LA-8632

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Ballistic Missile Defense:
A Potential Arms-Control Initiative

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Los Alamos, New Mexico 87545

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Photocomposition by Barbara J. Velarde and Mary Louise Garcia

LA-8632

UC-2
Issued: January 1981

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BALLISTIC MISSILE DEFENSE:
A POTENTIAL ARMS-CONTROL INITIATIVE

by
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SUMMARY

United States strategic forces must be restructured to meet national-security objectives in a changing world. Growth and modernization of Soviet strategic missile forces are causing our land-based strategic missiles to become increasingly vulnerable to Soviet nuclear attack. American policy for deterring such an attack has evolved from strict reliance on the threat of assured Soviet destruction to include nuclear war-fighting concepts intended to deny Soviet hopes of winning the ensuing conflict. At the same time, events in Iran and Afghanistan have underscored the need to expand and modernize our conventional forces, requiring strict limitation of our strategic investments.

For some strategic force configurations, the goals of flexible nuclear deterrence and strategic arms limitations appear mutually inconsistent. With such forces, prospects for arms limitations would degrade further if the current Soviet build-up were to continue, or if the Soviets were to install unilaterally an anti-ballistic missile system capable of wide-area, multicity defense, or both.

However, if the United States installs an anti-ballistic missile system along with reduced but modernized offensive strategic forces, arms limitation appears compatible with both assured destruction and war-fighting deterrence policies. This conclusion appears equally valid for expanded Soviet forces even if the Soviets also install ballistic missile defenses. In particular, we have analyzed an American strategic posture including layered defense of MX missiles based deceptively in silos. The exoatmospheric-intercept component of this defense system could also defend some of our cities and industrial and military installations. If the United States were to adopt this strategic posture, we believe it would create incentives for the Soviet Union to restrain strategic-arms expansion. Mutual arms-control initiatives could follow. In addition, this defense system might offer stabilizing features: damage limitation for small attacks; nonoffensive crisis response; and relative insensitivity to technological change. These results do not seem to be available by deploying strategic offensive forces alone.

Test and installation of the needed defensive systems are now precluded by the Anti-Ballistic-Missile Treaty adopted in 1972. An opportunity for Treaty reconsideration occurs in 1982. Substantiation of our results would suggest that consideration be given to Treaty modifications or to replacing the Treaty with other agreements. Such actions could lead to improved national security for the United States by enhancing our deterrent posture and, at the same time, offer the potential for significant arms-control initiatives.

I. INTRODUCTION

Over the past two decades, significant changes have occurred in the long-standing competition between the United States and the Soviet Union. Many of these changes have been adverse to American interests. A shift in the global balance of power has taken place, as a result of a determined Soviet expansion of its military power through growing defense expenditures.

Critical strategic asymmetries between the two superpowers have thus emerged, including differing strategic concepts of nuclear deterrence and warfare. For some years American strategy rested on the premise that approximate equality of strategic forces would lead to stable nuclear deterrence, which would be achieved primarily through fear of mutual assured destruction. Consequently, policies on weapons systems that might threaten or undermine Soviet deterrent capabilities were eschewed by the United States as destabilizing. Although the Soviet Union has expressed enthusiasm for the goal of limiting American strategic forces, there is no clear evidence that they have embraced the restraint implicit in our policies. In contrast, the Soviets appear to have developed a strategy of seeking strategic superiority through balanced offensive and defensive forces, with survival as the objective if nuclear war should occur. The Soviets have exploited these asymmetries to attempt to undermine American assurances to its allies and to call into question the guarantee of America's nuclear umbrella.

In recognition of the growing strategic imbalance, the United States recently announced a modification of its nuclear targeting policy.[1] In addition to a punitive assured-destruction strategy, our retaliation would attempt to deny the Soviets any prospect of achieving war-fighting objectives by destroying a range of needed military installations. Elements of damage limitation in this "countervailing" nuclear strategy are perceived both to enhance deterrence prospects and to provide needed options should deterrence fail. The adoption of the countervailing strategy blurs somewhat the distinction between United States and Soviet doctrines but cannot by itself compensate for existing force asymmetries. Restructuring of our strategic forces is also needed. To allow the flexibility needed within the countervailing policy, American forces must be configured to serve both damage-limiting and assured-destruction roles.

Invulnerable ICBMs can contribute to both deterrence policies. In an assured-destruction role, they provide an independent force within the strategic triad that could retaliate if the other triad elements become vulnerable. If the Soviets shelter or harden their strategic industry in an attempt to interfere with our assured-destruction deterrent,[2] ICBMs have the needed accuracy and yield to counteract these actions. In a war-fighting role, ICBMs are the only strategic element capable of damage-limiting attacks on time-urgent military targets.

As offensive technology improves, deterrent strategic forces become more vulnerable to attack. Force-structure or doctrinal changes may therefore be needed. In particular, the ICBMs are becoming increasingly vulnerable to Soviet nuclear attack. Remedies could include technology to reduce vulnerability, expansion of the forces, or changes in strategic doctrine. Doctrinal changes might include launch under attack or launch on warning, and might also necessitate preemptive attack upon time-urgent targets and disruption of an expected attack. Although such changes in strategic doctrine could be an effective way to counter increased vulnerability, they impose imperatives for action, which, in time of crisis, might increase the probability of nuclear war. To avoid this scenario, our strategic forces must be survivable and our policy for using them must be stable in a crisis: we must be able to gather information and deliberate before we have to act.

Expansion of strategic forces to compensate for increased vulnerability is not attractive from either an economic or an arms-control perspective. Thus, we are left with the alternative of developing remedial technology to reduce strategic-force vulnerability. There is, however, another constraint on our selection of strategic-force structures.

In recent years, the Soviets have been able to exploit political, economic, and security instabilities in the Middle East, Asia, Africa, and Latin America, without effective opposition from the West. The invasion of Afghanistan by the Soviet Union, coupled with the dilemma posed by the Iranian capture of the American hostages, underscores the inability of our strategic nuclear arsenal to deter attacks of a more limited or conventional nature. These events also give evidence of our failure to project an effective military presence sufficient to achieve American interests in low-intensity conflict.

Without sufficient conventional forces, we face the increasing risk that nuclear weapons would be used in otherwise conventional conflicts. First use might be by the United States. National frustration, or a Soviet-inspired attack on our vital interests, or an initially conventional war, might exceed our conventional-force response capacity. Depending on our distress, we might then use nuclear weapons under the assumption that a nuclear exchange could remain limited. The Soviets could begin the exchange for similar or disparate reasons. If then our deterrence forces were overly vulnerable, Soviet options would include an all-out counterforce strike as an extremely effective way for them to limit damage to the Soviet Union.

Thus, we will need expanded and modernized conventional forces to be able to avoid nuclear escalation from limited conflicts. This need defines a constraint on our strategic-force procurements: we cannot divert effort or funding away from the conventional forces that we need to support measured diplomatic and military responses.

Our impotence in the Iranian crisis combined with the Soviet move into Afghanistan have effectively prepared America for remedial action. Before these events, the cold war was thought by liberal strategists to be a thing of the past; the Soviet Union and the United States needed one another or, at least, were bent on coexistence. The SALT II agreement, though hotly contested, might well have been ratified by the Senate. Support for strategic programs was limited. Subsequently, what had sometimes been seen as the professional paranoia of the conservative military strategists began to appear as reality. America suddenly became aware that the Soviets had built up mammoth arsenals of both conventional and nuclear weapons. We now seem ready to seek solutions to the military imbalances.

Our objective in this report is to explore technologies that will allow us to reduce forces and still meet both assured-destruction and damage-limiting strategic objectives. We attempt to find forces that will require minimum inventories and investments so as to maximize funds available for conventional forces. With limited inventories, the effectiveness of the strategic forces must be maintained in the face of maturing Soviet technology. Therefore it is essential that the force structure be sufficiently diverse to withstand technological surprise. It must also be relatively insensitive to "cheating" on arms-control agreements; it becomes very difficult, in a political context, to acknowledge cheating or even inadequacy of verification once a treaty is accepted. The force structure must be able to respond economically to possible threat growth so that incentives for continued Soviet proliferation are reduced or denied. The force must be able to achieve arms-control, assured-destruction, and damage-limiting objectives regardless of Soviet strategic policy. Finally, it should promote crisis stabilization.

These goals, when coupled with strict force limitations, appear from our analysis to be incompatible if we seek strategies that use only offensive forces and exclude defensive systems. This report, therefore, concentrates on ballistic missile defense technology that could be introduced soon and might measurably foster the goals of deterrence, arms control, and stability. *Our analyses indicate that a properly configured force including a ballistic missile defense system may permit deterrence at reduced force levels while resisting erosion of the deterrent by technological advances.* Moreover, the effectiveness and structure of such a force do not appear to depend so crucially on treaty-specified actions as to be critically vulnerable to violations of arms-control agreements. Such a ballistic missile defense system would also add elements of crisis stability and damage limitation in case deterrence were to fail. Defensive systems could be installed economically, together with or separately from the deceptive-basing modes now under development for MX missile deployment.

Previous consideration of ballistic missile defense has been seriously constrained by a long-standing and widely held concern: ballistic missile defenses would be destabilizing if capable of defending military, industrial, and urban targets. Such area defenses would presumably interfere with the maintenance of assured-destruction retaliatory forces, thus tempting the nation possessing defenses to launch a preemptive strike. Defense installations would presumably also lead to a defensive arms race coupled with the ongoing offensive arms race. These concerns are still current, as stated during 1980 by Secretary of Defense Harold Brown (Ref. 1, p. 99):

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> . . . attempting to construct a complete [ballistic missile] defense against massive nuclear attack would be prohibitively costly, destabilizing, and in the end, almost certain to fail;

and by President Carter's Deputy Assistant for National Security Affairs, David Aaron:[3]

> I think we can be pleased that we're not engaged in both a defensive strategic arms race as well as an offensive one.

In this report we suggest how prospective ballistic missile defense systems might overcome these concerns.

If both the Soviets and the United States are bent on strategic arms reductions, they can apparently retain mutual deterrence by mutually assured destruction with moderate inventories of offensive and defensive strategic components. The systems need not be costly nor lead to instabilities. If, on the other hand, the Soviets continue their strategic arms build-ups at the current pace, then American force structures that include ballistic missile defense might provide the most economical and flexible options for deterring Soviet attack by the countervailing deterrence strategy. Continued offensive missile proliferation by the Soviets would not need to be mirrored by the United States. Our results suggest that we could instead maintain stable deterrence by moderate increases in hardware, mainly defense components. In this case, the Soviets would not be likely to perceive our response as a threat to which they would have to respond. Reciprocal pressures for an arms race could ease. Of course, the Soviets could continue their arms build-up anyway, and we would have to respond; but our results indicate significant economic advantages for the United States in this scenario.

The perceived Soviet/American balance of power rests on military capacities well beyond the maintenance of a reliable assured-destruction (punitive) nuclear deterrent. Thus our derivation of assured-destruction strategic forces represents but a first step in the needed force-structure analysis. We continue the analysis by suggesting some ways in which the countervailing strategy might be enhanced by the capacity for limited defense of military, industrial, and urban targets.

