Chapter 3

Designing a BMD System: Architecture and Trade-off Studies

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Chapter 3

Designing a BMD System: Architecture and Trade-off Studies

THE IMPORTANCE OF BMD ARCHITECTURE STUDIES

Researchers have performed proof-of-principle experiments for some Strategic Defense Initiative (SDI) technologies. But many of the basic technologies for the SDI are still in an experimental, or even theoretical, stage. Therefore it might seem premature to be designing full-scale ballistic missile defense (BMD) systems for deployment not only in the mid-1990s, but in the 21st century. In fact, such designs are key to assessing the feasibility of achieving U.S. strategic goals through ballistic missile defense. National decisionmakers can only fully evaluate proposed systems on the merit of system architectures, not on the promise of one technology or another. If called upon to appropriate funds for BMD development and deployment, Congress will be asked to decide upon an architecture-a specific system design comprising many technologies and components.

Attempting such designs, or "system architectures, as the Strategic Defense Initiative Organization (SD IO) calls them, compels systematic analysis of all the factors that will affect SDI feasibility. In the near term, such analysis helps guide the technology research effort. In the long term, it will provide the substance of the national debate over whether to deploy BMD.

System architecture analysis, if done well, will provide some of the key elements of information upon which to base decisions about whether to commit the Nation to deploying any proposed BMD system:

- Specification of Goals. Explicit identification of the particular strategic goals that BMD system designs will be expected to achieve (e.g., impose uncertainty on Soviet strategic planners); understanding of those goals in the larger context of U.S. national security; and cost-effectiveness comparisons of alternate means, if any, of achieving the goals.
- Specification of Threat. Projections of future Soviet missile and BMD countermeasures that BMD system designs would be expected to overcome.
- System Requirements. Specification of the missile-interception tasks and sub-tasks that effective BMD systems would have to perform to meet the project threats; specification of passive and active survivability measures for the system.
- System Designs. Proposals for integrating sensors, weapons, and command and control arrangements into BMD systems that would likely meet system requirements and that could be practicably modified to meet changing threats; and specification of how technologies under research would be incorporated into a BMD system-such a design is called a system architecture.
- Technology Requirements. Specification of the technologies needed to build the weapon systems required by the overall system design, by the deployment and maintenance plans, and by plans for adaptive evolution of the system to meet changes in the threat; and plan for bringing all technology developments to fruition when needed (full-scale engineering development plan).
- Manufacturing Requirements. Specification of the materials, manufacturing facilities, tools, and skilled personnel needed to manufacture all system elements.
- Deployment and Operations Analyses. Proposals for how the designed system can be put into place and maintained (in-

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

eluding space transportation requirements); and schedules for doing so.

- Cost Estimates. Estimates for what development, procurement, deployment, and operation of the proposed system design will cost; and proposals for reducing system costs.

This chapter will focus on two particular topics:

1. the ways in which system architects for SDIO have related strategic goals to BMD system performance needs, and
2. the general characteristics of the system architectures studied for SDIO.

The concluding sections of the chapter will identify areas of analysis within those topics where important work remains to be done.

It would be highly unrealistic now to expect system architecture studies to be definitive. Each category of analysis is subject to considerable uncertainty, some of which may never be resolved by analysis and limited experimentation. The architecture analysis will necessarily be tentative and iterative: as new information and ideas emerge, modifications will be inevitable. Moreover, the findings from anal sea in each category will and should affect the findings in other categories. For example, meeting a particular technology requirement may be judged possible, but too expensive. The system architecture design may have to be modified to utilize another technology to carry out the same function. On the other hand, new technological developments may make it cheaper to carry out a function in a way that previous analyses had shown to be too costly. For that reason, the system architects attempt to design "evolutionary" architectures into which advanced technical developments could be phased as they became available.

Even after a commitment had been made to develop a particular technology into a weapon system, the process of full-scale engineering development might prove more difficult than anticipated: alternate systems might have to be designed and developed. Moreover, while it is the goal of the architecture analyses to provide options for meeting a range of potential changes in the offensive missile threat, a fully deployed BMD system might still have to be modified in unanticipated ways if the Soviets were to deploy unforeseen countermeasures.

Despite the necessarily tentative nature of system architecture analyses, they compel a coherence in thinking about BMD that would otherwise be missing. They also bring into the open the assumptions implicit in the arguments for and against deploying BMD. Because these analyses will inevitably include assumptions and projections that reasonable people may disagree about, it is important that they be carried out competitively, by more than one group of analysts. Such competition will give both the Administration and Congress a basis for identifying the uncertainties, varying assumptions, and alternative projections of the future that will underlie decisions about BMD. It will also be important, when these analyses are offered in justification of major decisions, that they be independently evaluated.

Recognizing the importance of system architecture studies, SDIO late in 1984 awarded contracts to 10 teams of military systems analysis contractors to provide competing analyses at a price of $1 million each. On the basis of that competition, five teams were chosen for $5-million, "Phase II" architecture studies, which were largely completed in mid-1986. In addition, a sixth contractor provided SDIO with analytic support to synthesize the findings of the five competitors into a "reference architecture" to help guide SDI research. As of this writing, the five Phase II teams had been awarded additional contracts to continue some analytic work common to all and to perform some tasks unique to each. Their reports were due at the end of January 1988.[1] It had

[1] Three other sets of "architecture" contracts should also be noted. First, through the Air Force Electronic Systems Division, contracts were awarded to three firms to design battle management and communications systems for a BMD system with land- and space-based elements. This work necessitated definitions of more or less complete BMD system architectures, thus to some extent paralleling the work of the general system architecture contractors, The SDIO has subsequently attempted

been planned that the five would be narrowed to two competitors in a final phase, but that decision was postponed through 1987. Eventually a single contractor team will be chosen to design a BMD system in detail.[2]

to better coordinate the parallel work of the battle management systems analyses and the main system architecture studies.

Second, the Army Strategic Defense Command awarded three other contracts for study of the battle management and communications systems for BMD composed primarily of ground-based components. Third, late in 1986 SDIO awarded seven contracts to teams composed of U.S. and European firms to begin designs of system architectures for European theater defense against intermediate-, medium-, and short-range ballistic missiles.

[2]For the future, SDIO has proposed two new organizations for carrying out work on system architectures. One organization would bean "SDI Institute, " a federally (and, specifically, SD IO) funded "think tank" to monitor the work on the actual system architecture to be proposed for deployment by SD IO. The Institute would be independent of particular defense contractors, thus reducing the possibility that the interest of current defense firms in selling hardware to the government would play a role in architecture designs.

A second new organization is to be a "National Test Bed, " which would be a network of computers, communications links, and some sensor hardware for simulating ballistic missile defenses. In some cases, the simulations would be purely conceptual, creating a computer "world" of BMD systems and offensive systems, and testing various assumptions about each. In other cases, this imaginary world might, with simulated incoming and outgoing data, test computer software actually intended for use in a real BMD system. In yet other cases, actual BMD hardware tests might be conducted, with data from the computers being fed into an actual test sensor system, and the sensor system sending processed signals back into the computer simulation. If a full-scale BMD system were deployed, the National Test Bed might then be used for simulated battle exercises of the system.

This report will offer numerous examples from the findings of the system architecture contractors and of SDIO adaptations of such findings. With a few exceptions, we will not cite specific contractor sources for those examples. OTA has not undertaken a systematic analysis and comparison of all the dozens of documents that emerged from the several contractor studies. Therefore, a few selected citations might give an unfair impression of the overall performance of any given contractor. Our purpose here is to convey an understanding of the system architecture analysis process and to report some of the results—not to conduct management oversight of any Department of Defense (DoD) contractor. In addition, the system architecture work is continuing, and constant revision of previous findings is both necessary and desirable. Thus any given conclusion might not reflect the current views of the particular contractor.

