kinds of information SDIO seeks to provide for BMD development decisions. According to this figure, SDIO does not see "complete understanding" of *later* system phases as prerequisite to *initial* commitments to develop and deploy BMD. Instead, it proposes to seek a "partial understanding" of the issues surrounding the follow-on phase and provide "reasonable estimates" that the necessary systems could be available as needed.

SDIO has affirmed the so-called "Nitze criteria" as requirements for the BMD options it offers: that the defenses be militarily effective, adequately survivable, and "cost-effective" at the margin, that is, "able to maintain their defensive capabilities more easily than countermeasures could be taken to try to defeat them."[5]

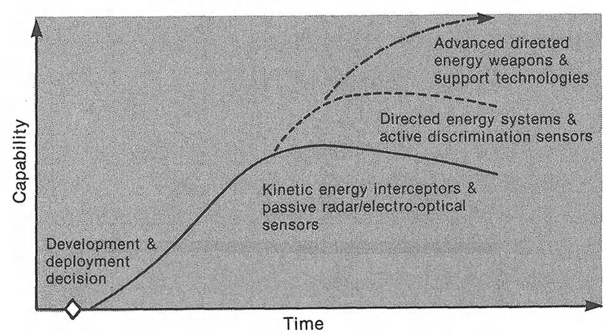
[2]Strategic Defense Initiative Organization, *Report to the Congress on the Strategic Defense Initiative* (Washington, DC: April 1987), p. II-13.

[3]Lt. General James Abrahamson, personal communication to OTA staff, July 7, 1987.

[4]Ronald Reagan, televised speech, Mar. 23, 1983.

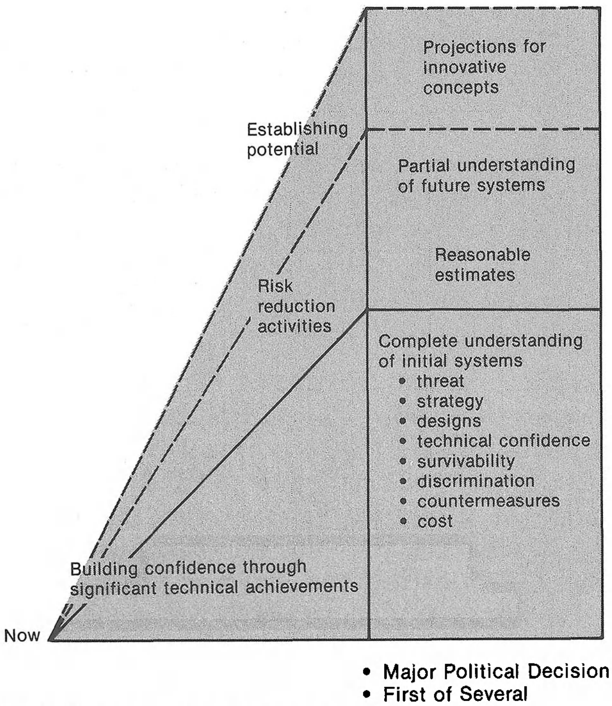
[5]SDIO, op. cit., footnote 2, p. IV-3.

Figure 1-1.—The Path to "Thoroughly Reliable" Defenses



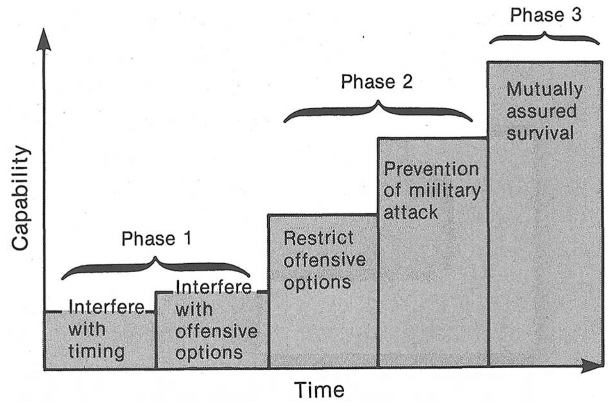
SOURCE: Department of Defense, Strategic Defense Initiative.

Figure 1-2.—Development Decision Content



SOURCE: Department of Defense, Strategic Defense Initiative.

Figure 1-3.—Mission Effectiveness Improves With Phased Deployment



SOURCE: Department of Defense, Strategic Defense Initiative.

