Chapter 6

System Development, Deployment, and Support

CONTENTS

Box

Figures

Tables

Chapter 6

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INTRODUCTION

The preceding chapters review the status of key ballistic missile defense (BMD) technologies, describing the progress made and the additional advances still needed to meet various BMD goals. These technologies would have to work together in an integrated system. The United States would have to develop the infrastructure to fabricate, test, deploy, operate, and maintain that system, and modify it in response to Soviet countermeasures. In the case of space-based elements, now considered essential for a highly effective defense, the United States would have to design, test, and build anew space transportation system. Anything but the fastest development of this transportation system could delay all but the most modest space-based BMD deployment to well into the 21st century.

This chapter explores the steps involved in moving from the current research and development phase to operational status. These steps include:

- architecture definition,
- system development,
- system testing,
- fabrication,
- deployment, and
- operation and maintenance.

Given the complexity of a global BMD system and the immaturity of many technologies, this chapter can only outline and give some indication of the multitude of challenges that would face engineers and manufacturers if a decision were made to proceed to full-scale engineering development (FSED) and then to deployment. From the beginning, the development and deployment of dependable computer software would be a key issue; the subject of software is deferred until chapter 9.

ARCHITECTURE DEFINITION

The first step toward deployment would be to complete the detailed system design or architecture. As noted in chapter 3, five defense contractors have competed with different BMD system designs. The Strategic Defense Initiative Organization (SDIO) has conducted additional analyses outside the main architecture contracting framework. A single system architect is to be chosen in 1988. This architect is to define the actual BMD system in detail, providing information for a decision on whether to proceed to the next step: full-scale engineering development. The SDIO has proposed an early 1990s decision on FSED but its schedules are slipping as a result of funding levels that are below its earlier expectations.

In the meantime, common elements in the existing architecture studies can be used to guide the research program.[1] All of the space- and ground-based architecture designs included space-based infrared (IR) sensors and space-based interceptors (SBIs). All assumed

Note: Complete definitions of acronyms and initialisms are listed in Append-x B of this report.

[1] Each architect defined three architectures: a combination space and ground-based system, a ground-only system, and a theater defense system. In addition, most architects have considered various time-phased options. For this discussion we are considering primarily the combined space- and ground-based architectures.

some type of ground-based exe-atmospheric reentry interceptor system (E RI S). All saw a critical need for midcourse interactive discrimination, although this task might be too difficult for a near-term, phase-one deployment.

The "concept validation" program approved by the Secretary of Defense in September 1987, included work on SBIs, ERIS, and associated sensors and battle management technology.

SYSTEM DEVELOPMENT

The system engineer must combine various components and sub-systems defined by the architecture into a working system. A typical BMD system as envisioned by system architecture contractors for intermediate-term ("phase-two") deployment might have included 30,000 major sub-systems of nine different types (for suggested major components of a phase-two system, see table 1-2 inch. 1). The sub-systems would be tied together by a communications network. These sub-systems would have to work together under the direction of battle management computers.[2]

For each of these components, the system engineer would have to consider the following issues:

- Mass is particularly critical for SBIs: they would have to be light to reduce space transportation costs and to achieve the necessary velocity during battle.
- Total volume may be limited by the space transportation system. All space sub-systems would have to conform to the launch vehicle internal dimensions, preferably with minimum wasted payload space.
- For early deployment (late 1990s), the choices for space base-load power would be limited to solar (which is vulnerable), or nuclear, which would have to be developed and space-qualified in the power ranges needed for BMD. Far-term directed-energy weapons could be driven by liquid oxygerd/liquid hydrogen turbogenerators or fuel cells for a few hundred seconds. The weight of power supplies might dominate future systems.
- Heat rejected by the various devices would have to be minimized and properly managed, since cooling systems take up weight and power.
- Almost all sub-systems would have to be produced in large quantities compared to previous space systems. These components would have to be capable of mass production, as compared to the one-of-a-kind laboratory fabrication used in many of the SDIO technology demonstration projects. The United States has never mass-produced any satellites.
- All components would have to withstand severe radiation environments, including nearby nuclear explosions. This would be particularly stressing on electronic components such as IR detectors. The detectors and most electronics used for demonstration experiments would not be suitable for BMD deployment.
- These systems would have to endure and operate on call after sitting dormant (except possibly for periodic tests) for years. The current goal is at least 5-year life for first-phase deployment, with 7 years desirable. Limited lifetimes would further burden the space transportation system with replacement or repair missions.
- Many systems might have to operate within seconds or minutes after warning, although there might be an alert status lasting for days or weeks. Trade-offs between long alert times and fuel consumption might be necessary.
- All space-based systems would have to operate automatically, compared to the careful "hand tweaking" common in experiments. In particular, there would be little or no opportunity for the routine

[2]As discussed inch 7, this battle management function would likely be distributed among many computers on different satellites for survivability.

maintenance common to all terrestrial military systems.

- Various sub-systems and components would have to work together. For example, radiation from a nuclear power supply must not degrade the operation of sensitive IR sensors or electronics. Similarly, fumes from a propulsion system must not fog the optics of critical sensors, and vibration from power sources must not degrade weapons pointing accuracy.
- If components are prone to failure, they should be easily replaceable or adjustable. For space-based systems, a key issue would be whether to replace entire satellites when they failed, or to attempt periodic manual or robotic repair.
- All systems and components should survive both natural and man-made environments. Survivability measures such as decoys, redundancy, shielding, maneuverability, electronic jamming, and shootback would add mass to space-based components. One system architect estimated that survivability measures would account for 70 percent of on-orbit mass for SBI systems.
- The communications channels would have to be secure against interception, manipulation, and jamming.
- The systems should be safe in manufacture, assembly, transport, and operation.

SDIO is funding research in all of these areas. Optimists believe these characteristics may be achievable; pessimists question whether the break necessary from past practice and experience is possible; others say it is too early in the research program to judge whether the United States could achieve all of these attributes in a working system.

SYSTEM TESTING

Testing of both hardware and software is essential to any engineering project. Components are tested and modified to overcome deficiencies. Sub-systems are tested and modified. Finally, prototypes of the complete system are built and tested under full operating conditions whenever possible. These system tests invariably reveal faults in the original design, faults which must be corrected before production begins.

A ballistic missile defense system could not be tested in a full battle condition. Instead, the systems engineer would have to rely on some combination of computer simulations and operation under simulated conditions. The anti-ballistic missile (ABM) treaty prohibits space-based tests in an ABM mode which would be necessary to establish even minimal confidence in SBIs.