The force structures postulated in this study would require defense components whose development and testing are now precluded by the Anti-Ballistic-Missile Treaty, which was adopted in 1972 and is scheduled for review in 1982. At that time either party can withdraw or propose modifications without prejudice to future treaty activities. Strategic defense concepts discussed in this report suggest that serious consideration should be given to modifying the Treaty or replacing it with an agreement that would allow the benefits of the new defensive technologies to accrue in support of both national-security and arms-limitation goals.

Consideration of possible treaty actions rests partly on the readiness of ballistic missile defense technology. The Ballistic Missile Defense Program Manager, Major General Grayson D. Tate, Jr., in testimony presented to the Senate Appropriations Committee in March 1980, was subdued but positive in his overall assessment of the technology.[4]

> [Low-altitude defense] technology is low risk and ready for preprototype demonstration now. The exoatmospheric element of layered defense represents less mature technology. However, . . . advances [in exoatmospheric ballistic missile defense technology] make it feasible to develop autonomous long-range interceptors . . . [This system] is being validated . . . and promises to give defense the cost advantage for the first time . . .

Based on a brief review of ballistic missile defense technology conducted by Los Alamos during 1980, we concur with General Tate's optimism. We believe ballistic missile defense soon could be ready to assume the postulated strategic roles.

In the next section of this report, we describe some elements of the current technology and summarize our technical assessment, comparing it with the Department of Defense assessment. We then continue our analysis of assured-destruction deterrence postures by describing simple mathematical models and applying them to a set of strategic options available to the United States. We use the results to amplify our suggestions that timing and cost advantages may accrue to strategic options including ballistic missile defense.

II. TECHNOLOGY OF BALLISTIC MISSILE DEFENSE

The ballistic missile defense systems considered in this report can be categorized according to where an offensive weapon is intercepted along its trajectory. System concepts include early-trajectory or boost-phase intercepts, midcourse or exoatmospheric intercepts, and terminal or endoatmospheric intercepts. Systems that specify two groups of intercepts, one after the other, are referred to as layered defense systems.

Boost-phase or early-trajectory intercepts by "directed-energy weapons" (intense laser beams or particle beams) hold the potential for an extraordinarily effective defense of all national assets. Directed-energy-weapon development in the United States is at so limited a stage at present that it is extremely unlikely that such systems could improve our strategic position in the coming decade. Well-funded 5- to 10-year research programs will be required to establish the needed technology bases in these areas before we can begin to realize their potential. These systems are not part of the present analysis.

Our analysis is based on conventional exoatmospheric and endoatmospheric defense systems that intercept between the midpoint of the ballistic trajectory and 1-2 kilometers before impact. These systems operate by guiding rocket-powered vehicles to intercept incoming warheads. They require

- early warning that a threat has been launched;
- detection and assessment of the approaching threat;
- derivation of trajectories and prediction of impact points;
- discrimination between warheads and decoys;
- commitment, launch, and guidance of interceptors; and
- destruction of the warheads.

These functions are depicted in Fig. 1; the subsequent system descriptions and assessments are discussed in terms of these system functions and the technologies supporting them.

Current ballistic missile defense technologies are substantially different from predecessor technologies used by the Safeguard ballistic missile defense system of the early 1970s. Safeguard was widely perceived as incapable of fulfilling the missions it faced. It is appropriate, therefore, to contrast Safeguard with current

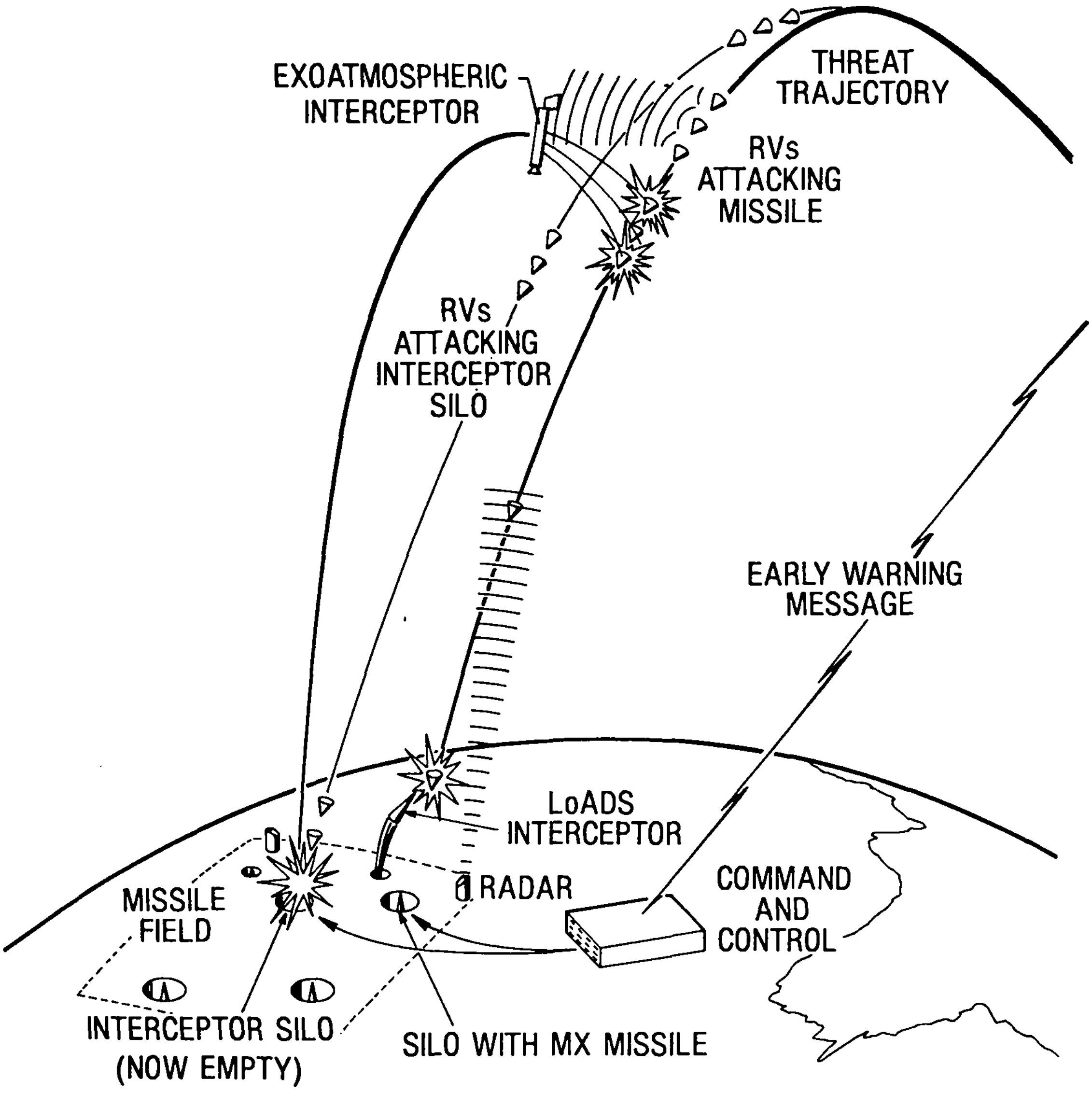

Fig. 1.

Layered ballistic missile defense of MX missiles deceptively based in silos. In this depiction three warheads are on a trajectory aimed at an MX missile in one silo, and three more are aimed at an exoatmospheric interceptor in an adjacent silo. The exoatmospheric interceptor is launched and destroys two of the warheads attacking the missile. Warheads attacking the now-empty interceptor silo are ignored. The surviving warhead aimed at the missile is intercepted by the terminal defense. Not shown explicitly are the separate threat detection and assessment functions.

systems and show how the deficiencies of Safeguard can be overcome by the new technology.

A. Safeguard

Safeguard was a layered defense that used ground-based radars for detection, assessment, tracking, discrimination, and interceptor guidance for both mid-course and terminal defenses. Long-range perimeter acquisition radars provided early warning and determined the size of the attack and its targets. As attackers neared the intercept range, battle management and engagement were taken over by smaller missile site radars, coupled to central computers, with one radar-computer assembly for each wing of the Minuteman force. For the exoatmospheric layer, multistage Spartan interceptors, guided by the radars, operated out to several-hundred kilometers. The Spartan carried a single high-yield nuclear warhead. Those warheads leaking past the Spartan's defense layer would be intercepted by fast-reacting Sprint low-yield nuclear interceptors at altitudes of 3-30 kilometers also guided to intercept by radar. Each interceptor would engage one warhead.

The large ground-based radars were Safeguard's weakest point. It was soon recognized that the first Spartan nuclear explosions would render large regions of the atmosphere opaque to radar propagation, thereby blinding the radars and making them vulnerable to attack. Other problems existed as well:

- the computers needed were beyond the state of the art;
- discrimination by radar signatures was only marginally effective; and
- the system was easily defeatable by a cost-effective increase in the threat size.

B. Exoatmospheric Defense for the 1980s

Current designs for exoatmospheric ballistic missile defense depend on two major innovations: (1) small, high-resolution, sensitive, long-wavelength infrared detectors, installed with computers in space-borne threat-assessment sensors and in interceptors, which replace large ground-based radars and central computers for long-range threat acquisition, assessment, tracking and discrimination; and (2) homing infrared guidance that enables each interceptor to disperse many vehicles for multiple nonnuclear intercepts instead of single-vehicle nuclear interceptors.

In the current designs, early-warning messages either from satellites or radars trigger the threat detection and assessment functions carried out by infrared sensors. These sensors can be emplaced on satellites or carried aloft on rocket-borne probes launched from the continental United States. Each payload consists of a sensitive infrared telescope, a data-processing computer, and down-link communications equipment. The sensors scan the threat corridor specified by the early-warning message and detect, at ranges of several-thousand kilometers, the attacking reentry vehicles, accompanying objects, and penetration aids.

Typical threats could have approximately 5000 reentry vehicles and upwards of 20 000 other objects in the field of view; the computer must process information for all of them. The sensor tracks all these objects for minutes, measuring angular information and infrared spectral intensities in several bands as a function of time. The on-board computer stores this information, computes approximate trajectories and launch and impact points, and uses infrared discrimination algorithms to differentiate the reentry vehicles from the other objects in the threat. This information is then relayed to a ground-based battle-management computer in real time via multiple-path communications links. Based on the attack breadth, predicted impact points, and relative strength of the defense, the battle-management computer assigns targets to interceptors and launches them.

Impact-point prediction, if accurate enough, permits the battle-management computer to defend targets preferentially, that is, to defend some targets and to ignore warheads attacking others. Such a capability is important if the attack size is larger than the defense can intercept fully, or if deceptive techniques are being used by the attacked party to thin the effective attack on each real target.

Following launch, the exoatmospheric interceptor rockets operate autonomously, reacquiring their assigned portions of the threat via infrared sensors, repeating the discrimination procedures, and finally deploying multiple-kill vehicles to engage the attack while still several minutes from impact. Using still another infrared sensor, each kill vehicle homes on a separate warhead, getting close enough to destroy it by direct impact or by firing a conventional explosive warhead.

