Chapter 8

Feasibility

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HYPOTHETICAL BMD SYSTEM

Introduction

As a way of illustrating the scope and the nature of the technical and operational feasibility issues, this chapter hypothesizes an imaginary system architecture. Since an official proposed architecture does not yet exist, the following system is presented as a structure which is at least plausible enough for illustrative purposes. We do not suggest or predict that all or even any of its parts can or will actually be proposed or built.

The example described is not intended to be definitive or exhaustive. We suggest it to convey a feeling for the nature of the problems to be resolved in planning a workable BMD.[1] Several levels of effectiveness are hypothesized. Consonant with conservative strategic planning, we assume, in outlining the system, that it must deal with Soviet force modernization and Soviet countermeasures (a "responsive threat' '). It is conceivable that future levels of the Soviet offensive threat, rather than increasing, could decrease as a result of negotiation, in which case the hypothesized architecture would be more effective than otherwise.

The hypothetical BMD architecture is treated as a nested set. That is, the first system, consisting of one layer of terminal defense, is the simplest and most readily achievable; the second incorporates and extends the first by adding another layer; the third incorporates and extends the second, and so on, through the fifth system. The reader is also referred to the discussion of a layered defense in chapter 7. It is imaginable that an entire architecture could be deployed in this order. The first system could be realized soonest; the others might be added in succession, if and when the required technology is developed. There is a rough correspondence between the elements of this set of systems and the four levels of defense capability described in chapter 5. The first system might have the capability of chapter 5's Level 1. The second or, more likely, the third system might have roughly the capability of Level 2; the fourth system is meant to have the capability of Level 3, and the fifth system is meant to have the capability of Level 4.

The first layer of defense hypothesized is a terminal defense for hardened sites. The defense is not structured to defend large areas or soft targets, but rather has as its purpose the defense of a significant fraction of U.S. missile silos and hardened command and control sites. The purpose would be to provide the United States with the assured survival of a significant fraction of its land-based retaliatory force in the face of a Soviet ICBM attack, and thus bolster the other legs of our "triad" in deterring a Soviet first strike. This layer might not be very effective against a responsive threat without the presence of other layers, and, by itself, would not follow the path of current Administration policy, which is to develop methods of defending populations, not weapons.

The second level adds a layer with some midcourse capability to the terminal defense. This begins to provide some area defense and is also intended to assure the survival of a larger fraction of the U.S. retaliatory force. Any reentry vehicles (RVs) destroyed or decoys discriminated during the midcourse phase will correspondingly reduce the stress on the terminal defenses. A structured attack may be disrupted by this capability, and the overall number of targets presented to the terminal layer might be significantly reduced.

[1] cf. J.C. Fletcher, "Technologies for Strategic Defense, " issues *in Science and Technology, vol. 1,* No. *1,* fall 1984, for a similar exercise.

The third level adds a significant midcourse capability. The fourth level incorporates boost-phase and post-boost-phase layers, intended to give an effective layered defense with low overall leakage.

The fifth level illustrates the magnitude of the requirements of a near-perfect ballistic missile defense. It improves capabilities for all layers, and augments terminal defenses to try to make the total leakage extremely small, having as its goal the neutralization of all incoming warheads. This level of defense would logically require that all other practical means of nuclear weapons delivery could be similarly neutralized. Otherwise, the aggressor would use those alternate delivery strategies and the advantage of this level over the fourth one would vanish.

Each section of this chapter lists a series of technical requirements to be met in order for the given system to be effective. Some of these requirements could be met today or in the near future. For example, endoatmospheric nuclear interceptors have been developed for years and would likely be able to reach significant performance levels (defending hardened targets) within a short period of time. Appropriate communication systems with survivable links are likewise highly developed and should be available very soon.

The technologies for satisfying most requirements, however, are not nearly as mature as in the above examples. One class of requirements consists of those which appear feasible, but need to be scaled up in magnitude, capability, or both. These are generally considered to be midterm prospects. A hardened system of passive sensors, adequate for some target discrimination and able to survive in a nuclear environment, could probably be developed with known technology. However, such a system would probably require many years of development and testing. Similarly, homing kinetic-energy weapons, which are relatively inexpensive and fast (5 to 8 km/sec), can almost certainly be developed, but would also require a number of years of development before effective deployment became possible.

Another class of requirements includes those technologies which still need substantial research effort in order to demonstrate feasibility. Among these would be space-based particle beams of sufficient brightness, pointing capability and kill assessment capability; lasers powerful enough for boost-phase kill; and space-based mirrors of many meters in diameter, which could aim laser beams with great accuracy in less than a second. In general, as the layers in the hypothetical system become more numerous and more complex, the corresponding requirements tend to need longer term development. For some requirements, there is general agreement on whether they could be available in the near term, in the midterm, or are still to be demonstrated, but for others, experts may disagree on the prospects for success and on the time needed for development.

There is another type of requirement which is more difficult to assess, namely, the capability of a subsystem to respond effectively to an adversary's countermeasures. The survivability of a system in a nuclear environment or under direct attack is especially difficult to gauge at this stage, particularly in the absence of a well-defined architecture and of a well-defined threat.

In addition to the development of the appropriate technology, other requirements to be met include questions of reliability and maintenance of the system's components. Discussion of these matters can be found in chapter 7, pp. 169-170 and p. 190.

Terminal Defense

This layer of defense would have to intercept incoming RVs in the last 30 to 60 seconds of flight as they reenter the atmosphere. Detection and tracking of targets in the earlier phases of their trajectories is required, but little discrimination would be possible before atmospheric reentry.

The elements of the hypothetical terminal defense system would consist of:

Table 8.1.—Hypothetical Multi-Layered BMD System

System level	System elements	Description	Comments
Level 1 Terminal Defense (defense of hardened sites using endoatmospherlc rockets to Intercept reentry vehicles (RVs) as they approach their targets)	Early warning satellites ground-based radar airborne optical sensors, ground-based battle management computers fast endoatmospheric Interceptors	Warning of launch provided by high-orbit satellites. RVs detected and tracked in region of ground targets by ground radar and airborne sensors ground computers assign Interceptors to RVs kill assessment[a] permits reassignment of defense interceptors atmospheric interception used, air effects used to discriminate between RVs and decoys	Homing either infrared (IR) or radar, interceptors should be relatively inexpensive, since many needed, may be nuclear or nonnuclear
Level 2 Light Midcourse and Terminal Defense (additional layer added with some Interceptlon capability in midcourse and some ability 10 discriminate RVs from decoys in space to reduce burden on terminal layer, some area defense)	Level 1 plus exoatmospheric homing Interceptors range hundreds of km, pop-up[b] IR sensors (possibly satellite-based Instead), self-defense capability for space assets	As in level 1 for terminal defenses longer range Interceptors added which can intercept some RVs above atmosphere, providing some area defense. this requires some discrimination capability, furnished by passive IR pop-up sensors, launched towards cloud of decoys and attacking RVs, the new layer reduces the burden on the terminal layer	Passive IR sensors used for crude discrimination and possibly kill assessment data base of Soviet RV and decoy signatures needed, sensors must be able to function in a hostile nuclear environment
Level 3 Heavier Midcourse Layer (effective midcourse layer added giving realistic two-layer system, with each layer highly effective)	Level 2 plus ultraviolet laser radar (ladar) Imaging on satellites, highly capable space-based battle management system space-based kinetic energy weapons effective self-defense in space, significant space-based power	Satellite-based ultraviolet laser radar (ladar) used to image objects, discrimination provided by comparing images with data base of Soviet RV and decoy characteristics, RVs attacked by In-orbit kinetic-energy weapons, which also defend all space-based components of system, this level has fully developed terminal and midcourse layers, but no boost or post-boost phase defense	Ladar Imaging rapid with resolution good to 1 meter or less for adequate discrimination and birth-to-death tracking of RVs, kinetic weapon homing capability good to less than a meter
Level 4 Boost-Phase Plus Previous Layers (boost-phase Intercept added to kill boosters or post-boost vehicles before RVs and decoys dispersed)	Level 3 plus ground-based high Intensity lasers (either excimer or free electron space-based mirrors for relay and aim: high resolution tracking and imaging in boost phase, self-defense for all phases	This level adds a boost- and post-boost-phase layer, consisting of very bright ground-based laser beams directed to their targets by orbiting mirrors, sensing by Infrared sensors, Imaging by ultra-violet ladar, battle management to handle all layers doing discrimination, kill assessment, and target assignments and reassignments Boost- and post-boost-phase layers may be combined, since post-boost phase could be shortened to 10 seconds or so	Extremely capable battle management system needed, kill assessment required for boost phase as well as midcourse
Level 5 Extremely Effective Layer (Level 4 with better capability. meant to permit only minimal penetration to targets by enemy RVs)	Level 4 plus more terminal and exoatmospheric interceptors, electromagnetic launchers for midcourse and boost-phase intercepts large capacity space-based power, all systems extremely reliable	More Interceptors are added in terminal and midcourse layers. electromagnetic launchers used for boost post-boost and midcourse Intercepts, high capacity space power needed all systems including battle management must be extremely reliable	Essentially same as Level 4, but more of it and higher reliability newer technologies used as they become available