In place of complete system testing, the SDIO is developing the National Test Bed. This test bed (see ch. 8) is to tie together many communication nodes and computers via satellite, simulating some of the complexity of BMD. Some types of hardware (such as sensors) would also be coupled into this test system as they became available, "talking" to the computers as they would in a real battle. The cost of simulation will be high, but this is the only way to give leaders some degree of confidence in system operation. One of the key judgments the President and Congress will have to make about the SDI program will be the level of confidence to be placed in a global system that has never been tested in a full operational mode.

Testing so far under the SDIO program has been limited to the component or sub-system level, usually under simplified or artificial conditions. These experiments have yielded valuable information necessary for the ongoing research and development effort; the United States should not, however, confuse a demonstration test with operational readiness (see box 6-A).

Box 6-A.—SDIO Demonstration Experimental

Homing Overlay Experiment: The HOE demonstrated on the fourth test (June 10, 1984) that an experimental IR homing vehicle can acquire and collide with a simulated reentry vehicle in flight. The RV was launched aboard a test ICBM from Vandenberg AFB in California. After detection by radars on Kwajalein, a rocket carrying the experimental ground-launched interceptor was fired from a nearby island toward the oncoming RV. The IR sensor on the interceptor then acquired the RV and guided the interceptor to a direct hit high above the Pacific.

While this was an encouraging and successful experiment, it does not mean that the United States could deploy operational exoatmospheric interceptors tomorrow. The HOE experiment used parts of an existing missile, too large and expensive for an affordable BMD system. The IR sensor was cooled for many hours prior to the test; an operational system could not be maintained at such cold temperatures. The detectors were not hardened against nuclear radiation; new types of detectors would be required for the operational system. The simulated RV fired from Vandenberg AFB in California radiated about 10 times more IR energy than that expected from today's Soviet RV, and future RVs could have even lower IR signatures with thermal shrouds. There was only one RV, and the experimenters knew when and where it would be fired; the real issue for exoatmospheric interception is decoy discrimination-separating one RV out of a cloud of hundreds or thousands of other objects, including tethered balloons. Opinions differ on how difficult this would be.

Delta 180: The Delta 180 mission (Sept. 5, 1986) launched a Delta missile into space; the two upper stages of this missile were both placed in orbit. Each contained sensors later used to measure radiation from the other and from another missile launched from White Sands, New Mexico during one orbit. One stage also contained a radar sensor used to guide the two stages into a collision course at the end of the experiment.

The Delta 180 was a very successful measurement program, providing useful information about radiation from rocket exhaust plumes, both at close range in space and from the ground-launched Aries rocket. Some radiation patterns confirmed expectations, but there were some surprises which could improve our ability to detect and track future missile plumes. Tracking algorithms were also tested in the final interception with the target stage accelerating, which is more difficult than for targets with constant velocity. The entire Delta 180 mission took only 18 months from start to finish, requiring extraordinary management and dedicated performance by defense contractors.

However, this measurements program should not be confused with a demonstration of the near operational readiness of space-based interceptors. This interception had little resemblance to the BMD problem–and could not have without violating the ABM treaty. The relative velocities and ranges of the two stages were far less than those required for BMD. The target stage had a large radar reflector (over 1 square meter). The size and mass of the interceptor stage (over 2,000 kg compared to a goal of less than 200 kg for SBIs) would eliminate any possibility of achieving the velocities required of a SBI to kill an ICBM. All planned SBIs discussed to date would require an IR sensor for final homing, while Delta 180 used a Phoenix air-to-air missile radar. Finally, the near head-on aspect of the final kill would not be typical for a BMD mission, and did not stress the divert capability of the interceptor.

FLAGE: Six of nine planned tests of the "flexible, light-weight agile guided experiment' '(FLAGE) short-range terminal interceptor missile have been completed. On the second test, the radar-guided homing interceptor passed very close to the target, again indicating that hit-to-kill interceptors are feasible under appropriate conditions.

In the FLAGE tests, the target vehicle was flown into a highly instrumented volume of air above the White Sands Missile Range. Although artificial, this controlled environment is appropriate for an experiment, which should collect as much data as possible. The successful interception

'These comments on the SDI validation experiments should not be construed as criticism of SDIO management. These are all sound experiments properly designed to collect bits of information necessary on the path to developing a working system. At this time we have no major element of a non-nuclear ballistic missile defense system which has been tested in a system mode with equipment suitable for actual operation.

does not imply that the United States could build a FLAGE interceptor system today that would be effective against uncooperative targets in all types of weather. A FLAGE-derived interceptor would not be suitable for defending soft targets such as cities.

MIRACL Laser Test: The MIRACL DF laser at White Sands was aimed at a strapped-down Titan rocket casing. The booster casing was stressed with high pressure nitrogen to simulate the stresses expected in flight. The laser beam heated the skin of the tank, which then exploded in a few seconds as the shell weakened.

This experiment essentially tested target lethality: how much IR energy is required to weaken a Titan tank until it ruptures? The laser beam was about 100,000 times less bright than one required to destroy a responsive Soviet booster from a distance of 1,000 km or more. It was not a test of a directed-energy weapon system. The key issues for any DEW are target acquisition and tracking, beam pointing over very large distances, and particularly the questions of retargeting and beam jitter: could one keep the laser beam focused on one spot on the booster body while the booster and the DEW platform travel through space at many kilometers per second? Other more complex experiments would be required to answer these crucial questions. Real confidence in any DEW would require space-based testing under dynamic conditions.

FABRICATION

Once a system had been developed and tested to the degree possible, it would have to be manufactured. The manufacturing tools and facilities to fabricate much of the specialized equipment needed for BMD are not yet available. In some cases, expansion or modification of existing manufacturing facilities might be adequate. In other cases, entirely new manufacturing techniques would have to be developed and skilled workers trained. The SDI research program is addressing some key manufacturing issues, such as mirror and focal plane array (FPA) fabrication techniques.

Some of the key manufacturing challenges are summarized in table 6-1, along with an estimated comparison of current manufacturing capacity with second-phase BMD needs. These comparisons are not always valid, however. For example, current (FPA) manufacturing capacity is for non-radiation hardened arrays with less than 180 detector elements. Ballistic missile defense sensors must survive in a radiation environment, so new types of detectors are being developed, along with all new manufacturing techniques.

The items in table 6-1 represent only phase-two BMD deployments, excluding items such as interactive discrimination apparatus and directed-energy weapons (DEW).[3] Building hundreds of space-qualified neutral particle beam accelerators or high power lasers with their rapid pointing and retargeting mechanisms would certainly stress manufacturing capability.

Any manufacturing process must minimize cost and delivery time while maintaining high quality. These three virtues have added significance for BMD.