OVERVIEW OF SYSTEMS ARCHITECTURE ANALYSES

Initially, each of the system architects undertook the same general task of designing BMD systems whose deployment might begin in the mid-1990s and that might evolve into more advanced systems after the year 2000. Each group produced designs that it believed could, when fully deployed, provide near-perfect interception of Soviet ballistic missile reentry vehicles (RVs) forecast for deployment in the mid-1990s.[3] Each also argued, however, that lesser percentages of interception would achieve desirable military goals along the lines described in chapter 2 of this report.

[3]A mid-1990s threat posed against a BMD system that could not be fully deployed until after the year 2000 is unrealistic. Not all architects used the same threat numbers for the same time frames. The architects did, however, project this "baseline" threat into larger numbers of reentry vehicles and decoys for later years. They also ran "excursions" on the baseline threat to explore the impacts of larger and smaller threats on defense effectiveness. The excursions into larger threats, with one exception, do not generally appear in the summary documents produced by the contractors.

Goal Specification

As part of their analyses, the architects used computerized strategic nuclear exchange models (see next section on this topic) to simulate the numerical results of hypothetical nuclear wars between the United States and the Soviet Union. These simulations assumed various levels of defense capability on the two sides (in general the projected offensive capabilities for the mid-1990s were assumed at this stage) for the purpose of showing what differences those defenses might make.

From these simulations, the analysts drew conclusions about how defenses might contribute to the goals of security and strategic stability. In chapter 2, we described the kinds of measures used to define BMD effectiveness. In this chapter we will further describe some of the assumptions that went into and conclusions that came out of these strategic exchange simulations.

Threat Definition

A preliminary step to running the strategic exchange simulations was to state the Soviet offensive threat that BMD systems would be designed to counter. The starting point was an SDIO-supplied projection of the offensive missile forces the Soviets might have in the mid-1990s. From this starting point, the architects made varying "excursions," positing possible future Soviet missile developments and deployments. In addition, they hypothesized various types and numbers of anti-satellite weapons that the Soviets might conceivably deploy to attack space-based components of BMD systems.

Subsequently, and under different program managers, SDIO began a "Red Team" program to attempt to anticipate possible Soviet responses to U.S. BMD deployments. A major project of this program has been to bring together groups of experts to attempt to design plausible Soviet countermeasures to the technologies under consideration in other parts of SD IO. These potential countermeasures are then presented to SDIO "Blue Teams" so that they can adapt their technology research and system designs accordingly.

In mid-1987, SDIO presented to the Defense Acquisition Board a proposal to proceed with "concept demonstration and validation" ("Milestone I") for the first phase of a "Strategic Defense System" (BMD system) to be deployed in the mid-1990s. This presentation included an officially approved "threat" description for that period.

In reviewing DoD proposals for any BMD system, Congress should understand whether the officially assumed Soviet threat is "responsive" —i.e., whether it reflects plausible countermeasures that the Soviets could have taken by the time the BMD system were full deployed.

System Requirements

In showing what numbers of nuclear weapons would have to be intercepted to provide various levels of protection for different types of targets (cf. ch. z), the strategic exchange models also yielded basic requirements for strategic defense system performance. Additional "end-to-end" computer simulations helped define requirements for interception at each stage of flight.

(In SDIO presentations accompanyingmid-1987 proposals for an initial, less effective BMD system, this process was reversed. First, a number of warheads to intercept was established, then the strategic goals that might be served analyzed afterward.)

Systems Designs

The system architecture contractors designed BMD systems intended to intercept a very high percentage of the projected missile threat. The working assumption was that early stages of BMD deployment would be stepping stones to the ultimate goal of protecting cities and people from nuclear ballistic missile attack. The designs were not optimized to less ambitious goals. For example, systems that might protect hardened missile silos but could not serve as elements of city defenses were not considered. Systems designed from the outset to preserve nuclear deterrence might well look materially different from those designed toreplace it altogether.

Each architect was asked to design:

1. a system that was both space-based and ground-based;
2 one that was primarily ground-based; and
3. one that was intended primarily for defense of U.S. allies against intermediate and shorter range ballistic missiles.

In the second phase of system architecture contracts, analysts placed greatest emphasis on the first type of system, somewhat less on the second, and least on the third. Each architect considered systems that might be deployable in the mid-1990s, but each also offered concepts for more advanced systems that might be deployed against more advanced Soviet offensive systems out to the year 2015 or so. For each case, analysts identified counter-countermeasures intended to neutralize Soviet attempts to penetrate or directly attack the BMD system.

The details of the systems designs (for example, a given type and number of space-based rocket interceptors) were built into simulation models that expanded on the nuclear exchange models described above. These "end-to-end" simulations represented the details of intercepting ballistic missiles throughout all phases of flight, from rocket boost to warhead reentry. Some of the results of these "end-to-end" simulations are discussed below. These models also aided "tradeoff" analyses of various types of BMD system components arranged in various configurations. The models were also used to evaluate excursions in the technological requirements forced by particular types of So viet anti-BMD countermeasures.

Technological Requirements

The architects quantitatively analyzed the relative costs and effectiveness of various approaches to each defensive task. For example, an analysis might examine trade-offs between highly capable missile-tracking sensors on a few high altitude satellites and less capable sensors on many more low-altitude satellites. Many of these "trades" are discussed in subsequent chapters of this report.

Operational Requirements

Because system designs are still preliminary, it is difficult to specify their exact operational requirements. The system architects did attempt to estimate the continuing space transportation and maintenance requirements for space-based systems over their lifetime. Other SDI programs are conducting research on the logistics of maintaining various space-based and ground-based systems.

costs

In general, system architects estimated costs for their nearer-term, "interim" designs—those not including directed-energy weapons for boost-phase missile interception. These systems were estimated to cost on the order of $200 billion, depending on the projected need to respond to various types of Soviet countermeasure. Costs of complementary air defense systems were not included. It should be recognized that, given the conceptual nature of the architectures, accurate cost-estimating is virtually impossible at this stage. It does appear that, with thousands of space platforms envisaged, considerable changes would be needed in the way such equipment is now designed and manufactured if space-based BMD systems were ever to be affordable. In addition, a major new space transportation system would have to be designed, developed, manufactured, and deployed.

NUCLEAR FORCE EXCHANGE MODELS: DERIVING REQUIREMENTS FROM GOALS

The SDI system architects-and several other groups as well-have run several types of strategic nuclear exchange computer simulations to try to show how defenses might affeet the U.S.-Soviet nuclear balance. These simulation models assume various U.S. and Soviet offensive nuclear force levels, beginning with U.S. Government estimates for 1995. Then they assume various strategic targeting plans on the two sides and analyze how the attempted execution of those plans might be affected by various levels of defense capability on the two sides.

The intermediate measure of defense effectiveness is usually the percentage of nuclear warheads intercepted or its complement, the number of "leakers." The models translate the numbers of leakers in various cases into numbers or percentages of different types of targets surviving the attack. (For examples of such target types, see ch. 2, box 2A.) Each type of target, in turn, is given a different weight based on judgments about how U.S. and Soviet leaders might value them. Thus the numbers of different types of targets surviving are translated into "surviving strategic value."[4] The percentage of surviving strategic value on the two sides is then linked with particular strategic goals. (For a discussion of goals for BMD and ways of measuring BMD effectiveness, see ch. 2.) In some cases, "leakage" rates were linked (via asset survival expectations) to strategic goals to show what kind of BMD system performance would be needed given a particular assumed level of offensive threat (for example, see table 3-l).

Some Conclusions Drawn From Nuclear Exchange Models

Strategic Goals and Defense Leakages

The system architects' strategic nuclear exchange simulations provide a useful basis for studying BMD performance goals. However, because each architect used a different computer model and different assumptions for the sizes and compositions of future U.S. and Soviet offensive nuclear forces, the results are difficult to compare.

