Chapter 3

BALLISTIC MISSILE DEFENSE

Chapter 3.—BALLISTIC MISSILE DEFENSE

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BALLISTIC MISSILE DEFENSE

Ballistic missi e defense (B MD) systems — also called ant ballistic missile (ABM) sys-terns —would seek k to ensure MX survivability by destroying attacking reentry vehicles (RVS) either in space or after they entered the at-mosphere. Different BMD concepts can have very different capabilities and weaknesses which suit them for different MX basing roles Thus, it is important to keep clear the context for which the defense is intended, i.e , whether it is desired to defend a large number of mul-tiple protective shelters (MPS) or a relatively small number of sil os This chapter discusses the technical aspects of the entire range of endoatmospheric and exoatmospheric defense systems but will concentrate on the two BMD concepts most often discussed in the context of a near-term decision regarding MX basing: the Low-Altltude Defense System (LoADS), which is suited for the role of enhancing the survivability of MX in MPS; and the Overlay component of a Layered Defense, appropriate i n theory for defense of MX based i n conven-tional silos.

There have been many changes in the tech-nical nature of BMD systems in the past dec-ade regarding both systems concept and underlying technology. Systems contemplated today are quite different f rot-n those discussed in the ABM debate of a decade ago. From a technical point of view, therefore, the issues relevant to that debate have been replaced by a n entire l y new set of issues. Though there are many parallels, intuitions based on previous acquaintance with BMD will not always be relevant — again from a purely technical point of view — to the systems cent emplated today

OVERVIEW

Technical Possibilities for BMD

It is useful to distinguish BMD systems ac-cording to the altitude regime in which they track their targets and make their intercepts, since this largely dertermines the effectiveness possible with such a system. Endoatmos-pheric — or "endo " — defense systems perform tracking and intercept within the sensible at-mosphere, from the Earth's surface to about 300,000-ft altitude, For various technical reasons, U. S endo BMD efforts have concen-trated lately on the low-altitude regime, below about 50,000 ft Low-altitude endo systems such as LoADS are limited to making a small number of intercepts over a given defended target If the number of targets is relatively small, as in the case of silo basing, such defen-sive systems can only exact a small number of RVS from the attacker Low-altitude systems by themselves are therefore of limited value unless the number of targets or aim points is large, as with MPS basing. The very fact that their goal — forcing the offense to target a small number of RVS at each aim point instead of one — is modest, means that low-altitude systems do not lave to perform very well to achieve this goal

Exoat mospher c — or "exe" – defenses track and intercept RVS in space I n contrast to low-altitude endo defenses, exo systems can in principle intercept many RVS attacking the same target Systems with an exo component can therefore in theory defend a small number of targets such as silo-based missiles from a large attack However, this more demanding task means that an exo system must be very good indeed to accomplish it. Thus, an exo system —even when accompanied by an endo system in a "Layered Defense" — must have a higher performance to do its job than a low-altitude system requires to do its more modest job.

In addition to specifying the capabilities of a BMD system, the altitude regime determines the type of sensor and interceptor required, which in turn establishes the type of technology required for the system and its potential vulnerabilities (see fig. 59).

Endo systems normally employ ground-based radars and nuclear warheads to track and destroy targets. Radar blackout caused by nuclear detonations in the atmosphere is not a crippling problem for low-altitude endo systems, as it is for high-altitude endo systems, but it (along with other factors) imposes the limitation discussed above that only a very small number of intercepts can be made within a small area. Operation in the dense air at low altitudes means that it is very difficult for an opponent to fool the defense with decoys.

Operation in space would allow exo defense to make use of nonnuclear kill mechanisms and the tactic of preferential defense. Multiple kill vehicles can also be mounted on a single interceptor missile, resulting in some savings given the cost of boosting defensive vehicles into space in the first place. Infrared sensors are preferable to radars for exo defense. Without the filtering effect of dense air within the atmosphere, exo sensors are vulnerable to offensive tactics makin g use of decoys and other penetration aids.

LoADS With MPS Basing

This use of BMD would be an alternative to increasing the number of shelters in an MPS system in the face of a growing Soviet threat. In the Air Force baseline horizontal MPS system, for example, a LoADS defense unit would be hidden in one of the 23 shelters in each cluster and programed to intercept the first RV approaching the shelter containing the MX missile. Since the Soviets would be presumed not *to know* which shelter contained the MX, they would have to assume for targeting purposes that each of the 23 shelters contained an MX missile defended by LoADS. If the defense were only able to intercept one RV over each defended shelter, the Soviets would have to target two RVS at each shelter instead of one. Thus, LoADS would increase the attack price for an MX missile from 23 to 46 Soviet RVS.

It is possible to have high confidence that LoAIDS could exact this price of 2 RVS per shelter if the locations of the LoADS defense unit; and the MX missiles could be concealed and if the defense unit could be hardened to survive the effects of nearby nuclear detonations. This confidence, conditional on successful deception and nuclear hardness, results both from advances in BMD technology in the last decade and from LoADS' relatively moclest goal of exacting from the Soviets one more RV per aim point.

Preservation of location uncertainty (PLU) would be made more difficult with the addition of LoADS to the MPS system, since the LOADS ,defense unit, MX missile, and simu-

Figure 59.—Comparison of Ballistic Missile Defense Systems

	"Exo" atmospheric defense		"Endo" atmospheric defense	
	Overlay	Safeguard/ Spartan	LoADS	Safeguard Sprint
oparating area	space	Space	Lower atomosphere	Upper atmosphere
Type of sensor	Infrared	Radar	Radar	Radar
Location of sensor	On interceptor	On ground	On ground	On ground
KIH mechanism	Non-Nuclear	Nuclear	Nuclear	

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lator must all have indistinguishable signatures. The nuclear effects requirements for LoADS are unprecedented. The design goals of PLU and hardening must furthermore be met simultaneously. It is not possible to have confidence that these goals can be met until detailed design and testing are done,

In addition to PLU and hardness, there are stylized attacks or "reactive threats" which could pose a long-term threat to LoADS. These risks are judged moderate,

The Overlay and Layered Defense of Silo-Based MX

The Army's concept of Exo defense, called the Overlay, would consist of interceptors, about the size of offensive missiles, launched into space from silos. Each interceptor would carry several kill vehicles that would be dispatched, using infrared sensing, to destroy attacking RVS before they entered the atmosphere. The Overlay could be deployed with an endo "Underlay" to make a Layered Defense of silo-based MX.

High efficiency would be required of the Overlay if it was to be able to defend a small number of MX silos against a large Soviet attack. The Overlay is in the technology exploration stage, and there is no detailed system design such as exists for LoADS. There are many uncertainties about whether the Overlay could achieve the high level of performance it would require to satisfy the needs of MX basing. These uncertainties concern both the underlying technology and the defense system as a whole. In addition, there is a potential "Achilles' heel" in the vulnerability of the Overlay to decoys and other penetration aids.

For the moment it would be quite risky to rely on the Overlay or Layered Defense as the basis for MX survivability.

Other BMD Concepts

This chapter will also discuss briefly other BMD concepts which have been studied,

A concept called "Dust," "Environmental," or "Ejecta" defense involves burying "clean" nuclear weapons in the vicinity of missile silos. The bombs would be exploded on warning of a Soviet attack, filling the air with dust which would destroy Soviet RVs before they reached the ground. Though there is little technical doubt about the high effectiveness of dust defense, there is considerable concern about public reaction to plans for the deliberate detonation of nuclear weapons on U.S. territory.

Various low-altitude or "last-ditch" concepts based on simple or "novel" principles have been proposed. Though perhaps relevant for other BMD roles, these concepts do not appear to have an application in MX defense, given the requirement to preserve a small number of MX missiles against a large number of Soviet RVS.

The Army's Site Defense is a derivative of the Sprint component of the Safeguard defense system of a decade ago. Based on the technology of the 1970's, Site Defense is preserved as an option in the event of a decision to field a BMD system based on known technology in a short period of time. Though inadequate for the role of MX defense, Site Defense could be appropriate for other limited BMD roles.

The ABM Treaty

The 1972 ABM Limitation Treaty was negotiated as part of the SALT I package of strategic arms limitation agreements. A Protocol specifying further I imitations was signed in 1974. The Treaty is of unlimited duration but is subject to review every 5 years. In addition, the Standing Consultative Commission created by the Treaty meets about every 6 months to review implementation of the provisions of the Treaty and to consider such matters as 'the parties might wish to raise.

Briefly, the Treaty and Protocol allow development of some types of ABM systems but limit their deployment to small numbers at specified sites. Development of other types of ABM beyond the laboratory is forbidden altogether.

No meaningful defense of MX missiles, either in silos or MPS, would be permitted within the Treaty, since any such deployment could consist of at most 20 radars (18 small, 2 large) and 100 interceptors confined to the vicinity of Grand Forks, N. Dak., or Washington, DC.

Limitations on development constrain the types of ABM work that can pass beyond the laboratory stage. Since LoADS consists of radars and interceptors of the kind permitted by the Treaty, development of this system can proceed without abrogation or renegotiation of the Treaty except where such development concerns the specific features of mobility, more than one interceptor per launcher, or a hypothetical reload capability. Development of the Overlay interceptors can proceed to the extent of testing single kill vehicles on interceptors, but development of multiple kill vehicles outside of the laboratory is forbidden. Development of space-, sea-, or air-borne ABM system components outside of the laboratory is also forbidden. The Treaty specifies that development of ABM systems based on "new technologies" unforeseen or unspecified at the time the treaty was drafted cannot be deployed.

ENDOATMOSPHERIC DEFENSE

Technical Overview of Endoatmospheric BMD

Endoatmospheric —or "endo" – defense systems perform tracking and intercept within the sensible atmosphere, from the Earth's surface to about 300,000-ft altitude. It is important to distinguish high-altitude systems, which acquire and track their targets above about 100,000 ft, from low-altitude systems, which track and engage below 50,000 ft. The Sprint component of the Safeguard system is an example of the former type and the Army's present LoADS concept is an example of the latter.

Endoatmospheric defense normally employs ground-based radars for tracking. Optical or infrared sensors would be inappropriate for endo operation because, among other reasons, they cannot supply accurate range information and low cloud cover or dust could obscure their view of incoming RVS.

Nonnuclear kill is possible in the atmosphere, but nuclear warheads provide a more certain kill mechanism. A nonnuclear kill would require that the radar provide very accurate trajectory information to the interceptor or that the interceptor have its own sensor. Because the kill radius of a nuclear warhead is much greater, less accurate information suffices to guarantee RV destruction.

Neutrons released from a defensive nuclear warhead provide the mechanism for disabling the offensive RV. An RV warhead contains fissionable material that absorbs neutrons very readily: this is the property that allows the nuclear chain reaction to proceed when the RV is detonated. When the fissionable material in an incoming RV absorbed the neutrons from the defensive warhead, it would be rendered unable to detonate. Physical destruction of the RV would therefore not be necessary: though blast from the defensive warhead could play a role, it is a less certain kill mechanism. The neutron kill is sure because the incoming RV must contain neutron-absorbing material to do its job, and it is very difficult to shield against neutrons. A relatively low-yield defensive warhead (tens of kilotons) could generate a neutron fluence lethal to RVS at ranges of several hundred feet from its detonation point. The defensive interceptor therefore would not have to be very accurate to ensure disabling of the RV.

Use of nuclear interceptors does involve special procedures for their release, however. Release of offensive nuclear weapons must be authorized by the National Command Authorities. The procedures for defensive nuclear release have not been worked out since the United States has no deployed, working BMD system.

Vulnerabilities of High-Altitude Endo Defense

The radar for the endoatmospheric Sprint component of Safeguard tracked incoming RVS above 100,000-ft altitude, Because of a number of technical problems associated with such high-altitude operation, U.S. BMD efforts in recent times have tended to focus on the low-altitude regime below 50,000 ft.

Target tracking and discrimination at high altitudes requires radars which are large and expensive, These radars, which must for cost reasons be few in number, would make tempting targets for a concentrated precursor attack designed to overwhelm the defense in the area of the radars and penetrate to destroy them. The defense system would then be blind.

I n addition to the vulnerability of the radars, high-altitude endo defense suffers from two crucial technical problems: target discrimination and radar blackout. Discrimination refers to the ability to distinguish RVS from the bus and tank fragments which accompany them and from light decoys or other penetration aids which an attacker could design to confuse the defense. The defense would waste costly interceptors if the radar mistook a decoy or other object for an RV, and an RV would leak through if it were mistaken for a nonlethal object. High-altitude systems like the Sprint component of Safeguard would have high wastage and leakage because of the intrinsic difficulty of radar discrimination in the upper atmosphere. In the thin air at high altitudes, objects reentering the atmosphere without heat shields, such as bus fragments, have not yet started to burn up, and light decoys fall at the same rate as heavier RVS The dense air in the lower atmosphere, on the other hand, acts like a filter: unshielded objects burn up, and light shielded objects slow down. I n either case the heavy shielded RV can be distinguished after it has reached low altitudes.