Table 6-1.—Examples of Current v. Required Manufacturing Capacity for Proposed BMD Systems

	Current capacity	Required capacity for Phase-n BMD
Large area mirrors (square meters per year).	1-2	100-2,000
Focal plane arrays (number of elements made per year)	10^6	10^7-10’
Sapphire windows (for HEDI; number per year) .	50	600-1,000
Precision guided missiles (per year)	loos	1,000-5,000
Satellites (per year)	10s	300-500
Space-launch rockets	10s	loos

SOURCE: Office of Technology Assessment, 1988,

‘Note, however, that recently the SDIO has suggested the possibility of including such elements in phase two.

Photo credit: U.S. Department of Defense

Delta 180 payload—The payload of the Delta 180 experiment, atop a Delta booster, is shown during shroud installation on Pad 17 at Cape Canaveral. Multiple boxes carrying optical sensors are mounted on the side of the rocket's second-stage truss at bottom. The mast on top of the third stage is a Phoenix missile sensor, which helped guide an intercept between the two vehicles to obtain rocket motor plume data at short distances.

Photo credit: U.S. Department of Defense

Lethal test of high-velocity projectiles.—Electromagnetic launchers might hurl small homing projectiles at distant missile stages or warheads. In this test of the effects of high-velocity impact, a small (unguided) plastic projectile hit a cast aluminum block at 7 km/s. This was a test of lethality, not of a weapon: the projectile was not launched from an electromagnetic launcher.

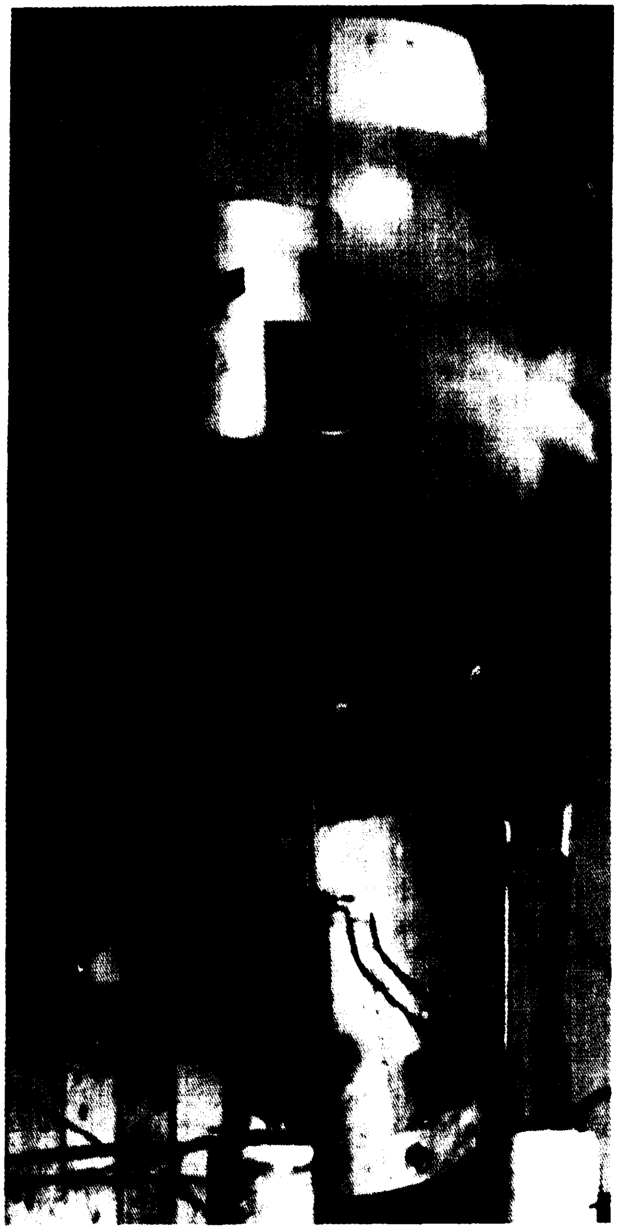


Photo credit: U.S. Department of Defense

Laser lethality test.— In September 1986 this test at White Sands Missile Range, N. M., investigated the possible effects of a laser beam on a rocket booster. The test vehicle was the second stage of a Titan I booster missile body. External loads were applied to the booster to simulate flight conditions typical of current operational Soviet missile systems. The test vehicle contained no liquid propellant or explosives. It was irradiated with a high-energy laser beam for several seconds before being destroyed. The laser used, the Mid-Infrared Advanced Chemical Laser, generates a beam energy greater than 1 MW/sr. It is a test laser, not developed for deployment in space.

cost

The projected costs for a BMD system will strongly affect a national decision on whether to proceed with production or deployment. In addition to total costs, the incremental costs of BMD would have to be less (some think substantially less) than the perceived incremental cost of Soviet countermeasures. Thus the unit costs of a deployed SBI might have to be less than l/370th to l/12th the cost of a Soviet booster.' On the other hand, the leverage provided by a successful "adaptive preferential defense" might improve this cost-exchange ratio (see ch. 1).

The allowable costs for aground-based exoatmospheric interceptor would depend on the system architecture. With low leakage from the boost phase and good discrimination, each interceptor would have to engage only a small percentage of the attacking Soviet reentry vehicles (RVs), and the interceptor could be relatively expensive. If discrimination were poor, which might be the case in a phase-one deployment, then the interceptor might be competing with cheap decoys. The defense would not be cost-effective at the margin if every exoatmospheric interceptor had to costless than 10 light-weight decoys, or even less than 10 heavy decoys.[5]

Time

The time to manufacture components for BMD might be crucial in several respects. Ideally the system should be deployed quickly to avoid transition instabilities, although system architects differ on this point. Components could be produced and stockpiled until deployment began.[6] To the degree that space transportation would pace deployment, production times would not be critical.

But the United States would also be locked in a race with Soviet countermeasures. If the United States could not produce and deploy enough SBIsbefore the Soviets had reduced a substantial number of their booster burn times below 140 seconds, then BMD boost-phase system effectiveness would drop significantly, perhaps to zero. The SBIs might force the Soviets to faster post-boost vehicle (PBV) dispersals, which could reduce the number of RVs At some point, however, there would be no sense in deploying SBIs(and particularly SBIs Which did not have any midcourse capability against RVs) until DEW were developed. (See also ch. 5 and the key-issues section at the end of this chapter for more analysis of SBI effectiveness against boosters with moderately fast burn times.)

On the other hand, if the United States could produce and deploy an SBI system in a few years, and if it could build and deploy a credible DEW system as the Soviet Union converted to faster-burning boosters and fast-dispersing PBVs, then BMD effectiveness might continue.