With that important qualification, here are some conclusions drawn frequently (but not universally) by the different system architects. First, for a mid-1990s Soviet strategic nuclear threat, a BMD system that allowed a few thousand Soviet RVs to penetrate into the United States might complicate Soviet attack plans, but probably would not stop them from destroying most of their chosen targets.[5]

In support of SDIO's mid-1987 proposal for an initial BMD system, other SDIO contractors argued that a strategy of "adaptive preferential defense" might prevent the Soviets from destroying as high a percentage of certain sets of targets as they would wish (as estimated by U.S. analysts).

A system that allowed fewer Soviet RVs to leak through would begin to deny the Soviets certainty of destroying many of the military targets that their planners might have designated. But if the Soviets chose to concentrate on economic targets in the United States, they might still be able to deny the United States the possibility of economic recovery from the nuclear war. (Compare this finding with the second set of projections in table 3-l.)

With yet lower leakage, the Soviets could still inflict immense damage on the United States. Note, for example, that 10 percent of an attack with 10,000 nuclear weapons would still result in 1,000 nuclear weapons exploding in the United States. But since the Soviets could not be sure which 1,000 of the 10,000 launched would reach which targets, confidence in achieving precise attack goals on a given set of targets would be low.

Analyses also seem to show that if the United States had a relatively highly effective BMD system against a mid-1990s Soviet threat while the Soviets had no BMD, the Soviets would improve their relative strategic situation more by adding defenses to limit damage to themselves than by adding offensive weapons in hopes of increasing the damage they could inflict on the United States.[6] In attempt-

[4] In these models the Soviets are assumed to have a larger number of strategic targets than the United States, and the Soviet targets are assumed to be harder to destroy. Part of the difference is due to the existence of numerous nuclear-hardened shelters for Soviet political leaders; see *Soviet Military Power*, 1987, (Washington, D, C.: Department of Defense) p. 52,

"—S The exact percentages in this conclusion and the others below were apparently classified by the system architecture contractors because the computer simulations from which they were derived include classified estimates of U.S. and Soviet military capabilities.

[6] This conclusion assumes that the addition of offenses could not improve the leakage rate—the same percentage of every added group of warheads would be intercepted, This is not necessarily a valid assumption: much would depend on the composition of the offensive and defensive forces on the two sides.

Table 3-1.—Two Perspectives on BMD Effectiveness and Strategic Goals

Soviet warheads leaking through	Expected strategic consequences
A. One system architect's strategic exchange model and conclusions	
Many	Increase in Soviet attack planning uncertainties. They are forced to launch all their strategic forces at once or reduce their military objectives. A strategic exchange would result in more losses to Soviets than to the United States.
	The Soviets could no longer reliably achieve the military goals of a strategic nuclear attack while maintaining a secure reserve of missiles for later attacks. Preserves full range of U.S. strategic offensive force retaliatory flexible response options. Each new Soviet ballistic missile has only a fractional chance of being useful.
Fewer	Survival of a large portion of the population and industrial base, a high proportion of military targets other than strategic offensive forces, and sufficient strategic offensive forces to preseve full range of U.S. retaliatory flexible response options. If Soviets attack only other military targets (not strategic offensive forces), medium-high survival of those assets.
	Would preserve the full range of U.S. "flexible response" options in war with the Soviets even if Soviets devoted entire attack to U.S. strategic offensive forces (presumably only if Soviets do not have comparable BMD capability —OTA).
	Assured survival of the Nation as a whole: 3 to 5°/0 U.S. casualties in population attack.
Extremely few	Assured survival: Soviet ability to put U.S. population at risk is negligible; the United States needs no strategic nuclear retaliatory capability.
Assumptions:	• Mid-1990s projections of Soviet and U.S. strategic forces. • Effectiveness of Soviet BMD not specified. • Status of air defenses not specified.
Alternate analysis: As U.S. strategic defenses improved, an option for the Soviets would be to change their offensive target priorities to maintain a deterrent "assured destruction' capability. Instead of concentrating their forces on hardened missile silos, for example, they might concentrate them on key military industries or other economic targets; they might even focus on cities per se. Various non-SDIO analysts have previously calculated potential consequences of such nuclear attacks, as indicated below.	
B. If the Soviets retargeted to maintain assured destruction	
10 "/0	The Soviets attack industries in the 71 largest U.S. urban areas; the equivalent of 500 l-megaton and 200 to 300 100-kiloton weapons get through. Of the U.S. population, 35 to 45 percent is killed or injured; 60 to 65°/0 of U.S. industry is destroyed.[b]
30/0	The Soviets attack industries in the 71 largest U.S. urban areas; the equivalent of 100 l-megaton and 200 to 300 100-kiloton weapons get through. From prompt blast and radiation effects, 20 to 30°/0 of U.S. population is killed or injured; 25 to 35% of U.S. industry is destroyed.[c]
1 **to** 2%	Case 1: The Soviets attack 77 U.S. oil refineries; the equivalent of 80 l-megaton weapons get through. From prompt blast and radiation effects, 5 million Americans die. The U.S. economy is crippled.[d] Case 2: The Soviets attack 100 key military-industrial targets with the equivalent of 100 l-megaton weapons. Three million die of blast and radiation effects, another 8 million from fires; dead and injured total 10 to 16 million.[e] Case 3: The Soviets attack 100 U.S. city centers with the equivalent of 100 l-megaton weapons. Fourteen million die from blast and radiation effects alone, a total of 42 million die from blast, radiation, and fires; total dead and injured are 32 to 51 million.[f]
Assumptions:	• Total Soviet strategic attack of 10,000 weapons. • Air defenses equally effective as BMD.

[a] Adapted from Martin Marietta Aerospace analyses. percentages of weapons leaking and assets surviving deleted for security classification reasons.

[b] From U.S. Congress, *Economic and Social Consequences of Nuclear Attacks on the United States*, A Study Prepared for the Joint Committee on Defense Production, Published by the Committee on Banking, Housing, and Urban Affairs, U.S. Senate (Washington, D. C.: US. Government Printing Office, 1979), pp. 4-14,

[c] Ibid.

[d] From U.S. Congress, Office of Technology Assessment, *The Effects of Nuclear War* (Washington, D, C.: U. S. Government printing Off ice, May, 1979), pp 64-75. Calculations on casualties were performed for OTA by the the U.S. Defense Civil Defense Preparedness Agency. About 125 500-kiloton weapons would have the same blast effects as 60 l-megaton weapons, but the pattern of distribution of blast might in fact do more damage.

'William Daugherty et al., "The Consequences of 'Limited' Nuclear Attacks on the United States," *International Security,* spring 1966 (vol. 10, No. 4), p 5 Findings based on the authors' computer simulations. About 160 500-kiloton weapons have about the same blast effects as 100 l-megaton weapons.

'Ibid,

ing to assess the effect on deterrence of various levels of defense, the strategic analysts compared the amount of damage the Soviets might suffer (as a weighted percentage of given types of targets) with the amount the United States might suffer. Differences in surviving (value-weighted) percentages of military targets were assumed to confer strategic advantages or disadvantages that would affect Soviet decisions about how to respond to U.S. weapon deployments, whether to go to war, or whether to escalate a conflict to nuclear exchange.

Even very low leakage of the BMD system (and assuming comparable leakage of air-breathing nuclear weapon delivery vehicles) could still kill several million Americans, if that were the Soviet objective. (Note that the alternative projections in table 3-1 suggest higher possible casualties.) This level of protection (given the mid-1990s projected nuclear threat) might assure survival of the United States as a functioning nation but would not assure survival of the whole population. Most of the system architects appeared to believe that in the long run they could design systems capable of keeping out a very high percentage of Soviet ballistic missile RVs (assuming the mid-1990s projected threat); none appeared to believe that leakage levels compatible with "assured survival" of the U.S. population would be possible without negotiated limitations of Soviet offensive nuclear forces.