A fraction of the attack can survive this engagement. Some objectives are deliberately ignored (penetration aids, accompanying objects, warheads allowed through by a preferential defense). Some engaged objects penetrate the defense (leakage). The surviving warheads either reach their targets or are further depleted by subsequent defense layers.

Assessment. The Ballistic Missile Defense Program Office is guardedly optimistic about the potential for exoatmospheric technology. General Tate reported that[4]

> The [exoatmospheric component of the] Layered Defense Concept is feasible because [of] advances made in the extensive research and development . . . [The] first two flights [of an experiment] . . . confirmed that optical sensors can be used to perform [ballistic missile defense] functions.

His Deputy Program Manager, William A. Davis, supplied a more conservative and detailed treatment:[5]

> Midcourse technologies are relatively immature, pose a higher technical risk than terminal technologies, and enjoy only a meager data base. There are a host of technical issues to be addressed in [our] research and development program over the next several years, two of which are examined here: optical discrimination and nonnuclear kill.
>
> Technical evidence exists that optical discrimination is sufficiently developed to make midcourse operation feasible. Some optical flight data is available on both reentry vehicles and exoatmospheric penetration aids, and there is extensive laboratory data that correlates well with the flight data. Moreover, the essential finding from simulation exercises carried out jointly with the Air Force's Advanced Ballistic Reentry Systems (ABRES) shows that all but the most sophisticated penetration aids can be readily discriminated. However, more data and more functional demonstrations are necessary, and there are plans to meet these needs.
>
> The evidence is that nonnuclear kill can be achieved in one of two ways—with a warhead or by direct impact. In both cases, passive homing rather than the conventional radar command guidance will be used. The primary approach is to use a warhead, and actual flight tests (Homing Overlay Experiment) to demonstrate this approach will be held in several years. Guidance simulations indicate a warhead can be brought close enough to achieve a kill. Impact kill is a back-up approach that was demonstrated in laboratory tests several years ago.

Based on our review of exoatmospheric technology, Los Alamos supports the optimism expressed by the Program Office. The technology base for the exoatmospheric system appears to be either in hand or on the immediate horizon. We also are able to add detail to the Program Office assessment. Integrated circuit technology is progressing so rapidly that adequate computer capability appears assured. Laboratory models, experiments, and calculations of nonnuclear kill give high confidence in performance capabilities. Infrared detection and discrimination have been studied carefully, and useful techniques and knowledge of their limitations appear in hand, pending proof test within a few years. Impact-point prediction is expected to be capable of permitting preferential exoatmospheric defense of silos,* but it is not expected to be able to resolve impacts among closely spaced shelters of any of the multiple-protective-structure emplacement schemes under consideration.

We identified several outstanding technical issues needing further study. These issues are dominated by concern over extreme system complexity. Some analysts have considerable reservations about system operability; others are optimistic. Large-scale simulations in progress lend credence to system operability. Other issues include operability of sensors, computers, communications, and interceptors in a nuclear environment, potential for means of overcoming infrared discrimination, and integration of active defense with an already strained national command-communications-control system. The special problems of attacks launched by nuclear submarines lying close to American shores are particularly stressing to exoatmospheric defense, owing to the short flight times. Intercepting such attacks would require previous placement of threat assessment sensors or—at reduced efficiency—operation without them. In addition, a number of actions could be taken by the Soviets in response to our installation of an exoatmospheric defense

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*For impact resolution within 5 km, silo-to-silo preferential defense would be effective. For poorer resolution, preferential defense of groups of silos would be used.

system that could degrade its capabilities. They include maneuvering reentry vehicles, defense suppression attacks, and new decoy techniques.

Although exoatmospheric defense capabilities are not yet fully perfected or demonstrated, we feel development is advanced enough to warrant beginning studies of potential applications.

C. Endoatmospheric Defense for the 1980s

Endoatmospheric defense uses radars for all sensing functions. Small radars can be specified because the radars need not have ranges necessary for exoatmospheric defense (a departure from Safeguard). Discrimination against decoys is based on different radar signatures, as objects penetrate the atmosphere, depending on weight, shape, and surface characteristics. Such atmospheric effects begin to be apparent on radar signatures at altitudes below 90 km. Based on time delays associated with discrimination and interceptor flight, a practical upper altitude for intercepts is 20-30 kilometers.

The limiting lower altitude for intercept is determined by the capacity of the defended target to withstand defensive weapon bursts and, possibly, nuclear detonation of the intercepted warhead. By this criterion a shelter or silo could be defended successfully with intercepts spaced as closely as 2 kilometers.

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United States endoatmospheric defense research and development effort is concentrated in two programs: Baseline Terminal Defense and Low-Altitude Defense System.

(1) *Baseline Terminal Defense* is a direct descendant of Safeguard. It uses improved Sprint interceptors, a commercial computer, and phased-array radars considerably smaller than Safeguard's missile site radar. This system, based on established technology, would be less vulnerable than Safeguard because it would use multiple radars in dispersed sites. Since intercepts would occur in the altitude range of 10-20 kilometers, this system would be useful for soft targets.

(2) *Low-Altitude Defense System,* the major ongoing low-endoatmospheric intercept program, is shown schematically in Fig. 2. A derivative of the Baseline Terminal Defense System designed mainly for defense of MX-MPS, it uses single-stage nuclear-warhead interceptors with a range of only a few kilometers. The Low-Altitude Defense System uses phased-array radars of modest power, coupled to minicomputers. Because of small component size, the system can be deceptively based in any of the basing modes proposed so far for MX. In modified configuration it could also be used to defend silos.

Assessment. In his Senate testimony regarding terminal defense, General Tate reported:

> [Low Altitude Defense System] is considered a low-risk development because of the extensive validation testing accomplished . . . on the Terminal Defense (Site Defense) concept. This testing . . . has proven beyond reasonable doubt that we have the technology to build an effective terminal defense system that can detect, discriminate, and intercept ICBM warheads even in the extreme environment caused by massive ICBM attacks . . . and penetration aids.[4]
>
> * * * *
>
> The basic technology for Low Altitude Defense—LoAD—has been demonstrated with the exception of nuclear hardness for the radar and the interceptor. Nuclear hardness will be tested and demonstrated . . . prior to MX IOC* and the LoAD preprototype demonstration flight tests.[6]

As was the case for exoatmospheric defense, we concurred with the Program Office assessment of terminal defense technology. We felt that the use of smaller and less complex components make low-altitude defense a relatively low-technical-risk system with less costly components than exoatmospheric systems. However, the stressful nuclear environment envisioned requires interceptor and radar hardness values exceeding those of predecessor systems. Ability to defeat an intense attack against any single target will be limited because, with the very short time available for acquisition, track, and intercept, multiple sequential intercepts will be difficult. The limited space available for interception would also reduce the ability of the system to cope with repeated attack, due to nuclear-fireball interference with radar propagation and to interceptor-interceptor fratricide. In such a dense attack, fratricide between attacking warheads could also be a problem for the attacker.

Interceptor technology for endoatmospheric defense is well in hand, provided that nuclear warheads are carried. (Nonnuclear kill may become feasible, particularly for engagements at higher altitudes, but will require further

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*That is, the date currently scheduled for initial operational capability of MX in multiple protective structures.

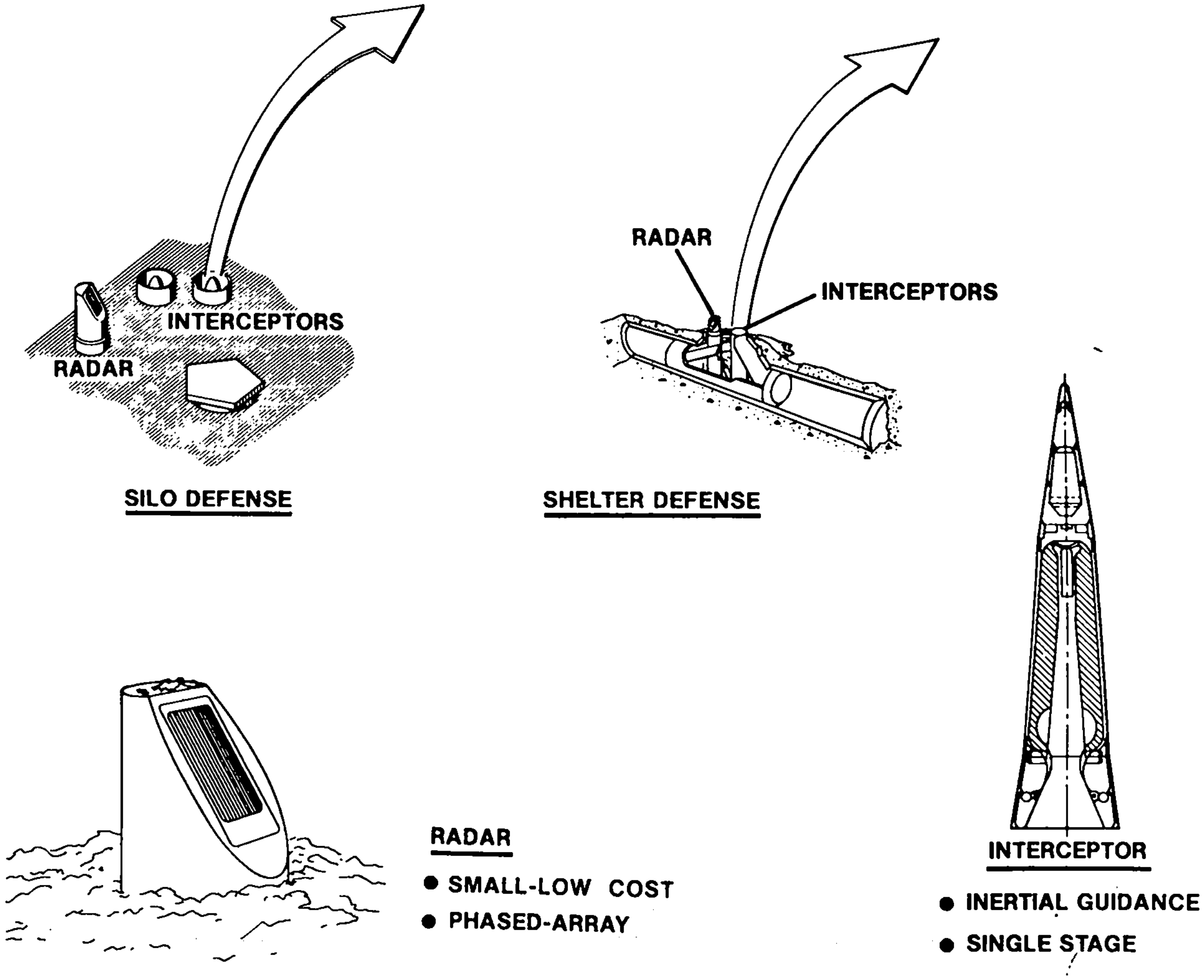

Fig. 2.
Low-altitude endoatmospheric ballistic missile defense.

development in sensor, guidance, warhead, and missile technology.) Distributed data processing and the use of multiple small, hard radars would ensure that the system performance would degrade gracefully against even moderately heavy attack. For low-altitude defense of hard targets, an endoatmospheric system of the Low Altitude Defense System design could be ready for deployment by the mid-1980s, as reported by General Tate:[6]

> [With $25M additional funds starting in Fiscal Year 1981 it would be feasible] to enter engineering development in Fiscal Year 1982 to support a [low-altitude missile defense] deployment concurrent with MX deployment in 1986.*

At the end of the trajectory, as an alternative to conventional hard-target endoatmospheric defense, several last-ditch methods for destroying warheads by nonguided missiles have been proposed. We considered a number of techniques using nonpowered missiles (projectiles, dust clouds) and felt that none was feasible. However, a concept specifying dense barrages of powered but unguided missiles, which recently came to our attention, may offer near-term potential for endoatmospheric defense of hard targets.