Production time involves not only the production rate, but the time to design, build, and debug the manufacturing facilities, including necessary training of production workers. Since many new technologies are contemplated, there might be relatively long periods before routine production could begin.

Quality

Quality control would be essential, particularly for space-based deployment. Repair or even replacement of failed assets in space

'The 12-to-1 cost ratio assumes that 8 percent of the SBIs would be within range of the Soviet missile fields and that one SBI is fired at each booster or PBV. There are no extra SBIs for redundancy or shoot-back against Soviet ASATS. In this case the United States would have to add about 12 SBIs (and another carrier satellite) for each new Soviet booster. The 370-to-1 cost ratio comes from a concentrated basing of new Soviet boosters in a relatively small area, say 150 km by 150 km. In this case the United States would have to deploy 370 extra SBIs and their associated satellites for each new Soviet booster to achieve an 85 percent probability of destroying that extra RV.

[5]If the boost phase defense let through 10 percent of the boosters, and each booster carried 10 warheads, 10 heavy decoys, and 100 light decoys, then the exe-atmospheric interceptor system would have to engage one warhead, one heavy decoy, and 10 light decoys for each booster launched With perfect discrimination, one deployed interceptor would have to cost less than one loaded booster. Without any discrimination, one interceptor would have to cost l/12th of the booster.

'See U.S. Congress, Office of Technology Assessment, *Ballistic* Missile Defense *Technologies,* OTA-ISC-254 (Washington, D. C.: U.S. Government Printing Office), p. 119.

might severely stress space transportation, particularly if space launch facilities were completely occupied over a period of 5 to 10 years just to lift the initial BMD equipment into place.

DEPLOYMENT

Given that some boost-phase defense capability would be key to a highly effective BMD system, and given that the United States currently has very little space launch capability, deployment of space-based assets would most likely limit the operational starting date for BMD. As shown in the space transportation section of chapter 5, the United States would have to build a new space launch system to lift into orbit the necessary number of SBIs and their supporting satellites. The timing of the development and availability of a new space launch system is unclear, but it is doubtful that it would be possible to launch significant numbers of SBIs before the mid to late 1990s.

Several years of continuous space launch activities from several launch pads would then be necessary to deploy enough SBIs to provide one shot against each missile or PBV in today's fleet of Soviet intercontinental ballistic missiles (ICBMs). The SDIO, however, does not propose deploying that many SBIs in a first-phase system. It argues that lesser capabilities would still have worthwhile deterrent value. (See section below on scheduling and deployment issues for discussion of the effect of deployment rates on SBI system effectiveness.)

OPERATION AND MAINTENANCE

Once deployed, the BMD system would have to be kept in operating order. Ground-based elements such as ERIS could be periodically tested, disassembled, and repaired as needed. For space-based assets, both testing and repair would be difficult unless built into the initial design. Methods would be needed to determine if the sensor or the guidance system on a dormant SBI would operate in a war. Computer systems would have to be exercised to make sure radiation in space had not altered a key software bit that might subsequently inhibit successful operation. The status of dormant space assets would have to be monitored carefully and frequently.

Once defective space systems were diagnosed, they would have to be replaced or repaired. The system architecture would have to incorporate some combination of redundancy or on-orbit repair or replacement to maintain the total system. The space transportation system would have to be sized to handle this load.

Space-based assets might also need to be modified in response to Soviet countermeasures. SBI sensors initially designed for tracking only booster plumes with short or medium-wave IR sensors might become worthless against faster-burning boosters. Should a second-phase system add LWIR sensors to previously deployed SBIs to give them mid-course kill capability? Trade-off studies would determine whether it would be more cost-effective to replace components on obsolete satellites or simply to add entirely new satellites.

EXAMPLE BMD SUB-SYSTEM: SSTS

To appreciate some of the complexity of a BMD system, consider just one of the systems in table 1-2: a moderately sophisticated Space Surveillance and Tracking System (SSTS). The potential sub-systems of an SSTS are shown in table 6-2. Almost every subsystem on this list would require development to meet the probable BMD specifications.

At the next level down, just one sub-system from the SSTS, a three-color LWIR sensor, would include the components listed in table 6-3. Again, most of these components must be developed to meet BMD specifications. An analysis of the other SSTS sub-systems and the other major sub-systems in the three phases of SDI would reveal literally hundreds of sizeable development programs which would have to come together to form the complete system.

Table 6-2.—SSTS Subsystems

	Development required
Propulsion (for station-keeping)	Low
Communications (space-to-space)	High
Communications (space-to-ground)	High
Power source	High
Three-color LWIR sensor(s)	High
SWIR/MWIR sensor(s)	Medium
Laser ranger/designator	High
Star tracker(s)	Medium
Computer and memory	Medium
Waste heat rejection	Medium
Support structure	Low

SOURCE: Office of Technology Assessment, 1988

Table 6.3.—Three-Color LWIR Sensor Components

	Development required
Primary mirror	High
Secondary mirror	High
Cryo-cooler	Medium
Three-color focal plane array (FPA)	High
Signal processor	High
Three-axis gimbal	Medium
Servo control system	Medium
Thermal control system	Low
Sun shield	Low
Support structures	Low

SOURCE: Office of Technology Assessment, 1988.

KEY SYSTEM ISSUES

Building and deploying a system on the scale of proposed BMD architectures would stress the U.S. engineering and manufacturing infrastructure on many fronts. However, three critical systems issues are unique to ballistic missile defense with space-based components: the lack of realistic system testing, the necessity for automated, computer-controlled operation, and the difficulties of scheduling and space deployment.

System Testing

The inability to test fully a global BMD system (both hardware and software) would cast doubt on its operational effectiveness. The administration and Congress will have to decide on the deployment of a system whose performance would have to be predicted largely by computer simulations. The National Test Bed and future component tests would improve the verisimilitude of those simulations, but they could not encompass all of the complexity of the real world. Some issues such as sensor operation against a nuclear explosion background in space could not be tested even at the component level without abandoning the Limited Test Ban Treaty. Except in computer simulations, the system could not be tested, short of war, with even 10 percent of the possible wartime threat.

It is true that all military systems are subject to uncertainty when they first go into battle. A fighter aircraft, despite the best flight test program, can never be tested with all the variables that will arise in a real battle. An aircraft-carrier battle group could never anticipate all possible situations in some future battle with a capable adversary, and might be susceptible to unforeseen vulnerabilities. The U.S. carrier battle groups have never fought against an enemy with modem “smart weapons. ” There is uncertainty in the performance predictions of these conventional military systems.