The SDIO has identified three "phases" of BMD deployments that might extend from the mid-1990s well into the 21st century (see figure 1-3). In mid-1987, SDIO proposed to proceed with a series of "technology validation experiments" to build and test hardware that might demonstrate the feasibility of components of a "first-phase" system. These experiments would require SDI budgets substantially above the levels appropriated by Congress in the first 4 years of the SDI.

In deciding about funding and directing the SDI program, then, Congress must decide whether to accept, modify, or reject the phased research and deployment scenario proposed by SDIO. Options for Congress include:

- accept the SDIO phasing scenario and plan now to decide in the early 1990s whether the full-scale engineering development of a first-phase system is feasible or attractive, but with only a "reasonable estimate" at that time of whether the second and third phases would later prove feasible; such a decision would imply an intention to deploy the first phase in the mid-1990s while beginning full-scale development of the second phase, but the actual mid-1990s decisions would depend on the progress made;
- decide soon to begin immediately to develop whatever technologies may be available for deployment in the early 1990s, bearing in mind that space-based weapons are, in any case, unlikely to be deployable in quantity until 1995 or beyond;
- plan to delay a decision on a first phase of development and deployment until advanced research confirms that the second and third phases would be feasible;
- return to the pre-SDI BMD research program intended to hedge against technological surprise and to deter Soviet BMD deployment, but not intended to work toward a specific deployment scenario; or
- add to the previous option a new emphasis on terminal defense systems designed specifically to protect elements of U.S. strategic nuclear retaliatory forces.

Nature of This Report

To assist Congress in making these choices, this report surveys the technologies under research in the SDI and reports, as of early 1988:

- which technologies might be available for each of the projected deployment phases;
- what is known and what remains to be learned about the feasibility of develop-

ing those technologies and manufacturing and deploying weapons based on them;
- what can now be said about how survivable against enemy attack space-based BMD systems themselves may be; and
- what can now be said about the feasibility of producing the computer software of the requisite performance and dependability.

Most experts would agree that the technical issues for BMD present severe challenges. Thus, in attempting to provide the above information, this report identifies numerous demanding technical problems. The technical challenges to the SDI have been variously interpreted:

- **From the point of view of SDI officials and contractors, questions of feasibility are challenges that the application of sufficient time and resources can overcome.** They are working on most, if not all, the issues identified in this report.
- **In another view, the obstacles to effective BMD are great, and may not be overcome for several decades; nevertheless, the kind of research SDIO is sponsoring will have some long-term military and economic benefits for the United States whatever the SDI outcome.** In addition research on BMD is necessary to avoid technological surprise and to hedge against Soviet breakout from the Anti-Ballistic Missile (ABM) Treaty.
- **From a third point of view, the obstacles to accomplishment of the SDI's ultimate goals are so complex and so great that SDIO's goals are simply implausible.** Therefore, although the United States should conduct some BMD research to avoid technological surprise and to hedge against Soviet break out from the ABM Treaty, research needed for other military or civilian purposes should be carried out under other auspices.

OTA attempts in this report to present realistically the available evidence about SDI feasibility. The reader must decide how optimistic or pessimistic the evidence should lead one to be and which approach to BMD research would be best for the nation.

This summary organizes OTA's findings around the kinds of system designs, or "architectures," for the three phases that SDIO has recently been studying and discussing. It **should be recognized, however, that, except for the first phase, these architectures are illustrative, not definitive.** They provide a means of thinking about and understanding how various BMD technologies might be integrated into working systems and in what time frames. **Only the first represents SDIO's proposal for actual systems to develop and deploy.**

Table 1-1 outlines SDIO's suggested first phase of deployment; the time frame 1995-2000 is strictly an OTA assessment of a very optimistic but arguably plausible period for the beginning and completion of deployments of the various elements of the system phase. Table 1-2 outlines OTA's projections of the second and third phases of BMD deployment, based on SDIO descriptions of the technologies it is researching. The overlapping time frames (2000-10 and 2005-15) reflect OTA assessments of very optimistic but arguably plausible periods for the beginning and completion of deployments of the various elements of each system phase.