Blackout occurs when the heat and radiation from a nuclear explosion ionize the surrounding volume of air. This ionization causes attenuation and reflection of radar signals passing through the affected region. At the high altitudes where the Safeguard radars tracked their targets, blackout over large areas of the sky could be created by a rather small number of detonations. An attacker was therefore encouraged to launch a first salvo of warheads fuzed to detonate at high altitudes, thereby blacking out the defense's radars. The nuclear warheads on the defense's own interceptors could also produce this effect. The attacker could then bring in his main attack behind the protective blackout "shield."

Advantages and Limitations of Low-Altitude Endo Defense

Because of the vulnerability and cost of the radars and the severe technical problems of discrimination and blackout for high-altitude endo systems, U.S. efforts in endo defense have tended to focus on low-altitude systems, which track targets and perform intercepts below 50,000 ft.

Low-altitude systems are relatively impervious to decoy attack because it is possible to assess the weight of a body falling through dense air from its radar return. Weight is a strategically significant discriminant, since offensive boosters have limited throwweight. Beyond a certain point, loading decoys onto a missile requires offloading RVS, a trade that becomes unfavorable for the offense if the decoys must be heavy in order to fool the defense, The trade is clearly absurd (leaving aside the fact that a decoy might be cheaper than an RV) if the decoy must be as heavy as the RV itself, for the RV at least stands a chance of penetrating the defense and exploding whereas the decoy does not.

The procedure by which a low-altitude radar obtains a falling object's weight is difficult for even the cleverest decoy designer to sidestep because it is based on fundamental principles which is not within the power of the offense to alter: the presence of dense air at low altitudes and some basic laws of physics. The rate of fall of an object — RV, decoy, bus fragment, etc. —through the atmosphere is determined by the ratio of its weight to its area, called its ballistic coefficient, The higher the ballistic coefficient, the faster the object falls. Of two objects of equal area, the heavier will fall faster because it has more force of gravity to overcome the resistance, or drag, of the air. of two objects of equal weight, the smaller or more streamlined will fall faster because it does not have to push as much air out of its way. Thus, a flat sheet of paper falls slowly whereas the same sheet, when balled up, drops rapidly.

By tracking an object, a radar can measure its rate of slowdown and therefore the ratio of its weight to its area. In the thin air at high altitudes, however, differences in ballistic coefficient do not lead to large differences in rate of fall because there is not much drag. At low altitudes the differences are quite pronounced. Thus, discrimination on the basis of ballistic coefficient is more reliable at low altitudes.

Measuring the ballistic coefficient might not be sufficient for discrimination, however, since a small light decoy could have the same ballistic coefficient as a large heavy RV. It would in fact be quite difficult to design decoys which matched the ballistic coefficient of an RV at low altitudes since the shape of the RV (and hence its ballistic coefficient) changes in a complex way as its heat shield ablates. But as a hedge against a very carefully designed decoy, the defensive radar can employ another technique, involving the disturbance made in the air as the body passes through it, to obtain the area of the falling body. Combining the area with the ballistic coefficient gives the body's weight, a quantity that is not in the interest of the offense to match. Thus a low-altitude defense system which made use of these radar discrimination techniques would be virtually impossible to sidestep with decoys, since the fundamental discriminant is weight and the techniques rely on **the basic** properties of gravity and hydrodynamics.

Radar blackout is not a crippling problem for low-altitude systems as it is for high-altitude systems.

However, fireball effects impose a basic limitation on the effectiveness of low-altitude defenses. The ability of low-altitude or "deep endo" systems such as LoADS to make multiple intercepts within a short time over the same site — a conventional missile silo or a shelter in an MPS system — is severely constrained, no matter how many interceptors the defense deploys. This limitation arises both from blackout in the regions of nuclear fireballs and from trajectory perturbations suffered by follow-on RVS passing through these regions. The technical nature of this problem, and the extent of the I imitations it imposes, are discussed further in the Classified Annex. Even if a hypothetical future technology allowed the defense to overcome this fundamental limitation, there might still be strategies available to the attacker that were more efficient than saturation, such as precursor attack on the defense itself or use of various penetration techniques.

How Good is Good Enough?

It is an important feature of low-altitude systems that only aim to make an attacker target one more RV at each aimpoint that they do not have to be very capable to force an attacker to pay this price. In fact, if the defense is only good enough that it succeeds in making its single intercept more often than it fails — how much more often is irrelevant–the attacker will conclude that he makes better use of his RVS by targeting two RVS at a lesser number of defended aimpoints than by targeting one RV each at a larger number. The attacker's conclusion is not a result of conservative offensive perceptions but of sober calculation.

To take an explicit, if oversimplified, example, suppose an attacker has 1,000 RVS to target at 1,000 aim points, each of which is defended by a defense system whose goal is a single intercept per aimpoint. Suppose also that the defense performs so poorly that it succeeds in making an intercept only *51* percent of the time and fails 49 percent of the time. The attacker has the choice of targeting all 1,000 aimpoints with one RV (Case 1) or 500 aimpoints with two RVS (Case 2). In Case 1, the attack destroys 490 aim points because the defense fails this many times. In Case 2, all 500 aimpoints targeted 2-on-1 are destroyed by assumption. Thus the attacker concludes that he actually does better by "doubling up" on a smaller number of aimpoints (Case 2). But this is exactly what the defense seeks to force him to conclude.

Therefore, if the odds that a single-shot system actually makes its intercept are greater than 50 percent, it achieves its goal of forcing the attacker to target one more RV at each a impoint. Whether the odds are 51 or 99 percent is immaterial, since the offense does not have the option of targeting fractions of RVS at each aimpoint, but only one or two.

Once the limited single-shot goal is accepted, a relatively poor system is as good as a perfect one. Although low-altitude endo interception is a very challenging task, defense systems do not have to perform it very well if they accept a goal of only one intercept per aimpoint. This stands i n contrast to exo defenses, which aspire to a higher attack price than one RV per aimpoint. Such defenses are not worthwhile unless their performance is very good.

In the example above, the attacker was given the choice between l-on-l and 2-on-1 targeting of ballistic reentry vehicles. Stylized attacks or "reactive threats" involving nonballistic RVS, precursor barrages, radar interference, etc. pose another set of challenges to single-shot defenses which must be analyzed on a case-by-case basis.

The Need for Leverage

A generic low-altitude defensive system that could only claim a single RV per defended site would not be effective unless some additional defensive leverage could be found. One U.S. defense unit (radar plus interceptor) would be a poor cost trade for a single Soviet RV unless intercept of this single RV resulted in the survival of a defended target valuable to the United States. But this would only be the case if the number of targets were so large that the Soviets could not afford to target multiple RVS at each one. If the number of targets were small, the Soviets could attack each with multiple RVS, overwhelm the defense, and destroy the U.S. value at an extra price, relative to the undefended case, of a small number of RVS. For instance, 100 single-shot low-altitude defense units defending 100 silos containing MX missiles would only be able to claim 100 RVS from a Soviet arsenal of thousands.

Additional leverage for the low-altitude defense could be provided in three ways.

Deceptive basing, such as for LoADS in association with MPS, would allow a small number of defense units to force the Soviets to expend a large number of RVS because they would not know which shelters were defended and would have to assume that all 4,600 shelters contained MX missiles defended by LoADS. Therefore, 200 LoADS defense units capable of a single intercept each would be able to exact a price of 4,600 RVS, forcing the Soviets to attack each shelter twice for a total of 9,200 RVS.

A so-called "cheap" or "simple" defense system such as Swarm jet, to be discussed later, could conceivably improve the cost tradeoff for single-shot defense, but the overall attack price would still be small if the number of defended targets was small, as with silo basing. If the simple system were *very* inexpensive, one could conceive of deploying one defense unit with *each* shelter in a MPS system. This would have the same effect as deceptive basing without the need for PLU. There does not as yet appear to be a simple interception system cheap enough to allow this possibility. However, dust defense could be cheap enough to deploy in this way.

Last, a capable "Overlay" defense operating outside of the atmosphere would also be a powerful source of leverage for an associated "Underlay" endo defense. The Overlay (if effective) would thin the attack and break up the structured laydowns of RVS needed to penetrate the Underlay. The Soviets would have to target many RVS at each defended site in order that a few leaked through in the right sequence to penetrate the Underlay. Such an attack strategy based upon leakage through the Overlay would be costly of RVS and exceedingly risky for the attacker.

Because of the need for extra leverage, proposals of low-altitude defense for MX missiles have focused on deceptive low-altitude defense for a many-aimpoint MPS basing system or on Overlay/Underlay (Layered] defense for a force of MX missiles deployed in a small number of conventional silos.

LoADS With MPS Basing

LoADS Description

THE DEFENSE UNIT (DU)

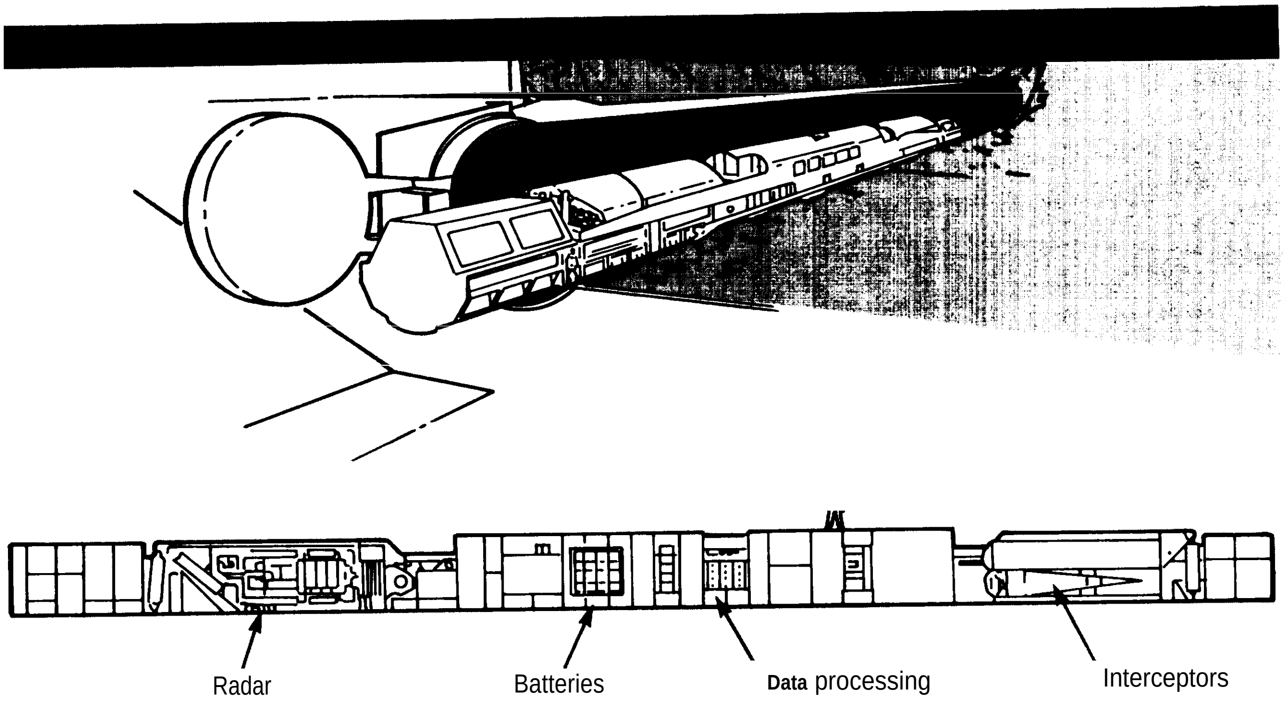
The LoADS defense unit (DU) would consist of a radar, data-processor, and interceptor missiles. The radar would be of the phased-array type, operating at high frequencies and with high power and narrow beamwidth for extra anti jam capability. The data processor would employ distributed processing for rapid throughput of large amounts of trajectory data. The interceptor missiles, roughly one quarter the length of an MX missile and half as wide, would be capable of extremely high accelerations and rapid change of direction, The inertially guided interceptor would be directed at launch towards a predicted impact point with the RV but its course could be updated in flight as well. The interceptor would be armed with a low-yield nuclear warhead. The technologies embodied in these elements of the DU represent significant advances beyond earlier U.S. endo BMD systems.

For the purpose of LoADS/MPS combination basing, the elements of the DU would be packaged into cylinders capable of fitting into the same spaces in the shelters and transporters occupied by the MX missiles and simulators (see fig. 60). The DU, MX cannister, and simulator would be so designed that they presented identical signatures to sensors which the Soviets might use to distinguish them in the shelters or in transit, It would be essential to the effectiveness of the LoADS/MPS combination that it be impossible to distinguish MX, DU, and simulator.

One DU would be deceptively emplaced in each cluster of 23 shelters, along with the MX missile and 21 simulators. The DU would be programed to defend the shelter containing the MX missile. Upon receiving warning of a Soviet attack, the DU would erect vertically, pushing the radar face and the interceptor cannister through the roof of the shelter (see fig, 61). The DU would then be ready to defend the shelter containing the MX. Breakout would be an irreversible process, since it would destroy the roof of the shelter. Various schemes have been studied to avoid breakout. For instance, the DU could roll out the door of the shelter and erect like the MX missile. But the DU in this exposed position would be too vulnerable to destructive effects of nearby nuclear detonations. The broken-out DU would still have the protective shielding and structural support of the remainder of the shelter.