A global BMD system would have even more complex, untestable sub-system interactions. Even full interception tests, using SBIs fired against ICBMs launched from Vandenberg AFB, could involve at best a salvo launch of a few missiles. This would not substitute for the launching of a thousand missiles by the Soviet Union at a time of their choosing, preceded by anti-satellite weapon (ASAT) attacks and nuclear precursor explosions. Individual components such as sensors, data processors, and communication equipment could be tested by themselves to full operational capacity in the laboratory or in simulated space chambers, and some effects of nuclear explosions could be tested at the Nevada test site. In any case, the complete BMD system could not be tested as an integrated unit against a real threat. Neither, on the other hand, could the Soviet offensive ballistic missile force.

Automatic Operation

Automation has made dramatic changes in factories and some military weapons systems. Robotics is firmly established in many manufacturing situations, and will grow in the future. However, space-based BMD systems would cross into new engineering domains of automatic operation on several counts:

- continuous unattended stand-by operation for years,
- a continuously changing constellation of components which would have to operate together as a unit, and
- operation under adverse conditions against an opponent determined to defeat the system.

None of these limitations is encountered in automated factories.

Automatic fire control systems are common in today's weapons. Human intervention is always possible, however, to repair and maintain the system. The United States has never operated a weapon system in space. Both the United States and the Soviet Union have operated sensor systems ins ace for surveillance and early warning of ballistic missile attack. The challenge would be to integrate more sophisticated early warning satellites with actual weapon platforms thousands of kilometers away.

Sensor satellites currently in orbit operate autonomously, with directions from a few ground-based mission control nodes. Once the battle began, BMD systems might require the autonomous operation of 30 to 40 sensors working in conjunction with hundreds or thousands of SBI carrier satellites. Sensors and carrier satellites would be moving in different orbits, so that the particular weapons platforms and sensors making up a “battle group” (in one possible battle management architecture) would be constantly changing with time. (See ch. 7 on wartime operation.) These battle groups would have to be connected by secure communication links. Higher system effectiveness would entail tighter coordination.

Automatic operation would be further challenged by Soviet defense suppression tactics. The system would ideally adapt to lost or noisy communication links and continue to manage the battle on the basis of degraded information. (See ch. 9 for a fuller discussion of BMD software dependability.)

Scheduling and Deployment: An Illustrative Scenario

If an administration and Congress were to decide that our national security would be improved by deploying some type of BMD, a major issue would be when to begin deployment. Early deployment (e.g., 1995-2000) of a phase-one system would risk "locking in" immature BMD technology that might be less effective against the projected threat. Waiting for more advanced technology would give the Soviet Union more time to prepare countermeasures, increasing the risk that the defense effectiveness would remain low. Early deployment would strain space transportation facilities, and the long deployment time would preclude a fast transition from offense- to defense-dominated status. But a decision to wait for later deployment could, some fear, indefinitely postpone any deployment at all.

Ballistic missile defense system effectiveness would depend not only on the U.S. deployment schedule, but also on the timing of Soviet countermeasures. The longer it took to deploy a defense, the more time the Soviets would have to respond by improving their offensive forces. To illustrate the interplay between defensive and offensive deployments over time, OTA constructed a plausible scenario for the 1994-2010 period, then estimated the effectiveness of an SBI system as a function of time. For the defense, we assume that:

- SBI deployment would be limited only by the capacity of future United States space transportation systems. That is, the United States could produce and operate in space as many SBIs as it could launch. *Note that it is emphatically not the SDIO proposal to deploy this many SBIs.*
- The SDIO two-track space transportation scenario succeeds in building a heavy lift expendable launch vehicle by 1994 with 30,000 kg lift to near polar orbits, and this same technology simultaneously evolves into an economical, partially reusable vehicle with 44,000 kg capacity by the year 2000.
- Three new launch pad complexes would be built at Vandenberg AFB and launch rates would be increased from 3 per year per pad up to 12 per pad per year, bringing the total lift capacity to near polar orbits to 2.2 million kg per year by 2004.
- Three different classes of SBIs might be available with varying masses and velocities: a "state-of-the-art" a "realistic," and an "optimistic" interceptor. (Specification of the characteristics of each are in the classified version of this report.)
- The SBIs would be replaced at the end of a useful life of 5 to 1O-years, which limits the number of SBIs in orbit unless the space transportation system capacity continues to grow with time.

For the Soviet offensive response, OTA assumed:

- a gradual decrease in the burn-time of Soviet ICBM boosters and in the RV and decoy dispersal time of its PBVs through the introduction of one new class of 10-warhead missiles every five years;
- that these new missiles would be clustered at three existing SS-18 missile sites, which would cover an area of 500,000 square km;
- retirement of old Soviet missiles as the latest models were introduced, keeping the total RV count at 10,000 (case 1), or an increase of their ICBM's by 100 per year after the year 2000 (case 2);
- no other Soviet countermeasures, except a significant Soviet A SAT capability, implied by our resewing a substantial fraction of U.S. SBIs for self-defense or to account for inoperable SBIs that fail over time.

While these assumptions are technically plausible, they are not based on any Department of Defense or intelligence community estimates of what the Soviets could or would do.

Table 6-4.—Assumed Distribution of Soviet ICBMs for 1990.2010

All ICBMs are assumed to carry 10 warheads. Please note that the mix of forces here reflects neither Department of Defense nor intelligence community estimates of what the Soviets actually may do. Instead, this table merely lays out a purely hypothetical sequence of a phasing-in of faster-burning ICBMs at 5-year internals beginning in 1990, Older missiles are retired as new ones are deployed, keeping the total RV count fixed at a hypothetical number of 10,000. The slow-burn boosters are distributed over existing Soviet missile fields, while the other four classes are assumed concentrated at three existing sites.

	Number of ICBMs				
ICBM type	SBB	MBB-1	MBB-2	FBB-1	FBB-2
Year:					
1991	500	500	–	–	–
1992	500	500	–	–	–
1993	500	500	–	–	–
1994	500	500	–	–	–
1995	500	500	–	–	–
1996	400	500	100	—	—
1997	300	500	200	–	–
1998	200	500	300	–	–
1999	100	500	400	–	–
2000	—	500	500	–	–
2001	—	400	500	100	–
2002	—	300	500	200	–
2003	—	200	500	300	–
2004	—	100	500	400	–
2005	—	—	500	500	–
2006	—	—	400	500	100
2007	—	—	300	500	200
2008	—	—	200	500	300
2009	—		100		400
2010	—	—	—	500	500

Legend:
SBB: Slow-Burn Booster
MBB-1: Medium-Burn Booster—First Generation
MBB-2: Medium-Burn Booster—Second Generation
FBB-1: Fast-Burn Booster-First Generation
FBB-2: Fast-Burn Booster-Second Generation

SOURCE: Office of Technology Assessment, 1988

Space Transportation Limits on Deployment

As indicated in chapter 5, a new space transportation system would be needed to launch the space-based assets of a highly effective BMD system. Even a more modest system, such as that proposed by SDIO for the first phase, would call for considerable new space transportation capacity. The SDIO has identified two potentially conflicting space transportation goals: reducing launch costs by a factor of 10 and beginning some launches in the mid-1990s. Derivatives of existing Shuttle/ Titan launch systems are not likely to lead to major cost reductions; an entirely new system would be needed. But a revolutionary new space transportation system would not likely be ready before the year 2000.