U.S.-Soviet Asymmetries

With varying degrees of clarity, the system architects' use of nuclear exchange models brought out the current-and likely future–asymmetries between U.S. and Soviet offensive nuclear forces. The Soviet Union has more ballistic missile RVs than the United States. More of the Soviet RVs are based on land than on submarines, while the reverse is true of the U.S. RVs. The United States has more strategic nuclear bombers and air-and sea-launched cruise missiles than the Soviet Union, while the Soviet Union has a more extensive air defense system than the United States.

If the Soviet Union had ballistic missile defenses comparable to those of the United States, the net effect of trying to defend our land-based missiles against a Soviet strike would be to reduce the U.S. ability to carry out planned retaliatory missions. Here is why. If defended, a sizable number of U.S. land-based missiles that might otherwise have been destroyed on the ground might survive a Soviet offensive strike. On the other hand, they would then have to survive *defensive* attacks as they attempted to carry out their retaliatory missions against Soviet territory. In addition, the U.S. submarine-launched missiles (SLBMs), which would not benefit from the defense of land-based missiles, would also have to face Soviet defenses. Furthermore, if the intercepted SLBMs were aimed in part at Soviet air defense assets, such as radar sites, the ability of U.S. bombers and cruise missiles to carry out their missions might also be impaired.

Besides the asymmetries in weapons, there are asymmetries in targets on the two sides. The Soviet Union, for example, reportedly has more than 1,500 hardened bomb shelters for its political leadership. The Soviets also are said to spend copious sums on other types of civil defense. The combination of passive defense measures and BMD might do more to protect valued Soviet targets than BMD alone would to protect valued U.S. targets.

Given the asymmetries in U.S. and Soviet weapons and defenses, then, the net effect of mutual deployments of comparable levels of defense could be to weaken, not strengthen deterrence-if deterrence were still measured primarily by the penalty that we could impose on Soviet aggression through nuclear retaliation. (If deterrence were measured by denial to the Soviets of some attack goals other than reducing damage to the Soviet Union, then deterrence might be strengthened.)

The United States might compensate for U.S.-Soviet asymmetries in three ways:

1. The United States could attempt to build and maintain BMD that was notably su-

perior to that of the Soviet Union, so that a greater proportion of the smaller U.S. ballistic missile force could be expected to reach its targets. This was the recommendation of at least one of the SDI system architects, who argued that until very high defense effectiveness levels had been reached, equal defensive capabilities on the two sides might confer an exploitable strategic advantage on the Soviet Union (SDIO officials disagree with this assessment).

2. The United States could attempt to maintain and improve the ability-of its air-breathing weapons (bombers and cruise missiles) to penetrate Soviet air defenses so that the loss in effectiveness of our ballistic missiles was offset by the other means of nuclear delivery. This course was assumed in the calculations of a second system architect.
3. If U.S. strategic defenses against all types of nuclear threat (air-breathing as well as ballistic missile) could be made extremely effective, we might not care about imbalances in punitive abilities on the two sides; the Soviets would have little or nothing to gain by threatening nuclear attack. Then, even a minimally destructive retaliatory ability on the U.S. side should fully deter the Soviets from even contemplating attack. This was the ultimate goal hypothesized by all the system architects. (It should be noted that most, though not all, analysts believe that this kind of deterrence now exists. If so, BMD would not significantly reduce the risk of nuclear war.[7])

However, some would argue that future Soviet "counterforce" capabilities, plus Soviet civil defense and perhaps active (BMD and air defense), could reduce prospective Soviet damage to levels acceptable to them. A U.S. BMD system, it is argued would either maintain the survivability of the U.S. deterrent, or equalize the prospective damage on the two sides, or both.

In ***sum,*** the force exchange models employed by some of the SDI system architects seem to show that BMD performance levels must be high to substantially alter the current U.S.-Soviet strategic nuclear relationship:

- Some increments of uncertainty could be imposed on Soviet planners by defenses able to intercept about half the Soviet missile force. If an "adaptive preferential defense" strategy could be executed, significant fractions of some sets of "point" targets might be protected.
- The ability to intercept a high percentage of all Soviet strategic nuclear weapons including air-breathing ones (assuming threats projected for the mid-1990s) might actually deny the Soviets the ability to destroy many military targets.
- However, at such levels of defensive capability, because of asymmetries in U.S. and Soviet strategic postures, U.S. missile and air defenses might have to perform conspicuously better than Soviet defenses to prevent the Soviets from holding an apparent strategic advantage.[8]
- The design of a system that could, in the long term, protect U.S. cities from potential nuclear destruction seems infeasible without sizable, presumably negotiated, reductions in Soviet offensive forces.

At the conclusion of this chapter, we return to the subject of nuclear force exchange models to indicate the scope of future work OTA believes should be carried out if a decision on BMD development and deployment is to be considered fully informed.

'That is, given the threat of retaliatory punishment, it would be highly irrational for the Soviets to start a nuclear war. In this view, whatever calculations the Soviets may make about the "military effectiveness' of their ballistic missiles, the price (in damage to the Soviet Union) would be too high to justify a nuclear attack.

'However, if the United States maintained a substantial bomber-cruise missile threat, if Soviet air defenses were ineffective, and if the Soviets did not pose a substantial bomber-cruise missile threat to the United States, such a Soviet advantage might be avoided.

Limitations of Nuclear Force Exchange Models

Although force exchange analysis is important, applying the results of the analyses requires extreme caution. The greatest danger lies in accepting the numbers generated by the computer as representing reality: they do not. The verisimilitude of a computer simulation can only be checked by comparisons with measured results in the real world that the model is trying to simulate. There has never been—and we all hope there will never be—a real nuclear war to calibrate the correctness of nuclear force exchange models.

Instead, such models combine what is known or estimated about the characteristics of weapons and potential targets on each side with a myriad of personal, even if carefully considered, judgments about how nuclear attacks would take place and what the immediate physical results might be. If national leaders are to make wise use of the outcomes of such analytic models, they need to judge whether they agree with the assumptions that go "into the models (see table 3-2).

Table 3-2.—Judgmental Assumptions in Nuclear Force Exchange Models

- **Soviet valuation of Soviet targets**
- **Estimation of U.S. targets selected by Soviet planners**
- **Priorities Soviets would attach to destroying particular targets**
- **Soviet estimates of the reliabilities and capabilities of their weapons**
- **Soviet estimates of the reliabilities and capabilities of U.S. weapons**
- **U.S. estimates of the reliabilities and capabilities of U.S. weapons**
- **U.S. estimates of the resistance or vulnerability to nuclear attack of various Soviet targets**
- **Estimates of casualties on both sides from nuclear attacks**

SOURCE: Office of Technology Assessment, 1988.

Aside from the many subjective judgments that must go into force exchange models, there are other aspects of the real world that cannot be included in a quantitative computer simulation. The models generally include estimates of prompt casualties from nuclear attacks, but they do not even attempt to account for the longer term medical, social, political, and economic consequences of nuclear war. Computer simulations also abstract strategic calculations out of political context. We can only guess, with varying degrees of informed judgment, under what circumstances the Soviets would contemplate starting or risking nuclear war. We do not know how leaders on either side would actually behave in a real nuclear crisis. We do not know, in particular, how and to what degree their decisions would be affected by military planners' strategic exchange calculations.

In sum, nuclear force exchange models can serve as a useful tool for thinking about the goals we might use BMD to pursue. But they cannot demonstrate as scientific fact that those goals will be accomplished, nor can they offer certainty that the effects of deploying BMD would fulfill predictions.

SYSTEM DESIGNS AND END-TO-END MODELS

Force exchange models such as those described above can help analysts estimate how many nuclear weapons a BMD system must intercept to achieve various levels of protection. In this way, decisionmakers can set the overall requirements for BMD performance. Much more detailed analysis is needed to evaluate systems designed to meet those requirements.