D. Layered Defense

Combination of exoatmospheric, infrared, non-nuclear-intercept technology and endoatmospheric, small-radar, nuclear-intercept technology into a layered

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*The Ballistic Missile Defense Program received an additional $15M in Fiscal Year 1981 funding following General Tate's testimony.

defense system offers a number of synergistic advantages over either system operated alone:

- leakage factors can be multiplicative, so that two relatively leaky components can combine into a system with very low leakage;
- two different discrimination phenomenologies place severe demands upon decoy designs;
- the low leakage produces lower costs per intercept;
- reduced inventories and complexities accrue to both layers, relative to single-layered defenses;
- the upper layer avoids saturation of the endoatmospheric defense component; and
- exoatmospheric-system threat assessment improves engagement planning for the endoatmospheric defense components.

An equivalent set of factors was reported by General Tate (Ref. 4, p. 2872).

III. FORCE-STRUCTURE ANALYSIS

On the premise that current ballistic missile defense systems will mature as anticipated, it becomes necessary to consider how such systems would affect the strategic situation. We begin this consideration by exploring, with simple models, the arms-control implications of ballistic missile defense and other strategic options. Alternately, we explore how well these options could do in a world devoid of arms-limiting agreements.

We perform the analysis by estimating United States strategic inventories needed to ensure the expected survival of a predetermined deliverable retaliatory strike by the United States after a Soviet first strike. For assured destruction, the retaliatory strike is taken to consist of a fixed number of warheads that can be delivered against Soviet targets of value—cities, industry, transportation, etc. The number of deliverable warheads is taken arbitrarily as 1000 (that is, 100 MX-equivalent payloads). Other numbers can be postulated, but our qualitative conclusions do not change if this assumption is varied.

Deterrence could be based alternatively on developing a war-fighting posture, in which forces are so structured as to permit their flexible use throughout a nuclear exchange. In this case the needed analysis is much more complex and is less amenable to simple modeling. Consequently, we are limited to discussing at the end of this section some elements of war-fighting deterrence in qualitative terms, and deferring quantitative treatment.

The needed strategic inventories for deterrence depend on the offensive and defensive systems used. We treat four options:

(1) new ICBMs (MX) based nondeceptively in silos, no defenses (extension of current status);
(2) new ICBMs (MX) in multiple protective structures (MPS), no defenses (current DoD planning);
(3) MX-MPS, defended by terminal missile defenses (extended DoD planning); and
(4) MXs based deceptively in silos, defended by layered defenses.

We assume that when the United States implements a particular technology, such as exoatmospheric defense, the Soviets can simultaneously implement an equivalent Soviet technology if they choose to do so. We do not attempt in this analysis to account for differences in emplacement dates for American and Soviet inventories.

The forces required for the United States to achieve the specified deterrence criterion also depend on the forces maintained by the Soviet Union. The result achieved by any change in American force structures thus depends strongly on the Soviet response, or lack of response, to the United States initiative. Expectations concerning Soviet responses depend on Soviet motivations and policies. We consider two cases:

- a responsive Soviet behavior in which the Soviet aim is also to maintain a minimal expected deterrent in the face of possible United States counterforce attack, and
- an independent Soviet behavior in which the Soviet forces are determined by internal considerations not dependent on American force structures.

The initial forces needed to achieve the deterrent criterion can be estimated, based on known, inferred, or assumed capabilities of the opposing force structures and policies for their employment. Such computations must be quite detailed to account properly for design variations within and between Soviet and American forces. Consideration must be given to many aspects and details beyond the capability of the simple sorts of analyses we can attempt here. For example, to model correctly the missile-force exchange we study here, one must consider variations of such parameters as warheads launched on each missile, their accuracies, and their delivery-vehicle performance.

However, an estimate of the required force sizes can be obtained from simple models that average over these variables. Such models are much too limited to define actual strategic forces needed, but they are valuable in estimating how extensive those forces must be to achieve specified deterrence levels. They are thus also useful in comparing force inventories and costs, both between first striker and retaliator, and among the various strategic options considered by the retaliator. Our approach uses such a simple model.

A. Force-Structure Model

To estimate the required deterrent forces, we assume the following scenario: the Soviets strike first, using their entire missile inventory to attack our ICBM fields; we ride out the attack, using any active defenses we have to defend our missiles; our subsequent retaliatory attack is aimed at Soviet value targets; and any Soviet active defenses attempt to intercept the fraction of the retaliatory strike within range of the Soviet defense system.

Attack on our land-based ICBMs by the entire Soviet missile force is only one of many possible scenarios, although it is the one often considered in arms-control analyses. This scenario is not realistic, but for our purpose it is conservative in that any lesser attack against the ICBMs either destroys fewer of our missiles or engages fewer of our defenders. The additional survivors would then be usable in damage-limiting roles. Although implications of Soviet reserve forces are neglected in this preliminary study, they are critical and must be treated subsequently in the broader context of countervailing deterrence.

To determine force structures, we derived formulas relating survivable, deliverable warheads to initial inventories, based on the above exchange scenario. In the responsive case, both Soviet and American inventories were assumed coupled. Inventories were increased together until the calculations showed each side achieved the specified deterrence criterion. This approach produced minimum inventories and costs for both sides. In the independent case, Soviet missile inventories were postulated at fixed levels, and the remaining Soviet and American inventories were varied until the United States achieved the specified deterrence criterion. United States inventories were structured for minimum cost at each threat level.

With the notation given in Table I, and using primed quantities for Soviet hardware, the needed formulas are*

Option (1) Missiles based nondeceptively in silos, no defense. All silos are assumed to have missiles in them (H = M).

$$S = M\,(1 - p')^{\mu' M'/M} \quad ;$$

and

$$W = \mu S \quad .$$

Option (2) Missiles based deceptively in multiple protective structures (H > M); no defense.

$$S = M\,(1 - p')^{\mu' M'/H} \quad ;$$

and

$$W = \mu S \quad .$$

Option (3) Missiles based deceptively in silos or multiple protective structures (H > M); with low-altitude missile-only defenses.

$$S = M\,(1 - p'\,L_n)^{\mu' M'/H} \quad ,$$

where

$$L_n = (1 - r)^{yH/2\mu' M'}$$

for MPS,* or

$$L_n = (1 - r)^{yH/\mu' M'}$$

for silos*; and

$$W = \mu S \quad .$$

Option (4) Missiles based deceptively in silos, with partially ambiguous exoatmospheric defenses coupled with low-altitude missile-only defenses.

For this model, we assumed that there are no empty silos; each silo contains either a missile or an exoatmospheric interceptor (H = M + X). We assumed that two rockets

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*The expression $(1 - p')^{\alpha}$ is rigorously correct in these formulas only for integral values of α. For nonintegral values, the correct expression would be $(1 - p')^{[\alpha]}\,(1 - \langle\alpha\rangle\, p')$, where [α] is the integer part of α and <α> the fractional part. For conciseness, we continue to show the simpler form; however, we used the corect form in all our inventory estimates.

*The rationale for this difference is that for MPS the defense unit is assumed to be in a shelter adjacent to the missile's shelter, far enough away to require defending it explicitly, whereas for silos, the defense unit is assumed close enough to the silo to be defended implicitly as the silo is defended.

TABLE I

NOTATION

(Values used in this analysis are given in [ ])

Inventories	M	Missiles
	H	Silos/Shelters
	X	Exoatmospheric interceptors
	N	Endoatmospheric interceptors
	y	Endoatmospheric interceptors per defense cluster (defense unit)
Outcomes	S	Missiles surviving missile-field attack
	W	Warheads delivered on target
Parameters	μ	Warheads/missile [10][a]
	χ	Kill vehicles/exoatmospheric interceptor [10]
	f	Ambiguity factor[b]
Kill Probabilities	p	Warhead on silo or shelter[c] [0.80]
	q	Exoatmospheric kill vehicle on warhead[d] [0.80]
	r	Endoatmospheric interceptor on warhead[d] [0.70][e]
Leakage Factors	L_x	Exoatmospheric defense of missiles
	Λ_x	Exoatmospheric defense of value targets
	L_n	Endoatmospheric defense (missiles only)

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[a] As specified in SALT II for new missiles.

[b] The "ambiguity factor" represents the degree to which the exoatmospheric defense can be used to defend value (area) targets. f is defined as the fraction of value targets, attacked by the retaliatory strike, that are within range of the exoatmospheric defense. Reasonable values are 0.5 to 0.8. We treated f as a parameter, using f = 0.6 for comparative results.

[c] Includes an estimate of operational reliability.

[d] Approximates in one constant both interceptor-related factors (reliability, warhead lethality) and system-related factors (detection, discrimination, radar availability).

[e] For first intercept; degrades by 20% for each subsequent intercept.

share booster hardware and differ only in the payloads; they thereby look enough alike that the opponent cannot tell which silos have missiles. To maintain long-term deception, covert missile-to-interceptor interchanges would be required periodically. These interchanges could be made by small vehicles transporting only the payloads, thus eliminating transport of entire missiles, as is required in the MX-MPS concepts.

To strike first, the opponent must target all silos. We assumed that we can determine by infrared tracking which warheads are aimed at missiles. We intercept only those warheads, not wasting interceptors on warheads targeted on (now empty) interceptor silos.

To select the optimum mix of interceptors and missiles, we chose the inventories that would minimize the expression (M + X + 0.2N), representing a factor approximately proportional to cost. This expression assumes that exoatmospheric interceptors and missiles cost the same, and that endoatmospheric interceptors cost 1/5 as much. We constrained N to be an integer y times H, that is, we assumed deployment of y endoatmospheric interceptors per silo.

$$S = M\,(1 - p'\,L_n\,L_x)^{\mu'M'/H} \quad ,$$

where

$$L_x = (1 - q)^{xXH/\mu'M'M} \quad ,$$

$$L_n = (1 - r)^{yH/\mu'M'L_x} \quad ;$$

and

$$W = \mu S\,[f'\Lambda'_x + (1 - f')] \quad ,$$

where

$$\Lambda'_x = (1 - q')^{x'X'/\mu Sf'} \quad .$$

1. Responsive Soviet Behavior. The underlying assumption of a responsive relationship based on minimal mutual deterrence capabilities is not justified by Soviet writings or behavior. Nevertheless, the responsive assumption results in estimates of minimum force levels for both sides, and so provides a means of determining lower limits for the strategic inventories needed to assure deterrence. Those options that require unreasonably large inventories in this environment would fare even worse under less constraining assumptions and can be eliminated from further consideration.

