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Strategic Defense Requirements for Progressive Applications

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Strategic Defense Requirements for Progressive Applications

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STRATEGIC DEFENSE REQUIREMENTS FOR PROGRESSIVE APPLICATIONS

by

Gregory H. Canavan and John C. Browne

ABSTRACT

Strategic defenses are applicable to a progression of threats that range from accidental or unauthorized launches, through third country or subnational threats, to limited or strategic exchanges. Technologies exist for long range launches, but launches close to shore are feasible, stressing, and favor the attacker. Space based interceptors are suited to meeting the bulk of the launches; directed energy has significant advantages in reducing the threat to manageable levels. Current interceptor concepts appear adequate, but discrimination is both pivotal and delayed.

I. INTRODUCTION

A companion paper discusses various applications for which strategic defense concepts could be used.[1] The applications form a progression in size and complexity from accidental or unauthorized launches, through third country or subnational threats, to limited or strategic exchanges. This report attempts to quantify the requirements for meeting those applications and to assess the maturity of current strategic defense concepts relative to them, concluding that there are adequate interceptors for all of them, but that sensitivities to uncertainties in discrimination are awkward at all levels and bothersome at the high end.

II. APPLICATIONS

The catalogue of applications discussed earlier is quantified roughly in Fig. 1. Its abscissa is the number of missiles launched in the threat; the ordinate is the number of objects per missile, which includes the number of weapons or reentry vehicles (RVs) and decoys carried. The main applications form a progression along the diagonal, which is broken into three steps.

The first starts at a single third country or subnational launch and goes up through multiple-weapon submarine launched ballistic missiles (SLBMs). The second covers deliberate attacks by limited numbers of M = 10-100 missiles with 1-10 reentry vehicles (RVs) each. The third finally crosses into 300-1,000 missile strategic engagements. The number of objects increases much faster than the number of missiles there because of the many RVs and decoys that could be used in large-scale exchanges.

The main progression is largely along the diagonal and against the gradient in the total number of objects faced. Accidental and unauthorized launches lie above and to the left of the diagonal; they could involve 1-10 multiple independent reentry vehicles (MIRVs) with many decoys each. Their area is uncertain because the number of decoys deployed depends on the nature of the defenses. There is also a large area to the right that is not presently filled in, but which could be by large numbers of decoyed, single-warhead missiles, should future arms control agreements favor that configuration.

The map also indicates the level of defenses required from different interceptor concepts. Boost phase defenses such as space based interceptors (SBIs) destroy the missiles themselves. Thus, the number of SBIs required for a given threat is roughly equal to the number of missiles launched, shown along the abscissa, corrected for the SBIs' absenteeism.[2] The number of missiles launched is also the primary consideration for other boost-phase directed energy concepts such as lasers and neutral particle beams (NPBs). For them the number of RVs or decoys the missile carries is a secondary consideration.

Midcourse ground-based interceptors (GBIs) must address both the number of RVs released, which could multiply the threat by an order of magnitude, and the number of RVs and decoys deployed on each, which could increase the number of threatening objects by another factor of 10-100. Thus, GBIs' performance scales on the product of the number of RVs and decoys. For undecoyed singlets, GBIs could intercept as many weapons as missiles, but for RVs and decoys, GBIs must intercept each credible object. Thus, for multiple objects, the number of missiles the GBIs can address falls back along one of the diagonal lines of constant object number.

Terminal concepts face the residue. The concepts are simple and cheaper. That is offset at high threat levels by the truncation of their battle space by nuclear effects, although at low threat levels that should be less of a constraint. Terminal concepts must also account for the concentration of high threats in order to overwhelm selected targets, which can bypass most of them, increasing their requirements 2- to 5-fold.[3,4]

III. REQUIREMENTS

This section addresses the technical requirements for the applications discussed in the previous section. It primarily discusses requirements for SBIs, lasers, NPBs, and GBIs. Terminal interceptors, sensors, and other concepts are mentioned in passing. Their main constraints, which are largely non-quantitative, are discussed in the companion paper. Sensitivity to decoys and discrimination is primarily addressed in conjunction with the high-end threats.

A. Third Country and Subnational Threats

While lowest in term of the number of objects, third country and subnational threats should be delayed in time. There is no evidence that such threats exist today, but it is clear from the growing commerce in ballistic missile, nuclear, biological, and chemical technology that such threats could mature in about a decade, which is about the timescale of posited defenses.

The distinguishing characteristics of third country and subnational threats are thought to be modest numbers of missiles and few objects per missile, although there is no particular reason to believe that the technology for deploying penetration aids is diffusing any slower than that for missiles. Their distinguishing characteristic as a threat is that their missiles would almost certainly be aimed at value targets to maximize psychological impact. Thus, meeting those threats would require very competent defenses with very low leakage. Several oversized layers would probably be required to achieve adequate overall kill probabilities with today's technology.