This kind of analysis begins, as do force exchange analyses, with projections of the Soviet missile threat during the period for which one expects to have BMD deployed. In this case, however, analysts must consider more than the destructive capabilities of the offensive missile threat. Analysts must also estimate the precise technical performance of the missiles, the numbers of each type, and the tactical plans under which the Soviets might launch them. In addition, the analysis has to include possible changes in Soviet offensive forces[9] in response to U.S. BMD deployments. Among the techniques used for this kind of analysis are "end-to-end" computer simulations, which model both the offensive attack and the roles of each type of BMD component, from the sensor that first detects an enemy missile launch to the last layer of interceptors engaging reentry vehicles as they approach their targets.

As table 3-3 indicates, an ICBM flight includes four broad phases: the boost, post-boost, mid-course, and reentry or terminal. System architects for SDI have proposed ways of attacking ballistic missiles in all phases.

Space- and Ground-Based Architectures

Suggested components and functions of a multi-phase BMD system are outlined in tables 3-4 and 3-5. (Chs. 4 and 5 examine the technology for many of these components in considerable detail.) The SDI system architects subdivided the primarily space-based architectures into nearer- and farther-term BMD systerns, with the nearer-term systems envisaged as evolving into the farther-term systems as the Soviet missile threat grows and as more advanced BMD technologies become available. Except for the projected timing, the architecture in table 3-4 reflects SDIO's proposal in mid-1987 for a first-phase 'Strategic Defense System." The design would also be intended to lay the basis for expansion into phase two and three systems.

The architectures in table 3-5 draw on information provided by SDIO, but do not constitute their-or anyone else's—specific proposal for what the United States should plan to deploy. Instead, the examples provide a framework for analyzing how the parts of a future BMD system would have to fit together to try to meet the requirements set for it. The tables do include the leading candidates for sensors, discrimination, and weapons described by the system architects. The projected dates in the tables reflect OTA rather than SDIO estimates for the earliest plausible periods over which each phase might be deployed if it were proven feasible.

The SDI system architects subjected their various BMD constructs to detailed computer simulations. (These are called "end-to-end" simulations because they attempt to model

'Including offensive countermeasures such as decoys and defense suppression measures such as anti-satellite weapons.

Table 3-3.—Phases of Ballistic Missile Trajectory

Phase	Duration	Description
Boost	Several 10s to 100s of seconds[a]	Powered flight of the rocket boosters lifting the missile payload into a ballistic trajectory
Post-boost	10s of seconds to 10s of minutes[b]	Most ICBMs now have a "post-boost vehicle" (PBV), an upper guided stage that ejects multiple, independently targetable reentry vehicles (MIRVs) into routes to their targets. If these RVs are to be accompanied by decoys to deceive BMD systems, the PBV will dispense them as well.
Mid-course	About 20 minutes (less for SLBMs)	RVs and decoys continue along a ballistic trajectory, several hundred to 1,000 kilometers up in space, toward their targets.
Reentry	30 to 60 seconds	RVs and decoys reenter the Earth's atmosphere; lighter decoys first slow down in the upper atmosphere, then burn up because of friction with the air; RVs protected from burning up in friction with the air by means of an ablative coating; at a preset altitude, their nuclear warheads explode.

aNow in the hundreds of seconds, in the future boost times may be greatly reduced.
bPost-boost dispersal times may also b, shortened, though perhaps with penalties in payload, numbers of mid-course decoys, and accuracy.

SOURCE Office of Technology Assessment, 1988.

Table 3-4.—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: Office of Technology Assessment, 1988.

BMD performance from booster launch to final RV interception.) Such simulations help show the interdependence of the system components and the requirements posed for the technologies that go into them. These analyses show that, at least in the long run, intercepting a substantial portion of the missiles in the boost phase and early post-boost phase would be essential to a highly effective BMD system. This conclusion follows from the fact that 1,000 to 2,000 boosters could dispense hundreds of thousands of decoys that would greatly stress mid-course interception.[10]

The system architects noted that this boost-phase interception task would eventually (barring sizable offensive arms limitations) have to be accomplished by means of directed-energy weapons, rather than by the space based interceptors (SBIs) envisaged for the first stage of BMD deployments. The speed-f-light velocity of directed energy would be needed because the development of faster-burning rocket boosters and faster-dispensing post-boost vehicles (PBVs) would eventually permit Soviet missiles to finish their boost phases before the space-based interceptors (SBIs) could reach them.

The SDIO contends, however, that interception of PBVs may suffice to meet SDI goals. Although a fast-burn booster would burn out inside the atmosphere, the PBV must clear the atmosphere to dispense light-weiglit decoys. It then would be vulnerable to SBIs. If SBI interception of PBVs were adequate, directed-energy weapons might not be necessary. If successfully developed, though, they might prove more cost-effective.

The interplay of offensive and defensive technologies is discussed in more detail in chapters 6, 10, and 11 of this report.

[10]SDIO officials point out that an arms control agreement reducing offensive forces would make the defensive job easier and cheaper. On the other hand, the Soviets may not be persuaded to enter into such an agreement unless they can be shown that potential defensive options would make offensive countermeasures on their part futile.

Table 3-5.—OTA's Projections of Evolution of Ground- and Space. Based BMD Architecture

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

SOURCE: Office of Technology Assessment, 1988.

Battle Management Architecture

Specifying Battle Management Architecture

Any BMD system architecture will contain a kind of sub-architecture, the "battle management architecture. " The battle management design shows how BMD system components would be integrated into a single coordinated operating entity. The battle management software, which would direct the battle management computers and control the actions of the system, would carry the burden of integration. A communications system would transmit data and decisions among the battle management computers and between the computers and the sensors and weapons.

The system would probably divide the volume in which the battle would be fought into a set of smaller battle spaces. A regional or local battle manager would consist of the battle management software and computer with responsibility for controlling the resources used to fight within a particular battle space. The battle manager and the resources it controlled would be known as a battle group. The battle management architecture specifies the following:

- the physical location of the battle management computers and the nodes of the communications network;
- the method for partitioning resources into battle groups so that battle management computers have access to and control over appropriate numbers and kinds of sensors and weapons;
- a hierarchical organization that specifies the authority and responsibility of the battle managers, similar to a military chain-of-command;
- the role of humans in the battle management hierarchy;
- the method used for coordinating the actions of the battle managers through the battle management hierarchy and across the different battle phases so that hand-over of responsibility, authority, and resources between boost, post-boost, mid-course, and terminal phases would take place smoothly and efficiently; and
- the organization of and the method used for routing data and decisions through the communications network, probably organized as a hierarchy that would govern how the nodes of the network were connected.

Battle management architectures proposed so far have varied widely in their approach to these issues. For example, some architects proposed placing their space-based battle management computers on the same satellite platforms as the Space Surveillance and Tracking System (SSTS), some on the carrier vehicles, and some on separate battle management platforms; some proposed that the battle managers exchange track information only among neighbor battle managers at the same level of the battle management hierarchy, while others proposed that the same data also be exchanged between upper and lower levels; some architects permitted humans to intervene in the midst of battle to select different battle strategies while others allowed humans only to authorize weapons release.

Table 3-6 describes two different battle management architectures that are representative of those proposed. It shows the physical locations of the battle managers, the criteria used for partitioning resources into battle groups, the data exchanged by the battle managers, the methods used for coordinating responsibility and authority between phases of the battle, the degree to which human intervention would be allowed during battle, and the structure of the communications network.