For each option, we derived minimum inventories needed on both sides to achieve the specified deterrence criteria. Such criteria, and the resulting inventories, need not be symmetric. For example, the Soviets could specify that ***their*** deterrent be twice what we choose. Differing parameters, such as warheads per missile, would also result in asymmetric inventories.

We have solved here only the fully symmetric case in which all inventories, parameters, and kill probabilities are equal for the two sides. This case retains many of the characteristics of the general solution, but the equations are much easier to solve.

Inventories needed to assure a 1000-warhead retaliatory force were computed using the formulas given earlier and the parameters listed in Table I. The assumptions of cooperation and symmetry were treated by setting all primed quantities in the formulas equal to their nonprimed counterparts. The results are summarized in Table II.

Three of the four strategic options considered can produce satisfactory results in this symmetric, responsive case. The exception is offensive missiles based nondeceptively in silos; in this case assured destruction and crisis stability are mutually unattainable. MX-MPS, defended or undefended, requires only 115 to 150 MX-type missiles, emplaced deceptively among a few-thousand shelters, to achieve deterrence. Use of missile defenses with MX-MPS halves shelter and land requirements. Such basing options are vulnerable if the deceptive basing is not fully effective. This vulnerability would not be prevented by expanded terminal defense.

What may be surprising in this analysis are the moderate inventories associated with layered defense of silos. Although many believe that mutual deterrence would be overly costly if systems included ballistic missile defenses capable of wide-area defense, our model suggests that this belief may not be entirely correct. Even in the case of a totally ambiguous exoatmospheric defense component capable of defending all values attacked by a retaliatory force, stable assured-destruction deterrence could be achieved with as few as 300 silo-based MX missiles and 200 silo-based exoatmospheric interceptors.

Whereas MX-MPS is catastrophically sensitive to failures of deception, failure modes for layered defense of silos are apparently more gradual and therefore forgiving. A number of examples support this assertion.

First, the required degree of deception for this layered defense concept is much less demanding than that needed for MX-MPS; deception, therefore, is much less likely to fail. But suppose deception were to fail for a symmetric layered defense posture with the inventories given in Table II for $f = 0.6$. In this case, failure of deception would reduce the deliverable retaliatory deterrent from 1000 to 400 warheads, a serious but not catastrophic degradation. On the other hand, if we learn that deception is no longer reliable, we can increase inventories to reestablish the full deterrent. Without deception, symmetric inventories would be 260 missiles, 760 silos, 500 exoatmospheric interceptors, and 260 endoatmospheric interceptors; although significantly greater than those needed with reliable deception, these quantities are still reasonable.

Another calculation shows the resilience of layered defense in the face of treaty verification problems. Optimal cost-effectiveness for both sides would be achieved with a 220:200 ratio of siloed missiles to siloed exoatmospheric interceptors. It is easy to verify how many silos are in use but difficult to verify the mix between missiles and interceptors. What if the Soviets cheat on some future treaty by replacing interceptors by missiles, or *vice versa*, within the verifiable fixed number of silos? Our model indicates that departures by the

TABLE II

APPROXIMATE INVENTORIES TO ACHIEVE MUTUALLY ASSURED DESTRUCTION (W = 1000) IN THE RESPONSIVE, SYMMETRIC CASE

			Inventories				
Option	Basing	Defense	Silos, Shelters	Missiles	Exos	Endos	Notes
(1)	Silos	None	10^9	10^9	---	---	Passive posture[a] (ride out attack, crisis stable).
			5000	5000	---	---	Dueling posture[a] (launch under attack, crisis unstable).
(2)	MPS	None	3500	150	---	---	Assuming 23 shelters per missile as in DoD plans for MX-MPS.
(3)	MPS	Endos	1600	115	---	230	Optimized by using 14 shelters per missile.
(4)	Silos	Layered[b]	500	300	200	1000	f = 1.0 (worst case).
			420	220	200	420	f = 0.6 (nominal case).

[a] Following terminology and treatment developed by R. H. Kupperman and H. A. Smith, Ref. 7.

[b] Inventories depend on missile-to-exoatmospheric interceptor ratio. This ratio was chosen to minimize the expression (M + X + 0.2N), representing a factor approximately proportional to system cost.

Soviets from this optimum mix could indeed degrade our retaliatory capability in the face of a Soviet first strike. The Soviets, however, would at the same time incur much greater degradation of their ability to retaliate against an American first strike.

Figure 3 relates the number of retaliatory warheads that could be delivered following a first strike to the number of missiles deployed by the Soviets in their 420 silos. United States retaliation following a Soviet first strike is plotted as the solid curve; Soviet retaliation capacity after an American first strike is plotted as the broken curve. The symmetric solution, resulting in 1000 warheads deliverable after either side strikes first, is shown as a dot.

As an example of the situation if the Soviets cheat, consider what happens if the Soviets convert 80 of their exoatmospheric interceptors to missiles, giving a total of 300 missiles. If the Soviets strike first, the United States retaliation produces approximately 850 warheads on target, not a significant degradation. But if the United States were to strike first, the weakened Soviet defense would leave them with less than 200 retaliatory warheads, a highly significant concern to Soviet planners. The same disparity exists across the range of Soviet missile counts producing substantial degradations of the United States deterrent.

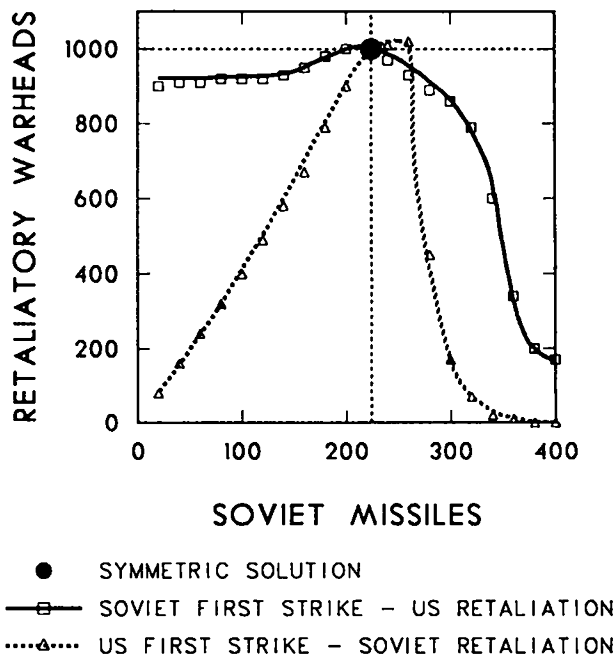

Fig. 3.
Decrease of retaliatory warheads due to assumed departures by the Soviets from solutions of the symmetric equations for layered defense. The total number of Soviet silos is assumed constant.

This disparity may prove to be a strong incentive for each side to keep close to the optimum missile-interceptor mix, even in the absence of any verifiable or unverifiable treaty agreements.

As a third example of gradual response by layered defense to failure modes, clandestine increase in the number of warheads carried by each Soviet missile is a potentially serious threat. Such fractionation is inevitably accompanied by reduced warhead yield, but this decrease can be more than overcome by the increased numbers of warheads in the threatened attack. Figure 4 shows how Soviet fractionation might affect our deterrent. For $\mu' \leq 20$, we estimate serious but not catastrophic deterrent degradation. For even greater Soviet fractionation, ICBM survival could become problematical. Of course, if the fractionation were overt, or if we became aware of it by intelligence means, we could counter its effect by modest increases of our inventories.

For most of the potential failure modes of layered defense, degradation of the retaliatory force would become more severe and abrupt if the Soviets were able to defend a larger fraction of their assets. Evaluation of this effect awaits more detailed computations.

2. **Independent Soviet Behavior.** In this case, we assumed the United States faces a fixed Soviet threat that is not responsive to American arms-reduction initiatives.

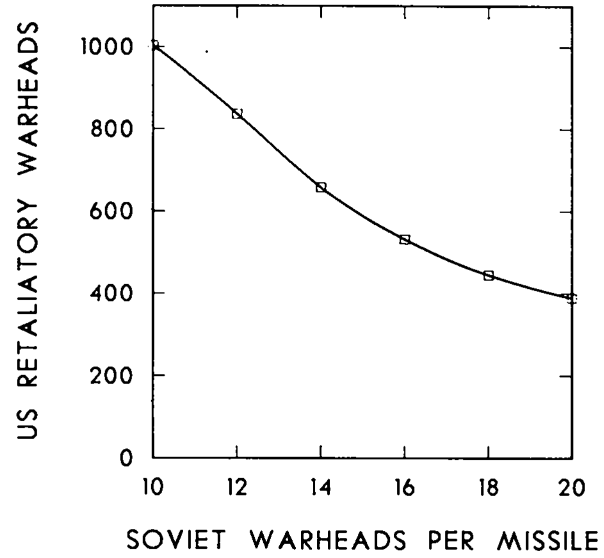

Fig. 4.
Degradation of United States nuclear deterrent (established with layered defense of silos) when the Soviets clandestinely add more warheads.

This appears to many observers to describe recent Soviet behavior more accurately than does the "responsive" assumption. Consistent with this assumption, the Soviets have publicly repudiated the mutual deterrence philosophy that has formed the basis of much recent American thinking in the field of arms control.

The United States forces required for deterrence were estimated as a function of the Soviet force by using the same formulas and parameters used previously, without the assumptions of complete United States/Soviet force symmetry. The results were applied in two eras:

- *Near term.* Some analysts project a continued growth of the Soviet threat consistent with recent history. We evaluated how each strategic option would respond throughout the next decade under the assumption that Soviet missile forces grow at a rate of 10% per year. This assumption imposes a time scale with which to compare the options, rather than suggesting a realistic estimate of Soviet intentions, a matter well beyond the scope of our effort.
- *Long term.* We estimated how well and at what (approximate) cost each of the strategic options could respond to continued growth of the Soviet threat, past the next decade. Without regard to a specific time scale, this analysis permits comparisons of long-range costs among the strategic options and cost-exchange comparisons between threat and response.

a. Near Term. The postulated Soviet threat growth is plotted in Fig. 5. We used this threat as an input condition and estimated the year-by-year capability of each strategic option to respond to it. To make these estimates, we needed to project availability of the technology for each option. Such projections have a high degree of uncertainty. Estimates are best for systems already planned and whose technologies are in hand. Estimates are worst for systems with untested, immature technologies.

Ballistic missile defense suffers from a larger degree of predictive uncertainty than the other strategic options. In some areas its technology is new. In other areas, where the technology is mature, budget constraints have precluded prototype construction. Not only defense suffers from such uncertainty, however. Schedules for MX-MPS could be delayed by social and political issues being raised at present. Technology problems associated with maintaining deception and yet permitting verification have yet to be fully resolved. Nevertheless, MX-MPS is

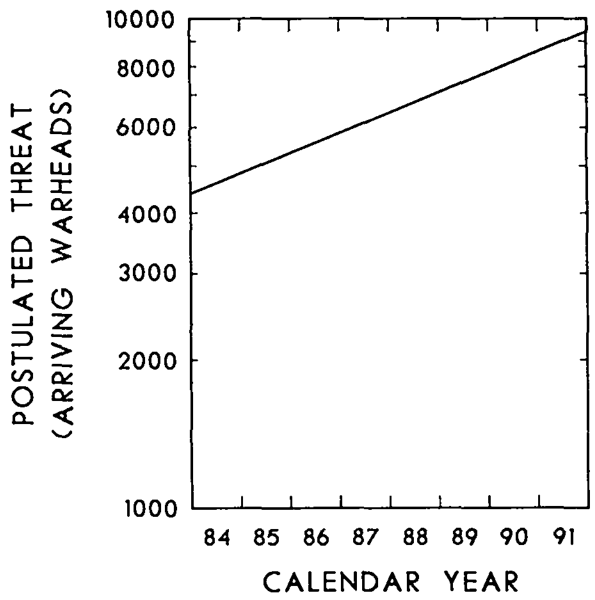

Fig. 5.
Postulated Soviet threat growth.

much farther along the chain of approvals than any of the ballistic missile defense programs.