It would be absolutely essential that the defense received adequate warning that Soviet RVS were approaching so that it could awake electronic equipment from its dormpnt state and break out. It appears that this process of readying the LoADS DU could be performed in a short period of time. If achievable, this would mean that it would not be necessary to have warning sensors which detected a Soviet attack at the moment of launch, but only as the attacking RVS approached the United States. This late warning would be easier to provide than the early warning required to support launch under attack or exo BMD. It would also be easier to protect warning sensors of this type from a Soviet precursor attack. it might also be desirable to have some information ,about the size of the attack before a decision were made to break out. (This is discussed further in the context of Shoot-Look-Shoot in the Classified Annex.) Finally, the command, control, and communications to support timely breakout would require procedures and hard\ware immune to a determined Soviet ef-

Figure 60.— LoADS Defense Unit Before Breakout (human figure indicates scale)



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fort to disrupt them. Several technically feasible approaches to these problems have been proposed, and their provision would be essential to effective defense.

LoADS OPERATION

The LoADS DU in each cluster would be programed to defend the shelter containing the MX missile, Since the Soviets would not know which shelter contained the MX if PLU were maintained, they would have to assume for targeting purposes that each of the 23 shelters contained an MX missile defended by LoADS LoADS would intercept the first RV attacking the MX shelter, so the Soviets would have to target ***each shelter twice*** in order to destroy the MX. LoADS would double the price the Soviets would have to pay for an MX missile from 23 to 46 RVS. Thus U.S. deployment of LoADS would be essentially equivalent to doubling the number of shelters in the MPS deployment while keeping the number of missiles the same.

deployment while keeping the number of missiles the same.

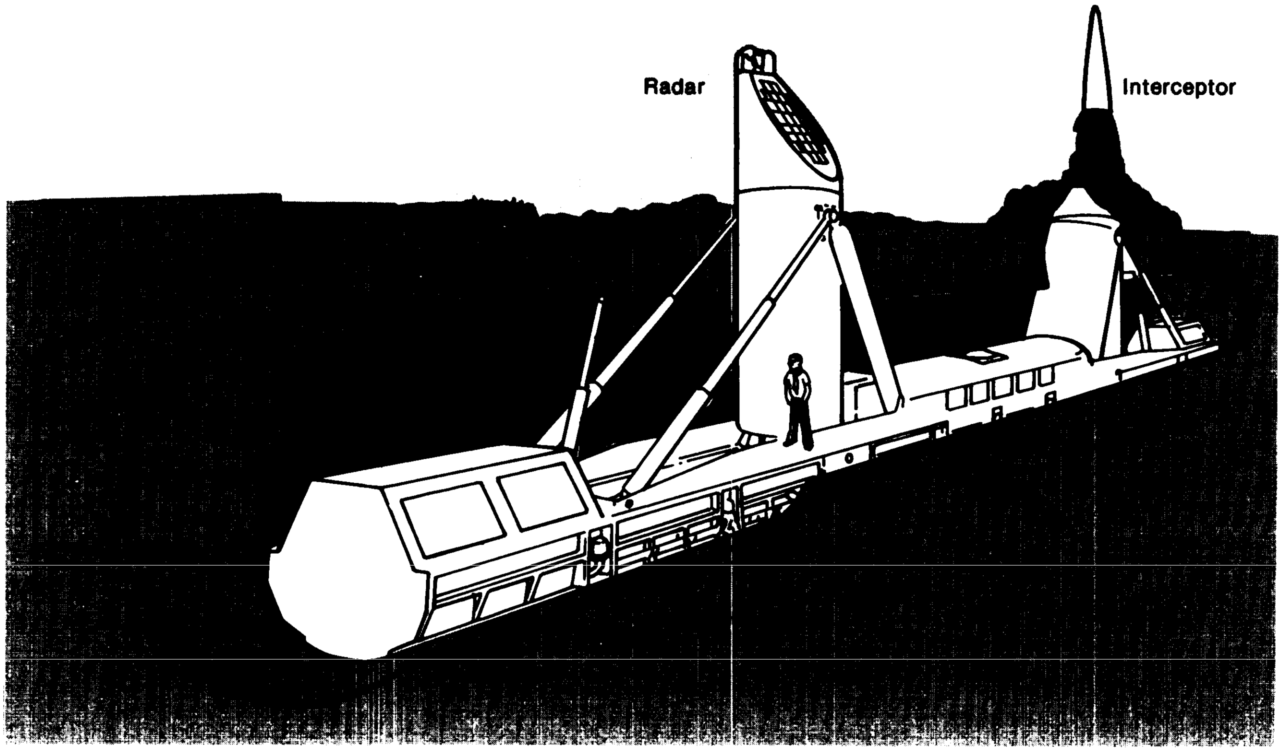
It is desirable for each DU to have more than one interceptor in order that it could defend itself if it came under attack before the MX shelter did.

It would be essential that the location of the MX be unknown to the Soviets. It would also be necessary to conceal the location of the DU, since if this were known the Soviets could attack the defense first, forcing it to use up its interceptors in self defense, Subsequent attack on the other shelters would find them undefended.

LoADS WITH VARIANTS OF MPS

The operation of LoADS would be essentially unchanged if the MPS deployment were organized into "valley clusters" containing several missiles instead of discrete clusters of

Figure 61 .— LoADS Defense Unit After Breakout (human figure indicates scale)



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23 shelters for each missile. A DU could still be provided to defend each missile, and the attack price per missile would again be doubled.

From the point of view of LoADS defense, there would be significant tradeoffs between horizontal and vertical shelter deployment but no clear reason to prefer one to the other. For vertical shelters, it would be necessary to put the radar and missile cannister in different shelters, since they would be too large to fit side-by-side in a single shelter. There would have to be a data link to connect the two elements of the defense unit. Since the units would be moved from shelter to shelter periodically, the communications equipment would have to connect all pairs of shelters, potentially a costly addition. The links would furthermore have to be resistant to disruption from nuclear effects. On the other hand, breakout would not be required, since the defense could egress through the blast door of the vertical shelter. Matching four objects (MX, simulator, radar module, and interceptor cannister) would be more difficult than three, but there would be more design flexibility for the separate radar module and interceptor cannister because each would be, so to speak, "half empty. " The extra room could be used for PLU countermeasures. Protecting the DU elements from nuclear effects could conceivably be easier for vertical shelter deployment.

It is not possible at this time to assess these tradeoffs in detail, but it is not apparent that either vertical or horizontal offers clear advantages. More study has been made of the horizontal alternative.

LoADS Effectiveness

Active defense systems are very complex: the interception process is complicated, with many distinct sources of leakage and wastage. There are many attack scenarios, offensive countermeasures, and defensive counter-countermeasures to consider Analysis of the effectiveness of a BMD system can therefore be more involved than analysis of basing systems that ensure survival of MX by passive means such as mobility, concealment, or deception It is therefore important in assessing how well LoADS would do its job to be very clear what that job is

Suppose LoADS sought to double the price the Soviets would have to pay to destroy an MX missile from 23 RVs to 46 RVs, In this case, LoADS would have the rather modest task of intercepting the first RV targeted at the MX missile within each cluster I n order to destroy the MX missile within a cluster, the Soviets would have to target two RVS, or "double up, " at each shelter, This assumes that PLU would be successful and the Soviets would have no knowledge of the location of the MX or the DU.

In fact, LoADS could exact the price of 2 RVS per shelter even if the defense system were rather inefficient. Roughly speaking, if the Soviets believed that LoADS would successfully intercept the first RV targeted at the MX shelter more *than half of the time*— that is, if the efficiency of LoADS were greater than only 50 percent — then the Soviets would calculate that they made better use of their RVS by doubling up on fewer shelters than by targeting many shelters with one RV,

For example, suppose that the Soviets had 6,900 RVS to target at 4,600 MPS shelters, (These numbers are chosen to make the arithmetic easy and for no other reason,) Suppose also that LoADS were only *51-percent* efficient in a 1 -on-1 attack: that is, if one RV were directed against every shelter, LoADS would successfully intercept 51 percent of the RVS directed at the shelters containing MX. This is the same as a leakage of 49 percent. Assume also that all targeted Soviet RVS actually arrived on target and further that if two RVS arrived at the MX shelter within a short space of time, LoADS would not even attempt to intercept the second and the MX missile would be destroyed,

The Soviets would have the choice of using their 6,900 RVS either to target 100 clusters (2,300 shelters) with one RV and 100 clusters (2,300 shelters) with two RVS (Case 1) or to double up on 150 clusters (3,450 shelters) and leave 50 clusters (1,150 shelters) untouched (Case 2). In Case 1, all 100 MX missiles targeted 2-on-1 would be destroyed, and 49 of the missiles targeted l-on-l would be destroyed because LoADS would only be 51-percent efficient by assumption. Thus in Case 1 the Soviets would destroy 149 MX missiles, In Case 2, the 150 missiles targeted 2-on-1 would be destroyed and the remaining 50 untouched The Soviets would therefore actually destroy more MX missiles by doubling up (Case 2), even though LoADS failed to make an intercept almost as many times as it succeeded.

It therefore appears that LoADS would not have to be very efficient to exact a price of two RVS from the Soviets. At the same time, it would be exceedingly difficult to exact a price of several RVS.

So far, the analysis has considered only simple 1 -on-1 or 2-on-1 attacks. The conclusion is that, as far as these attacks are concerned, and *assuming* the DU survives nuclear effects to do its job and that PLU is maintained, it is possible to have confidence that LoADS is capable of its job. Although low-altitude interception of RVS is a very challenging technical task, and there are many uncertainties about LoADS operation and potential contributors to inefficiency (radar and interceptor performance, RV radar cross sections, radar traffic handling, kill mechanisms, etc.), there are none which should stop LoADS from doing its job as well as it needs to,

If the defense only sought to make one intercept over the MX shelter, then the United States could assume that the Soviets would pay the price of 46 RVS per MX missile if given the choice of l-on-l or 2-on-1 targeting. Could

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they do better by using special attack strategies?

There are many such reactive threats to LoADS, For instance, decoys are a hypothetical threat: precision decoys seek to fool the radar into intercepting them, while traffic decoys simply aim to fool the radar long enough to consume precious data-processing time. As discussed in the Technical Overview, the ability of radar to weigh falling objects at low altitudes means that decoys are probably not a serious threat to LoADS. Jammers deployed along with attacking RVS could seek to blind the radars. Maneuverable reentry vehicles (Ma RVs) could try to evade the interceptor; and if MaRVs were provided with radar- homing devices, they might destroy the LoADS defense units before they had done their job. These reactive threats are discussed in the Classified Annex. Defense barrage, blackout, and exhaustion attacks are discussed under Hardness to Nuclear *Effects* and its Classified Annex, and Spoof and Shoot-Look-Shoot, both threats to deception, are discussed under *Preservation of Location Uncertainty [PLU)* and its Classified Annex.

One can raise legitimate questions as to whether a prudent Soviet planner would use any of these techniques to sidestep LoADS, but the defensive planner must fortify the system design against all of them. The attractiveness of these special threats to Soviet planners would presumably be weighed against the benefits they would derive from the simple expedient of deploying two Soviet RVS for every U.S. shelter. Detailed analysis of these special threats, presented elsewhere in this report or its Classified Annexes, indicates that some of them are worrisome and represent a long-term risk to the effectiveness of LoADS/MPS.

Hardness to Nuclear Effects

The close shelter spacing–1 mile–means that LoADS must operate in a nuclear environment of a severity unprecedented for so complex and exposed a piece of equipment. Failure to meet the requirements could lead to pronounced degradation in system performance. It is also vital that measures taken to protect the DU do not betray its location, i.e., break PLU. Providing for nuclear hardness requires detailed understanding of the expected nuclear environment and its effect on critical mechanical and electrical components. Especially important for LoADS, given the unprecedented character of the hardness requirements, is testing of actual equipment. DU design and nuclear effects analysis—and, in the case of LoADS, PLU analysis — must proceed in concert. These studies are just beginning. Testing is required before it will be possible to have confidence that LoADS can meet its hardening needs, especially within the severe design constraints imposed by PLU.

AS with the analysis of system effectiveness, it is important to have a clear idea of LoADS' hardening needs and of the consequences of failing to meet these needs. The key requirements concern the survival of the DU, and especially the radar, after it has broken out of the shelter and is waiting to intercept the RV targeted at the MX shelter. Other concerns, probably less serious, are the hardness of the interceptor as it flies to make its intercept and the hardness of the DU before it breaks out.

HARDNESS OF THE DU AFTER BREAKOUT

For LoADS to do a single-shot job, no less than 46 Soviet RVS may suffice to destroy an MX missile. The attacker must either be made to fail to destroy the DU before it has made its intercept or be made to pay a heavy enough price to destroy the DU that nothing is gained by trying.

The hardness of the broken-out DU defines a "keep-out zone" around the unit: RVS which detonate within the keep-out zone are assumed to destroy the DU and must be intercepted if they arrive before the DU has made its intercept above the MX shelter. It is for self-defense that each DU should contain more than one interceptor missile.

