Chapter 1

Summary

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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 SD I 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.

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.

[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.

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.'

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:

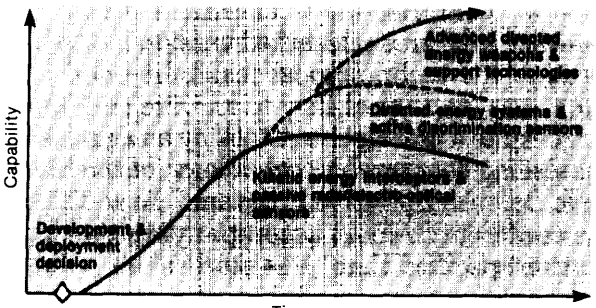
1. a research and development program continues until the early 1990s, when a decision could be made by a future President and Congress on whether to enter into full-scale BMD engineering development;
2. the Defense Department begins full-scale development of a "first-phase" system while continuing advanced 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.'"

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



SOURCE: Department of Defense, Strategic Defense Initiative.

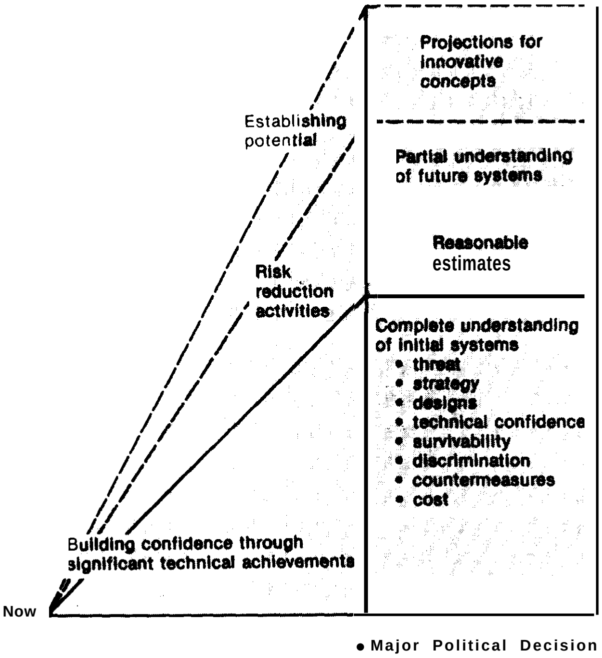
'Strategic Defense Initiative Organization, *Report to the Congress on the* ***Strategic Defense*** *Im"thtive* (Washington, DC: April 1987), p. 11-13.

'Lt. General James Abraharnson, personal communication to OTA staff, July 7, 1987.

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

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

Figure 1-2.—Development Decision Content



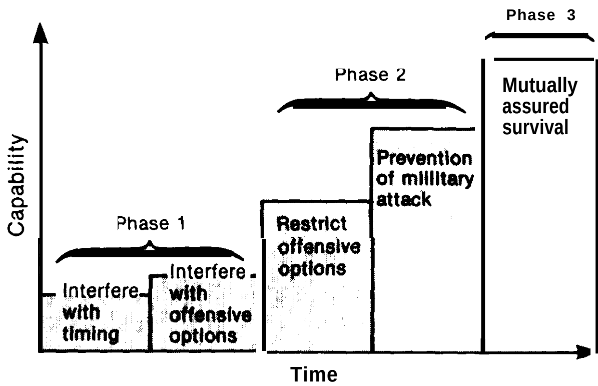
SOURCE' Department of Defense, Strategic Defense Initiative.

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

Figure 1.3.—Mission Effectiveness Improves With Phased Deployment



SOURCE: Department of Defense, Strategic Defense Initiative

intention to deploy the first phase in the mid-1990s while beginning fill-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 SD I 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 timeframes. 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 timeframe 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 timeframes (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	loos	Satellite-borne infrared sensors	
Exe-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: Off Ice 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 l-l). 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-

'Ibid., footnote 2, p. 11-11.

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

Component	Number	Description	Function
Second phase (approximately 20004010) replace first-phase components and add:			
Airborne Optical System (AOS)	10s in fright	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, nom 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 aititude simiiar 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 l-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 l-A.—Adaptive Preferential Defense

The SDIO has proposed that a first-phase ballistic missile defense system (see table l-l) 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 filtereds 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.

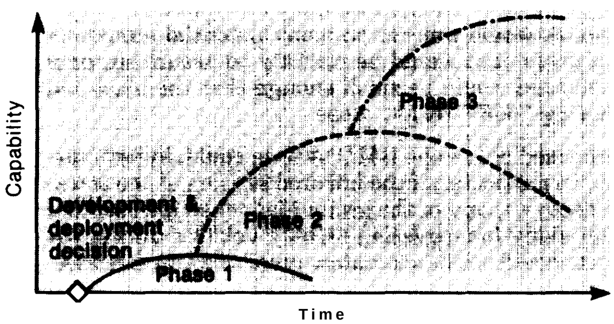
Serious questions also remain about whether SDIO's proposed phase-one BMD system could, in fact, successfully execute a strategy of adaptive preferential defense. In particular, if the infrared sensors of the tracking system could not discriminate between Soviet RVs and decoys, many of the ground-launched 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, exe-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.