FIRST-PHASE TECHNOLOGIES AND SYSTEMS (OTA Estimates Approximately 1995-2000)

Goals of a First-Phase System

In the fall of 1986 SDIO and its contractors began to study options for "first-phase" deployment of BMD. They attempted to design systems that the Nation might select in the late 1980s for initial deployments in the early 1990s. OTA estimates that as a practical matter—given the development, manufacturing, and space transportation needs—deployment

Table 1-1.—SDIO's Phase One Space- and Ground-Based BMD Architecture

Component	Number	Description	Function
First phase (approximately 1995-2000):			
Battle Management Computers	Variable	May be carried on sensor platforms, weapon platforms, or separate platforms; ground-based units may be mobile	Coordinate track data; control defense assets; select strategy; select targets; command firing of weapons
Boost Phase Surveillance and Tracking Satellite	Several at high altitude	Infrared sensors	Detect ballistic or ASAT missile launches by observing hot rocket plumes; pass information to tracking satellites
Space-based Interceptor Carrier Satellite	100s at several 100s of km altitudes	Each would carry about 10 small chemical rockets or "SBIs"; might carry sensors for tracking post-boost vehicles	On command, launch rockets at anti-satellite weapons (attacking BMD system), boosters, possibly PBVs.
Probe	10s	Ground-launched rocket-borne infrared sensors	Acquire RV tracks, pass on to ERIS interceptors
or			
Space Surveillance and Tracking System	10s	Satellite-borne infrared sensors	
or			
Space-based Interceptor Carrier Satellites	100s	Satellite-borne infrared sensors	
Exo-atmospheric Interceptors (ERIS)	1000s on ground-based rockets	Rocket booster, hit-to-kill warhead with infrared seeker	Cued by satellite-borne or rocket-borne infrared sensors, home in on and collide with RVs in late mid-course

SOURCE: Office of Technology Assessment, 1988.

of the systems discussed could not begin until 1995 or later and would probably take at least until the end of the 1990s to complete.

The first-phase options generally exclude *space-based* attack on Soviet reentry vehicles in mid-course (see table 1-1). While limiting the effectiveness of a BMD system, this omission eases the sensing, discrimination, and battle management tasks.

Depending on the nature of the Soviet attack assumed, and depending on the effectiveness of Soviet countermeasures, the kind of system described by SDIO officials system might destroy anywhere from a few up to a modest fraction of the (now predicted number of) Soviet reentry vehicles in a full-scale attack. The SDIO has suggested such a system as only the first phase of what in the longer term would expand to a more effective system. However, the organization cites as "an intermediate military purpose"

> . . . denying the predictability of Soviet attack outcome and . . . imposing on the Soviets significant costs to restore their attack confidence. These first phases could severely restrict Soviet attack timing by denying them cross-targeting flexibility, imposing launch-window constraints, and confounding weapon-to-target assignments, particularly of their hard-target kill capable weapons. Such results could substantially enhance the deterrence of Soviet aggression.[6]

SDIO officials assert that the military effectiveness of the first-phase system would be higher than indicated by the percentages of reentry vehicles intercepted. They envisage a strategy of "adaptive preferential defense." In this strategy, first the space-based layer of defense disrupts the structure of the Soviet attack. Then the ground-based layer defends only those U.S. targets of the highest value *and* un-

[6]Ibid., footnote 2, p. II-11.

Table 1-2.—OTA's Projections of Evolution of Ground- and Space-Based BMD Architecture

Component	Number	Description	Function
Second phase (approximately 2000-2010) replace first-phase components and add:			
Airborne Optical System (AOS)	10s in flight	Infrared sensors	Track RVs and decoys, pass information to ground battle management computers for launch of ground-based interceptors
Ground-based Radars	10s on mobile platforms	X-band imaging radar	Cued by AOS, track RVs as they enter atmosphere; discriminate from decoys, pass information to ground battle managers
High Endo-atmospheric Interceptors	1000s	Rocket with infrared seeker, non-nuclear warhead	Collide with RVs inside atmosphere, but before RV nuclear detonation could cause ground damage
Space Surveillance and Tracking Satellite (SSTS)	50-100 at few 1000s of km.	High-resolution sensors; laser range-finder and/or imaging radar for finer tracking of objects;	Track launched boosters, post-boost vehicles, and ground or space-launched ASATs; Track RVs and decoys, discriminate RVs from decoys;
		May carry battle management computers	Command firing of weapons
Space-based Interceptor Carrier	1000s at 100s of km altitudes	Each carries about 10 small chemical rockets or "KKVs"; at low altitude; lighter and faster than in phase one	On command, launch rockets at anti-satellite weapons (attacking BMD system), boosters, PBVs, and RVs
Space-based Neutral Particle Beam (NPB)	10s to 100s at altitude similar to SSTS	Atomic particle accelerator (perturber component of interactive discrimination; additional sensor satellites may be needed)	Fire hydrogen atoms at RVs and decoys to stimulate emission of neutrons or gamma rays as discriminator
Detector Satellites	100s around particle beam altitudes	Sensors to measure neutrons or gamma rays from objects bombarded by NPB; transmitters send data to SSTS and/or battle management computers	Measure neutrons or gamma rays emitted from RVs: heavier objects emit measurable neutrons or gamma rays, permitting discrimination from decoys
Third phase (approximately 2005-2115), replace second-phase components and add:			
Ground-based Lasers, Space-based Mirrors	10s of ground-based lasers; 10s of relay mirrors; 10s to 100s of battle mirrors	Several laser beams from each of several ground sites bounce off relay mirrors at high altitude, directed to targets by battle mirrors at lower altitudes	Attack boosters and PBVs