Setting these qualifications aside, it is appropriate to estimate how soon the various technologies could be effective if they were driven by technical constraints alone. We used the technology schedules given in Table III. Actual availability could approach these schedules if technological preparation continues while the political debate about American implementation of the various strategic options goes on.

Using our model, we estimated how the American ICBM retaliatory deterrent could recover as the newly available strategic forces become available in the next decade and beyond. We assumed that installation of new offensive and defensive hardware occurs at the technology-limited schedules given in Table III. Until the new systems are emplaced in quantity, the existing silo-based Minuteman missiles represent a significant element in our deterrent posture. Consequently, we assumed that Minuteman missiles (with an average of 2.5 warheads each) are permitted to remain active in existing silos not required for MX missiles or interceptors. We assumed a Soviet attack given by the postulated threat projection of Fig. 5 and apportioned between MX missiles and Minuteman missiles so as to destroy the maximum possible number of United States warheads.

We also considered the effect a Soviet area-defensive system could have on recovery of our retaliatory deterrent. Currently, the Soviets have a limited ballistic missile defense system installed around Moscow (as reported by Secretary Brown, Ref. 1, p. 57), but its area-defense capabilities appear too limited to affect our retaliatory deterrent appreciably. However, if the Soviets were to install an *effective* area defense, as for example one with capabilities equivalent to those projected for American technologies, then recovery of our retaliatory deterrent could be delayed further. The additional delay would arise from the Soviet capacity to intercept United States warheads that survive the Soviet first strike and are then launched in retaliation. The assumption that the Soviets would add an area defense cannot be ignored if the United States were to install one. On the other hand, the Soviets may—overtly or clandestinely—install an effective area defense whether or not we do.

To quantify this effect, we computed retaliatory-force recovery for two cases, one without Soviet area defenses, and one in which we assumed Soviet area-defense capabilities and schedules similar to those available in the United States. Although arbitrary, this assumption either represents Soviet responsiveness if both sides install ballistic missile defense systems or it is a realistic schedule if we do not but they do.

For both cases, we computed expected surviving and deliverable United States retaliatory warheads, for each of the four strategic options considered, on a year-to-year basis. In the first option, MX and Minuteman missiles based nondeceptively in undefended silos, none would survive the postulated Soviet threat throughout the near-term period. For the remaining three options, we have plotted in Fig. 6 the estimates of American retaliatory warheads that could be delivered after a Soviet first strike. The horizontal line marks the assumed deterrence criterion of 1000 deliverable warheads. We take recovery of adequate ICBM-force survivability to occur for each option at the date when the deterrent reaches that line.

In the absence of Soviet defenses (Fig. 6a), MX missiles in MPS, without defense, would achieve the specified deterrent criterion by about 1991. That is later than the current fully operational MX-MPS date of 1989 because the currently planned MX-MPS deployment (200 MX, 4600 shelters) is not adequate for the threat we have assumed. Two years later, the modeled MX-MPS deployment would have grown to 340 MX, 7820 shelters, attaining the expectation of 1000-warhead survival.

With defense by a low-altitude terminal-defense system, our model predicts that MX-MPS would reach

TABLE III

TECHNOLOGY-LIMITED PROJECTIONS OF HARDWARE AVAILABILITY

Technology	Current Schedule IOC/FOC[a]	Technology Permits: Hardware Availability During	Technology Permits: Subsequent Construction Rate
MX missile	1986/1989	1985	70/yr
MPS	1986/1989	1985	1610/yr
Endoatmospheric defense[b]	1991/?	1985	1000/yr
Exoatmospheric defense	Not scheduled	1987	100/yr

[a] IOC = initial operational capability; FOC = fully operational capability.

[b] Low Altitude Defense system.

Note: MX and MPS schedules taken from Ref. 8. Ballistic missile defense projections assume an accelerated, aggressive, but not crash approach to technology preparation. Endoatmospheric defense schedules are based on the Congressional testimony by Major General Grayson D. Tate, Jr., Ballistic Missile Defense Program Manager, cited on page 8. Exoatmospheric defense schedules are our own projection and appear realistic to us, but they have been criticized as unduly optimistic by others.

deterrence by 1988. This would be accomplished with a deployment of 130 missiles, 3000 shelters, and far fewer than the scheduled inventory of interceptors.

Our model suggests that layered defense of MX missiles in silos could not be effective much before 1988-1989, due to the expected availability dates of exoatmospheric defense components. Operating by itself in defense of silos, the endoatmospheric component of layered defense could be enhanced to protect silos before the availability of the exoatmospheric technology (dashed curve of Fig. 6a). This must be considered at best an interim solution because terminal defense by itself is easily overwhelmed as the threat grows.

If the Soviets were to add area defenses, the date when the American ICBM force could deliver the desired retaliatory force on Soviet targets would be further delayed by 3 to 5 years (or more) as shown in Fig. 6b. We again project deterrent recovery to be most delayed with undefended MX-MPS and to occur soonest with defended MX-MPS. But even in this best case, deterrent recovery is delayed until about 1990. The contrast between Figs. 6a and 6b quantifies concerns about Soviet ballistic missile defense breakouts, particularly if the United States cannot respond promptly with defense systems of its own.

According to our model, low-altitude defense of MX-MPS, or layered defense of MX missiles in silos, or both, offers the earliest recovery of ICBM survivability in the near term. Obviously, we have not accounted for other elements of our triad. Thus, in the near term, degradation of our deterrent capacity should not be as great as that suggested here.

b. Long term. To counter possible continued Soviet threat growth, continued growth of American strategic inventories is also necessary. The extent of that growth relative to Soviet investments in strategic inventories, in a sense, influences Soviet incentives to proliferate weapons systems. If our costs are much higher than theirs, continued Soviet proliferation may exceed our will or capability to respond. This might be a powerful incentive for the Soviets to continue proliferating. If, on the other hand, our costs can be much smaller than theirs, an equally powerful incentive may exist for them to limit proliferation.

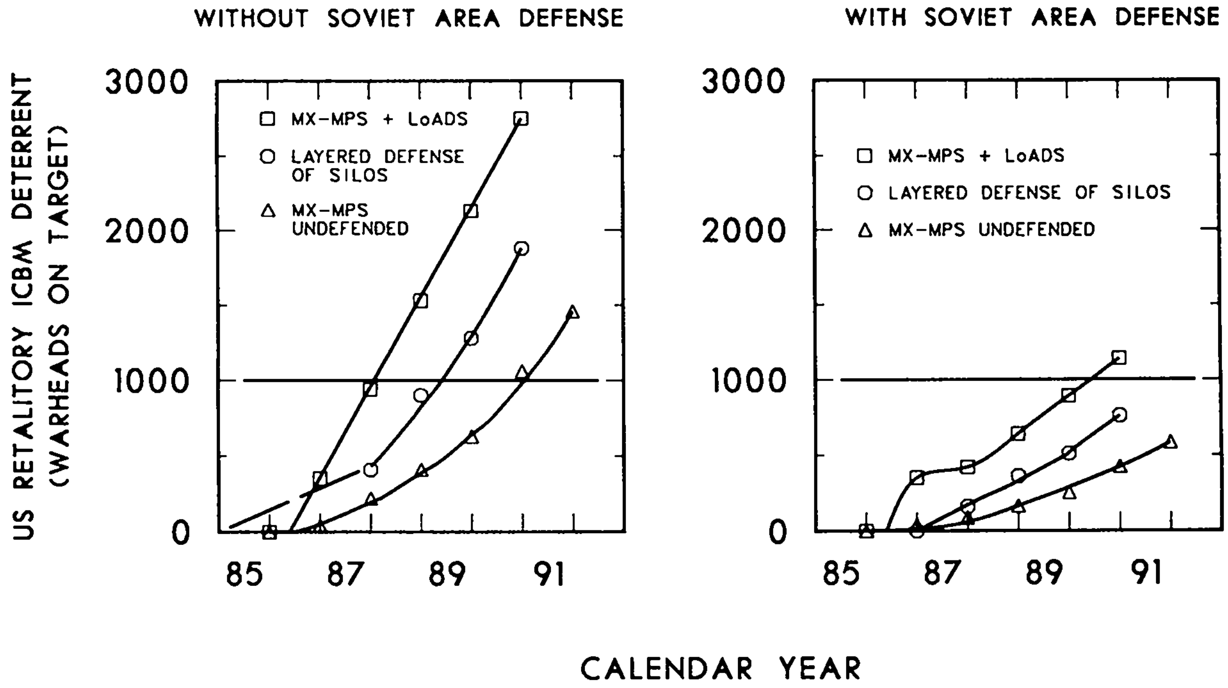

Fig. 6.

Modeled recovery of United States ICBM retaliatory deterrent if various American strategic forces are emplaced according to technology-limited schedules (Table III): (a) delays in ICBM recovery if the Soviets install no new area defenses, and (b) further delays incurred if the Soviets install a new area-defense system with technology and schedules similar to those available in the United States.

To evaluate this situation, we used our model to estimate American inventories needed to counteract threats much larger than those achieved in the short-term projection. Our short-term threat projection ended in 1992 with arriving threats of fewer than 10 000 warheads. For the long term we considered threats of up to 40 000 warheads (that is, the payloads of 4000 missiles with 10 warheads each). We then added an approximate cost model for comparisons among the strategic options.

Inventories. Estimated American inventories required to establish assured-destruction deterrence against potential long-term threats were computed with our model. We do not present results for missiles based nondeceptively in silos because the estimated inventories are too large to be considered achievable. In Fig. 7, we plot inventories for the other three options, and contrast them with Soviet missile inventories needed to launch the threat. We also show (as dots) inventories for the cooperative-symmetric case given earlier.

Figure 7a shows inventories for undefended MX-MPS. In this case, the United States would need to install roughly one-third as many missiles as the Soviets, but would have to emplace them among a huge number of shelters. For example, against a threat of 2000 Soviet missiles, we would need about 700 missiles and about 19 000 shelters.

With terminal defense installed with MX-MPS (Fig. 7b), estimated inventories would be significantly reduced; for the same example as above, the United States could maintain deterrence with 300-350 missiles, 8000-9000 shelters, and approximately 1500 terminal-defense interceptors.