Inadequate nuclear hardening would mean that the keep-out zone was too large. An illustrative, if presumably exaggerated, example consists of a DU so soft that a detonation anywhere within its shelter cluster would impair its function. In this case, the Soviets could target a few RVS (perhaps of higher yield than those targeted at shelters) to arrive at random locations within each cluster a few seconds before arrival of the main attack. The main attack would consist of one RV on each shelter. The DU would have no choice but to intercept all of the precursors, for otherwise it would be rendered inoperable, If there were as many precursor RVS as interceptors in the DU, then all the interceptors would be used up in self-defense, The main attack would then find the cluster undefended, as though LoADS did not exist. The attacker would then have paid not 46 RVS, but rather the undefended price of 23 RVS plus just a few additional RVS to exhaust the defense,

The defense suppression barrage described above is one of several scenarios where LoADS hardness plays a crucial role, In all of these scenarios, the attacker seeks to destroy an MX missile for an attack price of less than 46 RVS, The results of a more detailed analysis, presented in the Classified Annex, indicates that the 1-mile shelter spacing imposes severe requirements on the DU. Unlike the MX missile, protected by its steel and concrete shelter and several feet of earth, the DU is directly exposed to the nuclear effects. Not only must the DU survive, but its complex components must function through the attack. Thus, some effects— prompt radiation, certain effects of electromagnetic pulse (EM P), dust, etc. — which are not important for missile protection are severe threats to LoADS. Defense performance, measured by vulnerability to these stylized attacks, might be degraded appreciably by shortcomings in hardening.

Work on LoADS hardening so far has concentrated upon defining quantitatively the nuclear effects which the DU must be able to endure, not providing design fixes for potential vulnerabilities, Even defining the effects will require testing, since in some respects they exceed the predictive power of computer simulation codes. Understanding the interaction or "coupling" of these effects to the peculiar geometry of the broken-out DU, to electronics, and to radar performance will also require testing.

Nothing that is done to ensure its hardness must permit the DU to be detected when it is in the shelter. If the Soviets were able to detect which shelter contained the DU, they could target that shelter with a few precursors, forcing it to exhaust itself in self-defense. This and other threats to PLU are discussed in the next section. The important point is that hardening the DU —adding shielding, structural support, etc. — must not provide a signature which would allow the Soviets to detect the DU'S location. This synergism of hardness and PLU is a matter of testing and detailed design which has not yet been done.

Ensuring adequate hardness for the broken-out DU is thus a challenging task, and it will require some time 'before uncertainties can be reduced to levels where a final judgment is possible.

It is important finally to note the constraints that would act upon the offense if it were to seek to exploit potential vulnerabilities in LoADS. If the Soviets were to fractionate so as to be able to target as many shelters as possible, they would have to reduce the yields of their RVS. The lower yields would significantly alleviate the nuclear effects on LoADS in some, though not all, circumstances. If on the other hand, the Soviets kept their yields high with the aim of exploiting potential LoADS vulnerabilities, it would be difficult for them to fractionate their missiles,

HARDNESS OF THE IN-FLIGHT INTERCEPTOR

As the missile flew towards its intercept point, it would be buffeted by the shock waves from nearby detonations. Though the interceptor has the ability to correct its course, it has a limited duration of powered flight. If intercepting an RV at a relatively distant point, burnout would be complete before the interceptor reached the RV, When coasting in this way, it would have less ability to correct its course than when burning.

Interference with interceptor performance due to nuclear effects such as shock waves is one of the many contributors to system leakage. As described in the previous section, LoADS can tolerate a large leakage without impairing its overall effectiveness. Thus in-flight nuclear effects might not **serve** to increase leakage above an acceptable point. However, interceptors flying out to attempt multiple intercepts would be forced to fly in a severely disturbed environment.

HARDNESS OF THE DU IN THE SHELTER

In the context of a Spoof or Shoot-Look-Shoot attack, to be discussed in the next section, the DU might be required to survive a light precursor attack before it broke out of its shelter. I n this situation the DU would be relatively secure because it would be in the shelter and the scenario cal Is for a light attack.

Additional discussion of the problems with meeting LoADS' nuclear hardening requirements can be found in the Classified Annex.

Preservation of Location Uncertainty (PLU)

Successful deception is vital to LoADS' defensive leverage. If the location of the DU were known to the Soviets, they could exhaust the defense with a precursor attack. A subsequent one-on-one attack would find the shelters completely undefended, What is more, under certain circumstances, a breakdown of PLU for the LoADS DUS could cause a breakdown of PLU for the MX missiles as well. In this case, the United States would be worse off than if there were no defense at all.

For undefended NIPS, PLU appears to be a complex and challenging technical enterprise, but no signatures of the MX missile have been identified which present clearly insurmountable problems. PLU for the LoADS/MPS combination has not yet progressed this far, and the problem will have to be reduced to a comparable "acceptable" level of detail. In particular, the design requirements imposed by nuclear hardening must be taken into account.

Even if no "Achilles' heel, " or gross signature of the DU which is fundamentally incompatible with PLU, is found, a complex engineering task faces the LoADS designer. In the case of MPS alone, one is presented with 200 missiles and the task of creating 4,600 simulators which resemble the missiles in all observable respects. The simulator is created de novo, with no a priori constraints save to match the MX. The LoADS Defense Unit, on the other hand, is a functional object with unique signatures, related to its operation, which cannot be suppressed. It would therefore be virtually impossible to make the DU match a set of missiles and simulators which were not designed with the LoADS option in mind. The three objects — MX, simulator, and DU — must all be designed in concert.

PLU is therefore considerably more complex for MPS defended by LoADS. It is too early to tell whether deception can be arranged at all, but it is probable that the 200 missile canisters and 4,400 simulators would have to be altered from 'time to time as design and testing proceeded to accommodate distinctive features of the DU. The later that a decision were taken to give LoADS a place in the design of the overall system, the riskier and more costly the PLU process might become.

in addition to signatures, the operations by which the MXS and DUS were shuffled periodically among the shelters must not betray the location of either. It appears that acceptable "movement algorithms" can be devised to preserve PLU for both MX and DU simultaneously, whether the system were organized into individual clusters of 23 shelters or into larger "valley clusters. " it should be noted that if rapid reshuffle were required to redress actual or suspected loss of PLU, extra time might be required, depending on the availability of transporters, to move the DU as well as the MX missil e.

There is some concern regarding a tactic for attacking LoADS/MPS, called Shoot-Look-Shoot, whereby the Soviets could in principle induce a breakdown of PLU. I f the Soviets launched a first wave of attacking RVS which caused the LoADS DUS to break out and expose their locations to remote Soviet sensors, a second wave could be targeted on the basis of known DU locations. They would then be able to destroy MX missiles at about the undefended price or even less. However, to sidestep the defense in this way, the two waves of attacking RVS would have to be well-separated in time. The Soviets would therefore have to reckon with the possibility that the United States would simply launch MX missiles at the Soviet Union between waves rather than await the outcome of a subtle Soviet strategy. For this and other reasons, reliance on Shoot-Look-Shoot would entail high risk to the Soviets, The Soviets would presumably weigh these risks against the simpler expedient of building more RVS and attacking the shelters directly

There are two scenarios for which a Soviet Shoot-Look-Shoot capability could be intended. In the first (sometimes called "Spoof") scenario, an initial attack on LoADS/MPS is intended to cause the DUS to break out of their shelters. A second wave of RVS is then targeted on the basis of known DU locations. I n the second case, appropriate to long war scenarios, a second attack is not necessarily planned at the t i me of the first, but after an initial exchange in which the DUS had broken out to perform their defensive job, the Soviets could sense the locations of the exposed DUS. I n a subsequent exchange, the remaining U.S. force would be left essentially undefended. Shoot-Look-Shoot would in this case mean that the LoADS defense did not have the endurance that the MX missiles themselves would have.

Since deception is necessary for defense effectiveness, since the defense unit must break out and expose itself to defend, and since the Soviets would know that a shelter defended in the initial attack must have contained an MX missile, a Shoot-Look-Shoot strategy would enable the Soviets to compensate for LoADS with only a few hundred more RVS than they would need to attack an undefended MPS, *pro-provided* the U n i ted States did not launch out between the first and second waves Calculations of the outcomes of various Shoot-Look-Shoot scenarios, and a discussion of the problems faced by the offense in mountin g them and the defense in countering them, are provided in the Classified Annex.

Cost and Schedule

OTA has not performed independent cost and schedule analysis for the LoADS/MPS combination. The data presented in this section were supplied to OTA by the Army's Ballistic Missile Defense Systems Command (BMDSCOM). Comments that accompany these data are those of OTA and do not necessarily reflect opinions of BMDSCOM.

The Army's most recent (October 1980) cost estimate to deploy a LoADS defense for the 4,600-shelter Air Force baseline MPS system and operate it for 10 years is 8.6 billion constant fiscal year 1980 dollars. The $7.1 bill ion acquisition cost would include the costs of the DUS, 200 separate transporters to move the DUS, a modest amount of construction of operating buildings in the deployment area, and program development and management. Operating costs are estimated at $153 million per year. A detailed breakdown is presented in table 20. These cost estimates do not include the costs of potential modifications to the Air Force baseline system in order to accommodate LoADS nor the cost of additional tactical warning and threat assessment systems and command, control, and communications (C) systems to support LoADS.

The present LoADS Program schedule is funding- and Treaty-constrained, and precise schedule information is classified. A schedule

Table 20.—Army's LoADS Cost Estimate, October 1980'
(constant fiscal year 1980 dollars in billions)

Research, development, testing, and engineering	1.75
Defense units	3.20
Transporters	1.13
Military construction	0.16
System engineering and program management	0,54
Other investment	0.32
Acquisition cost	7.10
Operations cost (10 years @ 0.15)	1.53
Total	8.63

[a]From figures supplied by Army BMDSCOM

SOURCE Off Ice of Technology Assessment

that assumes that the decision to remove constraints were not made until late in the decade provides for final operating capability (FOC) for the LoADS addition to MPS several years after MPS FOC. This schedule would not require amendment of the ABM Treaty reached at SALT I until later in the decade.

An accelerated schedule, assuming an early decision and release from constraints, could provide for LoADS deployment on about the same schedule as MPS deployment. This would require early amendment or abrogation of the ABM Treaty and funding well above that now projected for the LoADS Program.

Other Endo Concepts

Other endo BMD concepts besides LoADS have been proposed and investigated. Dust defense is technically feasible and very capable but could have very low public appeal as well as a few potential technical drawbacks. Terminal or low-altitude defenses based on “simple” or “novel” concepts could be adequate as single-shot last-ditch defenses of hardened targets against a small attack but have not been proposed with the demanding MX role in mind. The Army’s Site Defense represents the technology of the 1970’s and is inadequate for the MX role.

Dust Defense

Dust defense–also called environmental defense – provides for burying “clean” nuclear weapons in silo or MPS fields and exploding them shortly before attacking RVS arrive. The dust and debris lofted into the air would destroy approaching RVS either by direct collision with large earth fragments or by dust erosion of the RV’S heat shield. The detonations would be placed so as not to damage the ICBMS in their silos or shelters.

There are two possible ways of employing dust defense. In the first, nuclear weapons would be buried north of each silo or shelter and exploded seconds before RV arrival. Small radars placed north of each site would provide the detonation signal. The RV would be destroyed in passage through the dense plume of debris thrown up immediately by the explosion. The dust cloud which forms a little later at higher altitudes would provide additional protection for a longer period of time than the debris stem, which falls back to Earth in a short time.

In the second scheme, a smaller number of weapons of higher yield would be exploded throughout the fields several *minutes* before Rv arrival, The heavy debris would thus have fallen by the time the RV arrived, but by that time the dust cloud would have formed. Since the dust cloud from a high-yield weapon can be tens of miles in width and breadth, many silos could be protected by a single dust cloud. Protection would last for approximately 20 minutes after which another set of weapons would have to be detonated to provide continuing protection.

The weapons detonated would destroy far more megatonnage than they constituted themselves, a fact which makes the deliberate detonation of nuclear weapons on U.S. territory somewhat more palatable from the standpoint of fallout. But a more important factor in reducing fallout is the possibility, much discussed in the 1960’s at the time of the PLOWSHARE Program studies of the peaceful use of nuclear explosions, of constructing nuclear weapons which produce very little residual radioactivity.

Conventional nuclear weapons give rise to radioactive fallout in two ways. First, a certain fraction of the weapon yield is produced by fission. The fission products are unstable isotopes which give off harmful radiation when they decay into more stable species. The rest of the weapon yield is provided by fusion. Large numbers of neutrons are formed in the fusion process, and when these neutrons encouunter ordinary material in the vicinity of the detonation, they transform it into radioactive material.