SOURCE: Office of Technology Assessment, 1988.

der attack by the fewest reentry vehicles remaining after the winnowing by the space-based layer (see box 1-A). In this way, a meaningful fraction of a large set of "point targets" (e.g., missile silos or command posts) might be protected. Such a strategy, however, would require successful discrimination of RVs and decoys by the first-phase system sensors—a technology that remains to be proven. In addition, the Soviets could counter the strategy if they could modify their current offensive systems and deploy substantial numbers of maneuvering reentry vehicles.

Figure 1-3 presents SDIO's description of how the phases of SDI deployment might satisfy a spectrum of strategic goals. In evaluating the desirability of the goal of enhancing

Box 1-A.—Adaptive Preferential Defense

The SDIO has proposed that a first-phase ballistic missile defense system (see table 1-1) employ a tactic of "adaptive preferential defense." If successfully executed, this tactic could give an outnumbered defense some leverage against a large attack.

"**Preferential defense**" means defending only a selected set of high-value targets out of a larger number of targets under attack, thus concentrating the defensive forces. In essence, some targets would be sacrificed to increase the chances of survival of others.

"**Adaptive preferential defense**" means deciding during the course of the battle which targets to defend by adapting to the distribution of the attacking RVs (missile warheads) that survive earlier layers of defense. Of the high-value targets under attack, those with the fewest RVs coming at them are defended first.

Two Layers of Defense

A first-phase Strategic Defense System (SDS) would include orbiting interceptors and land-based interceptors. The orbiting interceptors would first destroy a small fraction of the rising Soviet missile boosters and post-boost vehicles. Since the SDS could not at this stage predict the targets of the Soviet missiles, the defense would not be preferential: instead, it would merely subtract at random some warheads from the Soviet attack. Even if the Soviets had initially aimed the same number of RVs at each target, some would have been filtered out by the first layer of defense.

Land-based rockets would carry other interceptors into space to destroy RVs that survived the space-based attack. Tracking sensors would determine the targets of the RVs to within several kilometers. Battle management computers would determine which high-value targets were under attack by only one RV and launch ground-based interceptors against them first, until all were covered. Then the computers would determine which targets were under attack by two RVs and assign interceptors to them, and so on. In this way, few interceptors would be wasted defending targets that would later be destroyed anyway by additional, unintercepted RVs.

A Simple Example

Suppose, for example, that 2000 RVs were attacking 1000 targets, with 1 RV aimed at each of 500 targets and 3 RVs aimed at each of another 500 targets. Assume that the defense had only 1000 interceptors (each with a 100 percent chance of interception). If the defense assigned interceptors randomly to 1000 of the 2000 attacking RVs, about 312 targets would be expected to survive (50 percent of those under single-RV attack and 12.5 percent of those under 3-RV attack). But if it assigned 500 interceptors to defend the targets under a single-RV attack, and then assigned 3 interceptors each to defend the next 166 targets, a total of 666 targets might be saved.

The SDI Case

Analysts for SDIO have concluded that a first-phase system applying this tactic could protect a useful fraction of selected U.S. targets against the kind of attack the Soviets are predicted to be able to carry out in the mid-1990s.

Some Qualifying Considerations

If feasible, an adaptive preferential defense would be suitable mainly for protecting fractions of redundant, single-aimpoint targets, such as missile silos, command posts, or other isolated military installations. Large-area, soft targets (such as cities or large military installations), would present so many potential aimpoints that defending, say, a third or a half of the aimpoints in a given area would be unlikely to assure survival of the that area. In addition, the aimpoints that could be defended would be small enough that the blast and fires from exploding nuclear weapons would affect neighboring "soft" target areas.