With layered defense of MX missiles based deceptively in silos, the estimated inventories depend on whether the Soviets also install an area defense. If they do not (Fig. 7c), the United States can maintain its ICBM deterrent with the minimum inventories of any of the options considered. For the 2000-missile threat, we would need 115 missiles, 660 exoatmospheric interceptors, and 775 silos and endoatmospheric interceptors.

If the Soviets choose to install an area defense, the United States layered defense inventories needed to maintain our ICBM deterrent (Fig. 7d) would be larger than without such Soviet defenses. To assess American inventory growth, we assumed (as before) that the Soviet defense inventories mirror our own. For the 2000-missile

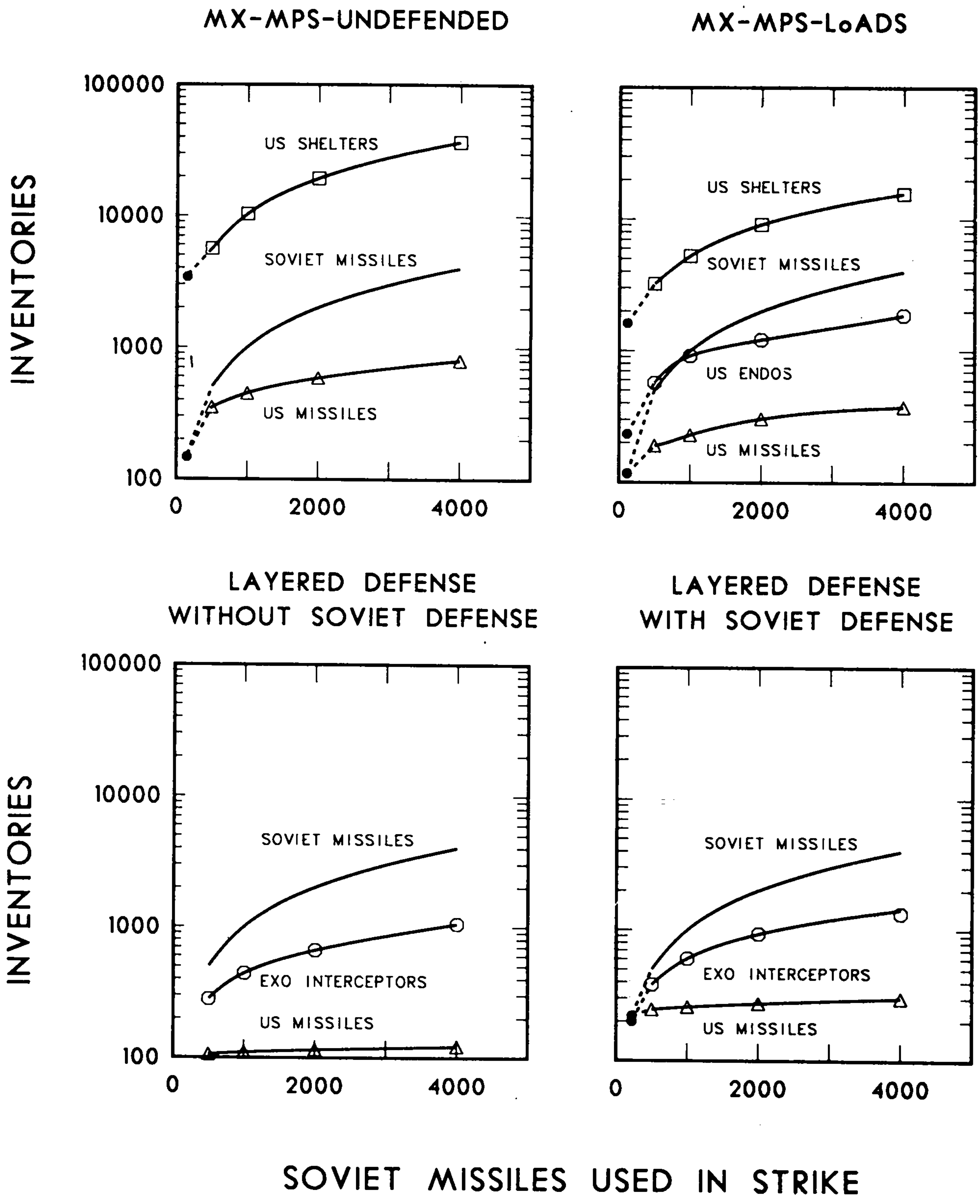

Fig. 7.
Inventories needed to achieve deterrence criterion (W = 1000) against possible long-term Soviet threats. (a) MX-MPS undefended; (b) MX-MPS with low-altitude defense; and layered defense of MX based deceptively in silos, without equivalent Soviet defenses (c), and with them (d). Dots show inventories given earlier for the cooperative-symmetric solutions.

threat, the American inventories would be: 270 missiles, 930 exoatmospheric interceptors, and 1200 silos and endoatmospheric interceptors. The Soviet force would also have 930 exoatmospheric interceptors, and would specify 2930 silos and endoatmospheric interceptors. This option also has the stabilizing feature that the best American response to increased Soviet threat growth is to add dominantly exoatmospheric interceptors, with but a few additional missiles.

Costs. The economic comparisons among strategic options were based on two functions: the initial installation costs, and the way costs would grow as the threat grows. A system whose initial cost exceeds that of the threat, and whose cost continues to grow faster than that of the threat, is less effective by this definition than a system that consistently costs much less than the threat it faces.

Costs were based on dollar estimates of development and inventory expenses of the various components. The same estimates were used for equivalent Soviet and United States systems—for example, Soviet missiles and MX missiles—as a basis for comparing Soviet and American costs. The cost data from which estimates were derived are given in Table IV.

There are additional costs associated with nuclear warheads that cannot be quoted in an unclassified format. Including warhead costs would make all responses appear more cost-effective relative to the threat, and would favor the nonnuclear ballistic missile defense responses relative to the other responses.

Cost curves are presented for the modeled strategic options, giving the emplacement costs as a function of threat, in Fig. 8. All three American options we considered cost about the same at the low end of the Soviet threat spectrum. However, the costs of the three options become very different as the threat grows.

MX-MPS, undefended, consistently costs twice as much as the Soviet threat because of the large number of shelters needed. This cost behavior suggests that expanded Soviet arms build-ups might eventually cause the United States to reach limits of national resolve or capacity to respond. This certainly violates the spirit of any arms-control climate ever proposed. By adding terminal defenses to MX-MPS, United States costs decrease to approximate Soviet costs; this offers neither side marginal incentive for or against arms limitations.

Layered defense of MX missiles based deceptively in silos appears to offer stabilizing economic advantages that tend to deny incentives for continued Soviet arms build-up. The lower curves of Fig. 8b represent cost vs threat estimates if the Soviets do not install an area defense but the United States does. Here, our estimated costs exceed the Soviets' at the low end of the threat spectrum; costs are equal at moderate threats; and American costs remain significantly below Soviet costs thereafter. The economics of introducing layered defense

TABLE IV

ASSUMED COSTS AND SCALING FACTORS OF OFFENSIVE AND DEFENSIVE SYSTEMS AND COMPONENTS

Component	Symbol	Development ($M)	Quantity Cost(a) ($M)
Missile	M	8000(b)	$60\,(M+X)^{.78}$(b)(c)
Exo interceptor	X	7000	
Endo interceptor	N	5000	$16\,N^{.78}$
Silo	H	0	$6\,H$(d)
Shelter (MX-MPS)	H	5000(b)	$3\,H$(b)

(a)The scaling function $N^{.78}$ for the cost of N units, as applied to missile and interceptor hardware, was suggested by McDonnell Douglas Aircraft Corporation.

(b)Based on MX development costs obtained from Congressional Budget Office Budget Issue Paper, Ref. 8.

(c)Figuring the exoatmospheric interceptor to use missile hardware.

(d)Silo cost assumed to be twice that of shelter cost due to added complexity.

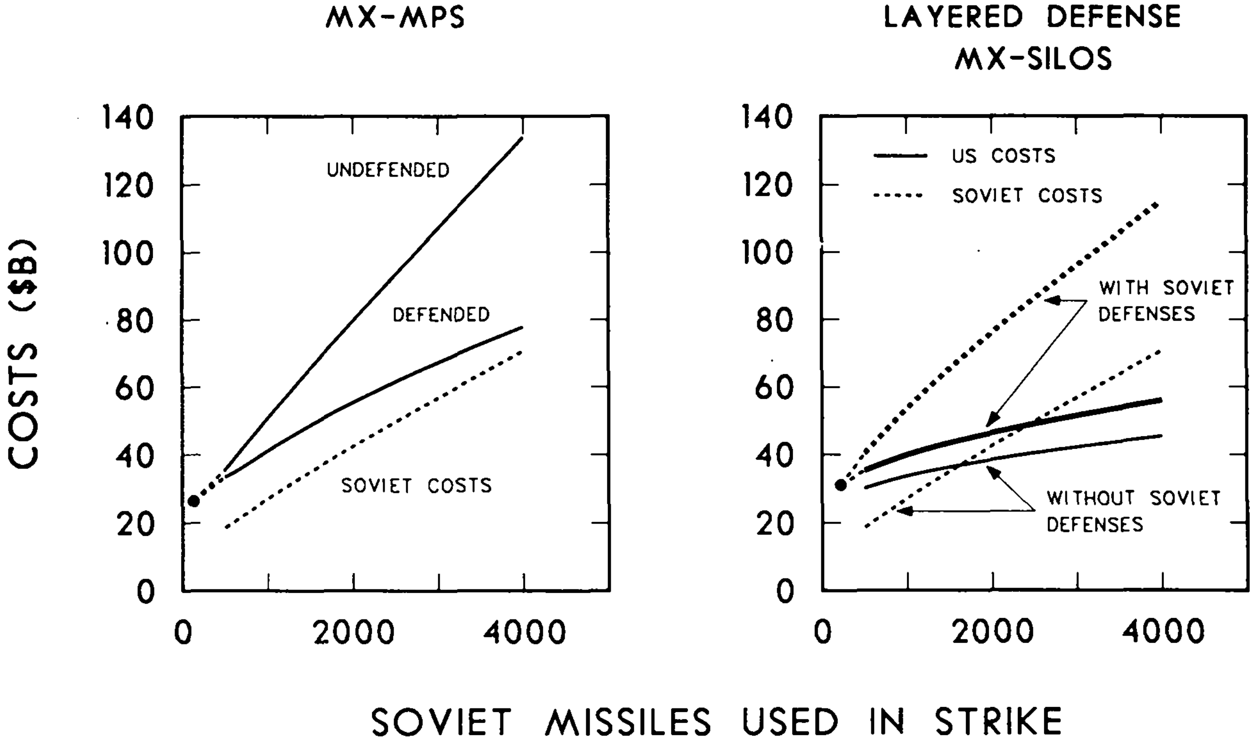

Fig. 8.
Estimated costs of strategic options configured to ensure deterrence (W = 1000) against long-term Soviet threats. Dots show costs associated with symmetric solutions.

using deceptive basing of MX missiles in silos thus inhibits Soviet expansion of its ICBM force by placing the Soviet forces at a substantial cost disadvantage.