[a]Kill assessment refers to the process of determining whether a struck target has been effectively disabled.
[b]Pop-up components are ground-based assets which are launched into space for action upon warning of an enemy attack

SOURCE: Office of Technology Assessment.

- Ground-based radars, for sensing RVs and decoys as they approach.
- Several thousand fast acceleration interceptor rockets with infrared (IR) or radar homing capability; nonnuclear kill capability would be preferable; in case nonnuclear kill could be defeated by offensive countermeasures, or were too expensive, small nuclear warheads would be substituted.
- Early warning satellites to give notice of attack launch.
- Use of air-based infrared sensors to track incoming RVs and decoys at large distances.
- A battle management system, consisting of computers, sensors, and communication links, which would take data from tens or hundreds of sensors aboard satellites and on the ground, and register the reentry of the attacking objects in the upper atmosphere; it would calculate track files for thousands of such objects, and use atmospheric effects (e.g., deceleration) to discriminate between RVs and decoys in the upper atmosphere. The system would assign particular interceptors to targets identified as RVs, would determine whether or not the RVs were killed, and would revise target assignments accordingly. It would also present real-time information to command authorities on the progress of the battle.

Several of these elements are now available or could be shortly. Geosynchronous early warning satellites have been in dependable use for many years. Ground-based radar technology, capable of multi-object discrimination using atmospheric effects, now exists, for intercepts taking place at sufficiently low altitudes. In the face of an attack using nuclear precursor explosions, however, such radar could be blacked out or otherwise put out of operation in the early stages of the assault.

The development of aircraft-based infrared sensors could provide a more survivable and flexible backup for the ground-based radar. Another possibility, one within current capabilities, involves the use of hardened, disposable radars. Normally buried for protection, a few would expose themselves to attack in order to perform their tracking tasks. Those destroyed by early nuclear explosions would be replaced by others, which would rise from bunkers following the destruction of their siblings. These radars would have to be rather inexpensive, since many of them would be needed. Survivability would be provided by their numbers and distribution as well as their protective shelters.

Fast interceptors with nuclear warheads have already been developed. In order to minimize control and command problems when nuclear weapons are used, to reduce collateral damage to one's own hardware and to reduce the chances of blinding or dazzling one's own sensors, it would be preferable to use homing interceptors with nonnuclear kill devices.

To defend an area 100 km in radius, rockets would have to attain the speed of several km/ec in a matter of 10 seconds or so. This should be achievable with current technology. One could imagine, for the sake of argument, a defense of 10 such areas, in order to assure some level of retaliation by U.S. ICBMs in response to a Soviet first strike. To defend against an attack of 5,000 RVs (about half of today's Soviet strategic inventory), with the aim of assuring the temporary survival of a significant fraction of U.S. silos, a preferential defense could be used. If one were to suppose that Soviet RVs were aimed, in a random distribution, at 1,000 U.S. silos, one would anticipate 5 RVs per silo. The defense then could pick a fraction of silos to defend and assign, say, three interceptors to each RV aimed at those silos, while allowing other RVs to penetrate. The number of interceptors to be used would then depend on how many silos would be preferentially defended. The interceptors could be mobile, making it more difficult for the offense to target them. Radar units could also be mobile.

A terminal defense could be used in conjunction with multiple protective shelter basing (MPS), as was once proposed for MX missile siting.[2] Since an extensive national debate at that time resulted in the rejection of such a plan, MPS is not considered as an option in this hypothetical architecture. However, its application, together with a terminal defense, would provide great leverage if one were to defend missiles preferentially. As described above, in the case of preferential defense, some sites are defended and others are not, while the information on which sites are defended is concealed from the adversary. In this manner, a small number of interceptors could protect a smaller number of missiles from a much larger attack.

The following technical requirements need to be met for such a terminal defense system to operate successfully:

- Effective homing devices; if infrared (IR), they must avoid being swamped by the strong infrared signal emanating from the nose of the interceptor, which is heated by its rapid passage through the atmosphere; if IR or if radar they must be able to function in an environment where many nuclear explosions may be occurring.
- A communication system with survivable links between its component units, able to operate in an extremely hostile nuclear environment.
- A battle management system able to survive and function while under nuclear attack.
- Battle management sensors and computer which can discriminate accurately between decoys and RVs at an altitude high enough so that interceptors can be launched in time to reach the RVs.
- Battle management systems able to assign interceptors to targets within fractions of a second per target.
- If ground-based radars are not sufficiently effective, air-based infrared sensors able to operate successfully in a hostile nuclear environment; important in this context is the problem of “redout”: “scintillation,’ or bright electromagnetic radiation, caused by a nuclear explosion in the upper atmosphere, which masks infrared signals from targets and could dazzle or neutralize sensors.
- The development of a relatively inexpensive homing interceptor with fast acceleration; a nuclear-tipped warhead could be necessary as a backup if a reasonably inexpensive nonnuclear kill device could not be developed.

in reacting to a defensive system which uses only terminal defenses, the Soviets could apply countermeasures which are well within the realm of today’s technology, They could simply proliferate RVs with relative ease. The marginal cost-exchange ratio between offensive RV and defensive interceptor might or might not favor the interceptor. It is not obvious which side would win the economic battle on this level, or whether a cost exchange analysis alone would be the determining factor in this competition.

Another countermeasure would be the development and deployment of more sophisticated penetration aids, which could fool the defensive battle management system into thinking that many more RVs are attacking than actually is the case. A variant approach would be to try to make the RV appear to be a decoy. The objective would be to saturate the defenses, and to reduce the time available for the defense to commit and intercept. The lower the intercept altitude, the harder it would be to simulate an RV’s behavior without making a decoy as heavy as an actual RV.

Yet another Soviet option would be a structured attack, where the incoming RVs, possibly fused to detonate when attacked (salvage-fused), would come in waves. The first wave would detonate at high altitudes, blinding the defenses long enough to permit subsequent waves to penetrate closer to the target. Following waves would repeat this process and, eventually, in this “laddering down, the tar-

[2]For an extensive review of MPS in the MX context. cf. U.S. Congress, Office of Technology Assessment, “MX Missile Basing, ” OTA-ISC-140 (Washington, DC: U.S. Government Printing Office, September 198 1).

gets would be reached and destroyed. The penalty of this technique to the offense is that several RVs would need to be expended per target. Its resources are correspondingly drained. The defense can extract a high price for each defended target, thus perhaps saving nondefended targets through attrition of the offense's RVs. If the Soviets were to pursue this option, they could be expected, therefore, to make a serious effort to increase greatly the number of warheads.

A further countermeasure would be for the offense to use maneuverable reentry vehicles. This would greatly stress homing capabilities for nonnuclear kill vehicles. However, the defense could then counter with nuclear warheads, which would reduce the need for high precision homing.

In general, the technology needed for the terminal defense system is either available or could be available within the short term. However, the overall operation of such a system in an environment of multiple nuclear detonations is not well understood. The system described above would be far more robust in the face of possible short-term threat responses if supplemented by other layers.