Exe-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 Exe-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 affordable 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 (A SAT), or else aground-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

SSTS) might employ combinations of various defense mechanisms against the ASAT threat. The SDIO argues that such combinations of measures potentially offer a high degree of survivability to space-based BMD system components.

For the near-term, however, no prototypes exist for carrier vehicles with these characteristics; the issue for SDI is whether in the 1990s such satellites could be developed, produced, and deployed. The Soviets, on the other hand, have already demonstrated the ability to field DANASATs by deploying rapidly accelerating, nuclear-armed anti-ballistic missiles near Moscow over 15 years ago and recently upgrading that system. Newer ballistic missiles, relying on mature technology, might also be adapted to this purpose. More advanced DANASATs appear feasible for the Soviets by the mid-1990s.

DANASATs would be a stressing threat against first-phase BMD systems and could probably degrade severely the performance of such systems. The SDIO argues, however, that strong survivability measures in the defensive system could successfully counter this threat.

The Soviets might also consider gradual attrition of the system in "peacetime." They might use co-orbital, non-nuclear ASATs or ground-based laser ASAT weapons to take "potshots" at the carrier vehicles.

Attack During Deployment

Should the Soviets deem U.S. space-based BMD deployments to be sufficiently threatening to their national security, they might resort to attack before the system was fully deployed. Whether they waited for full deployment or not, in the first-phase architecture SBI carrier vehicles would be so sparse that they would probably have only limited abilities to help defend one another, although each might to some extent defend itself. Other survivability measures, however, might offer some protection.

Attacks on Ground-Launched Systems

Insofar as the ERIS ground-launched interceptor relied on fixed, ground-based early warning radars for launch-commit information, its effectiveness could be greatly reduced by nuclear or jamming attacks on those radars.

Use of Comparable Technologies

Responses to threats from comparable Soviet weapon systems have not been defined by the SDIO or its contractors. Indeed, a working assumption of SDIO research and analysis has been that the United States could and would maintain a consistent lead over the Soviet Union in BMD technologies for the indefinite future. Because the Soviets lag in some of the technologies required for a space-based BMD system, it seems unlikely that they would attempt to deploy SBIS for BMD in the 1990s. A more attractive option for them might be to deploy kinetic-kill vehicles as a *defense suppression* system rather than as a *BMD* system—a less difficult task.

They could then choose orbital configurations designed to give their weapons temporary local numerical advantages over the U.S. BMD system. In a shoot-out between the systems, at a time of their choosing, the Soviets might then eliminate or exhaust those SBI carrier vehicles within range of a Soviet ICBM launch salvo. Effective non-nuclear ASATs would, however, require good space surveillance capabilities. If a BMD system were to cohabit space with a competent defense suppression system (possibly embodying a lower technical capability), the side that struck first might eliminate the other.

The fact that a lower level of technology would be needed for defense suppression than for BMD could drive a race to control access to space as soon as possible. For example, U.S. space-based ASATs might be needed to prevent Soviet ASAT deployments that could in turn interfere with U.S. BMD deployments.

SECOND-PHASE TECHNOLOGIES AND SYSTEMS (OTA Estimates Approximately 2000-10)

Goals

The goal of a phase-two system would be to "enhance deterrence, " first by imposing uncertainty on Soviet strategic attack plans, then by denying the Soviets the ability to destroy "militarily significant portions of important sets of targets (such as missile silos or command and control nodes) in the United States. As a result, the Soviets would retain the ability to inflict massive damage on the U.S. economy and population, but would lack the ability to accomplish certain precise military objectives. At least, such denial should decrease whatever incentives may now exist for the Soviets to commit nuclear aggression (though analysts disagree on whether such incentives do now exist); at best, the Soviets might be induced to negotiate away their militarily obsolescent missiles.

If the Soviets believed they could restore their compromised military capabilities at an acceptable price, they might attempt to do so by adding new offensive weapons and by attempting both active and passive countermeasures against the U.S. BMD system. Even if they did not believe they could recapture lost military capabilities, but only believed that they were in danger of losing any credible nuclear retaliatory power against the United States, they might still attempt to employ BMD countermeasures. If, however, they concluded that countermeasures would be futile, they might, as conjectured in the "SDI scenario," agree to mutual offensive arms reductions as a way of containing the U.S. threat. In that case, BMD combined with effective air defenses might offer much higher levels of protection of military and even civilian targets.

Currently available BMD technology for nuclear-armed, ground-based interceptors would probably allow the United States to build a system that could deny the Soviets confidence in destroying substantial fractions of certain sets of hardened or mobile targets.[8] An SDI "phase-one," non-nuclear system may also be able to provide such protection. This is more likely to be the case if the defense could be configured to defend subsets of targets preferentially, and in such a way that the Soviets could not detect which targets were defended more heavily. Moreover, if the Soviets continued to aim weapons at highly defended targets, they would have fewer weapons left over to aim at softer military and civilian targets.

There is less evidence that the United States could deny the Soviets the ability to strike with high confidence at many other kinds of militarily valuable, but more vulnerable, targets. There are, however, many ideas and some promising technologies for pursuing this goal.

Achieving the strategic goals of this kind of system implies air defenses of comparable potential. Otherwise, except for the most urgent targets, the Soviets could shift strategic missions from ballistic to cruise missiles.