However, what if the Soviets were to implement a comparable area-defense concept, one that we assume would force them to incur development and inventory costs mirroring our own? The results are shown as the upper curves of Fig. 8b. *In this case, an especially favorable arms control setting would ensue.* As the Soviet threat level increases, American costs to maintain its deterrent posture would increase as well; but the incremental costs needed to offset Soviet investments and reestablish the strategic balance would strongly favor the United States. In this setting, Soviet arms limitations would be driven strongly by the economics; a treaty might well be superfluous.

B. Additional Considerations: Countervailing Strategy

By concentrating on ICBM survival and assured-destruction deterrence, our analysis has so far ignored much of the real-world complexity of deterrence. As Secretary Brown noted in his 1981 Posture Statement:[1]

> For deterrence to operate successfully, our potential adversaries must be convinced that we possess sufficient military force so that if they were to start a course of action which could lead to war, they would be frustrated in their effort to achieve their objective or suffer so much damage that they would gain nothing by their action. Put differently, we must have forces and plans for the use of our strategic nuclear forces such that in considering aggression against our interests, our adversary would recognize that no plausible outcome would represent a success—or any rational definition of success. The prospect of such a failure would then deter an adversary's attack on the United States or our vital interests. The preparation of forces and plans to create such a prospect has come to be referred to as a "countervailing strategy."
>
> To achieve this objective we need, first of all, a survivable and enduring retaliatory capability to devastate the industry and cities of the Soviet

> Union. We must have such a capability even if the Soviets were to attack first, without warning, in a manner optimized to reduce that capability as much as possible. What has come to be known as assured destruction is the bedrock of nuclear deterrence, and we will retain such a capacity in the future. It is not, however, sufficient in itself as a strategic doctrine. Under many circumstances large-scale countervalue attacks may not be appropriate—nor will their prospect always be sufficiently credible—to deter the full range of actions we seek to prevent.

Secretary Brown went on to discuss the role of damage limitation in the countervailing strategy:[1]

> Our goal is to make a Soviet victory as improbable (seen through Soviet eyes) as we can make it, over the broadest plausible range of scenarios. We must therefore have plans for attacks which pose a more credible threat than an all-out attack on Soviet industry and cities . . . We could . . . attack, in a selective and measured way, a range of military, industrial, and political control targets, while retaining an assured destruction capacity in reserve.

But Secretary Brown did not emphasize defense in his strategy. The Department of Defense was constrained by concerns about instabilities associated with ballistic missile defense (see quote cited in Sec. I) and by the Anti-Ballistic-Missile Treaty of 1972. Secretary Brown noted (Ref. 1, p. 99):

> Our current programs of active defense reflect these constraints and the emphasis we place on offensive forces for deterrence.

If the concerns felt by the Department of Defense could be alleviated, what then would be some of the potential roles for ballistic missile defense in support of the countervailing strategy?

We have already shown how ballistic missile defenses might economically ensure the survival of enough land-based missiles to achieve assured-destruction deterrence. More of our land-based missiles would be needed for damage-limiting roles in support of the countervailing strategy; the optimal way to ensure their survival would very likely also include missile defenses. This remains to be confirmed.

Missile and area defenses structured to limit damage from a massive nuclear attack would probably be even more highly capable against limited nuclear attacks. Small attacking forces might be expected in a number of scenarios, for example,

- attack by a superpower in the early nuclear phases of the escalation ladder;
- attack by a superpower on selected, critical components of the national command authority and force structure;
- attack by an enemy with limited nuclear resources, including attack by a third party in an attempt to initiate a superpower exchange ("catalytic launch"); and
- accidental launch.

Against such limited attacks, interceptor inventories would be so large compared to the threat that they could be flown redundantly to reduce leakage. Against very limited attacks there might be a high probability of totally successful defense. The availability of a nonnuclear defensive response thus adds elements of crisis stability not available without defensive systems.

However, even against massive attacks, area-defense systems would provide additional means to limit damage to targets of a Soviet attack. Warheads attacking targets of value could be intercepted directly. Such defense would not be perfect, but it would offer much improved chances for military, industrial, and urban survival. A significant fraction of the defended targets would be available to deny Soviet objectives in any subsequent conflict. This capability of ballistic missile defense seems to meet in an optimal way a criterion specified for the countervailing strategy by Secretary Brown:[1]

> . . . leave open the possibility of ending an exchange before the worst escalation and damage had occurred, even if avoiding escalation to mutual destruction is not likely.

Such a prospect seems, at best, much less likely to be possible for strategic systems without ballistic missile defenses.

Enhanced capability against limited attack, seen as an asset by the United States, may be perceived differently by our allies. They have limited nuclear missile arsenals whose effectiveness might be seriously degraded in the presence of an extensive Soviet area defense. This concern is one of many such political/strategic questions regarding the assets and liabilities of ballistic missile defenses in our strategic posture. They must all be considered in the coming debate on ballistic missile defense. Our quantitative results, and this brief qualitative discussion of some elements of damage limitation and crisis stability potentially available through active defense, suggest that such analysis not be delayed.

IV. CONCLUSIONS

Strategic arms control is a national priority. Recent Soviet and third-world aggression has underscored the requirement to limit United States strategic investments so as to free effort and funds for needed conventional forces.

Paradoxically, the goal of significant arms reduction has appeared inconsistent with the deterrence objectives on which our military planning is based. Although often termed "unthinkable," we must face the possibility that deterrence by threat of assured retaliation may fail. Some means of damage limitation would then be America's only recourse: preparation of such means is also seen by many to strongly enhance deterrence.

Our purpose has been to investigate alternative technological and force-structure opportunities that could simultaneously achieve mutual assured destruction and contribute to damage limitation. We feel that ballistic missile defense, when deceptively based along with missiles in ICBM silos, may offer the opportunity for

- reducing armaments substantially;
- filling the gap between competing security and arms-control goals;
- thwarting limited ICBM attacks including accidental or catalytic launches against missile fields or urban targets;
- supplementing an inadequate theater nuclear force by maintaining a strategic force structure and balance, which would be relatively insensitive to the limited use of our strategic forces against theater targets; and
- offering additional crisis management and stabilization tools to the United States and the Soviet Union.

We emphasize the preliminary nature of our results, but they do suggest profound effects that should not be ignored. Credibility of the concept—even at the expense of reopening the anti-ballistic missile controversy—has been demonstrated. But much more analysis and very involved simulations are mandatory if the present results are to withstand scrutiny.

Specifically, the models provide these suggestions.

- Layered defense of ICBMs based deceptively in silos may provide an exceptional opportunity for strategic arms reduction.
- The resultant mix between ballistic missile defense and offensive weapons is stabilizing in that the effects of Soviet cheating, were a new SALT agreement in force, would be comparatively small.
- Arms-control objectives are satisfied; the system also provides a limited capacity to reduce damage to urban/industrial targets. Exoatmospheric interceptors can be used to defend both value and counterforce targets without denying the second striker his ability to retaliate.
- Similar economic and stability advantages are exhibited in non-arms-control settings.
- In contrast with other proposed measures for reducing ICBM vulnerability, ballistic missile defense does not depend on maintaining deception in basing.
- Crisis stabilizing measures are introduced by allowing for nonnuclear interceptor launch under real or apparent attack.
- Environmental problems posed by alternative MX schemes are avoided.
- Availability of exoatmospheric technology is the critical path constraining the implementation of such a system.
- In the search for near-term solutions, survival of the United States ICBM force could be significantly enhanced, with reduced environmental impact, if low-altitude terminal defense were installed concurrently with MX-MPS.

This preliminary analysis has given many indications of the potential value of a hybrid ballistic missile defense/deceptive MX-basing system. The subject clearly warrants further analysis. We will need detailed models, including large-scale computer simulations of targeting, time-phased attacks, defense-suppression attacks, and game theory.

Our analysis was based on assured-destruction deterrence, modeled by a 1000-warhead retaliatory force. Deterrence by this definition can be achieved even if there are large departures from missile parity, as evidenced by Soviet/United States inventory differences for layered defense of silo-based MX. However, our capability to achieve elements of war-fighting deterrence would be degraded if our forces were much smaller than the Soviets'. The actual American strategic forces needed against very large Soviet threats would be structured by striking a compromise between the large forces needed to achieve war-fighting goals and the smaller forces sufficient for assured-destruction deterrence. Ballistic missile defense appears to give the greatest latitude for such a compromise.

Arms control will continue to be a basic national goal, now emphasized by the need to modernize both strategic and conventional forces with limited funds. The prospect of using exoatmospheric defense to achieve this goal will surprise many arms-control advocates who will need time to rethink the ballistic missile defense issue. The extensive analyses needed to corroborate and extend the present results will take many months. The 1982 review of the present Anti-Ballistic-Missile Treaty is imminent. Prompt, vigorous action on these issues is needed.

Even if the analytic results hold, and even if our layered defense concept proves politically viable, we may find ourselves without the needed technology to implement the concept. It would seem prudent, therefore, to engage in accelerated research and prototype development of ballistic missile defense systems so that technology limitations do not constrain future decisions.

ACKNOWLEDGMENTS

A Los Alamos National Laboratory team assembled by E. O. Chapin was responsible for the brief assessment of ballistic missile defense technology upon which this analysis is based. R. G. Shreffler was the source of the idea that MX-missile/exoatmospheric interceptor similarities could offer advantages for deceptive basing. We thank D. R. Westervelt, T. W. Dowler, and S. A. Maaranen for critical review, Rongriego for preparing the figures, and J. W. McDonald and H. Frauenglass for editorial comments. We thank K. K. Fenner for processing the multiple drafts of this document.

REFERENCES

1. Secretary of Defense Harold Brown, 1981 Posture Statement, Congressional Record, Committee on Appropriations, United States Senate, March 12, 1980, pp. 49-51.

2. Some analysts report this action is already under way. See, for example, J. K. Davis, R. L. Pfaltzgraff, Jr., U. Ra'anan, M. J. Deane, and J. M. Collins, "The Soviet Union and Ballistic Missile Defense," Institute for Foreign Policy Analysis, Inc., Special Report (March 1980), pp. 6-7.

3. "The MX Missile Debate," Bill Moyers' Journal broadcast by the Public Broadcasting System, April 24, 1980.

4. Major General Grayson D. Tate, Jr., Ballistic Missile Defense Program Manager, "Status of the Ballistic Missile Defense Research and Development Program," (Prepared Statement) Congressional Record, Committee on Armed Services, United States Senate, testimony of March 12, 1980, p. 2869.

5. W. Schneider, Jr., D. G. Brennan, W. A. Davis, Jr., and H. Ruhle, "U. S. Strategic Nuclear Policy and Ballistic Missile Defense: The 1980s and Beyond," Institute for Foreign Policy Analysis, Inc., Special Report (April 1980), p. 42.

6. Major General Grayson D. Tate, Jr., testimony in response to questions by Senator John W. Warner, Ref. 4, p. 2923.

7. R. H. Kupperman and H. A. Smith, "Deterrent Stability and Strategic Warfare," in *Mathematical Systems in International Relations Research,* J. Gillespie and D. Zuines, Eds. (Praeger Publishers, Inc., New York, 1977).

8. "The MX Missile and Multiple Protective Structure Basing: Long-Term Budgetary Implications," Congressional Budget Office, Budget Issue Paper for Fiscal Year 1980 (June 1979).

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