Light Midcourse and Terminal Defense

While the requirements of the previous system could probably be met in the near term, this system and the following ones require technology which is somewhat further off. This additional layer could probably be added relatively quickly after the deployment of the previous one. Most of the technological requirements in this section should be achievable in the near to midterm.

In addition to the terminal phase described above, this level of the hypothetical system would add a set of hundreds of ground-based infrared homing interceptors, based near the borders of the United States, which are capable of exoatmospheric interception. These interceptors would have a range of many hundreds of kilometers. Their long range would make possible some level of area defense in

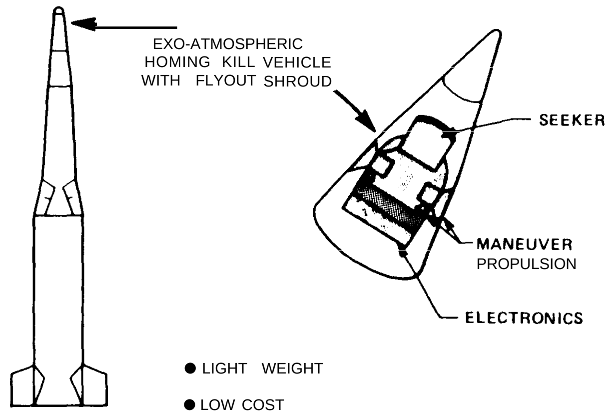


Photo credit: US. Army Strategic Defense Command

Exoatmospheric Reentry Intercept Subsystem (ERIS): Sketch of proposed concept for exoatmospheric interceptor.

addition to the defense of a few hard sites. This layer of the system would be intended to break up structured attacks and could relieve some of the stress from the large number of RVs and decoys which could otherwise confront the terminal defense system. The hard-target defense would therefore be more solid, and, by use of preferential defensive tactics, some soft targets could also be afforded some protection.

One possibility for a sensor system would be the deployment of perhaps 100 satellites, each equipped with sensors, which would have some ability to observe the deployment of decoys and RVs from the post-boost vehicle, possibly aiding in discruminating between the two. Perhaps a more survivable and cheaper alternative could be a set of pop-up sensors, to be launched on notice of a massive attack, which would serve the same purpose.

The sensors might be based on a passive infrared system which could be used to measure the infrared emissions of targets. Measurements at several different wavelengths might make decoying or deceptive simulations more difficult. This level of capability might be effective against certain types of simple decoys. Information on track files for targets identified as real would have to be transmitted to ground stations by links robust enough to be secure in a stressful nuclear environment.

The ground stations would relay the information to battle management computers, which would then assign targets to interceptors.

In order to build such a defense, the following requirements must be met:

- long-range interceptors with very rapid acceleration and exoatmospheric capability at relatively low cost per unit;
- passive infrared sensors which can observe characteristics of objects in midcourse with some ability to distinguish simple decoys from RVs;
- a data base of Soviet RV and decoy signatures at various wavelengths which can permit one to distinguish between the two;
- algorithms (rules incorporated in battle management decisionmaking) capable of accurate and rapid discrimination between RVs and decoys, using the data available from the sensors used in the system;
- communication links between sensors in space and stations on the ground which can function in a hostile nuclear environment, through redundancy or other means;
- the development and deployment of a constellation of satellites or pop-up rockets carrying the passive IR sensors;
- a sensor system capable of rapid return to effective operation, following nuclear detonations within the fields of view of individual elements;
- means of defending the satellite-based sensors (if used) from attack; and
- some kill assessment capability, with the ability to relay the information to ground.

The effectiveness of this system could be severely impaired by countermeasures employed to reduce the ability of the sensors to discriminate between decoys and RVs. Such countermeasures could include the use of chaff, aerosols, or other concealment strategies. It is also important to emphasize that the sensor system would have to be robust enough to return to operation rapidly if dazzled by nuclear detonations. This is because targets may be salvage-fused, or may be programmed to detonate at appropriate times in order to confuse defenses. The homing devices on the interceptors may not need to be as robust as the battle management sensors, in this respect, since only those explosions within the narrow field of view of a given interceptor's homing system would be of concern.

Heavier Midcourse Layer

To the terminal layer and light midcourse layer, one might add a space-based midcourse defense layer. The weapons of such a layer could supplement the ground-based exoatmospheric interceptors described in the previous section. More sophisticated space-based sensors might substitute for the infrared sensors of the previous system.

Such a layer would greatly relieve the stress on the terminal layer for three reasons: first, the total number of objects to be tracked and attacked in the terminal phase would be reduced; second, structured attacks intended to defeat the defense could be disrupted; and third, the more capable midcourse system would be better able to help discriminate between decoys and real RVs than the system described in the previous section. This information would be used by the midcourse layer and would also be passed on to the terminal layer. For this level of midcourse defense, the weapons could be space-based kinetic-energy nonnuclear kill vehicles, which are more mature than directed-energy weapons.

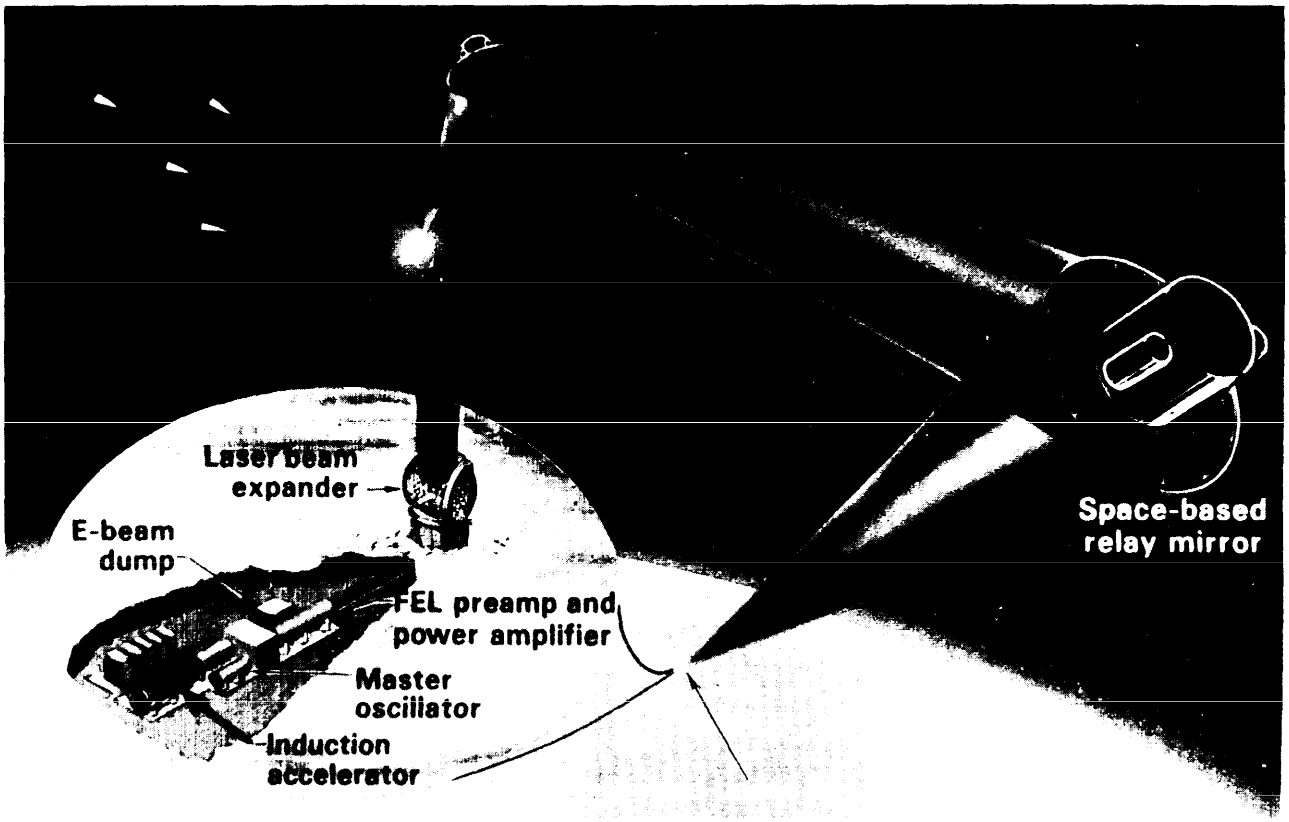
To function effectively, a midcourse system would have to be able to discriminate decoys from RVs. An ultraviolet (UV) imaging laser system might be used, with units based on a constellation of about 100 satellites. The exact number of satellites would depend on the angular resolution achievable and the altitudes of deployment. These would then replace the less capable sensors in the previous midcourse system. The laser imaging could be substituted for or augmented by a radar imaging system, located on the same satellites. The acquisition and tracking of the enemy targets, from post-boost vehicle (PBV) stage until atmospheric reentry, might be accomplished by a long wave infrared detection system. The sensor system would aim for birth-to-death tracking of RVs and decoys. The decoys would be identified by shape or other cues which might be detected during deployment from the PBV. Battle management computers must be able to calculate and store a track file for each object, frequently updating this file, and to hand off data on RVs and decoys, that are not intercepted in this phase, to the terminal defenses for interception there.