Technical Feasibility

Airborne Optical System (AOS)

An airborne infrared sensor system would tell ground-based radars where to look for reentering objects. Such a system appears technically feasible during the 1990s. The infrared sensors, however, might be subject to confusion by high-altitude light-scattering ice crystals created as debris reentered the atmosphere, or by nuclear detonations intended to blind the system.

Ground-Based Radar (GBR)

Imaging radar systems would observe lighter decoys slowing down more quickly than gen-

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'See U.S. Congress, Office of Technology Assessment, ***Ballistic*** *Missile Defense* ***Technologies***, OTA-ISC-254 (Washington, DC: U.S. Government Printing Office, September 1985), pp. 33-34.

uine RVs.Computers using this information would launch very high acceleration rockets (HEDI) with infrared homing sensors toward the RVs Tests to date indicate that such radars are feasible, but unresolved questions include their susceptibility to interference from nuclear burst, to jamming by radio-frequency jammers on incoming warheads, to signal-processing overloads created by many simultaneously reentering objects, and to deception by carefully designed RV's and decoys.

High Endo-atmospheric Interceptor (HEDI)

A rocket-borne high endo-atmospheric defense interceptor would attack incoming RVs after they had begun to reenter the atmosphere.

Because the rising interceptor's friction with the atmosphere would cause it to heat up, a cooled crystal window would have to protect its homing sensor. Experiments suggest that such windows are feasible, although researchers have not yet established whether they could be rapidly mass-produced.

Because the HEDI would have a limited "divert" capability, the sensor system would need to give it a very accurate target track. A relatively short-range ground-based radar, using the upper atmosphere as a discriminant against decoys, might be the easiest way to provide such a track. This tracking method, however, would restrict each interceptor to protecting a relatively small area. Intensive coverage of all U.S. territory would demand too many thousands of missiles. Instead, the HEDI mission would be to "mop up" small numbers of warheads leaking through the earlier defensive layers. Thus the most useful mission for HEDI might be to protect specific, localized targets, such as ICBM silos.

SDIO officials point out, however, that passive infrared sensors or long-range radars may be able to discriminate between RVs and decoys in space. Then the High Endo-Atmospheric Interceptor could be committed earlier and thus defend a much larger area. Nevertheless, in order to avoid the impression of providing a defense designed primarily to protect hardened strategic targets, rather than U.S. territory in general, the SDIO elected to omit the HEDI and its associated sensors (AOS and a terminal imaging radar or TIR) from its proposals for a first-phase BMD system.[9] Technically, however, initial deployments in the late 1990s period appear plausible.

SSTS and RV/Decoy Discrimination

A phase-two system would add to the first-phase architecture dozens of space-based sensors that could accurately track thousands of RVs and decoys from the moment of their deployment from the PBVs. Such sensors would require electro-optical focal planes of unprecedented size, or high-resolution laser radar systems, and considerable signal processing ability.

It seems likely that, by the time a substantial U.S. BMD system could be in place, the Soviets could deploy many reentry vehicle decoys and RVs disguised as decoys. Unless these RVs and decoys could be destroyed on their boosters and post-boost vehicles, some means of distinguishing between them would have to be developed. Otherwise, the defense's ammunition would be quickly exhausted.

In the terminal, "endo-atmospheric" phase of interception, the atmosphere might filter out all but the heaviest and most sophisticated decoys. But too many reentering objects might overwhelm local defensive sensors and weapons. In sum, effective discrimination in the mid-course of ballistic missile trajectories would be necessary to a highly effective BMD system.

One proposed technique for RV/decoy discrimination is a laser radar system that might observe the movements of RVs and decoys as, or after, they were dispensed from PBVs. Subtle differences in the behaviors of the less massive decoys might give them away. Concealing deployments off PBVs or other tactics might counter this technique, but much research both on decoy technologies and space-borne laser radars will be needed to judge the potential of either.

'Lt. General James Abrahamson, personal communication to OTA staff, July 7, 1987.

Various methods of passive and active discrimination have been suggested, including multiple wavelength infrared sensors, laser radar, and microwave radar. But if the Soviets could build sufficiently sophisticated decoys, differentiating decoys and RVs might be impossible without some means of externally perturbing all the objects being tracked and observing differences in how they react to such perturbations. This technique is known as "interactive discrimination."

So far there is no proven candidate system for the task of interactive discrimination. The program receiving the most funding has been the neutral particle beam (NPB). In this concept, a space-based atomic accelerator would fire high-energy neutral hydrogen or deuterium atoms at suspect objects. A sensor would then detect the neutrons or gamma rays emitted from heavier objects struck by the hydrogen atoms. A hundred or more NPB platforms, and perhaps several hundred sensor satellites, would be needed for a complete system. It may be more appropriate to consider such a system for a phase-three, rather than phase-two, BMD architecture.

A space test of a subscale NPB platform was scheduled for the early 1990s, although recent budget cutbacks have made the experiment's status unclear. Key issues determining the feasibility of NPB systems will include cost, the rapid and precise ability to point the beams at thousands of objects in a few tens of minutes, and the ability to gather and correlate the return information.

Other interactive discrimination ideas include, for example, space-based high energy lasers that would "tap" target objects. The greater recoil of lightweight decoys would give them away.