Clean weapons reduce both sources of fallout. First, the clean weapon is constructed in such a way that very litle of the yield is due to fission, Second, one can surround the weapon with material, such as berated water, which absorbs the fusion neutrons readily without becoming radioactive Such a clean bomb is not as compact as an ordinary nuclear weapon. It might occupy the volume of a room. For that reason, underground vaults would be dug in the silo fields to house the clean weapons. In this way the radioactivity from the clean explosions could be reduced to about one one-hundredth of the radioactivity from conventional nuclear weapons of equal yield

Though there is some uncertainty in the composition of the stems and dust clouds formed in nuclear explosions (which cannot be entirely resolved within the Test Ban Treaty), there is general agreement that dust defense is an effective way to destroy attacking RVS There appear to be no effective measures that the Soviets could take to protect their RVS. Moreover, large numbers of RVS could be destroyed within a short space of time i n this way, a feat that is impossible for more conventional endo defenses

Potential drawbacks to dust defense, besides its perceived unpalatability, are the need for warning, the need to provide multiple explosions if the attack occurs in waves well-spaced in time, and the fear of error

The cloud variety of dust defense requires warning because the weapons must be detonated sever-a I minutes before attacking RVS arrive. I n principle, the stem variety does not require warning beyond that provided by its radar, but it might be considered inadvisable to keep the system activated at all times, since a radar malfunction in peacetime might cause inadvertent detonation Since warning is not needed until late in the flight of the attacking RVS in either case, it is easier from the technical point of view to provide an adequate system of this type than one which provides warning at the time of missile launch. This type of warning is needed by all endo defense systems.

An attack that came in waves could require multiple detonations. If backup weapons were buried to provide the capability for multiple detonations, the weapons would have to be spaced far enough apart that the first detonation did not destroy the remainder One U.S. response to a multiple-wave attack would simply be to launch in retaliation rather than await the next wave, Offensive missiles can be made that can launch through dust clouds without damage. Dust defense could therefore extend the timeline for launch under attack by forcing the Soviets to attack in two waves. The first wave would be destroyed by the dust, and the second wave could not be launched until the dust cloud had dispersed. The United States would have this extra time to decide on a reponse.

Error in the form of inadvertent or unauthorized detonation of the buried weapons could be avoided by the same set of procedures which prohibit launch of offensive missiles. The real possibility of error lies in a false warning message causing authorized detonation Fear of this type of error and procedures to avoid it could lead to another type of error: failure to authorize detonation when the warning information was correct, The problems here are similar to those of a launch under attack system.

Dust defense could therefore be by far the most potent endo defense system. However, it is seldom taken seriously because of concern for public reaction.

Simple/Novel Systems

Simple/novel systems is a catch-all for a wide variety of low-altitude or last-ditch defenses of hardened targets. Examples go by such names as Swarm jet, Porcupine, Gatling Guns, SID CEP, Quickshot, SSICM, Bed of Nails, and Agile, The interceptors consist of rockets, shells, or inert projectiles with or without nuclear warheads and guided by land-based radars or homing sensors. Not all are simple, though many are novel indeed. LoADS itself could be classed with these systems, since it has a similar goal.

Because low-altitude defenses cannot guarantee multiple intercepts over a single target in rapid succession, they are inadequate to defend a small number of targets against a large Soviet threat Indeed, most simple/novel systems were conceived as cheap and quickly deployable ways to increase the Minuteman attack price and create uncertainty for Soviet targeters.

Some simple/novel systems might therefore have capabilities similar to LoADS, though none has been studied in the depth that LoADS has A simple/novel system might therefore in principle be capable of replacing LoADS in the MPS basing role. This could come about either by providing a last-ditch system simple and cheap enough to deploy in association with each of the 4,600 MPS shelters, or compact enough to fit into a shelter deceptively I ike the LoADS Defense Unit, However, none of the concepts yet proposed combine confidence in technical feasibilty with low cost or smal I size such that they would be attractive replacements for LoADS in the MPS role.

Because of the interest in simple/novel systems, two of the most promising examples are discussed briefly below,

SWARM JET

The Swarm jet concept consists of radars deployed north of each defended site and a launcher located near the site and containing thousands of spin-stabilized, rocket-propelled projectiles, When the radar detects an attacking RV, the launcher pivots in the direction of the predicted intercept point and the projectiles launch into the threat tube in a swarm. Each projectile weighs a few pounds and is designed to destroy an RV completely in a hypervelocity COII ision seconds before arrival at the silo Swarm jet is designed to be constructed from already-available or easily manufactured components.

The object of the defense is to fill the sky in the path of the attacking RV with enough projectiles to assure high probability of collision. Though there is agreement among those who have studied Swarm jet that collision with a projectile will indeed destroy an RV, there is disagreement about how may projectiles are needed to assure a high collision probability. This disagreement translates into uncertainty in the size and cost of an effective Swarm jet deployment. Factors that enter into the uncertainties are radar performance, the pointing and aerodynamic properties of the projectiles, and the effects of blast waves from precursor or nearby nuclear detonations.

Like other low-altitude defenses, Swarm jet is essentially a single-shot system and could therefore claim with confidence only one RV per silo from an attacker. The Swarm jet launcher might be too large to fit into an MPS shelter; if this were the case, the only way to deploy it with MPS basing would be to provide one Swarm jet unit for each shelter. This would be costly but might deserve consideration if deception proves too cliff icult for LoADS/MPS.

AGILE INTERCEPTOR

The idea of an Agile interceptor is to get beyond the single-shot limitation of low-altitude systems by providing an interceptor so maneuverable that it can intercept follow-on RVS after detonation of a first despite poor radar impact-point prediction due to firebal is and despite being thrown off-course by blast waves and winds, This program is i n the research stage.

The goal of the Agile interceptor is to intercept a few, but not many, RVS over a single silo. Because its goal remains modest and because the technology is yet unproved, this concept is considered unsuitable for MX defense.

Site Defense

The Army's Site Defense is a derivative of the Sprint component of the Safeguard defense system of a decade ago. As a high-altitude endo system, it is susceptible to blackout, penetration aids, and direct attack on its few, large radars, as described in the 7-echn;ca/ *Overview.* Based on the technology of the 1970's, Site Defense is preserved as an option in the event of a decision to field a BMD system based on known technology in a short period of time.

Though inadequate for the role of MX defense, Site Defense could be appropriate for other BMD roles. For instance, it could be used as a "threshold defense" for some important U.S. assets such as warning sensors. In the concept of threshold defense, no pretense is made that the defense can ensure survival of the defended asset; its role is rather to increase the attack price to the point where a Soviet attempt to destroy the defended targets would require such a large attack as to constitute a major provocation deserving of major U.S. response.

EXOATMOSPH ERIC AND LAYERED DEFENSE

Technical Overview of Exo BMD

Exoatmospheric — "exe" — defense holds high promise in theory because the long flight times of RVS outside the atmosphere and the large battlespace mean that many RVS **targeted at the same site can be destroyed. In contrast to low-altitude systems, systems with an exo component could** in theory defend a small number of targets such as MX silos against a large number of Soviet RVS, Additional strengths of exo BMD are the feasibility of nonnuclear kill, the possibility of mounting multiple interceptors on a single booster rocket, and the concept of adaptive preferential defense

Theoretical Advantages to Exo Operation

Nonnuclear kill is possible in space for several reasons First, the defensive sensors would have a relatively long time–minutes, as opposed to seconds for an endo defense— to track their targets, and the trajectories of attacking RVS would be predictable because they would be passing through empty space. It would therefore be possible for the interceptor to aim close enough to the RV that the large destructive radius of a nuclear warhead would not be necessary Deployment of barriers of material in the paths of approaching RVS would also be easier in the vacuum of space. Nonnuclear kill is preferable to nuclear methods because a nuclear defense's own warheads could interfere with its sensors (assuming the offense did not employ its own nuclear precursors), nuclear warheads are relatively expensive and heavy, and activation of a nuclear defense would require procedures for authorized nuclear release.

Interceptors boosted into space for exo defense could also carry many individual kill vehicles — much as a MIRV'd missile carries many RVS — resulting i n some savings considering the cost of putting defensive vehicles into space in the first place. Multiple warheads on the same interceptor are impractical for use with in the atmosphere, where the engagement timelines are too short to make multiple deployments feasible.

Preferential defense is a tactic for multiplying the effectiveness of a defensive system if it is only required to defend a subset of the targets under attack, For instance, suppose MX missiles were deployed amongst the six Minuteman wings and that survival of the missiles in two of these wings against a Soviet attack was considered a sufficient goal for the defense. The defense could then concentrate its exo interceptors upon destroying RVS targeted at the two defended wings and abandon the other four wings to the attacker. Which two wings were chosen for heavy defense could be kept secret from the Soviets or decided by the defense at the last minute, In their targeting planning, the Soviets would be unable to concentrate their RVS on the defended wings: they would either have to do their targeting as though all the wings were heavily defended or grant the defense its goal of two surviving wings. Adaptive preferential defense therefore effectively multiplies the number of defensive interceptors, In this example the Soviets would behave as though all six wings were defended as heavily as the two singled out by the United States. Adaptive preferential defense is not an effective tactic for endo systems because endo interceptors must be located near to the targets they are defending. The presence of the defense near the defended sites therefore gives the game away.

Infrared Sensing

An exo system that used large ground-based radars to acquire targets outside of the atmosphere could be blinded by direct attack or high-altitude blackout, and the view of ground-based optical sensors, which would be inadequate in any event, could be obscured by clouds and dust. It is therefore desirable to put the defensive sensors into space, either on the interceptors themselves or on other space vehicles. Space-based radars would be heavy, costly, and susceptible to jamming. For these reasons, many exo concepts employ space-borne passive infrared sensors, which are relatively light and compact, However, infrared sensors are susceptible to offensive countermeasures such as decoys and other penetration aids.

Layered Defense

Like endo systems, exo defense alone would be indequate to defend a small number of targets against a large number of attacking RVS. In this case, the reason is not saturation of the defense, but the cumulative effect of leakage. It only takes one leaker to destroy a silo. If many RVS were aimed at each silo, the odds that one would get through could be high even if the probability that each individual RV was intercepted were high. The defense could attempt to stanch this hemorrhage of leakers by attempting to intercept each RV more than once *(assuming* that the multiple interceptor vehicles targeted at the same RV would not interfere with one another). This tactic could be effective but would drive the defense to enormous arsenals of interceptors.

If an endo defense were associated with each silo, the combined exo/endo Layered Defense would be more effective. The endo system could catch leakers from the exo system and, moreover, the exo system would improve the performance of the endo system since it would break up the concentrated, structured attack patterns which saturate endo systems. Thus, exo (Overlay) and endo (Underlay) defenses in a Layered combination have a synergistic effect wherein the principal I imitation of each is alleviated by the presence of the other. An endo defense could also help to protect the launch sites for the Overlay interceptors from a disabling precursor attack. It would also be difficult for an attacker to designl decoys to confuse both the Overlay sensors *and* the Underlay sensors. However, since decoys are ineffective against low-altitude radar sensing anyway, an attacker would probably concentrate his penetration aids against the Overlay and not try to fool both layers. Last, the tactic of adaptive preferential defense for the Overlay loses some of its attractiveness when there is an Underlay because the Underlay cannot adapt: it can only defend the area (or individual silo) near which it is deployed. If the defense concentrates its Overlay resources on a subset of the silos and abandons the others to the attacker, then it leaves the endo defenses associated with the abandoned silos open to easy saturation and penetration. These endo resources—all bought and paid for— are wasted, whereas the whole purpose of adaptive preferential defense was to make optimum use of defensive resources.

The Importance of overlay leakage

In contrast to low-altitude systems, which can accept relatively high leakage and still do a single-shot job, high performance is required of the Overlay component of a Layered Defense. Thus one must take seriously the many sources of leakage which can be present in the complex process of exo interception and also the possibility of having to face attacks involving decoys and other penetration aids, In practice, poor Overlay performance drives the defense to large inventories of interceptors in order to maintain a given level of silo survival. The effect of this sensitivity to Overlay leakage is best illustrated in the context of specific calculations, Such calculations are presented in the next section,

The Overlay and Layered Defense of Silo-Based MX

Overlay Description

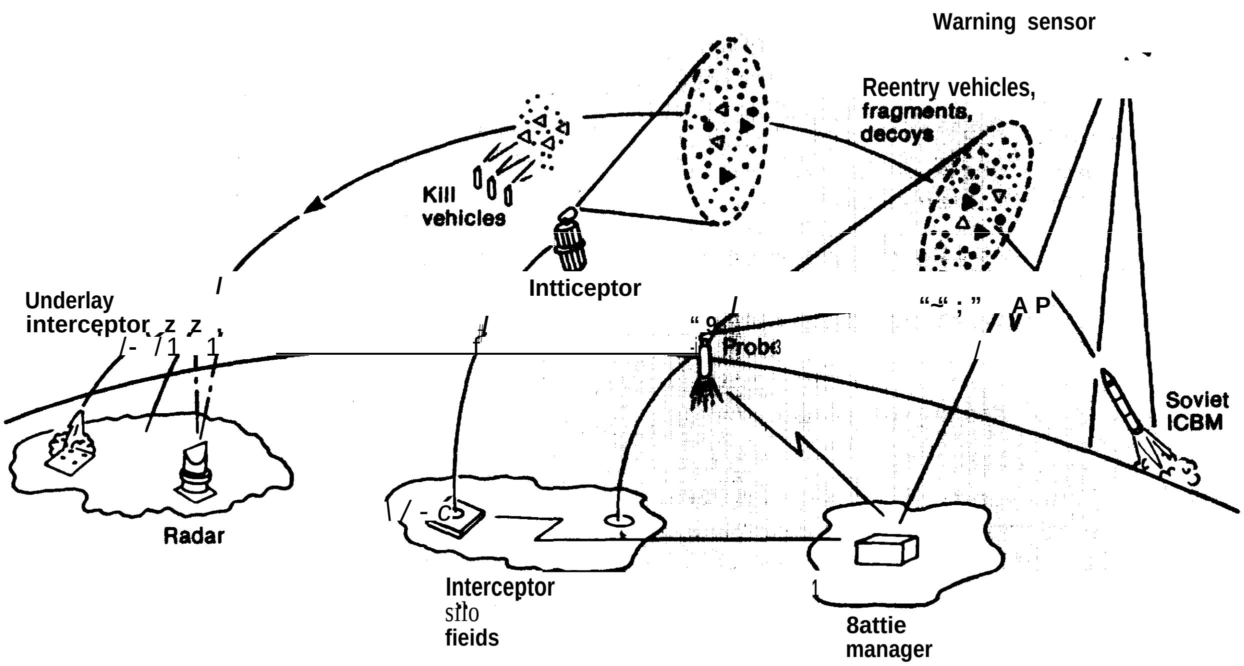
The Army's concept of the exo component of a Layered Defense — called simply the Overlay– is in the technology exploration stage. No detailed system design is available as exists for LoADS.