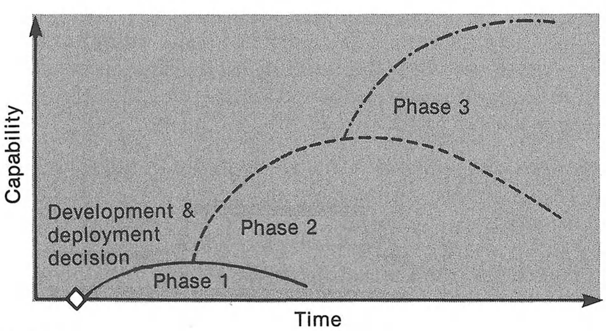
Serious questions also remain about whether SDIO's proposed phase-one BMD system could, in fact, successfully execute a strategy of adaptive preferential defense. In particular, if the infrared sensors of the tracking system could not discriminate between Soviet RVs and decoys, many of the ground-launched interceptors would be wasted on decoys. And if the Soviets could deploy many maneuvering reentry vehicles during the operational period of the first-phase defense system, the targets could not be accurately predicted and defended.

deterrence by forcing modification of Soviet attack plans, Congress should also be aware of the counter-arguments to that position:

- Many believe that, given the awesome consequences of nuclear war for the Soviet Union as well as for the United States, deterrence does not require enhancement because the U.S. threat of nuclear retaliation is already strong enough and can be kept so with timely strategic offensive modernization.
- Soviet military planners already face operational uncertainties, such as the unreliability of some percentage of deployed missiles.
- Other, less costly, more clearly feasible, methods of complicating Soviet attack plans, such as increased mobility for U.S. strategic forces, may be available.
- A corresponding Soviet deployment of BMD would impose uncertainties and costs on U.S. retaliatory attack plans.

The context for evaluating the goal of complicating Soviet attack plans changes, however, if one accepts the point of view that it is only the first benefit on a long-term path toward "mutual assured survival." In OTA's view, figure 1-4 illustrates, somewhat more realistically than figure 1-1, the *relative* levels of defense capability over time to be expected from phased BMD deployments, assuming their feasibility. **Whether or not initial capabilities could be sustained or improved upon depends on information not likely to be available by the early 1990s.**

Figure 1-4.—OTA Understanding of Projected Roles of BMD Deployment Phases



SOURCE: Office of Technology Assessment, 1988.

Technical Feasibility of Sensors and Weapons

In a first-phase system, space-based interceptors (SBI), also known as "hit-to-kill" or "kinetic kill" vehicles, would attack missile boosters and post-boost vehicles (PBVs), but not their dispensed reentry vehicles (RVs). The only mid-course interception would be near the end of that phase of missile trajectory by ground-based, exo-atmospheric interceptors.

Boost-Phase Surveillance and Tracking System (BSTS)

It appears feasible to develop by the mid 1990s high altitude satellites that would tell lower altitude satellites, or possibly SBIs themselves, where to look for rising missile boosters. Complex communications links among the satellites may be necessary to avoid enemy interference.

Carrier vehicles ("garages") for space-based hit-to-kill interceptors could receive data from the BSTS and track the boosters and post-boost vehicles with their own infrared sensors and laser range-finders.

Space-Based Interceptors (SBI)

A few hundred SBI carriers that would carry a few thousand kill vehicles (rocket interceptors) might destroy a modest fraction of Soviet missile warheads in the boost and post-boost phases. Such a system might be feasible to deploy starting in the projected first-phase period, but questions of engineering and cost remain unresolved. For example, considerable miniaturization of components for propulsion, guidance, and sensors would be needed to make a rocket fast enough to reach boosting missiles and light enough to be affordably launched into space. **Recent progress toward such miniaturization appears promising.** Substantial testing of prototype weapons would be necessary to show system feasibility. Once these technologies were proven, the affordable mass production of rocket-carrier vehicle systems for space deployment maintenance would remain a major challenge.

Exo-atmospheric Reentry Interceptor System (ERIS)

The Homing Overlay Experiment of 1984 and subsequent development work suggest **that it is feasible to design a ground-launched interceptor capable of homing in on objects in space under favorable conditions.** Such weapons could make up an Exo-atmospheric Reentry Interceptor System, or ERIS. More research, testing, and engineering remain to be done before the United States will know if the interceptor homing warheads can be produced cheaply enough to be affordable in large numbers. The ERIS, however, is likely to be deployable before space-based BMD interceptors.