During the midcourse phase, the defenses would try to kill as many identified RVs as possible, and to unmask or negate decoys as well. We might postulate a kinetic-energy kill system as a moderately near-term option. Reentry vehicles would be quite difficult to kill with optical lasers since they are already hardened to survive the stresses of reentry. Neutral particle beams might be possible candidates for kill systems, but kill assessment would be a serious problem (see chapter 7). The technology for practical space-based accelerators will likely not be available in the *near-term*, particularly in view of the fact that beam intensities would have to be greatly increased from the present state of the art to assure hard (i.e., visible) kills. However, *long-term* development of such a capability is possible.

More plausible for the near term are kinetic-energy carrier satellites, with large numbers of chemically powered two-stage rockets mounted on each one. These would orbit the Earth in a constellation whose size would depend on the acceleration and terminal velocity of the interceptors. The rockets would accelerate rapidly to 5 to 8 km/sec. They would have long wave infrared homing devices capable of detecting emissions from reentry vehicles. The homing devices would need to have cryogenically cooled detectors so that the infrared radiation given off by the sensor itself would not overwhelm the signal from the RV. The interceptors would destroy the target by colliding with it or by approaching closely enough so that a fragmentation charge could disable it. The kill vehicles would receive initial guidance information from the more capable infrared tracking system located on the sensor satellites; their own homing devices would take over when they approach their targets.

Technical requirements for this kind of system include the following:

- Kinetic-energy weapons with a homing capability of within 10 to 20 cm, and which are relatively inexpensive, since tens of thousands may be needed (depending on the threat size and the acceleration and velocity capability of the rocket interceptor).
- The launching satellites must be able to defend themselves against attack.
- High-speed imaging resolution (less than 0.1 sec per image) of less than a meter at ranges of 3,000 km, in order to discriminate RVs from decoys as they are deployed from the PBV.
- A data base of decoy signatures and RV signatures which would aid in discrimination.
- Tested algorithms for accurate discrimination based on target signatures at various infrared (and possibly other) wavelengths and based on other cues (balloon inflation, PBV accelerations during deployment, etc.).
- Computing capability to calculate track files for tens of thousands of objects or more.
- Accurate kill assessment based on UV or other imaging information after apparent hits are achieved.
- Battle management capability to reassign vehicles to new targets within seconds or less, based on constantly updated kill assessments and PBV observations. For this and the following systems it may be desirable to deploy redundant battle management computers both in low-Earth orbit and in orbits beyond geosynchronous, in order to aid in survivability.
- The ability to defend the weapons and satellite-based sensors from a precursor attack.



- Sufficient and reliable space-based power sources to supply energy for the sensing satellites.

An important issue is whether it is possible to image effectively the deployment of RVs and decoys from the post-boost vehicles, in the face of countermeasures achievable with current or near-term technology. More discussion of these questions may be found in the classified annex to chapters 7 and 8.

Boost-Phase Plus Previous Layers

A boost-phase defense might be added to the system described in the previous section. Effective boost-phase interception would have enormous leverage: for every kill, at least one and perhaps tens of RVs in addition to hundreds of decoys would be eliminated from the attacking force, thereby greatly reducing the stress on the succeeding layers of the BMD system.

For a boost-phase system, we hypothesize a set of ground-based excimer or free-electron lasers, with a constellation consisting of a small number of large geosynchronous orbit relay mirrors and a large number of low-orbit "battle" mirrors. Excimer or free-electron lasers were chosen over particle beams, X-ray devices, and chemical infrared lasers because of their ability to penetrate the atmosphere all the way to the ground. A ground-based sys-

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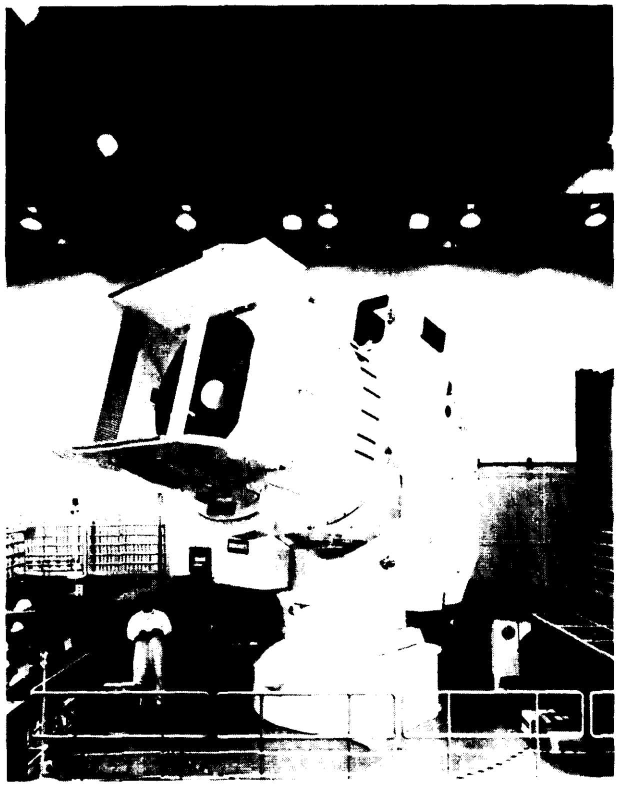


Photo credit: Department of Defense

Designed for use with high-powered lasers, this device aims, stabilizes, and focuses a laser beam to selected aimpoints. It will be used to gain experience in integrating a high-power laser with a precise beam director.

tern is easier to supply with power: it obviates the need for space-based power for the weapons of this layer.

The laser beams would be generated on the ground at a number of stations and be sent to the geosynchronous mirrors. From there, they would be directed to those low-orbit battle mirrors which are nearest the targeted boosters. These mirrors, in turn, would direct the beams onto the targets. If optically perfect, the geosynchronous mirrors would probably need an effective diameter of about 30 meters, given a laser wavelength of 0.5 microns (the requirement of a large diameter could be lowered by reducing the wavelength somewhat). The low-orbit mirrors, if optically perfect, would need to be about 5 meters in diameter. Hundreds of megawatts of electrical energy would be required to power the ground-based lasers.

In addition, adaptive optics would be needed to compensate for beam distortions introduced during passage of the radiation through the atmosphere. In one such technique, a pilot laser beam near the geosynchronous satellite would give information on atmospheric distortions along the path to the ground laser. The ground laser mirror would then be mechanically distorted in such a way as to compensate for the atmospheric effects on the laser beam.