Kinetic Energy Weapons

Missile boosters that completed their boost phase in about 120 to 140 seconds—slightly faster than current modern ICBMs–would greatly reduce the effectiveness of rocket-propelled SBIs in the boost phase. They could still intercept post-boost vehicles. However, fast RV dispensing technologies could reduce kill in the post-boost phase. On the other hand, if such countermeasures had forced the Soviets to greatly reduce missile payloads, mid-course discrimination might become easier: then the Soviets could only afford to deploy fewer, less sophisticated decoys. Improved SBIs, even though ineffective against boosters, could be useful in the mid-course. They would require long-wave infrared sensors for homing in on small, cold RVs. Alternatively, laser designators on sensor satellites might illuminate RVs with light that SBI sensors could see and track.

It seems likely that by roughly the period projected for the first phase ERIS (Exe-atmospheric Reentry Interceptor System) missiles could be refined to the specifications now envisioned. Provided that the challenge of RV-decoy discrimination had been overcome, they would begin to provide an important layer of missile defense. If the discrimination problem could not be solved, ERIS interceptors would be of doubtful utility. If it could be solved, ERIS effectiveness in phase two would be much greater than in phase one.

The question for HEDI in the phase-two period is whether the Soviets could deploy many maneuvering reentry vehicles to evade the system and sophisticated reentry decoys to deceive it. The more effective the earlier defensive layers might be, the less the Soviets could afford to use precious missile payload weights on heavier RVs and decoys. However, numerous, even slightly, maneuvering reentry vehicles, especially with depressed missile trajectories, could probably evade HEDIs unless the interceptors were equipped with nuclear warheads.

Software Feasibility

A phase-two BMD system such as envisaged here would need to account for hundreds of thousands (or more) of objects as they were dispensed into space. It would require a highly complex communications net for keeping track of all BMD space assets, boosters, PBVs, RVs, decoys, and space debris, then assigning weapons to intercept the selected targets. Concepts, but so far no genuine designs, exist for "partitioning" the battle space into local networks of sensors and weapons (taking into account that different combinations of satellites would be constantly shifting in and out of given regions of space).

In terms of sheer computing power, continued advances seem likely to provide the processing capacities needed for advanced BMD. The most difficult hardware engineering task will be to combine the qualities of high capacity and radiation hardness in space-qualified electronics.

A BMD designed for boost, post-boost, midcourse, and terminal battle is likely to be the most complex system ever constructed. In OTA's judgment, there would be no precedents for estimating the likelihood of the BMD software system's working dependably the first time it was used in a real battle. Moreover, no adequate models for the development, production, test, and maintenance of software on the scale needed currently exist. The system's complexity, coupled with the need to automate the use of technologies previously unused in battle, might result in unforeseen problems dominating the software life cycle. For example, large, complex systems that undergo continuous change sometimes reach states where new changes introduce errors at a greater rate than they remove errors.

A BMD system–as has been the case with other strategic nuclear systems—could be tested only with computer simulations and some piecemeal hardware exercises. Furthermore, no existing systems must operate autonomously (without human intervention) in the face of deliberate enemy attempts to destroy them.

Whether the risks of catastrophic BMD failure resulting from the inevitable software errors in a system of this magnitude would be unacceptable is a policy decision, not a technical one, that the President and the Congress would ultimately have to make. They would have to weigh those risks against the perceived risks and benefits of not building a BMD system but deploying national resources elsewhere. As with a first-phase system, another consideration would be the likelihood that the Soviets could not be confident that the BMD system would not work as advertised, and that they might be deterred from trying to find out by attacking. (On the other hand, if the Soviets found away to break into and tamper with the software system without U.S. knowledge, they might be confident that they *could* defeat it.)

Phase-Two Survivability

More advanced BMD systems would be designed and deployed with more advanced self-protection or survivability measures. Ground-launched, nuclear-armed ASATs (DANASATs) would continue to be a threat. The additional SBI carriers available after the year 2000, however, could begin to provide mutual defense for one another, which would not be possible in the first-phase architecture.

By that time, on the other hand, the Soviets could develop more advanced anti-satellite weapons and space surveillance sensor systems. Most BMD weapon technologies for use in space or against targets in space are likely to achieve ASAT capabilities before they become applicable to BMD missions.

Direct-Ascent Nuclear ASATs

As with phase one, DANASATs would be particularly threatening to a "phase-two" system. The U.S. Space Surveillance and Tracking System and any associated interactive discrimination platforms would now be primary targets for Soviet defense suppression attacks. Since many of these satellites would be at higher altitudes than the SBI garages, they would have more time to maneuver away from attackers. But they would also be heavier and therefore more fuel-costly to maneuver. They would be more difficult to shield against nuclear radiation.

Space Mines

The United States would have to consider the possibility of Soviet attempts to co-orbit nuclear or non-nuclear space mines with these platforms as they were being deployed. Such "mining" might be carried concurrently with the deployment of the BMD system assets. System designers have proposed "keep-out" zones to keep potential attacking weapons outside their lethal ranges. Whether the United States (or any power) could achieve this kind of dominance of near-earth space remains to be seen. In any case, very little analysis has as yet been carried out by the SDIO or its contractors on interim and long-term space-based threats to BMD systems.

Comparable Technologies

If the Soviets could develop technologies comparable to those of the United States, three might be of special concern. One would be advanced space-based surveillance systems permitting better-timed, more accurate ASAT attacks. Second would be the development of space-based neutral particle beam weapons, which could be very effective anti-satellite weapons from great range. Third, even though laser weapons might not have achieved the power levels necessary for the BMD missions, laser ASATs could begin to pose substantial threats to U.S. space assets. If only for self-defense, the United States might have to consider deploying directed-energy ASATs in the phase-two architecture period.