Under study are both space-based and ground-launched infrared sensor systems and ground-based radars to direct ERIS interceptors to the vicinity of their targets. Both the satellite and ground-based systems remain to be developed, tested, and affordably produced. Upgraded versions of now existing ground-based radars might also provide initial tracking information to the interceptors.

In this first-phase architecture, the ERIS would rely on radars or on passive infrared detection and tracking of potential targets. **Whether or not these sensors could adequately discriminate between decoys and RVs disguised as decoys remains to be demonstrated. Without such discrimination, decoys could probably cause serious problems for this late mid-course layer of defense. Developing a decoy system like this is within Soviet capabilities.** Even with good discrimination by external sensors, the homing sensor on the interceptor itself would need to find the genuine RV if it were traveling within tens of meters of other, closely spaced objects. In general, many scientists and engineers working on the SDI have agreed that such countermeasures may well be feasible for the Soviets in the near term. However, both within and outside SDIO there is some dissent on the potential type, quality, number, and deployment times of Soviet countermeasures.

There is widespread agreement that much more experimentation is needed on missile "penetration aids" such as decoys. Very little SDI money has gone to the design, construction, and testing of penetration aids, although a full understanding of their potential and limitations would be key to developing and evaluating the effectiveness of a BMD system.

Besides decoys, ERIS interceptors could face many other false targets, particularly those generated by debris from PBV activity, from intercepts made earlier in the boost phase by the SBIs, or from deliberate Soviet countermeasures. Warm objects in the field of view of the ERIS interceptor's sensors might distract it from its target RV, even if it had originally been correctly pointed toward the RV by a probe or Space Surveillance and Tracking System (SSTS) sensor.

Software Feasibility

In the first-phase system designs now under consideration for SDI, hundreds of satellites would have to operate automatically and, at the same time, coordinate their actions with those of other satellites. The battle management system would have to track hundreds of thousands of objects and decide when and how to attack thousands of targets with little or no human intervention.

Among the most challenging software tasks for such a first-phase system would be designing programs for the largely autonomous operation of hundreds of satellites. But even for ground-based components of the system, the number of objects, the volume of space, and the brevity of time would preclude most human participation in battle management. **Humans would decide at what alert status and state of activation to place the system. Once the battle began, computers would decide which weapons to use when, and against what targets.**

A first-phase system would have the advantage of a simpler battle management problem than that of more advanced BMD systems. In particular, the space-based segment of the system would not attempt to track and discriminate among hundreds of thousands of mid-course objects, or to assign weapons to any of them. The distribution of SBI carrier vehicles would be so sparse that the targets within its range would not be in the range of neighboring carrier vehicles. It could, for the most part, safely shoot at a target within its own range without the risk that some other vehicle had shot at the same target. Some coordination among carrier vehicles would still be necessary because the continual relative motion of carriers and targets would leave some ambiguities about which targets were most appropriate for each carrier to fire interceptors at.

Although a first-phase system would have simpler tasks than a later system, its software would still be extremely complex. **The nature of software and experience with large, complex software systems, including weapon systems, together indicate that there would always be irresolvable questions about how dependable BMD software was, and also about the confidence we could place in dependability estimates.** Existing large, complex software systems, such as the U.S. long-distance telephone system, have become highly dependable only after extensive operational use and modification.

Extrapolating from past experience with software, it appears to OTA that the complexity of BMD, the uncertainty and changeability of the requirements it must meet, and the novelty of the technology it must control **would impose a significant probability of software-induced catastrophic failure in the system's first real battle.** The issue for SDI is the degree of confidence in the system that simulations and partial testing could provide. **SDIO officials argue that such tests will permit adequate confidence and that this issue is no more serious for the SDI than for all advanced military systems developed to date.**

Computer simulations would play a key role in all phases of a BMD system's life cycle. Battle simulations on a scale needed to represent realistically a full battle have not yet been attempted. Whether or not sufficiently realistic simulations can be created is a hotly debated question. In particular, it is difficult for OTA to see how real-world data could be gathered to validate simulations of the phenomena that must be accounted for, such as multiple enemy missile launches, nuclear explosion-induced backgrounds, and enemy choices of countermeasures. **The differences between BMD software and previous complex software that is considered dependable suggests to some experts that BMD software might never be able to pass even its peacetime tests.** It should also be noted, however, that both the United States and the Soviet Union now base deterrence on an offensive nuclear delivery system that has never been operationally tested either.