To achieve both the cost and schedule goals, SDIO has proposed a dual-track formula: a new space transportation system would be developed with a goal of a tenfold cost reduction by 2000 or so, but parts of this new system would be available by the mid-1990s for early deployments, probably with reduced lift capacity and higher cost. This approach might create design compromises. Either cost reductions might have to be postponed to meet the schedule, or the schedule might have to be slipped to meet the eventual cost goals: a space transportation system designed to meet just one of these goals might look quite different from the hybrid. In this scenario, however, we assume that both goals could be achieved simultaneously.

The United States now has one pad capable of launching more than 10,000 kg to the high inclination orbits and altitudes of several hundreds of kilometers to be occupied by the SBI constellation.[7] The Shuttle pad at Vandenberg Air Force Base could be modified by 1992 to launch the Titan-4 (CELV) vehicle with a capacity of about 14,500 kg to SBI orbits. In the past, building new launch pads has taken from 7 to 10 years and there is some question whether there is adequate space at Vandenberg to add even a few more pads and their necessary assembly facilities. (The Air Force has been examining the possibility of launching rockets from an off-shore oil rig.) Survivability of launch facilities would also be questionable if all U.S. polar-orbit pads were located at one coastal site. In this scenario, we assume that these difficulties are overcome.

Launch rates have been in the range of three to five per year from one pad. This rate is

[7]The 4-East pad at Vandenberg Air Force Base in California is equipped to launch the Titan 34D and Titan-4 (CELV) vehicles into polar or high inclination orbits. The 4-West pad at Vandenberg can handle the Titan-2 vehicle, which has less than 2,000 kg capacity. Two pads at Kennedy Space Center (#40 and #41) can launch Titan 34Ds and Titan-4s, but not into near-polar orbits. There are no Delta launch facilities at Vandenberg.

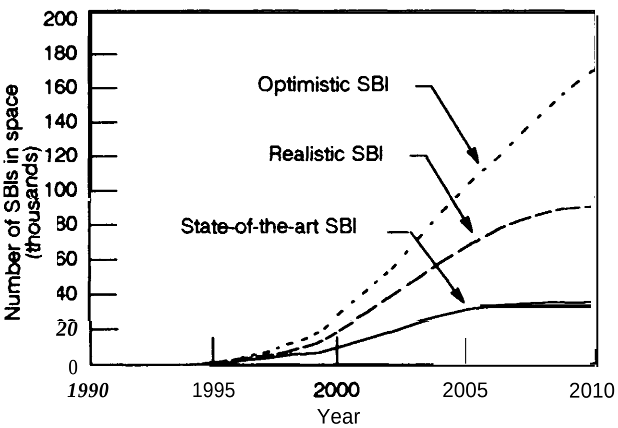
limited by the necessity to assemble the launch vehicles at the site. Studies are underway to determine if these launch rates could be increased to 6 per year, with some experts suggesting that rates up to 8 per year might be feasible in the future for the Titan class vehicles, and 12 per year per pad for the new vehicle.

SBI Characteristics

OTA analyzed three classes of SBIs, corresponding to assumed improvements in SBI technology as discussed in chapter 5. The "state-of-the-art" rocket would probably be the best technology available for a first-phase deployment in the mid-1990s. For the most part, this SBI would use components that have been demonstrated in the laboratory (as of 1988), but not as yet assembled into a working system. The "realistic" SBI represents a plausible level of technology after more component research and development, and might be available by the mid to late 1990s; the overall rocket mass assumption of well under 100 kg would be particularly challenging. The "optimistic" SBI assumes improvements in all areas of development, and would be much less likely, but possible. Other assumptions about SBI redundancy factors and kill probabilities are the same as those applied earlier in chapter 5 of this report.

Given the optimistic space launch projections from chapter 5 and the different assumptions for SBI masses, one can estimate the total number of SBIs that might be placed in orbit as a function of time, as shown in figure 6-1. The lifetimes of SBIs in space would be critical, since defunct interceptors would have to be replaced, taking space transportation capacity away from the tasks of increasing SBI deployments or other BMD assets. It might turn out, however, that on-orbit repair could reduce the numbers of spares and replacements needed. As shown in figure 6-1, the number of state-of-the-art rockets would reach a plateau by about 2006 if better SBIs could not be developed: a space transportation system sized to put the original constellation in place would operate full-time just to replace these

Figure 6-1.—Number of Space-Based Interceptors Launched Into Space (limited only by the space transportation system)



Maximum number of SBIs that could be launched into orbit based on the assumed space transportation revolution described in chapter 5. This chart assumes that all space launch capability is devoted to SBIs and their associated carrier vehicles. The net mass per SBI, including the pro-rated share of the carrier vehicle mass, would be 334, 179, and 129 kilograms for "state-of-the-art," "realistic," and "optimistic" SBIs, with life-times of 5, 7, and 10 years.

SOURCE: Office of Technology Assessment, 1988.

SBIs and maintain the constellation in a steady-state constellation.

For the lighter and faster "optimistic" SBIs, the assumed transportation system could lift up to 160,000 SBIs into orbit by the year 2010. This assumes that no other space assets would be launched into near polar orbits during the entire 1994-2010 period. Thus any later deployments of interactive discrimination systems or directed-energy weapons would reduce the possible number of SBIs in orbit. In any case, it is obvious that the United States would not try to manufacture, lift into space, and manage a constellation of 160,000 SBIs.

The "optimistic" SBI effectiveness curves which follow are therefore unrealistic; they are shown only to indicate upper bounds on SBI boost and post-boost effectiveness. They suggest that while SBIs might be considered for a system intended to enhance deterrence, they would not, by themselves, be suitable for a system intended to assure very RV low leakage rates. They also suggest that, barring substantial offensive force reductions, the initial effectiveness of an SBI system might be eroded by appropriate countermeasures. In that case, directed-energy weapons might have to be brought on line just to maintain previous defense capability.