In outline (see fig, 62), the concept consists of interceptors roughly the size of offensive missiles equipped with infrared sensors and carrying several kill vehicles (KVS), also equipped with infrared sensors. The multiple KVS would be mounted on the upper stage of the interceptor. The interceptors, of which there might be several hundred, would be based in silos in the Central United States in the same manner as offensive missiles.

When attacking Soviet RVS were about two-thirds of the way through their flight to U.S. targets — about 10 minutes before impact — the interceptors would launch into space, When an interceptor reached space, its infrared sensor would scan its field of view and attempt to discriminate approaching RVS from tank and bus fragments and from decoys or other penetration aids. The infrared sensors would detect these objects as warm spots —warm since they were launched from the Earth — against the cold background of space.

Each KV would be assigned a target determined to be a true RV and dispatched to intercept it. Using its own rocket power and infrared sensor, the KV would home in on the object and destroy it either by colliding with it directly or by deploying a barrier of material in its path, Since the closing velocity of RV and

Figure 62.—Overlay/Underlay Layered Defense System



SOURCE Off Ice of Technology Assessment

KV would be about 25,000 miles per hour, a small fragment of material from the KV could completely destroy the RV. Even a glancing blow could damage the RV'S heat shield, mean ing that it would either burn up or be carried off-course as it reentered the atmosphere.

System studies of the Overlay concept have shown that performance would be improved dramatically by providing an additional sensor which would make an early assessment of the size and nature of the attack, allowing interceptors to be assigned more efficiently to regions of space. One idea for such a forward acquisition system (FAS) would be rocket-launched infrared sensing probes lofted into space as soon as warning sensors indicated Soviet launches. The probes would arrive on station within a few minutes and remain there for a short time before falling back to Earth. During this time, they would relay information on the trajectories of attacking RVS back to the interceptor silo fields. Since at any one time in the attack a number of probes would be required to cover all the attack corridors and their time on station would be limited, a longer lived FAS system might be required as well. This might consist of infrared sensors mounted on high-flying aircraft maintained on continuous alert and capable of several hours of time on station. Alternatively, satellites could perform an FAS function. However, neither of these longer liived FAS systems would be as capable as the probe.

The data acquired by the FAS would be integrated and interceptors assigned by a Central Battle Manager or by Wing Battle Managers associated with each set of defended silos. The battle managers would decide on a defense strategy and make interceptor assignments accordingly.

The battle managers and their data links would have to be immune to disruption by precursor SLBM attack.

Last, an exo defensive system would require early, secure, and reliable warning of Soviet attack. Systems to provide this warning must be considered part of the Overlay architecture.

Risks to Overlay Effectiveness

The interceptors and kill vehicles, interceptor silos, FAS (probes, aircraft, or satellites), battle managers, and communications systems described above would comprise an extremely complex defensive system. The system architecture remains to be worked out in detail, and many technology issues are yet unresolved, 1 n the absence of a detailed system design, it is not possible to analyze in quantitative detail the effectiveness and vulnerabilities of a Layered Defense system based on the Overlay in the way that such analysis is possible for LoADS. Analysis of the Overlay in the context of MX basing must instead rely on a qualitative estimation of technical risk and the sensitivity of Overlay performance to factors which are yet unknown.

As in the discussion of LoADS effectiveness, this section begins by asking how well the Overlay must perform in order to guarantee acceptable protection for silo-based MX missiles. Unlike a LoADS deployment with a single-shot goal, the effectiveness of a Layered Defense based on the Overlay is very sensitive to the details of system performance. One must therefore take seriously the uncertainties in overlay performance which exist at present. These uncertainties concern both the fundamental technologies in the Overlay concept and potential vulnerabilities in the working system as a whole. For the moment, facing the relative immaturity of the Overlay concept and a near-term decision regarding MX basing, it would be quite risky to rely on Layered Defense as the basis for ensuring MX survivable it y.

THE IMPORTANCE OF LEAKAGE

"The ability of a Layered Defense to protect silo-based MX missiles against a massive Soviet attack depends sensitively on the performance of the Overlay component. For LoADS/MPS, by contrast, the defense would achieve a single-shot goal even if interception failed almost as often as it succeeded.

The effectiveness of a Layered Defense is a matter of probabilities, and the confidence of attacker and defender to acheive their goals could depend not only upon the odds themselves but upon how willing either side would be to "play the odds" in a nuclear war, The discussion which follows is intended t. be illustrative only: the precise numbers computed depend upon the assumptions and a myriad of details, but the overall trends, indicating the sensitivity to Overlay performance, do not. The assumptions made here tend to be rather favorable to the defense.

An illustrative silo basing arrangement for MX might consist of **200** MX missiles deployed in Minuteman I I I silos, The total U.S. ICBM force would then consist of 450 Minuteman I Is (one RV each), 350 Minuteman I I Is (three RVS each), and 200 MX (10 RVS each, say), for a total of 3,500 RVS in 1,000 silos. In what follows it is convenient to take each silo to be a target of equal value, as though all missiles were identical and carried between three and four RVS. In actual fact, of course, the Soviets would be likely to target, and the United States to defend, MXS more heavily than Minuteman IIIs and Minuteman 11 Is more heavily than Minuteman I IS

Assume further that the Soviets deploy *no penetration aids* or alternatively that *discrimnation is pertect.* This assumpt ion concedes quite a bit to the defense, as the section on Decoys *and Other Penetration Aids* shows.

There is a certain probability that the Overlay will succeed in destroying an RV if it detects, tracks, and assigns a KV to it. Call this probability the "efficiency" of the Overlay; the leakage is one minus the efficiency. (It will be necessary to assume that the probabilities that individual intercepts succeed are statistically independent; this would not be true if, e.g , the KVS concerned originated on the same interceptor,) A quite respectable value for the efficiency in the absence of Soviet penetration aids would be 0.85 (85 percent); this value would assume achievement of al I of the Overlay "specifications " A more modest value would be 70 percent, and so percent would be disappointing indeed. The point of this analysis is to show how strongly the number of U.S. RVS surviving Soviet attack depends on Overlay efficiency.

The Underlay must also be specified. Here many choices are possible, ranging from a high-altitude Site Defense to simple single-shot "terminal" defenses. Assume that associated with *each silo* is a low-a It itude defense with the capability to make a single intercept **70** percent of the time, a second intercept 50 percent of the time, and no capability to make three or more intercepts above the same silo. This constitutes a rather large and costly deployment and assumes effectiveness typical of low-altitude systems. A second endo intercept is allowed on the assumption that the second leaker could follow the first with a time delay.

For the Soviet arsenal, targeted against both MX and Minuteman, a range from 5,000 to 12,000 (reliable arriving) RVS could be considered; calculations will be done for a representative value of **8,000,** Each arriving RV is assumed to have a single-shot kill probability of one.

If the Soviets had 8,000 RVS and no reason to target particular silos preferentially, they could direct 8 RVS at each silo, timed to arrive (if they penetrate the defense) within a short time of one another. If the Overlay has an efficiency of 85 percent, then the probability that *all eight* RVS aimed at a *defended* silo are destroyed by the Overlay is 0.85 to the eighth power or 0.27 (27 percent). The probability that one RV penetrates is the probability that seven RVS are intercepted (0.85 to the seventh power) times the probability that one penetrates (0,1 5) times the number of RVS (8) which have a chance to penetrate, for a total probability of 0.38 (38 percent). (The apparently paradoxical result that one RV penetrates more often than none reflects the fact that zero penetration can only occur one way, whereas single penetration can occur eight different ways,) The probability that two RVS penetrate is 24 percent.

Thus, 27 percent of the time the silo is safe because all RVS are destroyed in space. One gets through 38 percent of the time, but the endo Underlay destroys this RV 70 percent of the time. Two RVS get through 24 percent of the time, but the first of these is destroyed TO percent of the time and the second 50 percent of the time. Thus the overall probability that the silo *survives is* (0.27) + (0.7) (0.38) + (0.24) (0.7)(0.5) = 0.62, or 62 percent.

How many silos would actually be defended at all depends on the number of interceptors the United States deployed. For instance, if the United States deployed 400 interceptors with 10 KVS each, 500 silos could be defended against the 8,000-RV Soviet attack. Since 62 percent of the defended silos would survive, a total of 310 silos or 1,085 RVS would survive the attack. The Soviets would have expended 8,000 RVS to claim 2,415 U.S. RVS, and over 4,000 Soviet RVS would have arrived on the United States.

Suppose now that the Overlay efficiency were not 85 percent, but only 65 percent. The probabilities of none, one, or two RVS penetrating to the Underlay are then 3, 14, and 26 percent, respectively if the *defense persists in directing one KV at each RV.* The result that two RVS can penetrate more often than one reflects the fact that there are more *pairs* of RVS (28) than individual RVS (8). The higher probabilities for multiple leakers means that the endo defense has a harder job. In this case, only 22 percent of defended U.S. silos survive. If 4,000 KVS were used to defend 500 silos, the total U.S. survivors would be 110 silos or 385 RVS.

But this would not in fact be the best U.S. defense strategy if the Overlay efficiency were low. A better result would be obtained by defending half as many silos with twice as many KVS per silo, i.e., defending 250 silos and directing two KVS against each Soviet RV. This strategy would result in 70 percent survival of the 250 defended silos, for a total of 175 silos or 613 RVS surviving. The Soviets would again have paid 8,000 RVS, and over 6,000 RVS would have arrived on the United States. The Underlay defense at the 750 undefended silos would have been saturated.

In this example, a 20 percent degradation in Overlay efficiency (from 85 percent to 65 percent) results in the number of U.S. survivors being reduced by almost one-half. This effect demonstrates that the effectiveness of Layered Defense to protect silo-based missiles depends sensitively on the Overlay efficiency.

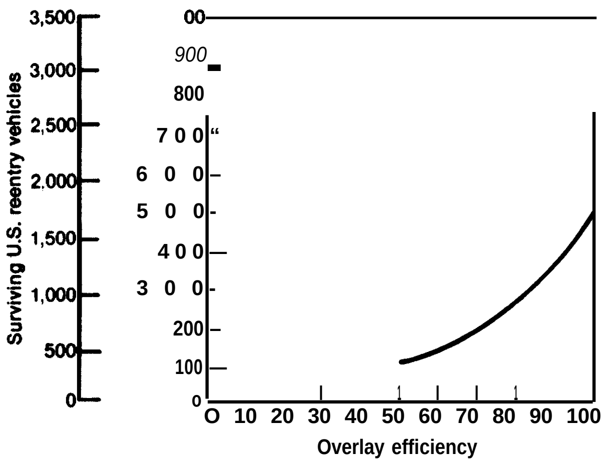
Figures 63 and 64 further demonstrate the importance of Overlay efficiency. Figure 63 shows that the number of U.S. survivors decreases dramatically as the Overlay efficiency degrades. Figure 64 shows that the size of the defensive arsenal needed to assure survival of 1,000 RVS (286 silos) quickly gets out of hand if the Overlay efficiency begins to slip. For a fixed number of U.S. silos the sensitivity to Overlay performance is more pronounced the larger the Soviet threat. For a fixed threat, the sensitivity is less pronounced the larger the number of U.S. aim points.