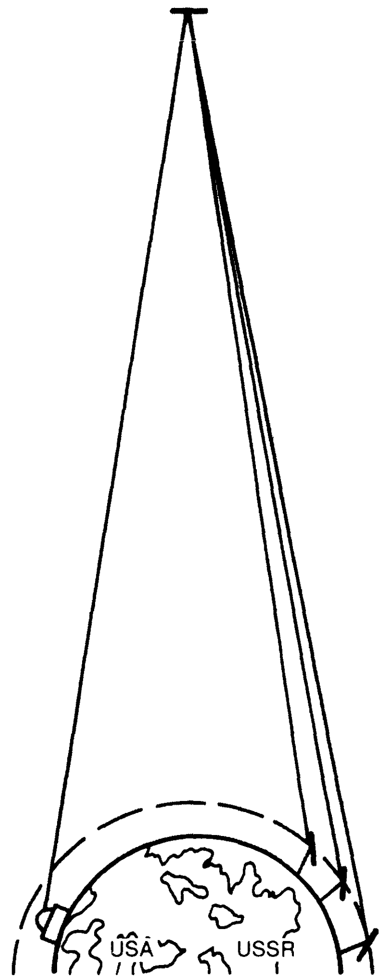
Initial acquisition of the attacking boosters would be provided by a geosynchronous shortwave infrared satellite system, using technology similar to current U.S. capabilities. More precise tracking needed for attack by the large ground-based laser could be provided by ladar (laser-based radar, referred to in chapter 7) systems mounted on the low-altitude sensor satellites.

In order to keep the number of mirrors from reaching well into the hundreds, slew times (time required to change pointing from one target to another) will probably have to be on the order of 1 second or less.

Technical requirements for this system include:

- the development of laser beams of sufficient brightness to destroy rocket boosters after traveling from the ground to geosynchronous orbit, back to a low-orbit mirror, and then to the booster;
- the development of many high optical quality, 5-meter diameter mirrors capable of being deployed in orbit while maintaining their geometry to a small fraction of a wavelength (visible or near UV), robust enough to maintain high optical quality in a hostile nuclear environment, and able to switch from target to target in a second or less;
- the development of a few 30-meter mirrors, with the same optical and physical capabilities as the smaller mirrors (except for the retarget rate, which could be slower);
- battle mirrors inexpensive enough so that the offense cannot overwhelm the boost-phase system by merely adding more boosters: if doubling the number of boosters (or decoy boosters) requires a near doubling of the number of mirrors and associated subsystems, the cost of the mirrors and their subsystems cannot be much more than the cost of the boosters;
- defensive capability to protect mirrors and space sensors against attack, including more subtle attacks designed to deteriorate the quality of the mirrors;
- the ability to track a booster by means of ladar to an accuracy of 10 to 20 cm at a range of thousands of kilometers;
- adaptive optics for high-intensity laser beams to compensate for atmospheric turbulence–some atmospheric distortions will be caused by the passage through the atmosphere of the powerful laser radiation itself, and thus proof of ability to compensate must be accomplished at power levels approaching those used in the actual weapon;
- power supplies able to provide extremely large amounts of power on short notice to the ground-based lasers;

Figure 8-1.— Boost-Phase Intercept With Ground-Based Laser



Beam from ground-based laser in the United States reflects off relay mirror in geosynchronous orbit to battle mirrors in low-Earth orbit, Battle mirrors redirect beam to ICBMs. (Geosynchronous orbit is shown to scale relative to the size of the Earth.)

SOURCE: Office of Technology Assessment

- communication systems to link the mirrors and lasers involved with the battle management system; the links must be able to function in a hostile nuclear environment;
- overall battle management software to coordinate functions of each defensive layer; and
- some kill assessment is necessary for both booster and post-boost vehicle. In the latter case, damage may be more difficult to ascertain, yet it is important to do so. If a PBV is unable to deploy its RVs to their targets, it may still be able to reach the defender's territory with one or more live RVs. This cluster would have to be handled by subsequent layers of the defense.

A future offensive countermeasure could be a fast-bum booster with a fast post-boost deployment phase. In the system described above, one could, in principle, not only attack the booster, but also attack the post-boost vehicle as it dispenses RVs. Therefore, against current systems having long boost and post-boost phases, hundreds of seconds could be available to the defense after booster burn out to destroy at least some of the RVs before they separate from the PBV. The offense could deny most of this advantage by using fast burn boosters and a rapid dispensing technique. The period for neutralization of the booster and the PBV could be reduced from today's 700 seconds or so to only some 50 seconds (assuming that the defense needs some 20 seconds to prepare to act and to begin engaging the offensive missiles). The offense would be penalized in terms of throwweight (on the order of 10 to 20 percent) and possibly in terms of accuracy as well.

Attacking during the PBV phase might be more difficult than attacking during the boost phase, since the PBV is much more difficult to find than the booster. Fifty seconds total engagement time would greatly stress the boost-phase/post-boost-phase intercepts, and would, at the least, greatly increase the quantity of defensive space assets needed.

Extremely Effective Defense

This system is intended to provide a nearly perfect defense against ballistic missiles. It would be designed with the object of preventing all incoming warheads of a massive attack from reaching their targets. In practice, since no system is likely to function perfectly on its first use, some leakers might be expected, although it would be hoped that they would be very few in number. Rationale for including this ambitious case is given in chapter 5.

For an attack of 20,000 warheads, which assumes more than a doubling of the Soviet strategic force in response to deployment of a U.S. BMD, the leakage rate would have to be no more than one- or two-tenths of a percent, equivalent to an overall system efficiency of above 99.8 percent. To accomplish this, all of the above systems would have to work at a high level of effectiveness. If one assumed that all four layers (including the ground- and space-based midcourse layers) were totally independent of each other (including independence of the sensors and battle management computers on which each of the layers rely), this could be accomplished via an 80 percent effectiveness for each layer. If one layer failed significantly, however, the others would have to be considerably more efficient, in order to maintain the extremely low leakage rate.

In addition to the elements contained in the previous system, this one would add a larger fleet of terminal and midcourse interceptors. These would have long-range capability and be relatively inexpensive. In principle, the same interceptors which were briefly described above would be appropriate, if highly proliferated. Other options for improving the effectiveness of the various layers could include improved sensors for midcourse discrimination and electromagnetic launchers for midcourse phase and possibly boost-phase intercept. These may be longer term options, depending on when the needed technologies are developed. The "conventional" kinetic-energy weapons driven by chemical rockets are effective if they can reach their targets, but they generally do not travel more quickly than 5 to 8 km/see. Further, time constraints on the period of acceleration (at most, a few hundred seconds) could make chemical rockets less desirable than electromagnetically launched projectiles. These could accelerate far more rapidly to faster speeds, thus possessing a greater range. Systems based on them may be more survivable than laser systems because of the vulnerability of space-based optical components; hence their possible advantage for boost-phase intercept.

Since the offense could preferentially attack certain targets, and since the defense would not necessarily know ahead of time which targets would be more heavily targeted, the requirement for very low offensive penetration is quite onerous. If one assumes that the first two layers (boost-phase and early midcourse, including PBV) are 80 percent effective, the last two layers must deal with some 800 leakers. It would be desirable for each interceptor to cover large areas of the United States so that one can defend against the eventuality that one area might be more heavily attacked than its neighbors. Long range would mean that interceptors assigned to neighboring areas could come to the help of those areas whose own defenses were in danger of depletion. As an alternative to long range, many more interceptors could be deployed. The exoatmospheric interceptors could be designed to have ranges of many hundreds of kilometers. If each rocket could defend the whole continental United States (CONUS), perhaps only 1,000 to 2,000 would be necessary.

The terminal defense interceptors would have a range of only 100 kilometers. Some 400 basing sites might be needed to protect the entire CONUS. Perhaps about 10 interceptors (amounting to a total of 4,000) might be placed at each *site. Each site* of comparable *value* should be defended to roughly equal levels, to avoid inviting attack by providing an "Achilles heel" of less well-defended sites. If one assumes that the long-range interceptor layer is 80 percent effective, only 160 leakers penetrate through to the terminal defense. Although most sites would be confronted with only O or 1 RVs, some would have to deal with 2, 3, or even 4, just because of statistical fluctuations in actual defense effectiveness. Conservatively, one would want to assign at least 2 interceptors per RV, so 10 interceptors per defended area is a safe minimum, assuming that any structure in the offensive assault is completely broken up by the earlier defensive layers.

In relying on 4,000 interceptors, the assumption is made that the previous defensive layers are each independently effective to a level of at least 80 percent.