Interaction Between Battle Management and System Architecture

Battle management architectural decisions would strongly affect the size, complexity, and organization of the battle management soft-

Table 3-6.—Two Representative Battle Management Architectures

Design by location of battle managers	Partitioning criterion	Data exchanged by battle managers	Method of coordinating between battle phases	Degree of human intervention	Communications network organization
Design i: SSTS	Local battle groups assigned to cover specific Earth-based geographic areas	Object tracks	Regional battle managers control hand-over between phases	Humans authorize weapons release at start of battle; can switch strategies during battle	Two-tiered hierarchy
Design ii: Carrier vehicles	Initially geographic, then by threat tube (the path along which a group of missiles travels)	Health (weapon status) information	All battle managers use same criteria for target allocation, taking into account locations of other battle managers	Humans authorize weapons release at start of battle	All nodes in line-of-sight of each other are interconnected

SOURCE: Office of Technology Assessment, 1988.

ware. Because of the close relationship between the battle management computers and the communications network, such decisions also would strongly affect the software that controlled the computers forming the nodes of the communications network. A good example of the interaction among system architecture, battle management architecture, and battle management and communications software is represented by the controversy over how widely distributed battle management should be. The two extremes of completely centralized and completely autonomous battle managers and a range of intermediate options are discussed in both the Fletcher and Eastport group reports and considered in all the architectural studies.[11]

Physical Organization v. Conceptual Design

Analyses often have reflected confusion between the physical organization and the conceptual organization of the battle managers. The physical organization may be centralized by putting all of the battle management software into one large computer system, or be distributed by having battle management computers on every carrier vehicle. Similarly, the software may be designed as:

1. a single, central battle manager that controls the entire battle;
2. a hierarchy of battle managers, with local battle managers each responsible for a small battle space, regional battle managers responsible for coordinating among local battle managers, and a central battle manager coordinating the actions of the regional battle managers; or
3. as a set of completely independent battle managers with no coordination among each other.

Any of these three software designs might be implemented using either a centralized or distributed physical organization. Variations on the three designs, e.g., introducing more levels into the battle manager hierarchy, are possible, but infrequently considered.

The physical organization and the conceptual design would impose constraints on each other, and factors such as survivability and reliability would drive both. A widely distributed physical design, involving many independent computers, would impose too heavy a synchronization and communications penalty among the physically distributed components of the software to permit use of a centralized conceptual design: the attendant complications in the software would make the battle manager unreliable and slow to react. Physical distribution requires the battle management software on each computer to be relatively autonomous. A system with completely autonomous battle managers would perform less well than a system with communicating battle managers. Accordingly, even a widely distributed physical organization would likely require some communications and synchronization among the battle managers.

A centralized physical design might not provide sufficient computer processing power for acceptable performance, but would significantly improve communications among the battle managers. The result might simplify the software development, and lead to greater software reliability. On the other hand, such an organization might result in a poorly survivable system: if the central computer were disabled, the remainder of the system could not function.

Integrating Battle Management Architecture With System Architecture

Since the system architecture, physical battle management organization, and battle management software design affect each other, all should be considered together. The relationships and interfaces among the battle managers should be defined either prior to or together with definition of the physical organization of the battle managers and their requirements for communication with each other and with sensors and weapons. As the Fletcher report

[11] *Report of the Study on Eliminating The Threat Posed by Nuclear Ballistic Missiles, Vol. V, Battle Management, Communications, and Data Processing,* October 1983. This was the only unclassified volume of the Fletcher commission report. See also "Eastport Study Group—A Report to the Director, Strategic Defense Initiative Organization" (Eastport Study Group, Marina Del Rey, CA, 1985).

stated, "The battle management system and its software must be designed as an integral part of the BMD system as a whole, not as an applique."[12]

Most of the SDI architectures proposed so far have shown little evidence of an integral design. Software design has been largely ignored, giving way to issues such as the location of the battle management computers and the criteria for forming battle groups. The SDIO has reported that it is attempting to better integrate overall system architecture studies and battle management studies in its current phase of system architecture contracting. However, the system proposed in mid-1987 for "demonstration and validation" seemed to reflect no such integration.

Some Important Results of the System Requirements and Design Work

Systems analysis for SDI is still, necessarily, at a preliminary stage. Its most valuable contribution so far has probably been the identification of key issues that research would have to resolve satisfactorily before the Nation could make a rational decision to proceed to development and deployment of BMD. In particular, the analyses have shown the following:

Boost-Phase Interception

Adequate boost-phase interception of missiles is essential to make the mid-course and terminal interception problems manageable; otherwise, the offense has the opportunity to deploy so many decoys and other penetration aids that they could swamp the other defensive layers. However, an adequate boost-phase interception may, over time, be countered by new offensive weapons and still have done its job: after deploying all the faster burning boosters and PBVs it could afford to counter the boost-phase defense, the offense may not be able to deploy enough decoys to overwhelm the mid-course defense.

[12] Ibid.

Ultimate Need for Directed-Energy Weapons

As a corollary to the need for effective boost-phase interception, it will be important to have a credible long-term system design which includes directed-energy weapons based in space to carry out boost-phase interception against boosters and PBVs that are too fast to be reached by kinetic energy weapons. Without such a credible plan, the boost-phase interceptors would face fairly predictable obsolescence. (It is possible, however, to imagine the development of new SBIs able to penetrate the upper atmosphere; if launched quickly enough, they could then reach some boosters.)

Need for Interactive Discrimination

Because of the potential for Soviet deployment of hundreds of thousands of decoys that passive sensors may not be able to differentiate from RVs disguised as decoys (" anti-simulation"), mid-course interception is likely to require means of perturbing RVs and decoys and highly capable sensors to detect the differences in the ways the two kinds of objects react. Such means of "interactive discrimination" have been conceived but not yet built and tested.

Interdependence of Defensive Layers

Ideally, independent layers of sensors and weapons would carry out interception of each phase of ballistic missile trajectory, thus eliminating common failure modes and common nodes of vulnerability to hostile action. In fact, for practical reasons, the system architects generally produced designs with considerable degrees of interdependence. In addition, as noted above, even if the functions of each layer were performed entirely independently, failure in one phase of interception (the boost-phase, for example) can severely affect the potential performance of succeeding phases.

Importance of Integrated Battle Management Architecture

Initially, system architecture and battle management architecture studies were separately contracted for, producing large discrepancies among those who had studied each subject the most. The two sets of studies are apparently now being better integrated, and presumably subsequent designs will reflect that integration.

Distributed Battle Management

Although considerable work on designing BMD battle management remains, analysis so far makes clear the importance of a battle management system that make decisions in a distributed, as opposed to centralized, fashion. Attempting to centralize the decisionmaking would both impose excessive computing, software engineering, and communications requirements and make the system more vulnerable to enemy disruption.

Heavy Space Transportation Requirements

The system architecture designs now permit better forecasts of the requirements imposed by space-based systems for space transportation capabilities-capabilities far beyond those the United States now possesses. (Primarily ground-based architectures do not share this problem.)

Requirements for Assured Survival

There appears to be general agreement on the importance of significantly reducing offensive force developments if one hopes to provide mutual assured survival for the U.S. and Soviet populations.

IMPORTANT SYSTEMS ANALYSIS WORK REMAINING

The SDI architecture studies have just begun to address the complex problems of designing a working, survivable BMD system with prospects for long-term viability against a responsive Soviet threat. Thus far, the architecture studies have served the useful purpose of helping to identify the most critical technologies needing further development. Future system designers would have to integrate the technologies actually available-and mass producible–into deployable and workable weapon systems.

Given that the system architects and SDIO are just over 2 to 3 years into an analytic effort that will take many more years, it is not a criticism to say that much work remains. However, it appears to be the case that the analysis supporting the first-phase architecture that SDIO proposed in mid-1987 simply did not address many key questions. The following are further tasks that analysts should carry out to help both the executive and legislative branches judge the potential effects of decisions on BMD.