While the United States could not be certain that a BMD system would work as intended, the Soviets could not be certain that it would not.[7] If they had at least some reason to believe the U.S. BMD system might be effective, they might be more deterred from attacking than before. On the other hand, the United States would not want to base a major change in its nuclear strategy on a BMD system in which it had little confidence. In the case of a first-phase system, whose effect on the strategic balance would be small anyway, the risk of software-induced system failure might seem acceptable.

The SDIO sees software problems as challenges to be overcome rather than as insurmountable obstacles to effective BMD. It is supporting some software research intended to address the challenges. Others argue that the limitations of software engineering technology and its relatively slow rate of improvement make it unlikely that dependable BMD software could be produced in the foreseeable future. Thus far, no new software engineering developments have appeared to contradict the latter view.

Survivability of a First-Phase System

The survivability of any BMD system will not be an all-or-nothing quality. The question

[7]Unless they had high confidence in the potential effectiveness of a secretly deployed countermeasure (perhaps a software bug planted by a saboteur programmer).

will be whether enough of a system's assets would survive for it to carry out its mission. The issue would then turn on whether the defense could make attacking the BMD system too costly for the offense, or whether the offense could make defending the BMD system to costly for the defense. (On the other hand, if the United States and the Soviet Union agreed to coordinate offensive weapon reductions and defensive deployments, they might do much to ameliorate BMD survivability problems.)

To protect satellites, the defense might employ combinations of such techniques as evasive maneuver, tracking denial, mechanical shielding, radiation hardening, electronic and optical countermeasures, and shoot-back. **Categorical statements that these techniques will or will not make any BMD system adequately and affordably survivable are not credible.** Judgments on specific cases would depend on the details of entire offensive and defensive systems and estimates of the techniques and tactics that the opponent would employ.

Space Mines

A space mine is a satellite that would trail another satellite and explode lethally either on command or when itself attacked. Space mines may or may not prove a viable threat to space-based BMD systems. Although *nuclear* space mines would be a very stressing threat, much more analysis would be needed to clarify the question of the viability of space mines. **After repeated attempts to locate such analysis within the SDIO or among its contractors, OTA concludes that it has not yet been adequately performed.**

Anti-Satellite Weapons (ASATs)

There is widespread agreement among experts on Soviet military practices that the initial Soviet response to U.S. BMD deployments would not be to try to develop and deploy systems based on similar technology. They would instead attempt a variety of less sophisticated countermeasures. These might include extensions of their current co-orbital, pellet-warhead anti-satellite weapon (ASAT), or else a ground-launched nuclear-armed ASAT (or "DANASAT," for "Direct Ascent Nuclear Anti-satellite" weapon).

The susceptibility of a BMD satellite system to degradation by DANASAT attack would depend on many complex factors, including:

- the maneuvering and decoying capabilities and the structural hardness of the BMD satellites;
- the precision and reaction time of Soviet space surveillance satellites; and
- the speed, numbers, decoying capabilities, and warhead power of the DANASATs.

Depending on target hardness, the radius of lethality of a nuclear warhead could be so great that the ASATs might need only inertial guidance (they need not home in on or be externally guided to the BMD asset). Thus they would not be susceptible to electronic countermeasures against homing sensors or command guidance systems. It appears that, at practical levels, maneuvering or radiation shielding of low-altitude satellites would not suffice against plausible numbers of rapidly ascending nuclear ASATs.

There appears to be no technical reason why the Soviets, by the mid-1990s, could not deploy DANASATs with multiple decoys among the nuclear warheads. Multiple decoys would likely exhaust the ability of the defenders to shoot back at the attack—unless extremely rapid discrimination of decoys and warheads were possible. It would be difficult to deny tracking of or to decoy near-earth satellites, especially large sensor platforms, if they were subjected to long periods of surveillance. If deployed while the satellites were under attack, satellite decoys would frequently not have time to lure DANASATs far enough away from the real targets.

If several SSTS satellites were a key element of a first-phase BMD system, they would be the most vulnerable elements. Otherwise, the most vulnerable elements of a first-phase BMD system would be the carrier vehicle satellites for the interceptors. The carrier vehicles, or CVs, as well as sensor satellites (BSTS and