In sum, for a nearly leak-proof defense, several vital needs must be satisfied:

1. A high level of boost-phase intercept effectiveness must be attained, in the face of all countermeasures, including the relatively straight-forward ones of fast-burn boosters, rapid PBV deployment, and warhead proliferation.
2. An excellent discrimination capability between light and precision decoys on the one hand, and RVs on the other, during the midcourse phase; this must be accomplished in the face of various concealment techniques, some of which are relatively well understood at the present.
3. The sensors must function nearly continuously in the face of a massive attack and in a nuclear environment.
4. The space-based assets must defend themselves or must be defended by other assets against concerted attack.
5. The communication links must function effectively in the face of attempts to interfere, concerted attack, and in a nuclear environment.

In addition to the above conditions, since a near-perfect system is envisioned, other means of nuclear delivery must be countered to a high degree of assurance. This means that an air defense system would have to be added to handle air-breathing threats (bombers, cruise missiles), and measures would have to be taken to protect against the introduction and emplacement of nuclear weapons within U.S. borders by surreptitious means. It may also be necessary to consider the application of significant civil defense measures.

Since a nearly flawless system is postulated for this level of defense, any deviation from perfection among the above conditions above would mean that the system would fail. For defenses less ambitious than this one, for example, for the previously delineated systems above, some small failures among the above five conditions could be tolerated. However, even for such nonperfect systems, a significant failure in any one category could seriously degrade the entire system effectiveness.

SURVIVABILITY

For any BMD system, both space- and Earth-based assets should be able to survive attacks on them. Survivability is a function of the mission of each asset and of the mission of the system as a whole, the threat faced by the system, and the effective redundancy of each asset in the system architecture. The *system* survivability depends on the details of the architecture and of the threat. Some discussion of the problems involved is given in chapter 7, p. 170ff and p. 186ff in sections on survivability and countermeasures. It should be noted that the definition of the needed level of survivability depends on the policy decision regarding the system's mission; i.e., is it to be 90, 95, or 99 + percent effective?

Earth-Based Assets

Ground-based assets consist of communication links, command and control posts, ground-based interceptors, terminal radars, ground-based sensors, ground-based laser sites, and power supplies. For the purposes of this discussion, airborne sensors are considered Earth-based.

These assets must survive long enough to do their job: to provide defense at their assigned levels. Ground-based interceptors might be made survivable by proliferation (many can be deployed) and mobility. Smaller terminal radars can be proliferated, made mobile (deployed on trucks which are assigned to rove defined areas, possibly at random, to avoid being targeted) and shielded. A disposable system has already been mentioned. Larger radars can be hardened to a degree, and higher operating frequencies can be chosen in order to provide greater resistance to blackout effects that are caused by nuclear explosions. Narrow beams can be used to make radars more jam-resistant.

Communication links can be made highly redundant, and can often be direct laser links, or other narrowly focused line-of-sight links. These are nearly impossible to jam and would be resistant to stress in a nuclear environment. Electronics can be hardened to survive electromagnetic pulses, which may be induced by nuclear explosions above the atmosphere. Command and control posts might also be made highly redundant, and different basing modes (mobile and stationary) could be utilized.

Airborne sensors might achieve survivability by maintaining uncertainty as to their exact locations, and by taking appropriate hardening measures. Ground-based sensors must be made highly redundant and must be defended against intense radiation from nuclear explosions.

Ground-based laser sites pose a particular problem, since they would be large, expensive, and therefore difficult to proliferate. They would, in principle, have to be provided with heavy terminal defenses, since they would be the object of strikes early in the engagement. Some would certainly survive the beginning of the engagement. If, as would be likely, they would be attacked simultaneously with many other military assets, they could participate in early battles: they could shoot at the first wave of attacking RVs for up to about 15 minutes before the first ones reach them. However, they would certainly be high priority targets and would very likely be attacked in the first wave. To guard against easy attack by cruise missiles, they should be located far inland, so that the cruise missiles could be detected and destroyed before they were able to reach the laser. Note that a cruise missile attack might, if detected, give the defense system warning even before the launch of the offense's ICBMs takes place. This might tend to discourage such an attack.

Sufficient survivability could probably be provided to most Earth-based assets by means of redundancy, hardening, and mobility. This does not mean that these system elements would be indefinitely survivable; it does mean that they could survive long enough so that they could perform their tasks when called upon.

Space-Based Assets

There are two broad categories of space-based assets which must be protected in order to assure the survivability of the space-based components of the BMD system: sensors and weapons.

Defense of space-based assets, particularly of sensors, is more problematic than in the Earth-based case. Since satellites follow predictable trajectories (unless they are constantly maneuvering), the offense may target them relatively easily. Knowing in advance where they will be at a given time, the offense has a long time to prepare an attack against them and might even be able to do some damage before a large-scale outbreak of hostilities.

Ground-based directed-energy weapons could damage sensors which are looking at or near them (the sensors might be observing such weapons for intelligence purposes, or might be observing nearby missile fields). The sensors would be particularly susceptible to damage if the lasers operated at a frequency in the band used by the sensors. Possible countermeasures are being investigated, including redundancy of sensing satellites to mitigate against potential losses.

During engagements, space-based sensors are vulnerable to blinding or temporary blinding (dazzling) by nuclear detonations. Sensor hardening and proliferation of sensors are again possible hedges against degradation of the system as a whole.

Sensors and weapons could also be vulnerable to direct attacks by the adversary. These attacks could include nuclear attack, kinetic energy or laser attack, or attacks on the integrity of mirrors by radiation, physical or chemical means. These attacks could be delivered by direct-ascent rockets or by space-based assets. Direct-ascent interceptors, armed with nuclear weapons, could be hardened against the BMD system to levels that would not be economical for ICBMs and might survive a counter-attack by the defense for long enough to get within lethal range. Attacks against space-based BMD assets could be made after the whole space-based BMD system is deployed, or at the very beginning of BMD deployment. In the latter case, the BMD system is at its most vulnerable stage, since it might not yet be able to defend itself adequately. It should be noted that such an attack could be considered an act of war and would be risky to the attacker for that reason. However, the attacker night view the prospect of his adversary having a ballistic missile defense of even moderate capability to be a serious enough threat to its national security that the risk would be justified. In any case, the possibility of an attack at this stage must be reckoned with.

In the case of BMD weapons stations, some defense could be provided by massive shielding. These stations would probably be too large, and orbits too low to be effectively concealed. Regarding sensor stations, although shielding is a possibility, concealment is a more likely option. One vulnerability of sensors is that during an engagement they have to function, and in order to function they must be exposed. Moreover, sensor satellites carrying large optical components will have to be large and will therefore be difficult to hide or decoy.

The case of space-based mirrors, which are used to relay radiation from space- or ground-based lasers to their targets, is somewhat different from other weapons from the point of view of survivability. During peacetime, the mirrors can be covered by protective shields against both enemy attack and small meteorites. It is reasonable to suppose that these shields will have to be removed from time to time for testing and maintenance. The mirrors would probably be extremely delicate, if only because of the very high reflective quality and the high optical precision needed to function properly and remain effective when high-power laser beams are reflected from them. Protection strategies against enemy activities could include hiding by various means. Also, shields could be in place most of the time. Since the surface coatings could be vulnerable to attack by certain chemicals (possibly including rocket fuel), the covers should be well sealed.

In almost all cases of attack by approaching rockets or mines, a "shoot back" tactic would be preferable to purely passive defenses. Either the battle station or satellite which is being attacked, or previously positioned defender satellites (emplaced during the early stages of deployment of a BMD system) could act in this self-defense role. Note that such a shoot-back policy would require at least the implicit declaration of a "keep-out zone" surrounding each asset to be defended.[3]

Such an assertion of sovereignty would require the institution of a regime unlike any now existing, including that now in effect on the high seas. Under that regime, maritime powers are free to station naval forces within lethal range of each other during peacetime.

The use of kinetic weapons for shoot back is one likely defense strategy. To be effective, they would have to have a lethal range greater than that of the attacking force. Other BMD kill technologies which have been discussed could also have a lethal capability against battle stations. In determining whether it is feasible to provide sufficient defenses of one's own space assets, particularly during early phases of deployment, a complex analysis of several factors is required. These factors include system cost of defense versus offense; attack and defense tactics; decoy, hiding, and deception tactics; hardness of defense systems; and offensive capabilities.