Further Strategic Nuclear Force Exchange Work

The strategic nuclear exchange modeling done so far by the SDI system architects provides a useful beginning to the larger and lengthier task of developing the information that will be needed for a national decision on whether to deploy BMD. If the limitations of these kinds of simulations are borne carefully in mind, they can help one to understand how BMD might affect the calculations of U.S. and Soviet national leaders, both indecisions about peace and war and indecisions about long-term strategic policies. They can also help to clarify the assumptions all participants bring to the U.S. national debate about BMD.

Introduce Comparability Among Analyses

It is desirable to have competing sets of computer simulation models for analyzing the same questions. In that way, decisionmakers could compare differing conclusions and identify the underlying assumptions of each. (Comparisons could also uncover errors in implementation of the models.) Analysts should run different models using the same sets of data about the Soviet missile threat, the same configurations of defensive systems, and the same offensive and defensive strategies and tactics. Thus far, differences in these elements have made the analyses of the system architects difficult to compare and judge.

Further Analyses of Soviet Offensive Responses

The simulations run so far have examined only limited variations on Soviet attack plans in the face of growing U.S. defensive capabilities: the assumption is made that the Soviets have an inflexible list of targets. The Soviets are assumed to optimize their exact attack plan to destroy the highest possible number of those targets at some level of confidence. Suppose, however, that if defenses drastically reduced Soviet confidence in their ability to destroy hardened military targets, they concentrated on softer military and economic targets. Analysts must carry out further exploration of this possibility if decisionmakers are to understand the full implications of BMD for all types of deterrence (see table 3-l).

Assumptions About Deterrence

An analytic focus on an inflexible Soviet target plan seems to be related to a simplified model of potential Soviet motives for attack. The usual working assumption seems to be that the Soviets would decide to launch a nuclear strike on the United States on the basis of calculations about the probabilities of destroying certain percentages of various types of targets. In this view, above a certain threshold for one or more of these probabilities, the Soviets would be willing to strike, and below it they would not because they could not accomplish their military purposes. One target set would be the weapons and command-and-control facilities that would permit a U.S. nuclear retaliation. But the exact role in Soviet decisionmaking attributed to fear of retaliation–as opposed to accomplishment of other military objectives—remains unclear. The nuclear exchange models should make more explicit their assumptions about the weighings given to denial of military objectives as opposed to the likelihood and intensity of U.S. retaliation as enforcers of deterrence.

Analysts should attempt to identify the ***increment*** of uncertainty added to the Soviet calculus of nuclear war provided by levels of defensive capability that might increase Soviet uncertainty about achieving attack objectives, but that could not assure denial of those objectives. Many things could go wrong with a nuclear attack precisely scheduled to achieve a specific set of goals (such as knocking out a given percentage of U.S. retaliatory capability). *How much* uncertainty would a given level of BMD add to that which already exists? What are the potential Soviet responses to this additional uncertainty?[13] To what extent would the increment of uncertainty strengthen deterrence? At what cost per increment of strengthened deterrence?

Strategic Stability Analyses

Closely related to the question of Soviet attack motivations is the question of strategic stability. In its 1985 report on BMD, OTA emphasized the importance of exploring this question thoroughly.

A simplified approach to crisis stability is as follows: in a military confrontation with the United States, Soviet decisionmakers would calculate whether or not they could achieve a given set of military objectives by launching a strategic nuclear first strike. If the objectives seemed attainable, they would strike; if not, they would refrain. The system architects have considered this scenario.

Another possibility they should address, however, is that *Soviet perceptions* of a likely *U.S.* first strike might affect Soviet behavior. System architects have been understandably reluctant to run or to report extensively on simulations in which the United States is assumed to strike first. Such analyses might imply to some that a change is being contemplated in U.S. policy not to launch a preemptive strategic nuclear first strike. Nevertheless, such analysis needs to be done, not because the United States would launch such an attack, but because the Soviet Union might not *believe* that it would not.

[13]A possibility suggested by one reviewer of the OTA study is that the Soviets discover, unbeknownst to the United States, a way of disabling the U.S. BMD system (perhaps by spoofing its command and control system). Further, the Soviets validate their countermeasure with undetected techniques before actually launching an attack. Certain that their technique will work, and their offensive forces augmented in response to the U.S. defensive deployments, the Soviets in this scenario end up *more* certain about the probable success of their attack than before,

It is conceivable, for example, that Soviet strategic exchange calculations could show that a U.S. first strike, backed up by U.S. BMD, might allow the United States to reduce significantly the damage from a Soviet "ragged" retaliation.[14] On the other hand, a Soviet first strike might have an analogous effect. If the Soviets believed that the United States, expecting a Soviet strike, might strike first, then the Soviets might try to get in the first blow. Thus, they would not make their decision to strike on the basis of accomplishing a clear set of military objectives, but instead on the basis of choosing the less terrible of two catastrophic outcomes.

Even if the Soviet Union and the United States avoided a nuclear crisis in which such calculations might play a role, the calculations could still influence the longer-range Soviet responses to U.S. BMD deployments. The Soviets might decide that it was extremely important to them to maintain a "credible" nuclear threat against the United States, and therefore be willing to spend more on maintaining offensive forces than "cost-exchange" ratios would seem to justify.

Administration officials have repeatedly stated their desire to negotiate (or find unilaterally) a "stable transition" path to a world in which strategic defenses play a large role. Finding such a path would require careful analysis of the incentives presented to Soviet leaders by U.S. actions. Estimating the consequences of a hypothetical U.S. attack is one key part of such an analysis. Only then might U.S. analysts identify offensive and defensive force levels that both sides could believe served their security. Some of this analytic work has been started, but more is necessary.

U.S. Responses to Soviet BMD

It is entirely possible that the Soviet Union will not wait until the United States decides whether deploying BMD is a good idea or not, but instead will unilaterally choose to expand its own BMD system.[15] The United States conducts BMD research in part to be able to respond in kind to such a decision. The system architects for SDI have conducted simulations to show how a responding U.S. BMD deployment might restore the U.S.-Soviet strategic balance. Before the United States chose such a response, however, two other kinds of analysis are desirable. First, analysts should compare the BMD option with the option of circumventing Soviet BMD by means of increasing U.S. air-breathing, low-flying cruise missile forces. Second, researchers should determine the ability of U.S. technology to find adequate offensive countermeasures to Soviet BMD.

These questions are partly amenable to the strategic exchange modeling technique. In the first case, the model could assume various numbers of cruise missiles with varying levels of probability of penetration in battle scenarios in which Soviet BMD was degrading the ability of U.S. ballistic missiles to get through. Analysts could compare these outcomes to those of similar scenarios in which the U.S. deployed BMD instead of additional cruise missiles. Then they could estimate quantities of BMD and cruise missiles required to produce similar outcomes. This information could provide the basis for cost-effectiveness comparisons between BMD and cruise missiles once data on the actual costs of the two types of systems became available.

Similarly, analysts could plug into the simulations the increases in warhead penetration of Soviet defenses caused by U.S. offensive countermeasures. Once estimates were available for the costs of these countermeasures, analyses could develop some idea of the relative cost-effectiveness of offense and defense.

[14] A "ragged" retaliation is one carried out after the first strike has destroyed at least portions of the nation's strategic forces and possibly degraded its command and control system, resulting in a relatively unstructured, diluted counter-attack.

[15] As permitted by the ABM Treaty, the Soviets have retained a limited, nuclear-armed ballistic missile defense system in the Moscow area; they are currently expanding the system to the full 100 interceptors permitted by the treaty, and could conceivably replicate the system elsewhere. They have also constructed a series of phased array radars around the Soviet Union which would provide warning and limited battle management capabilities for such an expanded system.

Analysis of Alternate Defensive Measures

The lesser goals of strategic defense–that is, enhancing deterrence by increasing Soviet uncertainty or denial of various military objectives—have thus far been considered as preliminary benefits on the way toward extremely high degrees of population protection. Therefore, alternate means of achieving the lesser goals as ends in themselves have not been analyzed. A few examples might clarify this point.