TECHNOLOGY ISSUES

Because of the sensitivity to performance described above, one must take seriously the uncertainties which exist at this stage of the

Figure 63.—Sensitivity of Layered Defense Performance to Overlay Leakage

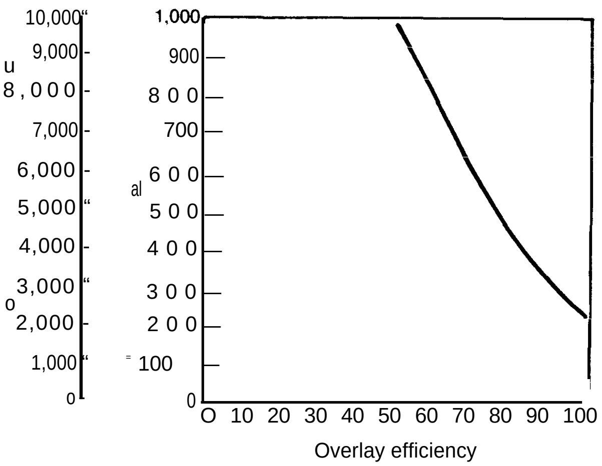
(Soviet **attack consists of** *8,000* **reentry vehicles)**
(U.S. **deploys 400 overlay interceptors)**



SOURCE: Off Ice of Technology Assessment

Figure 64.— U.S. Defensive Arsenal Needed to Assure 1,000 Surviving U.S. Reentry Vehicles

(Soviet attack consists of 8,000 reentry vehicles)



SOURCE Office of Technology Assessment

Overlay's development. Many aspects of the Overlay interception function require the frontier technologies of infrared sensor design, compact computer design, rapid computer throughput, software architecture, small homing and KV technology, and so on. The system requirements are demanding, and at al I stages of the interception process advances must be made to meet them. Furthermore the stages are interlinked in such a way that failure at one stage could cause failures at others and degrade overall system performance significantly, There is no reason to believe that, given time and money, the uncertainties in Overlay technology could not be reduced to a point where a clearer estimation of the value of an Overlay system for the protection of silo-based missiles could be made Nor is there any particular reason —with one exception, discussed in the section Decoys *and Other Penetration Aids* – to believe that fundamental technical problems will be encountered which by themselves would constitute "Achilles' heels" for an Overlay defense. Indeed, there is some reason for optimism, since the needed technology elements fall into categories— compact data processing, infrared sensing, miniature guidance systems, homing, etc. — in which rapid progress is occurring now and more is expected in the future. Rather, the risk lies in the cumulative effects of shortcomings in the performance of technology elements at many stages of the interception process. In many cases the capabilities of today's technology falls short of the requirements of the Overlay by wide margins. Though progress can and should be expected, even small shortcomings could ultimately prove significant, since poor performance in one area can induce failure elsewhere, and the cumulative effect could be to reduce total system performance below the high standard required for MX defense. Technology forecasting is always risky, and in the case of the Overlay one is simply faced today with an unknown quantity. Though the level of confidence in Overlay technology may in time increase to the point where it could support a decision regarding MX basing, at the moment it appears quite risky to depend on successful resolution of all outstanding issues. The following discussion seeks to highlight unresolved technology issues and convey a sense of the complexity of exo defense.

The interception process begins when the probes or other FAS vehicles survey the attacking "threat complexes, " the clusters of RVS, bus and tank fragments, and possibly decoys or other penetration aids, which are boosted into space by Soviet offensive missiles. In a large Soviet attack there would be tens of thousands of such objects in the sky. Each probe sensor should have as wide a field of view as possible so that a small number of them can survey the whole sky. But a wide field of view means either a large sensor, which is hard to protect from interfering background from the Sun, Earth, atmosphere, and other effects; or a slow scanning rate, which makes it difficult for the sensor to correlate what it sees on one scan with what it saw on previous scans, essential for discriminating RVS from other objects and for compiling accurate trajectory information. Unlike radars, infrared sensors cannot determine the ranges of distant objects but only their angular positions in the sky. Range must be inferred from changes in the angular positions of objects with time. Angular position must therefore be measured very accurately, requiring precise orientation of the sensors in space. The threat complexes might also be rather dense: a single spot in the sky could later resolve itself into several objects. The probes must resolve all objects and observe them long enough to attempt to discriminate RVS from nonlethal objects and compute accurate trajectories. If all this is done poorly or too late, too many interceptors will be allocated to some regions of space and not enough to others.

The probes must then "handover" their files of objects to the interceptors, telling the interceptor sensors where to find each object and what it looks like. The interceptors must reacquire each object in their respective sectors, attempt discrimination again, and determine how best to release their KVS. Again, poor performance at this stage degrades performance at the next,

Last, the interceptor sensors must hand over targets to individual KVS. The KVS must then maneuver in such a way that they come within lethal range of an RV approaching at 25,000 mph The KVS must also be able to distinguish the true RV from objects placed nearby. If the first intercept failed, a second wave of interceptors would have a very short time to perform all the required functions. It is not clear in any event that it would be possible to tell which intercepts had failed on the first attempt.

The infrared sensors are the most delicate element of the Overlay system. Infrared sensors can be disrupted by heat, nuclear radiation, and rocket exhaust gases. They would have to be mounted on very sensitive gimbal systems with accurate inertial guidance, Infrared sensors measure the temperature characteristics of approaching objects. These characteristics depend sensitively upon the position of the object relative to the Sun and Earth and on the time of day, season, and weather conditions on the Earth below. All of this data would have to be made available to the sensors before they could interpret what they saw. Infrared sensors of great sensitivity are also rather temperamental in that each behaves differently and must be calibrated separately, and a given i l l urn i nation of the same sensor can sometimes result in different output voltages. These latter factors introduce some fundamental limitations in temperature resolution, an important factor in discrimination.

SYSTEM ISSUES

In addition to the risk introduced by the high technology required, the Overlay as a system could have vulnerabilities much like the vulnerabilities of other basing modes. For instance, the Overlay would depend on tactical warning, since the system must begin to function early in the flight of Soviet ICBMS. The Overlay could thus share some of the potential vulnerabilities of other basing systems which depend on warning such as launch under attack and air mobile MX. The battle management function requires survival of the command centers and of secure, high-data-rate communications among the FAS, battle managers, and interceptor silo fields. The concerns here are similar to those regarding wartime survival of our national military C systems. Also, as with LoADS, attention must be given to offensive tactics designed to confuse or bypass the defense.

Limitations of the Overlay defense against submarine-launched ballistic missiles (SLBMS), which could attack the Overlay's own components, are discussed in the Classified Annex. Leakers from a precursor ICBM attack might also threaten critical system elements.

In the absence of a specific system design, it is again not possible to estimate vulnerabilities precisely. The interceptor silos and especially the probe silos would be few in number. Present Soviet SLBMS have limited silo-killing capability, and they are not normally deployed in large numbers near U.S. shores. Still, the Overlay defense assets would be high-value targets for an SLBM precursor attack, and depending on their hardness they could be vulnerable. Some thought has been given to providing an endo defense for the Overlay missiles themselves. Softer targets such as possible ground-based battle management bunkers and their communications links could be vulnerable to less accurate SLBMS.

If strip-alert aircraft were used to supplement the probes or to serve as battle management centers, they would have the same vulnerabilities as the bomber force and Air Mobile MX. One must also consider an antisatellite threat if satellites were used to aid an FAS,

Care must also be taken to provide for survival of the high-data-rate communications linking FAS, battle managers, and interceptor fields, The generic technical problems of providing survivability for communications are similar to the case of launch under attack and to the C systems of other basing modes.

A complex defensive system like the Overlay must also reckon with offensive countermeasures. The most important of these is the use of penetration aids, discussed in the next section. Other tactics are discussed i n the Classified Annex,

Detailed study of vulnerabilities at the total system level must wait until the Overlay concept is translated into a working design. Experience with the national military C' system and studies of launch under attack, air mobile MX, LoADS/MPS, and other basing systems give an idea of the scope of problems which can be encountered when a complex MX basing system faces a future Soviet threat. For the moment, the uncertainties in whether a robust wartime system can be fashioned from the Overlay concept are another source of risk to a decision to make Layered Defense the basis for MX survivability.

Decoys and Other Penetration Aids

The Overlay concept is based on the practicality of infrared sensing in space. However, infrared sensing is potentially critically vulnerable to offensive countermeasures in the form of decoys and other penetration aids. Unlike the LoADS radar operating at low altitudes, which could measure the weight of approaching objects, the Overlay infrared sensors would measure their temperature characteristics. Decoys able to fool the LoADS radar must be heavy, and adding heavy decoys to an offensive missile requires removing RVS, since the missile has limited throwweight. Measuring weight is therefore a strategically significant method of discriminating true RVS from decoys, since the offense would presumably not choose to offload RVS and replace them with equally heavy decoys. On the contrary, there is no impediment in principle to deploying lighweight decoys which have temperature characteristics indistinguishable from those of true RVS. Temperature, which is fundamental to the Overlay sensing method, is not a strategically significant discriminant. The offense might therefore be able to deploy a large number of excellent lightweight decoys on its offensive missiles without having to offload many RVS. This would call into question the effectiveness of an exoatmospheric defense of MX.

This section will indicate some of the elementary physical principles that permit the design of lightweight penetration aids. It will also indicate the practical difficulties which the offense would face in mounting decoyed attacks as well as those the defense would face in countering them. A more complete discussion is relegated to the Classified Annex.

To get a feeling for the importance of discrimination, consider the case if the offense provided along with each RV a sing/e *perfect decoy.* A KV approaching the two objects would then intercept the true RV 50 percent of the time. If the efficiency of the defense, as defined in the last section, were 85 percent in the absence of decoys, and if one KV were dispatched against each RV/decoy pair, then the true RV would be intercepted only (0.85) (0.5) = 43 percent of the time. This low efficiency (high leakage) would be catastrophic to the defense, as figures 63 and 64 in the previous section show. If on the other hand the defense directed a KV at both the RV and the decoy, then the same number of U.S. silos would survive as in the no-decoy case, but an arsenal of defensive missiles twice as numerous would be required to produce this result

In practice, no decoy is perfect, and on the other hand the offense could deploy many more than one decoy with each RV. In practice also, a tradeoff is made between leakage (intercepting the object judged most likely to be an RV and allowing an RV to penetrate if the guess is wrong) and wastage (intercepting everything). In the case of the Overlay, the need to keep leakage low means that the best solution for the defense is usually to accept high wastage. Thus, an offensive decoy deployment would tend to drive the defense to larger numbers of defensive interceptors — in the example above, applied to the model in the last section, twice as many, or almost as many defensive missiles as offensive missiles.

INFRARED SENSING AND TEMPERATURE

A metal bar heated to very high temperatures glows white-hot. If its temperature is lowered somewhat, it glows red-hot. if cooled further—to room temperature— it no longer glows in the visible part of the spectrum but at longer wavelengths, in the infrared part of the spectrum. A room-temperature object thus "glows infrared" and can be "seen" by a detector sensitive to infrared light.

An RV launched into space from the approximately room temperature condition of its silo forms a glowing spot against the dark (i.e., cold) background of space. Infrared sensors can measure both the color (i. e., the precise shade of infrared light) and the brightness of the RV and of any other objects, such as decoys, which accompany it. The color of the object reveals its temperature and its brightness reveals its size and the type of material it is made of. Decoy/RV *combinations* that appear to the infrared sensors to have identical color and brightness cannot be discriminated.

In addition to the warmth it brings with it from the Earth, the object absorbs energy from the Sun above and the Earth below and loses energy to cold space. Its color could therefore change as it were warmed or cooled. In addition to emitting light because of its temperature, the object also reflects infrared radiation from the Earth. An infrared sensor therefore senses the combination or sum of the emitted and reflected energy from the object.

T here is a relationship between the tendency of a body to emit thermal radiation because of its temperature and its tendency to reflect radiation which shines on it. For a body of a given size (more precisely, surface area) at a given temperature, the ***sum*** of its effectiveness in emittin g radiation of a given wavelength and in reflecting it is the same no matter what the body is made of. Therefore, the less infrared radiation a body in space emits, the more it reflects from the warm Earth and vice versa. The relative emittance and reflectance does depend on the nature of the body, but only on what the *surface* of the body is made of and not what is inside it.

Using only these elementary principles of physics, it is a straightforward matter to design RV/ light-decoy pairs which appear identical to infrared sensors. A wide variety of other examples of penetration aids based on simple thermal properties of materials can also be designed. These are discussed at some length in the Classified Annex.

MEASURE AND COUNTERMEASURE

In practice, the situation is more complex than simple physical principles alone would indicate, with many constraints and opportunities both for the offense and the defense. Despite these complexities, the fact remains that there is no principle and no detector that could guarantee perfect Overlay discrimination. The burden would thus rest with the defense to maintain its confidence that its methods of discrimination were adequate to meet a decoy threat.

I-o begin with, there would be practical constraints on the offense. Foremost among these is the fact that the best results would be obtained by altering the RV to make it easier for a light decoy to match. Though these changes are minor, inexpensive, and need not affect RV performance in the least, there could be some psychological reluctance to tamper with the lethal RV for the sake of a nonlethal decoy. It is also one thing to design the perfect decoy ancl quite another to package it, mount it on an ICBM, and deploy it in space so that its deployment process and in-flight motions *(assuming* these could be observed by the defense in an attack) resemble those of a true RV.

Constraints on the defense include the fact that infrared sensors are not perfect (i. e., cannot determine brightness and temperature precisely, especially in the presence of background) and they would not have a very long time to observe objects in an engagement. The temperature characteristics of objects in space furthermore depend on the position of the Sun and Earth relative to the sensor and the time of day and weather conditions on the Earth below. Overall, the interception process is difficult enough even in the absence of decoys, as discussed in the last section.