In the absence of a BMD system architecture, it is difficult to assess accurately the ability of a BMD system to defend its space assets. It would appear, however, that when only a few space assets have been deployed, a certain advantage would lie with the offense. Then, the offense can concentrate its efforts on a small number of defense targets. Assaults can be made repeatedly until one attacker leaks through the defenses to kill its target.

The offense might be deterred from attacking the BMD space assets for the same reason that neither side will launch a first-strike nuclear attack on the other in the absence of defenses: the threat of retaliation and all-out nuclear war. However, the attacker might calculate that his adversary would not risk mutual annihilation in response to the destruction of a few (possibly only one) satellites, and may conclude that the risk of not attacking a BMD system in its early stages of deployment are greater.

[9]Asserting sovereignty over a region of space would appear to violate Article II of the Outer Space Treaty which declares that "Outer Space . . . is not subject to national appropriation by claim of sovereignty . . ." See "Arms Control and Disarmament Agreements" (Washington, DC: Arms Control and Disarmament Agency, 1982), p. 52.

FEASIBILITY QUESTIONS

Technological Feasibility

Virtually all observers have acknowledged that the technical questions bearing on the eventual feasibility of a successful BMD are complex and cannot be answered until further research has been accomplished. The Strategic Defense Initiative Organization argues that the purpose of its research is precisely to answer questions of technical feasibility: before the research is done, there will not be enough information to make a determination.

However, there are various technical issues which appear to present the greatest challenges. These have been listed in the preceding discussion of a hypothetical defense system.

The principal outstanding technical problems in the development of a multi-layer ballistic missile defense system, with a large fraction of its assets based in space, areas follows:

- the feasibility of developing a boost-phase intercept system robust enough to be effective when confronted with plausible countermeasures;
- the ability of the system to discriminate between decoys and RVs in midcourse, when confronted with plausible countermeasures;
- the development of inexpensive ground-based interceptors, meeting required specifications for midcourse exoatmospheric intercept;
- the development of affordable terminal interceptors for high endoatmospheric intercept;
- the resistance of sensors to blinding, dazzling, or spoofing in a hostile nuclear environment;
- the development of very large and complex software packages which can be trusted as sufficiently reliable to enable the United States to make major changes in defense strategy without having been tested under battle conditions;
- the ability to retarget both sensors and (in the appropriate case) directed-energy weapons in times of the order of 1 second or less;
- the ability to deliver the required amount of energy for a kill within the time allotted by the parameters set by a responsive offense. These parameters include number of boosters and RVs, the length of time they are vulnerable to attack during their flight, and their hardness, which enables them to resist attack;
- the ability of the system to defend itself against a concerted attack when fully deployed;
- the ability of the system to be deployed without being destroyed during the early stages of deployment, when the full system is not available for defense;
- the development of computer hardware with 10-year maintenance-free reliability;
- the development of robust power systems which can deliver many megawatts, which are equally maintenance-free and which can deliver large power pulses; and
- the ability of the BMD system to operate in a hostile environment which may include many nuclear explosions—an environment which is currently poorly understood and which would be difficult to duplicate experimentally.

Within each of these categories lies a myriad of precise technical issues to resolve: for example, the degree to which an ablative shield can protect a booster from attack; the resolution achievable using UV laser imaging; the amount of infrared radiation produced by a nuclear explosion in the upper atmosphere; the difficulty of building a 5 (or more) meter diameter space-deployable mirror which is optically good to a small fraction of a wavelength.

In addition to the above technical conditions, the system should be able to be developed and deployed at an affordable cost.

Several of the above technical issues involve the battle of countermeasures versus counter-countermeasures and so on. No meaningful analysis can stop at a predetermined level; otherwise the predicted outcome would be prejudged. To determine which side, offense or defense, is likely to prevail in any particular facet of this contest requires a careful and detailed analysis.

At this stage, it is too early to predict the likelihood of success in the above areas. However, failure to satisfy even one of the above list of requirements could render many versions of the space-based BMD concept impractical. It is clear that although substantial progress has been made to date, most BMD technologies require major advances in the state of the art before their feasibility can be assessed.

After another year of research, at the end of fiscal 1986,2 years of the SDI research program will have elapsed. At this point, which is a good fraction of the time along to the much discussed decision point on further development in the early 1990s, it may be possible to have some idea of the rate at which important technical milestones are being met. An interim progress report might then contain significant indications of the viability of many important facets of the SDI project. Such a report would provide a vital input to decisions and directions regarding research funding beyond this point.

A major question is the degree to which defensive measures can outstrip offensive countermeasures in general. If one argues that the United States can maintain a 5-to 10-year technological advantage over the Soviet Union, the question reduces to: will current defensive technologies suffice to defeat countermeasures which are 5 to 10 years behind the state of the art? If the answer is not in the affirmative, or if the United States cannot achieve and maintain this level of technical advantage, the prospect of reaching a regime wherein U.S. defenses can reach and keep superiority over Soviet offenses will be dim. In such a case, U.S.-Soviet cooperation towards a mutual deployment of BMD defenses would be essential to their successful deployment, their effectiveness, or both. The Soviets would have to be persuaded that a stepwise transition to a BMD regime would be in their interest and preferable to engaging in an arms race with the United States.

Operational Feasibility

In addition to the matter of the technical feasibility of each of the components of a proposed BMD system, there is the problem of the operational feasibility of the system as a whole.

Assume that a BMD system that meets desired technical specifications can be constructed and deployed. The system would be have to be in a state of readiness for many years; that is, it would have to spring into action from a state of dormancy on very short notice. Perhaps a few days would be available, but any system requiring days of warmup would be useless against surprise attack—indeed, it could increase the incentive to conduct one. When called upon to act, some components may not be operating, since a 100 percent reliability is probably unattainable. This difficulty is countered by providing sufficient component and system redundancy. The degree of redundancy is set to counter the measured unreliability of the system.

Suppose, for example, it is calculated that 10 boost-phase intercept battle stations (one does not know in advance which 10) out of a constellation of 100 would be called on to participate in a battle, and suppose further that the reliability of each of these stations is 90 percent over a 10-year period. On the average, about one station would have to be serviced each year. If servicing is planned on a once-a-year basis, there will be times when one or perhaps two satellites are out of operation. This would imply a need for a 10 percent (or possibly 20 to 30 percent) increase in the number of satellites, to provide spares. These would need to be available to guard against the case where the nonoperating satellite may be one of the 10 that are needed to participate.

It is important to note that the number of required spares depends on the subsystem size, the number of elements of the subsystem which would have to participate in the battle, and, above all, on the reliability of the subsystem.

Similar arguments can be adduced for each subsystem and each layer of the BMD: the satellite sensors, ground-based sensors, and all weapons systems, power supplies, computing elements, etc., must have high levels of reliability in order to avoid large increases in systems sizes. For many parts of the whole, the 90 percent maintenance-free reliability for 10 years would be desirable.

To maintain reliability, the system would have to be monitored and tested constantly, a job which would require much ground- and space-based effort. Some human intervention might be needed in both cases. Testing and subsequent repairs would be a permanent and constant feature of a large space-based BMD system.

A totally different question, and a more serious one, arises from the fact that the whole BMD system would never have been tested in a realistic battle environment before it would have to operate at a high level of effectiveness. Without launching a massive rocket attack to test the system, replete with nuclear explosions in space and in the atmosphere, the synergistic effects of the hostile environment will not be well understood. Failures of more than one layer in this "common mode" could drastically reduce the effectiveness of the system as a whole.

As one example, the immense battle management system, including 10 million or more lines of software code, would have to function reliably the first time it is tested under full battlefield conditions. Large computer programs generally require much time and testing to debug. The question is whether simulated testing would be adequate and trustworthy enough for the reliance which would be placed in it.