Assumed Soviet Offensive Countermeasures

As the U.S. space transportation system (and hence the number of possible SBIs in space) grew, Soviet ICBM and submarine-launched ballistic missile SLBM forces would most likely also change with time. One central question for evaluating BMD effectiveness is whether reasonable Soviet countermeasures could keep ahead of possible U.S. BMD deployments. Here, OTA analyzed the effects of just three Soviet countermeasures: reduced booster burn and PBV dispersal times and clustering of new missiles at three existing missile sites. These analyses assumed that the Soviet Union reduced its booster burn and PBV times gradually over the next two decades, introducing anew class of weapon each 5 years with moderately improved performance. Three cases were assumed: optimistic (relatively long booster bum times), base case, and pessimistic threats. Even the "pessimistic" threat case assumes a 90-second bum-time by 2006, still more than the 60- to 80-second burn-times deemed feasible for the next century by some rocket experts. Thus these threat assumptions are all conservative compared to what may be technically feasible.

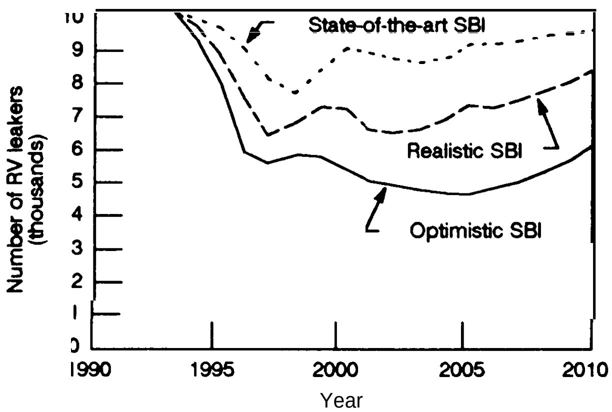
SBI Boost and Post-Boost Effectiveness

We next calculated the maximum possible number of RVs that could be destroyed each year by SBIs in either the boost or the post-boost phase, simply by calculating how many SBIs would be within range of the booster or the post-boost vehicle at the time each RV was deployed.

We assumed uniform, serial RV deployment over the PBV dispersal time. Each SBI attacked the booster first if it was within range, then the PBV at the earliest possible time. Two shots were taken if more than one SBI could reach a booster or PBV. Perfect battle management was assumed: the battle manager knew exactly where all boosters and SBIs would be at burnout, and assigned SBIs to their highest value targets without error. These calculations assumed that a substantial fraction of SBIs are used for self-defense (or are inoperable)—an on orbit repair system, however, might reduce the extra numbers needed. Other assumptions were that each SBI had a reasonably high single-shot kill probability against the boosters and and a slightly smaller one against the PBV.

The resulting system effectiveness (the number of RVs leaking through the boost and post-boost SBI defense) is plotted as a function of time in figure 6-2 for the three canonical SBIs

Figure 6-2.-Number of Warheads Leaking Through Boost and Peat-Booat Defenses



BMD system effectiveness in terms of the number of RVs (out of a hypothetical attack of 1,000 missiles with 10,000 RVs) which would leak through a boost and post-boost defense, limited only by the ability of the U.S. space transportation system to lift space-based interceptors (SBIs) into orbit (figure 6-1 indicates the number of SBIs available each year for each type of SBI). The SBIs have a reasonable probability y of destroying a booster and a slightly smaller probability y of killing a PBV; a substantial percentage of the SBIs are used for self-defense or are otherwise inoperative. The Soviet threat has a constant 10,000 warhead level, but with decreases in booster burn-times and PBV dispersal times as described in the text.

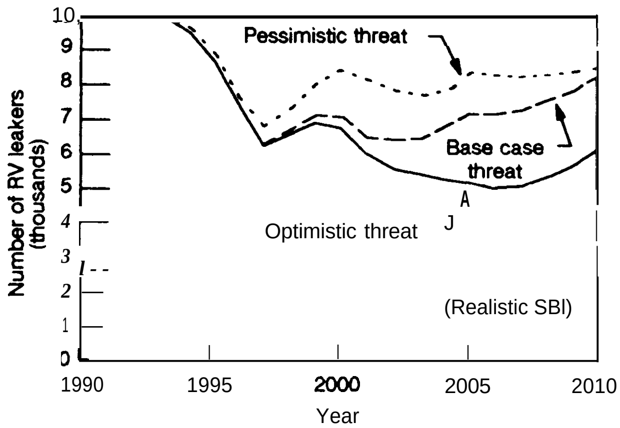
SOURCE: Office of Technology Assessment, 1988, of chapter 5, assuming OTA's hypothetical Soviet threat. In the very near term, the United States could only deploy the "state-of-the-art" SBI. According to these simplified calculations, this type of defense could at best destroy 2,500 RVs out of the OTA-postulated 1,000-missile, 10,000-RV threat by 1998 when the United States would have orbited 4,100 SBIs; 7,500 RVs (and their associated decoys) would pass through to the later defensive layers.

Performance would degrade over time with quicker dispersal of Soviet RVs. If the United States could develop the lighter and faster "optimistic" SBIs, then the defense could reach 50 percent effectiveness by 2001, but this would imply the deployment of 40,000 SBIs by then. Furthermore, to maintain this approximate level of effectiveness with 5,000 warheads leaking through to the midcourse, the United States would have to continue deploying these SBIs, reaching levels of 160,000 SBIs by 2010. Even then, the Soviet penetration to the midcourse would have increased slightly to 6,000 warheads.

The most likely "realistic" SBI would result in a minimum leakage of 6,000 warheads to midcourse. To come close to maintaining this leakage, the United States would have to continue devoting all space launch capability to the SBI system; by 2010 there would be 90,000 SBIs in orbit and 8,000 warheads would survive to midcourse. Again, such figures illustrate that SBIs should not be expected to stop high percentages of Soviet missiles in a massive attack. Nor is it reasonable to expect them to sustain initial boost- and post-boost phase capabilities against a "responsive" Soviet missile threat of the future. The SDIO does not support either expectation.

The sensitivity of SBI effectiveness to the Soviet threat is shown in figure 6-3, assuming the "realistic" SBI rocket parameters in all cases. With the "optimistic threat" scenario, the SBI BMD system could achieve 50 percent effectiveness by 2005, assuming that the United States had deployed 70,000 SBIs. Again, this constellation would have to be increased to 90,000 by the year 2010, and even then the Soviet RVs leaking through could

Figure &3. -Number of Warheads Leaking Through Boost and Post-Boost Defenses



Boost and post-boost system effectiveness as a function of time for three different Soviet threat models described above. "Realistic" SBIs were used in all cases.

SOURCE: Office of Technology Assessment, 1988.