Defense of Land-Based ICBMs.–If strengthening deterrence by increasing the survivability of U.S. land-based retaliatory forces, especially ICBMs were the goal of deploying BMD, then the system designs done for the SDI might not be optimal.[18] Instead, ground-based, low-altitude interceptors located relatively near the missiles to be defended might be less expensive (unlike cities, hardened missile silos or capsules might withstand low-altitude nuclear explosions). In addition, the United States would want to consider how it could use various forms of mobile or deceptive basing of ICBMsin conjunction with limited BMD to make the enemy's cost of attacking the missiles prohibitive.

Careful analysis of the goal of protecting strategic bomber bases from SLBMs launched not far off U.S. shores might also yield different BMD designs combined with different bomber basing tactics.

Defense of Command, Control, and Communications Facilities.—Similarly the strategic goal of increasing the survivability of the U.S. command and control system for nuclear forces might be achieved by some form of BMD, but the United States should also compare the cost and effectiveness of BMD with those of other measures for making the system more resistant to nuclear attack. Further analysis might show that some combination of passive survivability measures and BMD would be more cost-effective than either alone.

Defense Against Accidental or Terrorist Missile Launches.—Protecting the country against 10 or so incoming reentry vehicles is a much different task than protecting it against thousands. While SDI-designed systems might offer such protection as a side-benefit, if this kind of defense were to be the major goal of deploying BMD, one would consider different, much simpler and cheaper architectures than those designed for the SDI.[17]

Further System Requirements and Design Work

Analyze Additional Threats to BMD System Survivability

The SDI system architects recognized that survivability would be a critical feature of any BMD system. They devoted considerable effort and ingenuity to inventing ways to reduce system vulnerability to Soviet attack. The chief threat to survivability they examined was ground-based, direct-ascent anti-satellite weapons—rockets that the Soviets could "pop up" from their territory to attack U.S. space-based BMD assets with nuclear or non-nuclear warheads. This was a reasonable first approach to the survivability problem: such weapons probably represent the kind of defense suppression weapon most immediately available to the Soviets. If the defense could not counter this threat, then there would be no point in exploring other, more sophisticated threats.

In the second round of their "horse race" competition the system architects did very little analysis of other potential threats to BMD system survivability, particularly longer-term space-based threats. The threat of "space mines, " satellites designed specifically to shadow and destroy the various space-based BMD components, was not considered in depth. Moreover, no analysis assumed that the Soviets might deploy in space a BMD system

[16]See U.S. Congress, Office of Technology Assessment, *MX Missile Basing,* OTA-ISC-140 (Washington, DC: U.S. Government Printing Office, September 1981).

[17]For example, a few ground-based, long-range interceptors like the Exe-atmospheric Reentry Interceptor System (ERIS)—see ch. 5—could cover the continental United States; existing early-warning radars could give initial track information and a few "pop-up" infrared sensor probes provide final track information.

comparable to that of the United States; thus the potential vulnerabilities of such weapon systems to one another were not considered. Instead, it was assumed that the United States would, for the most part, militarily dominate near-Earth space. From the statement of work provided to the SDI system architecture contractors late in 1986, it remained unclear whether this assumption would be changed in the follow-on studies to be completed early in 1988.

Develop Realistic Schedules

The system architects were originally instructed to design systems that might enter full-scale engineering development in the early 1990s and be deployed beginning in the m.id-1990s. The systems they designed would have required challenging technical achievements even under the originally requested SDI budgets. For example, one system architect pointed out that a vigorous technology program did not yet exist for an active space-based sensor crucial to an "interim" defense intended for deployment in the mid-1990s. Or, to take another example, deployment in the mid-1990s of the space-based systems identified by the architects would require that the United States decide almost immediately to begin acquiring the massive space transportation system that deployment would require.[18]

Given the actual levels of SDI funding appropriated by Congress thus far, mid-19% deployment of the kinds of systems initially proposed by the system architects is clearly not feasible. Even with the requested funding, it is unlikely that researchers could overcome all the technological hurdles in time to permit confident full-scale engineering decisions in the early 1990s. Nor is it clear that the full-scale engineering process, including establishment of manufacturing capabilities for the complex systems involved, could be completed in just 3 or 4 years. (For example, the most optimistic expert estimate OTA encountered for engineering full-scale SDI battle management software was 7 years.) In short, the systems designated as "interim" (similar to those labeled "Second Phase" in table 3-5) by the system architects would not be likely to reach full operational capability until well after the year 2000.

Late in 1986, SDIO called on its contractors to orient their work to a much scaled-back system architecture, with scaled-back strategic goals (see the "First Phase" in table 3-4). Speculations emerged in the press about "early deployment" options under consideration. Analysis of the "phase one" designs, however, suggests that even they could not be ready for initial space deployment until at least the mid-1990s. Nor could they be fully in place much before the end of the century.

In the meantime, the Soviet Union might well deploy practical countermeasures against such systems. Specifically, many in the defense community believe that the Soviets could deploy decoys along with their reentry vehicles that would greatly stress the minimal mid-course discrimination capability of a phase-one system. In addition, the Soviets could at least begin to deploy new booster rockets that would drastically reduce the effectiveness of space-based interceptors (SBIs) in boost-phase defense.

Even if the United States could deploy SBIs beginning in the mid-1990s, another question remains: how confident do U.S. decisionmakers wish to be in the long-term viability of BMD before they decide to deploy such systems? Given the state of research on directed-energy devices for BMD, it is highly unlikely that U.S. leaders could have sufficient information by the early 1990s to determine whether full-scale engineering development of phases two and three would be feasible in the following decade. Thus, an early 1990s decision implies a commitment to a space-based BMD whose obsolescence would be made highly probable by the prospect of faster burning Soviet missile boosters, but whose replacement would remain unproven.

Develop Credible Cost Estimates

The SDIO has properly pointed out that trying to estimate total life-cycle costs for an un-

[18] The SDIO requested $250 million in supplemental funds for fiscal year 1987 to develop technology for low-cost space transportation.

precedented system is difficult. The aerospace industry would have to manufacture new components and weapons in new ways. The Nation would need a new space transportation system for a space-based system. The SDIO has agreed to estimate "cost goals" to indicate the kind of investment that the Nation would have to make in proposed BMD architectures. The system architects were instructed to develop cost estimates in their 1987 studies.

Develop Methods for Estimating Cost-Exchange Ratios Between Defense and Offense

As this report pointed out in chapter 2, one key criterion for the technical feasibility of the SDI scenario of transition to a "defense-dominated' world is that there be a favorable cost-exchange ratio between defense and offense. The system architects did try to address this issue in various ways, but there still seems to be no systematic approach toward it. The problem will be intrinsically difficult, because estimating in advance the costs of the U.S. BMD system will be difficult, estimating the costs of Soviet responses will be more difficult, and predicting Soviet estimates of these quantities will be most difficult of all. Nevertheless, analyses should at least begin to specify what information would permit sufficient confidence that the defense/offense cost-exchange ratio is high enough to justify going ahead. The system architecture contractor teams were instructed to address the problem in their 1987 work.

Assess the Role and Costs of Complementary Air Defenses

The Strategic Defense Initiative Organization is specifically limited to defense against ballistic missiles. The Air Force has undertaken an "Air Defense Initiative, " though at funding levels far below that of the SDI. Nevertheless, at least at the systems analysis level, U.S. decisionmakers need an integrated understanding of the role that air defense would have to play if ballistic missile defense were to achieve such goals as increasing Soviet uncertainty about attack success, denying Soviet abilities to destroy high percentages of certain types of targets, or protecting the population from nuclear attack. Moreover, insofar as BMD requires air defense to accomplish its purposes, the feasibility and affordability of air defense against possible Soviet attempts to circumvent BMD need to be included in any ultimate analysis of the feasibility of BMD.