As another example, it is not certain how much scintillation will occur in the upper atmosphere as a result of nuclear explosions there. The uncertainty includes the wavelengths, the intensities, and the duration of the scintillation. The resistance of radars, sensors, and sensitive optical surfaces to nuclear explosions in space and in the upper atmosphere is uncertain. Since these effects may be difficult to study in the laboratory or in underground nuclear tests, this uncertainty may not be resolvable in the absence of extended upper atmospheric testing.

The electromagnetic pulse induction in ground- and space-based systems, which is caused by nuclear explosions in space, is similarly not fully understood. The resistance of space-based power supplies and power conditioning systems to the various types of radiation from nearby nuclear explosions may be difficult to determine. Nuclear effects may protide significant problems to the defense in this context. The ability of a system to withstand a concerted attack may not be known in advance and the outcome of such an attack could be highly dependent on the tactics used by each side.

costs

General

Questions of cost are even more elusive at this point than questions of technical feasibility. Before the architecture of a system is defined, it is impossible to give a reasonable and credible estimate of total system costs. Estimates have ranged from tens of billions of dollars to $1 trillion and more,[1] not including operational and maintenance costs. Not surprisingly, BMD advocates tend to estimate lower numbers than opponents. Nearly all credible observers concede, however, that the system would require a very large investment.

The SDI Organization, recognizing the large uncertainties in current cost estimating, has formed a cost estimating working group. The

[1] E.g., see D. O. Graham, *High F'rontier: .4 New National Strategy* (Washington, DC: High Frontier, 1982), p. 9; Z. Brzezinski, R. Jastrow, and M. M. Kampelman, "Defense in Space is not 'Star Wars'," *New York Times Magazine*, Jan. 27, 1985; J. Schlesinger, National Security Issues Symposium, 1984, "Space, National Security and C'I, " Mitre Document M85-3, October 1984, p. 56; Department of Defense document presented to Senate Foreign Relations Committee by Senator Pressler, Apr. 24, 1984.

group is investigating possible new and better cost estimating techniques since the magnitude and novelty of the SDI may demand new estimating tools.[5] In addition to cost estimates, cost-exchange analyses will also be performed.

Cost-exchange analyses will be essential to demonstrating the attractiveness of the system. If it costs the offense less to counter a defense than it costs the defense to deploy one, it is generally not advantageous to proceed with the defense. On the other hand, suppose the offensive countermeasures cost less than the defenses, but suppose, additionally, that the United States has far greater economic resources which it can devote to the effort than the U.S.S.R. In that case, it could pay the United States to continue with the defense, even though it would be more costly than the cost to the Soviets of offsetting our move.

On the other hand, even a defense which the United States considered to be cost-effective might not be sufficient in itself to bring about a transition to defense dominance. First, Soviet calculations of cost-exchange ratios may not coincide with our own. Second, they might redirect their offensive forces along different delivery modes, concentrating on ones which could most cheaply penetrate defenses. This could change the assumptions inherent in some of the U.S. cost-exchange calculations.

More importantly, cost may not be a major determining factor for the Soviets in policy planning. They may be capable of spending more on offense than the United States spends on defense because of inflexibilities in their economic structure, because they are more easily able to direct their economy towards military expenditures, or because they may consider the benefits of maintaining their offensive capability to be of paramount national importance, thus justifying to themselves levels of expenditure that the United States would consider to be inordinate.

Indeed, the United States already considers Soviet expenditures on their offensive forces to be inordinately large. Secretary of Defense Weinberger has stated, "Whatever the reasons, the Soviets believe that their colossal military effort is worthwhile, notwithstanding the price it imposes on the Soviet society and its troubled economy.'"

It is difficult to do cost-effectiveness analyses on systems which are on the cutting edge of future technologies for another reason: technological obsolescence. The unpredictable nature of technological progress leads to unpredictable shifts, probably major ones, in both costs and effectiveness. It is possible that no analysis which assesses systems more than a very few years in advance will have much validity.

One additional point worthy of mention is, that in working out cost exchanges between offense and defense, one must account for the fact that both the United States and the U.S.S.R. are starting from a situation where they have little or no effective defense, but very effective offenses. The funds for this level of offense have already been spent. The funds to deal with this level of offense by defensive means have not. Therefore, a massive defense expenditure would be needed initially just to counter existing offenses. Cost-exchange ratios at the margin are meaningful in themselves only beyond this point, when offensive additions and countermeasures are met by defensive additions and countermeasures.

Total System Cost

Rather than present an independent estimate for system cost, this report will point out the requirements which must be met in order to devise a credible estimate.

It is possible to make some simple cost-exchange arguments regarding limits on what a system or a part of a system should cost. The following brief discussion is only illustrative, and subject to the reservations noted above

'Information contained in a speech by Lt. Gen. James A. Abrahamson at the annual meeting of the American Institute of Aeronautics and Astronautics, April 1985, reported in Military Space, Apr. 15, 1985.

C.. Weinberger, *DOD FY85 Annual Report* (Washington, DC: Department of Defense, 1984), p. 26.

concerning cost-exchange concepts in the context of BMD.

Suppose one plans a boost-phase intercept system consisting of 100 battle stations. In chapter 7, it was found that, for satellite altitudes of 1,000 km or more and slew times of 0.25 seconds or more, the number of battle stations required increases nearly linearly with the number of boosters. If one were to aim for a 30:1 kill ratio of booster to deployed battle station, this implies that a battle station should *not* cost much more than 30 times the cost of a booster. If it did, the offense could, in principle, force the defense to spend much more on staying ahead of the offense than the offense would have to spend in keeping up with the defense by the simple expedient of building more boosters. A cost of $50 million per booster would mean that the defense could spend $1.5 billion per battle station, and still keep up with the offense in the cost-exchange race. A $200 million cost per booster would imply that the defense would have to keep its battle station cost below $6 billion per station to stay in the running. This would mean that a total system cost of $600 billion would still be cost-effective.

This crude argument includes many simplifying assumptions, but it maybe useful as an aid to understanding the nature of cost-exchange studies.

There are ways of making rough direct cost estimates, rather than defining allowed upper limits, as above. One could estimate the fuel costs needed to place a given payload in orbit, or one could use other crude "order of magnitude" assumptions to make simple calculations. However, none of these techniques satisfactorily accounts for technological improvements, or, a fortiori, possible technical breakthroughs. The conclusion stands that it is too early to make useful estimates.

A cost analysis for a BMD system would use several tools and techniques.

First, a work breakdown structure would be made. This is a list of items needed to design and construct the system. Research, test and evaluation, maintenance, procurement, and deployment are all elements of the breakdown. As time goes on, broader categories of items are further broken down into more specific elements.

Second, cost estimating relationships are used. These are equations which use past history for estimating costs of elements in the project being investigated. One difficulty in making such estimates for highly innovative projects, such as BMD, resides in the fact that many of the estimates may depend on totally unknown or unanticipated future results of basic research. Another problem arises from the uncertainties in extrapolating costs from items in a historical data base to similar future items. For qualitatively different technologies, the accuracy of estimates derived from historical analogs may be poor.

A third tool is the use of learning curves. These are used in predicting cost reductions per unit resulting from gains in experience and volume of production.

Also, planning factors are used to predict costs. They are arithmetic factors used in making cost estimates based on general past experiences. One example would be to use the ratio of development costs to investment costs for similar programs in predicting the development cost of a new project, when the investment cost is known. This is similar to the use of cost estimating relationships noted above, but even more general and subject to error.

It is apparent that in order to use any of these tools for estimating the cost of a BMD system, the architecture and the technologies to be used will have to be defined.

The burden for providing cost estimates should be on those who maintain that an effective BMD will be affordable, including those who define potential system architectures. If one argues for the commitment of large sums of money to research in one particular area at the expense of others, with the intent of making deployment options available, one should provide a cost estimate for the eventual deployments envisioned. Clearly, if the end product appears to be prohibitively expensive, this indication would discourage decisions to fund the expensive large-scale research which might lead to this undesirable result.

In conclusion, attempts to provide a realistic and defensible cost estimate for an effective BMD system must await the presentation of a realistic and defensible suggestion for one or more alternative system architectures. At present, it is safe to say that, if, indeed, a space-based BMD system is defined which appears to be feasible; it will likely be considerably more expensive than any other weapons program yet developed.