THIRD-PHASE TECHNOLOGIES AND SYSTEMS (OTA Estimates Approximately 2005-15)

Goals

In the SDI scenario, the first goal of a phase-three BMD system would be to sustain the capabilities of the second-phase system as more advanced Soviet countermeasures came on line. Eventually, the system might achieve still higher levels of protection. As originally presented by the Administration, the SD I was to identify a path to the "assured survival" of the U.S. population against nuclear attack. An intermediate step on this path would be to design a BMD system that would make nuclear ballistic missiles "impotent and obsolete." In this scenario, the Soviets would then be confronted with the choice of negotiating away obsolescent missiles or engaging in a costly defensive-offensive arms race that would sooner or later leave their offensive missiles unable to penetrate U.S. or allied territory. Either way, in the end few or no nuclear ballistic missiles could reach U.S. territory.[10]

As with a second-phase system, extremely effective air defenses would be an essential complement to an extremely effective BMD system. And, as with earlier phases, deep reductions in offensive forces (by arms control agreement) could increase the effectiveness of the system.

Technical Feasibility

Directed-Energy Weapons

Directed-energy weapons for boost-phase interception are still far in the future. It is unlikely that confidence in their feasibility could be established by the early 1990s even with requested SDIO budgets. OTA judges that experimental evidence of the feasibility of BMD directed-energy weapons (DEW) is at least a decade away.[11] It is extremely unlikely that confidence in DE W could be established in the next several years, given continuation of the actual appropriation pattern.

[10] SDIO reports to Congress make no mention of "assured survival, " and cite as the ultimate objective of the SDI to "secure a defense-dominated strategic environment in which the U.S. and its allies can deny to any aggressor the military utility of ballistic missile attack." SDIO, op. cit., footnote2,p.II-11. Other SDIO documents, however, do still refer to the goal of "mutually assured survival" (see figure 1-3).

[11] "A similar conclusion was reached by a committee of the American Physical Society in 1987. *Science and Technology of Directed Energy Weapons: Report of the American Physical Society Study Group* (April 1987), p. 2.

Ultimately however, directed-energy weapons may be necessary to intercept long-range ballistic missiles and direct-ascent ASAT weapons in the boost and post-boost phases. If the Soviets could, over 15 or 20 years, develop and begin to deploy very fast-burn, laser-hardened boosters with single (or few) warheads (and associated decoys) and if they deployed those boosters at concentrated launch sites, the burden even on directed-energy weapons would be great. In that case, the time available for attacking each booster might be so short as to drive very high the requirements for power levels, retargeting speed, and numbers of directed-energy weapons. (However, PBVs would continue to be vulnerable to DEWs.)

Fast-burning Soviet boosters appear technically plausible—the main issue would be cost. The Soviets would have to deploy enough of these boosters to continue to deliver hundreds of thousands of RV decoys into the mid-course, and they would have to be aware that, for example, if U.S. DEWs achieved significant improvements in retargeting time, they might neutralize a good fraction of the Soviets' expensive fast-burning fleet.

Although some work has continued on chemical lasers, and proposed future budgets would increase the share going to them, most SDI laser funding in 1987 went to the free electron laser (FEL). The most likely way to deploy such lasers would be on the ground, with orbiting relay and battle mirrors to focus laser beams on Soviet boosters and PBVs. Scientists have made significant progress in FEL research, but they are a long way from having established the feasibility of a weapon. The SDIO has sponsored construction of laboratory versions of FELs and plans a major test facility at White Sands Missile Range. Among the outstanding issues to be studied with these experimental lasers are whether FELs can be made bright enough at useful wavelengths and the feasibility of optical techniques for successfully passing very high energy laser beams out of and back into the atmosphere. Other outstanding issues include: whether large, agile beam directing optics can be affordably manufactured and reliably based in space; the cost of building and maintaining several large laser ground station complexes; and the survivability of space mirrors and ground stations against defense suppression attacks.

Other directed-energy concepts are under consideration. Neutral particle beams (NPBs), which do not penetrate the atmosphere, might engage those missile boosters and PBVs that operated above about 120 kilometers. Advanced booster and warhead dispensing technologies, however, might evade NPBs. (Unlike most lasers, however, NPBs could penetrate and destroy reentry vehicles in the mid-course.) Another directed-energy weapon may be the nuclear-explosion pumped x-ray laser, which also could not penetrate far into the atmosphere. For various reasons, the x-ray laser appears more promising as an anti-satellite weapon than as an anti-missile weapon.

Software Feasibility

If an interactive discrimination system were added in the phase-two architecture, the phase-three architecture would not pose significantly different software challenges and prospects from the second phase. The very fine pointing and tracking needed for laser weapons could impose significant additional computing requirements on sensors.

As time went on, Soviet defense suppression threats-weapons aimed at the BMD system itself-could grow more intense. The additional burdens of self-defense for the BMD system against advanced ASAT threats would add to the complexity of software requirements. The challenges to producing dependable software cited above would persist in phase three.