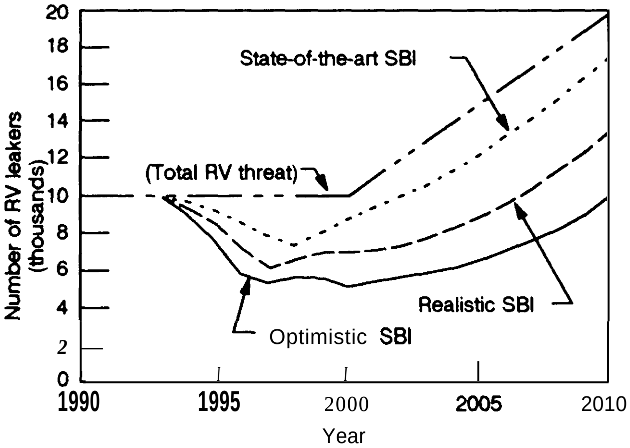
number 6,000 warheads and be increasing. These numbers suggest that directed-energy weapons would be needed, sooner or later, to achieve and sustain high kill levels against advanced Soviet boosters and PBVs.

The previous two figures assume that the Soviets retire old missiles as new ones are deployed, keeping the total at 10,000 warheads available. In the absence of arms control treaties, they could keep old missiles in place, and continue to add faster-burning boosters. The BMD effectiveness for this situation is shown in figure 6-4, assuming that all initial medium-burn boosters are retained, and that 100 of the faster-burning boosters (FBB) are added each year after 2000. Under the most optimistic (for the defense) conditions, the Soviets could maintain 6,000 warheads surviving into mid-course.

Assuming penetration aids to be available by the 2000-2005 time period, these 6,000 warheads and their associated decoys would make passive midcourse discrimination and RV kills very difficult. The leakage against SBIs in all cases would increase with time, most likely reaching the 10,000 warhead level by 2010, despite the presence of up to 160,000 SBIs in space.[8]

[8]For analytic purposes, we have ignored the questions of maintenance and battle management of so many interceptors.

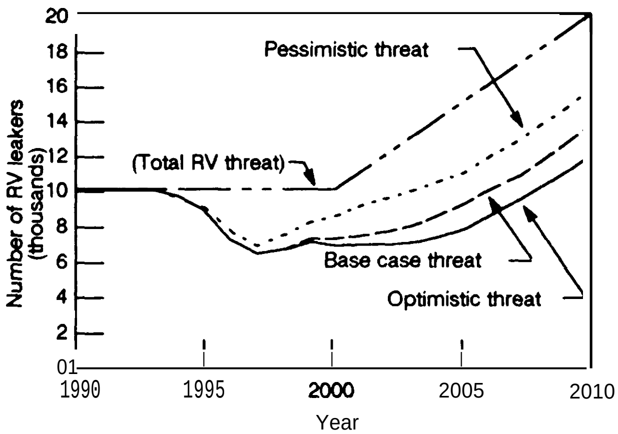
Figure 6-4a.—Number of Warheads Leaking Through Boost and Post-Boost



Boost and post-boost effectiveness limited only by space t ransportat ion capability, assuming that the Soviet threat increases in quality (shorter deployment times) and quantity (after 2000). Effectiveness shown for three different types of space-based interceptors against the "base case" Soviet threat.

SOURCE: Office of Technology Assessment, 1988,

Figure 6-4b. -Number of Warheads Leaking Through Boost and Post-Boost Defenses



Boost and post-boost effectiveness against three different Soviet threats, all assuming "realistic" space-based interceptors.

SOURCE: Office of Technology Assessment, 1988.

SYSTEM CONCLUSIONS

Testing

1. If the United States abandoned or achieved modification of the ABM Treaty, it could test a limited constellation of SBIs against a few ICBM's launched from Vandenberg AFB. But this would not replicate the conditions of a massive, surprise launch of hundreds or thousands of ICBMs, ASATs, and nuclear precursors from the Soviet Union.
2. A BMD system could not be tested against the real threat of up to thousands of ICBMs combined with defense suppression and nuclear precursors. However, neither could such a coordinated offensive attack be fully tested.
3. Key elements, such as IR sensors, could not be realistically tested against a background disrupted by nuclear explosions without abrogating the Limited Test Ban Treaty.

Automation

4. No technical barriers appear to preclude automatic operation of a space-based BMD system, but the task of operating an automatic, constantly changing constellation of sensors and weapons platforms in the face of defense suppression tactics would be a major challenge with little or no analogous experience from any other automated systems.

Scheduling and Deployment

Phase One

5. A near-term deployment (1995-2000) of state of-the-art SBIs might stop up to 2,500 of an assumed constant 10,000 Soviet warhead threat in the boost and post-boost phases—if the United States devoted all of its space launch capability to lifting SBIs into orbit.

This assumes that the burn times and post-boost vehicle dispersal times of future Soviet ICBM's decrease over time in a reasonable manner. Of course, fewer SBIs could kill similar percentages of boosters if a smaller attack were assumed. The SDIO argues that defenses that are far from perfect still offer significant enhancement of deterrence (see chs. 1,2, and 3).

Phase 2

6. An intermediate-term or "phase-two" deployment of more advanced SBIs might kill up to 5,000 of the hypothesized fixed number of 10,000 Soviet RVs in the boost and post-boost phases, but only by orbiting from 90,000 to 160,000 SBIs. Therefore, the United States would be unlikely to rely on SBIs for continued boost-phase interception of advanced Soviet missiles.
7. Given the assumptions of OTA analyses, under the most optimistic conditions the Soviet Union could maintain an RV leakage into midcourse at or above the 6,000 warhead level by increasing the number of ICBMs deployed by 100 per year after the year 2000. Under any of the assumed conditions, the Soviet Union could increase the rate of warhead penetration against SBIs and into midcourse after 2005, reaching the pre-BMD levels of 10,000 leaking warheads by 2010. Therefore, SBIs should not be expected to achieve the strategic goal of "assured survival" against nuclear attack by a Soviet missile force unconstrained by arms reductions and limitations.

Phase 3

8. A highly effective BMD system would require either very effective midcourse discrimination or a very effective directed-energy weapon (DEW) system, and preferably both, since an SBI system, as limited by the most optimistic space transportation system, could never assure that fewer than 5,000 Soviet warheads and their associated decoys would leak through to the midcourse,
9. As concluded in chapter 5, it is unlikely that the United States could determine the feasibility of DEW systems by the late 1990s, and deployment probably could not begin until 2005-2010 at the earliest. It therefore appears likely that the Soviet Union, unless constrained by offensive arms control agreements, would be able to maintain leakage rates of a few thousand nuclear warheads until at least the period 2005-2010.