Since there is no fundamental principle on which infrared sensors can rely to guarantee discrimination, there could be value **in some** advance knowledge of the type of penetration aids the offense deployed. It is possible (likely is too strong a word) that by observing flight tests, the defense could Iearn enough about the offense's penetration aids to devise a discrimination scheme based on some distinctive feature or detail of the offense's design or deployment procedure. However, since there appears to be a wide variety of effective penetration aids which the offense could use, this approach based upon particulars rather than principles could succeed for one penetration aid but fail for another.

Details and further discussion of penetration aids, constraints, and tactics can be found in the Classified Annex.

Overlay discrimination is a difficult problem, the practical details of which are not understood, though the principles are. Testing of penetration aids designed expressly *and exclusively* for the purpose of Overlay penetration is required before it can be known whether the perfect decoy of principle can be realized in practice and whether less-than-perfect decoys still make defense based on infrared sensing too difficult and costly to undertake. For the moment, the very fact that effective decoys are possible counsels caution.

HISTORY OF BMD AND THE ABM TREATY

The development of ABM systems by the United States in the early 1950's followed the decision to begin development of ICBMS. During the mid-1 960's, the johnson administration proposed the deployment of the so-called Sentinel ABM system to provide both area and point defense against a limited nuclear attack. This proposed ABM system was reviewed in 1969 by the Nixon administration which opted instead for an ABM system to defend Minuteman silos. Deployment of the Nixon administration's Safeguard ABM system was begun in the early 1970's but was brought to a halt following negotiation and ratification of the ABM Limitation Treaty of 1972. The Treaty was subsequently amended by the Protocol of 1974.

With the development of ballistic missile defense, doubts about the long-term viability of international security based on a "balance of terror" began to mount While alternatives to maintaining a balance of terror were explored through a variety of formal and informal channels, by the mid-1960's it seemed to many senior U.S. policy makers that some sort of arms limitation on ballistic missile defenses would be preferable to either an ABM arms race or a major revision in the post-World War II "balance of terror".

For example, Defense Secretary Robert S. McNamara noted:

> Should they elect to do so, we have both the leadtime and technology available to so increase both the quality and quantity of our offensive strategic forces –with particular attention to highly reliable penetration aids—that their expensive defensive efforts will give them no edge in the nuclear balance whatever.
>
> But we would prefer not to have to do that. For it is a profitless waste of resources, pro-

vialed we and the Soviet can come to a real istic strategic arms-limitation agreement.

Even though Secretary McNamara had serious reservations about ABM systems in general, he nevertheless proposed to deploy an ABM system to defend the United States against some nuclear attacks. The Sentinel ABM system proposed by the johnson administration included a long-range, high-altitude exoatmospheric interceptor missile, the Spartan, guided to targets by a very large radar and a smaller, shorter range interceptor missile, called Sprint, also guided to its targets by radar. Both missiles were armed with nuclear warheads which destroyed incoming reentry vehicles. The original johnson administration proposal envisioned deployment of the Sentinel ABM System at some 14 sites including ICBM silo fields in Montana and North Dakota as well as several major cities.

The Nixon administration reviewed the proposed Sentinel ABM system in light of both U.S. strategic requirements and the intense political opposition that arose over the potential deployment of nuclear weapons adjacent to American cities and concluded that the use of Sentinel radar and interceptor components to defend U.S. Minuteman fields would be an appropriate and strategically significant response to the Soviet deployment of an ABM system around Moscow. On March 14, 1969, President Nixon announced his plan to deploy an ABM system to defend ICBM silos in Montana and North Dakota:

> This measured deployment is designed to fulfill three objectives:
>
> 1. Protection of our land-based retaliatory forces against a direct attack by the Soviet Union
> 2. Defense of the American people against the kind of nuclear attack which Communist China is likely to be able to mount within the decade,
> 3. Protection against the possibility of accidental attacks from any source.[2]

At the same time, the United States undertook the preparations for the formal beginning of bilateral arms control negotiations with the Soviet Union for the purpose of limiting both strategic offensive and defensive weapons, seeking to obtain international security through balanced limitations on strategic arms, as well as the procurement of additional strategic offensive and defensive weapons.

The ABM Limitation Treaty

After more than 3 years of intense negotiations on strategic arms limitation, the United States and the Soviet Union concluded the SALT I agreements in 1972. Two agreements were concluded by President Nixon and General Secretary Brezhnev in May 1972. The first of these was the ABM Limitation Treaty; the second was the Interim Agreement on Strategic Offensive Arms. In 1974, the United States and the Soviet Union agreed to an amendment to the ABM Limitation Treaty further limiting the deployment of ABM systems.

At the time the ABM Limitation Treaty was negotiated, there was a general belief that the available ABM technology was not very effective. The Sentinel ABM System technology incorporated into the Safeguard system had several technical deficiencies. Radar data processing with available computer technology was limited in terms of number of targets that could be tracked and the number of interceptor missiles that could be guided to targets. The use of nuclear weapons to defend targets under attack could have blacked out the ABM radars, preventing them from detecting and tracking targets passing through the disturbed region. In addition, the number of interceptor missiles planned for deployment was so small that an adversary could easily attack the ABM system with a large number of reentry vehicles, thereby exhausting the defense.

[1] "Address by Secretary of Defense McNamara to United Press International Editors and Publishers, Sept. 18, 1967," in U.S. Arms Control and disarmament Agency, *Documents on Disarmament, 1967* (Washington, D.C.: U.S. Government Printing Office, 1968, p. 385.

[2] "Statement by President Nixon on Ballistic Missile Defense System," in U.S. Arms Control and Disarmament Agency, *Documents on Disarmament, 1969* (Washington, D.C.: U.S. Government Printing Office, 1970), p. 103.

In general, the ABM Limitation Treaty of 1972, as amended by a Protocol negotiated in 1974, prohibits ABM systems based on the technology deployed by the United States and the Soviet Union in the late 1960's and early 1970's, The Treaty as amended does permit each side to deploy one ABM system for defense of either its national capital or an ICBM silo field. The Treaty also permits continued research and development on allowed ABM systems, bans other types of ABM development, test, and deployment, and provides for further negotiations on specific limitations of new ABM systems based on technologies not deployed in the 1970's

Article I of the Treaty[3] prohibits ABM system deployments other than those specifically permitted by subsequent articles of the Treaty. Article I I defines ABM system components. Article I I 1, paragraph (b), permits the United States to deploy one ABM system with the following characteristics:

- not more than two large phased-array ABM radars,
- not more than 18 small phased-array ABM radars,
- not more than 100 ABM interceptor launchers and not more than 100 ABM interceptor missiles in a deployment area having a radius of less than 150 kilometers centered on the middle of an ICBM silo field.

Article IV of the ABM Limitation Treaty perm its development and testing of ABM components at designated test ranges without counting such components in the quantitative limits established in article I I 1,

Article V of the Treaty bans the development, test, or deployment of sea-based, air-based, space-based, or land-mobile ABM systems or components. Article V also bans the development, test, or deployment of ABM interceptor launchers which contain more than one interceptor or which are capable of automatic or semiautomatic interceptor reload.

[3]"The ABM Limitation Treaty," in U.S. Arms Control and Disarmament Agency, *Arms Control and Disarmament Agreements, 1980 Edition* (Washington, D.C.: U.S. Government Printing Office, 1980), p. 140.

Other official statements incorporated into the legal restrictions of the ABM Limitation Treaty also affect future ABM system development, test, and deployment. Agreed statement (D) contains the following provision:

> In order to insure fulfillment of the obligation not to deploy ABM systems and their components except as provided in Article I I I of the Treaty, the Parties agree that in the event ABM systems based on other physical principles and including components capable of substituting for ABM interceptor missiles, ABM launchers, or ABM radars are created in the future, specific limitations on such systems and their components would be subject to discussion in accordance with Article XI I I and agreement in accordance with Article XIV of the Treaty. [4]

Agreed statement (E) prohibits deployment of ABM interceptor missiles with more than one independently guided warhead.

The ABM Limitation Treaty Protocol negotiated in 1974 and ratified in 1976 further amended the ABM Limitation Treaty in the following respects. Article III of the Treaty original ly permitted both the United States and the Soviet Union to deploy two ABM systems in two deployment areas. One permitted system could defend an ICBM silo field; another could defend the national capital. Article I of the 1974 Protocol limits each side to only one ABM system deployment.

Article I I of the Protocol permits each side to shift deployment of its permitted ABM system once. In the case of the United States, the protocol would permit the dismantling and destruction of the ICBM silo ABM defense system at Grand Forks and the relocation of the ABM system to the Washington, D.C. area.

Application of ABM Treaty Provisions to MX Defense

ABM systems deployed to defend MX are limited by the ABM l-imitation Treaty of 1972 (as amended by the 1974 Protocol) in two distinct ways. First there are limitations on the deployment of ABM systems. Second, there

[4]Ibid, p 143

are limitations on the development of new ABM systems.

ABM deployments are limited by the ABM Treaty as amended in the following respects:

1. any U.S. ABM system may only be deployed in a circle of 150-km radius centered on the Grand Forks, N. Dak., ICBM field;
2. LoADS defense units could not be deployed if any system component were explicitly not of a fixed type;
3. since each LoADS unit would contain one small radar, no more than 18 LoADS DUS could be deployed under terms of the radar limitations of the ABM Treaty;
4. the total number of LoADS or Overlay ABM interceptor launchers and ABM interceptor missiles could not exceed 100;
5. LoADS defense units could not be deployed if each unit contained more than one ABM interceptor launcher. Alternatively, even if each LoADS defense unit contained only one interceptor launcher, it would still possess in principle automatic, semiautomatic, or rapid reload capability, barred by the Treaty;
6. since each Overlay KV is an independently guided warhead within the meaning of the Treaty, deployment of more than one such warhead on each Overlay interceptor missile would be prohibited under provisions of agreed statement (E).
7. deployment of space-based laser ABM systems is explicitly prohibited by article V of the ABM Treaty,

The development of future ABM systems is also limited under terms of the ABM Limitation Treaty. The United States and the Soviet Union have defined development of ABMs for purposes of the Treaty as follows:

> The obligation not to develop such systems, devices or warheads only to that stage of development which follows laboratory development and testing, The prohibitions on development contained in the ABM Treaty would start at that part of the development process where field testing is initiated on either a prototype or bread-board model. [5]

Thus, the following limitations would apply to the development of specific ABM systems such as LoADS, Overlay, or even space-based ABM systems:

1. mobile components of ABM systems developed beyond the laboratory such as LoADS defense units would be banned;
2. multiple independently guided KVS for the Overlay could not be tested beyond the confines a laboratory;
3. development of unique components for spaced-based laser ABM systems would be banned.

Future ABM Limitation Negotiations

The ABM Treaty provides that either side may propose amendments during semiannual meetings or special meetings of the Standing consultative Commission which was established to resolve questions of interpretation in the Treaty as well as to supervise and resolve questions of verification. The 1974 Protocol amending the Treaty arose out of just such Standing Consultative Commission discussions. The Treaty, which is of unlimited durat ion, also provides for a formal review conference every 5 years at which time either side may propose changes or amendments. The next ABM Limitation Treaty Review Conference is scheduled for October 1982.

Present ABM options for the defense of MX deployments are significantly constrained by the Treaty from the standpoint of final engineering. Substantial research on new ABM systems can be undertaken, and development and testing of ABM components whose purpose is to modernize the mothballed Safeguard system can also be undertaken, New radars, new interceptors, and new warheads

[5] "Ballistic Missile Defense," in U S Congress, House Committee on Foreign Affairs and Senate Committee on Foreign Relations, *Arms Control Impact Statements for Fiscal Year 1982* (Washington, D C U S (government Printing Office, 1981, p 195

for Safeguard are all testable and deployable under terms of article VI I of the Treaty permitting modernization of existing ABM systems, Even development of directed energy weapons for possible use as ground-based ABM systems would be permitted under terms of the Treaty, so long as deployment as modernization for the Safeguard system was envisioned.

The United States might wish to explore the possibility of further amending the ABM Limitations Treaty in a manner that would permit engineering development and possible deployment of the LoADS or Overlay ABM system as they are presently envisioned during the course of the 1982 ABM Limitation Treaty Review Conference. Reopening discussions of the substantive provisions of the ABM Limitation Treaty does, however, raise serious questions in need of further analysis beyond the scope of the study.

The process of renegotiating the ABM Limitation Treaty is subject to uncertainty. The Soviets, too, have an active ABM research and development program which is also constrained by the ABM Limitation Treaty. Modifications in the terms of the ABM Limitation Treaty which would permit the United States to proceed with development and testing necessary to advance the LoADS ABM technology into engineering and full-scale engineering development, or permit development of Overlay technology, would also permit comparable developments in the Soviet ABM program.

Hence judgments of the technical, political, and military benefits to be gained by reopening negotiations on ABM I imitations will have to be made should some basing mode for the MX missile requiring ABM systems be contemplated.