Phase-Three Survivability

If large directed-energy weapon platforms were deployed in space (whether these were laser generators with beam directors or only relay and battle mirrors for ground-based lasers), they would themselves become prime high-value targets for defense suppression attacks. Unless they were powerful enough to be deployed at rather high altitudes, they would have a difficult time either denying tracking to enemy sensors or maneuvering out of the way of attacks. They would probably have to defend themselves (and one another) as well as depend on “escort” interceptors. Third-phase directed-energy weapons systems could be survivable against the current or first-phase Soviet DANASAT threat; the question is, would they be survivable against a later DANASAT threat that might be in place by the time the directed-energy weapons were deployed?

Directed-Energy ASATs

Long before directed-energy weapons such as lasers or particle beams achieve the capabilities they would need as BMD weapons, they could be effective anti-satellite weapons. Anti-satellite laser weapons, if placed in space before more capable BMD laser weapons, might successfully attack the latter as they were being deployed.

In some cases, such as the nuclear bomb-pumped x-ray laser, the most likely application of an advanced directed-energy weapon would be as an ASAT. What little analysis has been done so far indicates that x-ray laser ASATs launched from the ground to fire from the upper atmosphere would be difficult, if not impossible, to counter. However, the feasibility of x-ray laser weapons remains to be demonstrated.

Soviet Possession of Comparable Technologies

As one attempts to project various combinations of survivability techniques and various modes of anti-satellite attack into the far term, the situation becomes even hazier. It does appear that two DEW ballistic missile defense systems occupying space could pose risks of crisis instability. The side that struck first in a simultaneous attack on all the other’s DEWS might seize an advantage. Much would depend on each side’s tactics and its ability to jam, spoof, or disable the sensors on the other side. At best, each side might neutralize the other’s BMD system, leaving both defenseless but with nuclear retaliatory capabilities (as is the case today). At worst, the side striking first might unilaterally neutralize the other’s BMD (and other military space assets), leaving him open to nuclear blackmail. Mutual fears of this possibility might lead to crisis instability.

On the other hand, if the two sides could define precisely balanced deployments and rules for ensuring the mutual survivability of their systems, and then arrive at verifiable arms control agreements providing for them, they might avoid such instability.

IMPORTANT GENERAL ISSUES

costs

Some experts in space systems argue that the major cost driver of space-based BMD would be the manufacture of hundreds or thousands of novel, yet highly reliable, spacecraft. The SDIO suggests that its research into new production techniques would result in substantially reduced costs. Until such techniques have actually been demonstrated in practice, this suggestion will be difficult to verify.

In any case, space transportation cost would be a major challenge. The SDIO has spoken of ultimately requiring launch operating costs one-tenth those existing today (not counting the costs for development of such a system). For the nearer term (late 1990s) the goal appears to be a threefold operating cost reduction. For the very near term, planners are being told to design systems that could evolve into less costly ones, but there is little expectation of immediate first-phase savings.

Components today are conceptual, so reliable cost estimates are not possible. Efforts to improve “producibility” and operations costs for SBIs, ERIS, and HEDI are also conceptual.

System architects' estimates put the costs of designs comparable to the second-phase architecture in the low hundreds of billions of dollars. Given that the United States would have to engineer, build, and deploy entirely new classes of space systems, cost estimates today are shaky at best. For any given component, unanticipated difficulties might increase costs, or technical breakthroughs might decrease costs. The SDIO has produced a rough estimate for the cost of a phase-one system: $75 billion to $150 billion.

Phase-three architectures are now so loosely defined and understood that few if any contractor cost estimates exist.

Nobody now knows how to calculate, let alone demonstrate to the Soviets, the cost-exchange ratio between offense and defense. Detailed defensive system designs and a thoroughly researched understanding of potential offensive countermeasures may help. But unless the ratio appears obviously to be much greater than one-to-one, it will be extremely difficult to determine whether the criterion of "cost-effectiveness at the margin" has been met by any proposed BMD system. At least in the first phase, it appears that the Soviets would have a strong incentive to add missiles, warheads, and countermeasures to attempt to restore their strategic nuclear capabilities. The question would be whether the Soviets were persuaded that in the long run the defense system would evolve into one that cost less per Soviet RV destroyed.[12]

Timing and Evolution

The Strategic Defense Initiative Organization (SDIO) has not pursued the SDI as an open-ended research program to be concluded only when a certain level of knowledge was attained. Instead, the research has been strongly oriented toward trying to provide the basis for an 'informed decision" on BMD full-scale engineering development by the early 1990s (the exact year, although it appears widely in the press, is classified). Nevertheless, implied in the SDI program was that whatever information might be available by the early 1990s, proposals for deployment would be offered.

Congress, however, has not funded the SDI at the level that the SDIO asserted was necessary to permit an informed decision about such proposals by the early 1990s. Nevertheless, by cutting back parallel technology programs and longer-term research while preserving programs believed to have near-term promise, the SDIO has attempted to maintain the goal of making detailed deployment proposals by only 1 year later than the appointed date.

In late 1986 and in 1987 the SDIO began developing the "phase-one" BMD system architecture described above. In its 1987 annual report to Congress, the SDIO said that its study of the first phase of a phased deployment". . . does not constitute a decision to deploy. Such a decision cannot be made now."[13] OTA concurs. First, the required space transportation system is unlikely to be available for early 1990s deployment. Second, the reductions in SBI weights essential to deploying significant numbers of effective weapons are not yet available. Third, the U.S. aerospace industry would have to engineer, mass produce, and deploy entire new classes of satellite systems. Fourth, cost estimates for all these steps today are shaky at best. The SDIO does argue that the first-phase option would lay the groundwork for the deployment of subsequent phases. This could be true if the subsequent phases were in fact known to be feasible, affordable, survivable, and cost-effective at the margin—and if the first-phase system retained some capability against a responsive Soviet threat.

Every part of the complex development, production, and deployment scheme would have to work well and on schedule. Otherwise, the Soviets could be well on the way to neutralizing the first-phase architecture before it was

[12]This discussion does not address whether the Soviets would accept the cost/exchange ratio criterion for their own decisions or whether they might simply do their best at improving their offense and hope the United States might not follow the ensuing offensive-defensive arms race through to its expensive conclusion.

[13]SDIO, op. cit., foot note 2, p. 11-10.

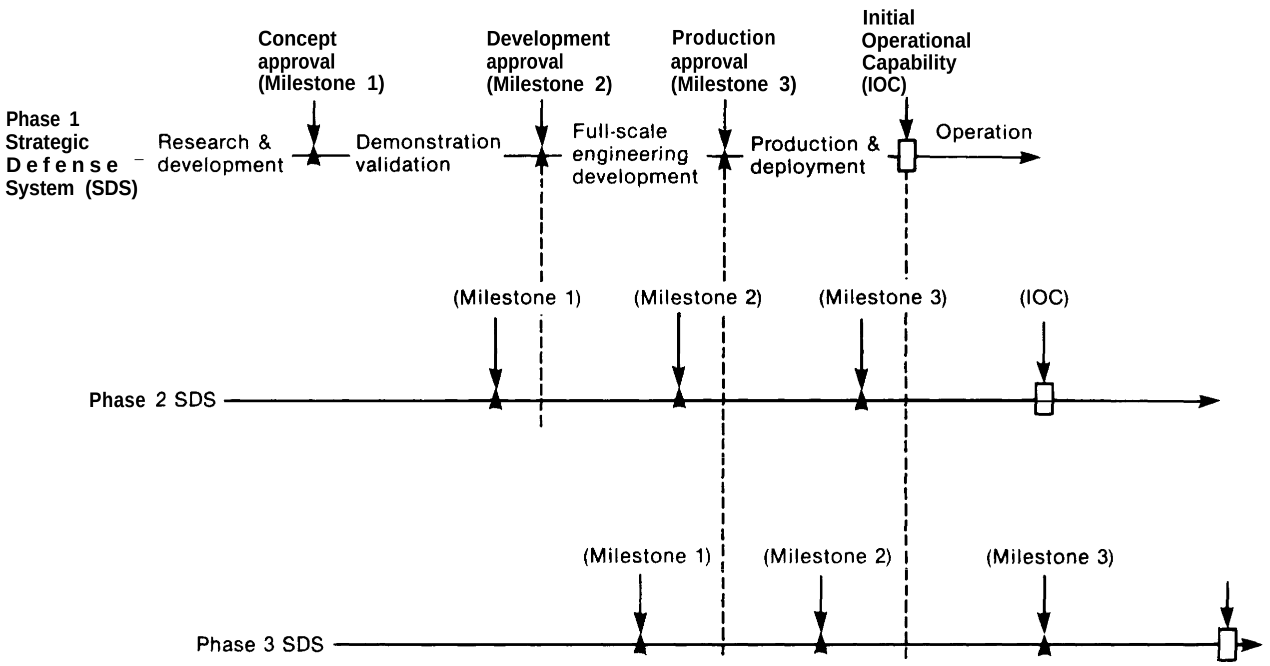
fully in place. Countermeasures could have greatly degraded SBI capabilities. For example, as the booster rocket burning times of Soviet missiles decreased (a process already occurring as the Soviets move to solid-fueled boosters), fewer SBI's could reach the boosters before their post-boost vehicles had separated and begun to dispense reentry vehicles and decoys. New post-boost vehicles, which would in any case be harder to track and hit than boosters, could also dispense their payloads more rapidly. Without altering their rocket technologies, the Soviets could concentrate their ICBM bases so that fewer SBIs would be in range when many ICBMs were launched at once (that is, the "absentee ratio' would be higher). While the Soviets would not find all such countermeasures cheap and easy, one should compare their cost and difficulty to those of developing and deploying a vast new space-based BMD system.

Adding more SBIs to the BMD constellation would allow attacks on more boosters, but the numbers of SBIs needed would become increasingly prohibitive as the Soviet ICBM force evolved. On the other hand, if the Soviets could not soon reduce the burn-times of their post-boost vehicles, SBI effectiveness might endure for some time-assuming that the first-phase SBI infrared sensors could effectively home in on the colder PBVs.

Although a phase-one architecture may be presented to Congress as the first step of a "phased deployment, " research on the later phases is far from demonstrating that those succeeding phases will be feasible, affordable, and compatible with first-phase systems. The feasibility of fully trustworthy battle management software systems may never be entirely demonstrable. The feasibility of directed-energy weapons and interactive discrimination systems remains to be demonstrated, and persuasive evidence one way or the other will probably not be available until after 1995. The feasibility of a new, post-2005 generation of Soviet fast-burn boosters that could stress even directed-energy weapons remains plausible and cannot be discounted.

Thus a "phased deployment" in which only the first phase was shown to be feasible would not necessarily be able to evolve and adapt to

Figure 1-5.—SDIO Proposal for Development and Deployment



SOURCE Office of Technology Assessment, adopted from Department of Defense information on the Strategic Defense Initiative a responsive Soviet **threat.** The SDIO plan calls for completing "demonstration and validation" of phase-two concepts before actual production and deployment of phase one. Therefore,

- commitment in the early 1990s to a phase-one development would imply confidence that phases two and three will ultimately prove feasible, and
- commitment in the mid-1990s to phase-one deployment would require an act of faith that phase three would prove feasible.

Otherwise, depending on how long deployment actually took and how effective the Soviet response was, either the first- or second-phase systems could be reduced to only modest effectiveness or impotence even before deployment was completed.

SDIO officials and contractors have surmised that the technologies needed to maintain and extend the defensive capabilities of first- and second-phase systems into the farther term will in fact become available. If a continuing, vigorous research and development program produced the necessary technologies, and if Soviet offensive developments could not keep pace, the first-phase concept might evolve into a more advanced BMD system. If the Soviets responded to the SBI system by developing faster-burning PBVs that could carry only much reduced payloads, then the ultimate task of discriminating RVs and decoys in the mid-course could be greatly simplified. (This conclusion assumes that the Soviets could not afford at the same time to double the size of their missile fleet.) The United States could add sophisticated SWTS satellites and SBIs with improved sensors. If Soviet decoys were few enough and simple enough, the sensor satellites might be able to track and discriminate RVs and decoys in mid-course, thus allowing improved hit-to-kill weapons to attack RVs individually after they were dispensed. Or, interactive discrimination techniques might turn out to make RV/decoy discrimination feasible.

OTA concludes that, if shown to be technically feasible and desirable, second-phase system production and deployment could not begin until around the year 2000 or be completed much before 2010. Soviet countermeasures coming into deployment by then could include more missiles, advanced RVs (possibly including maneuvering RVs or "MaRVs") and decoys, faster rocket boosters and post-boost vehicles, concentrated launch-sites for boosters, and advanced anti-satellite weapons. The utility of space-based SBIs for boost-phase interception would then be severely limited. Depending on whether and when the Soviets could field faster-dispensing PBVs, the SBIs might be of some utility for PBV interception. Overall system effectiveness, however, would probably depend heavily on how well the mid-course discrimination challenge had been met.

If the Soviets developed high-payload, fast-dispensing PBVs, the United States might have to add laser weapons to the defense system to increase boost- and post-boost intercepts to reduce the mid-course discrimination burden. As is noted below, however, even this step might not suffice.

As of 1988, three uncertainties about the viability of a second-phase system especially stand out:

1. evidence demonstrating effective and affordable technology for discriminating Soviet nuclear warheads from decoys will probably not be available before the mid-1990s, if then;
2. **a** follow-on, directed-energy BMD system would be needed to restore or maintain defense effectiveness once faster-burning boosters were able to evade SBIs; but directed-energy weapons for BMD mayor may not be technically feasible; such feasibility is very unlikely to have been determined by the early 1990s; if the Soviets were able to field a few thousand very fast-burning boosters with one warhead and several decoys each, even directed-energy weapons might not suffice to maintain a high level of defense effectiveness;
3. the survivability of a space-based system itself against a defense suppression attack by Soviet weapons likely to be available after the year 2000 may not have been determined by the early 1990s.

Ballistic missile defense deployments of dubious long-term effectiveness could stimulate the Soviet Union to offensive countermeasures and weapon deployments rather than to negotiations to reduce mutual offensive threats.

Competition in Anti-satellite Weapons

As noted above, the technologies applicable in exo-atmospheric weapons are, in most cases, liable to be applicable in ASAT weapons before they are applicable in BMD. Thus there will be pressures from the military establishments on both sides to field such weapons as they become feasible, whether or not they prove to have BMD potential. For example, the first mission for space-based SBIs maybe as defensive satellites, or DSATS, to protect the BMD system as it is being deployed. Space lasers may be attractive ASATs and DSATs whether they are adopted as BMD weapons or not. Neutral particle beam discriminators could be powerful ASAT weapons. If the nuclear-pumped x-ray laser can be developed as a weapon—which is far from proven—its most promising application may be as an ASAT. No credible answer to the x-ray laser as a BMD suppression weapon has been developed.

As the United States or the Soviet Union began to deploy substantial numbers of BMD weapons on the ground or in space, these weapons would greatly increase the anti-satellite threat to the other's space assets. (Space-based weapons themselves would, of course, be among those space assets.) Neither side is liable to permit the other the kind of unilateral control of space that such unchallenged ASAT capabilities would provide. Therefore, in the absence of arms control agreements to the contrary, we should expect from the beginning of BMD space deployments an intense competition between the superpowers for control of near-earth space.

A frequently proposed survivability measure for U.S. space-based BMD assets is the enforcement of keep-out zones against any potentially threatening Soviet satellites. Whether, when, and how the Soviets might challenge such assertions of U.S. exclusionary zones in space has not been analyzed by those proposing this tactic. Indeed, the whole question of the mutual occupation of space by weapons of comparable capability has not yet been adequately addressed by SDIO or its contractors.