The abscissa of Fig. 2 shows the range of boost times that might be expected from third country launches a decade hence. The ordinate gives the number of SBIs that would be needed to meet them according to calculations of availability for optimum inclinations[5] for the launch times shown.[6] On the lower curve for 1 missile, the numbers range from ≈ 10 SBIs at the long burn times of current boosters to ≈ 80 SBIs at the 150 s of modest boosters with no multiple RVs or buses. That latter, could be appropriate even for early single weapon threats, produces short engagement times. Still the SBI constellation sizes shown are relatively modest and would remain so even if increased several-fold to compensate for gaps in the constellation or to provide multiple intercepts for higher confidence.

It should be noted that time for man-made decisions would be subtracted from the engagement time, as would the SBIs' 10-20 s activation, warmup, and acceleration time. The constellation sizes turn up sharply at small engagement times, so those corrections could be important there. Still, it would appear that against moderate burn time missiles, a minute or more decision time could be available.

The upper curve is for a 10 missile launch. It is quite unlikely that such a launch would come from the third world, but such launches could come from current nuclear powers by accident or loss of control. The curve thus shows that if a 100-800 SBI constellation was deployed to protect against such launches, even fast burn launches from third countries would be covered as lesser included threats. It is interesting, however, that the ≈ 80 SBI constellation required for a fast, third-country booster would only be ≈ 50% smaller than that required for the longer engagement times of MIRVed heavy missiles.

SBIs are not necessarily the optimal way to prevent such attacks, but they do have the virtues of global coverage and insensitivity to penetration aids. Thus, their uncertainties are minimal and their presence acts to discourage the use of penetration aids against midcourse or terminal layers. Those attributes also obtain for boost-phase laser or particle beam defenses.

Ground based interceptor requirements are straightforward. For a single missile attack from abroad, existing sensors should be able to provide more than adequate warning time. Decision making could consume a reasonable fraction of the ≈ 2,000 s of midcourse without adversely impacting performance. For a single weapon, a few interceptors could suffice; for multiple objects per missile the number could increase to the few tens of GBIs shown on Fig. 1.

Without discrimination the number of GBIs would rise to the number of objects. Radars should be able to discriminate early third country penetration aids. Thus, there is a direct trade off between interceptors and radars. The launches could, however, come from a range of azimuths, so the number of radars required could be large. Existing warning radars could be upgraded to provide the basic track information; more sophisticated radars would be needed to screen decoys.[7]

As noted above, third country or subnational attacks would almost certainly be aimed at value targets, which means that multiple intercepts would be desirable. Presumably a mix of SBIs and GBIs would be used. Interestingly, from Fig. 2 less than half the 100 interceptor limit of the ABM Treaty could suffice for the boost-phase overlay, leaving ≈ 50 GBIs for the underlay. Thus, treaty-limited deployments in terms of numbers and GBI basing could be adequate for these launches, although space-basing the SBIs would require discussion.

Terminal interceptors could also be useful and should be relatively simple. In the absence of adverse backgrounds and penetration aids, their sensors could be reduced to elementary point detectors. The HEDI interceptor[8] could be quite useful in this application, since it could use the entire atmosphere to provide discrimination on the basis of drag.[9] Interceptors like FLAG-E could also be useful after reentry, although their keepout range would be marginal for protection of value. Both interceptors would have small footprints, but if they were based near the cities they protected, their redundancy need not be excessive.[10] They would not, however, be useful if based in compliance with the current treaty. Against limited threats distributed HEDIs would largely be an alternative to proliferated, capable radars.

Overall, modest SBI constellations could provide good protection against third country intercontinental launches. Used in layered defenses with existing GBIs, endoatmospheric interceptors, and sensors, they could provide high overall confidence intercepts. That statement is not surprising, because they would be facing essentially the simple, unitary threats for which they were designed. Penetration aids should not complicate that result greatly, but variations in range could.

B. SLBM and Short Range Launches

Third country launches are not necessarily limited to long-range, minimum-energy trajectories. The missiles could be made sufficiently small, and their guidance sufficiently accurate, for them to be fired from midocean or closer to the U.S. coastline. The resulting short ranges, timelines, and altitudes could cause additional complications that the attacker would presumably want to exploit. The complications due to ship and submarine launches are intimately related, so the two are discussed together below. Distant SLBM launches, which are somewhat simpler and provide a benchmark for comparison, are discussed first.

1. Distant SLBMs

SLBM launches from port, bastion, or far offshore resemble accidental or unauthorized ICBM in-country launches. The numbers of defenders required are proportional to those shown in Fig. 2, although SLBM-defense constellations would be multiplied by roughly the 1-20 missile launches expected, which puts the overall requirements somewhere between the middle and upper curves. Thus, the number of SBIs for accidental or unauthorized SLBM launches far from shore could be within the range of that for protections against accidental ICBM launches, and they could again constitute a lesser included threat.

A significant distinction from third country launches from range, however, is that most of the RVs from SLBM launches could be expected to be directed against military targets--not value. Those targets would presumably not be altered by the accident of launch. Thus, most weapons would be directed at targets far from value, so that, if necessary, coverage of value targets could be increased at the expense of neglecting RVs aimed at military targets, a form of defensive triage.

The effectiveness of boost phase defenses against SLBMs could be multiplied through the use of ultravelocity launchers or "slings." Even modest boosters could accelerate the 2-3 kg kill packages currently in development for "brilliant pebbles" to velocities of 20-30 km/s,[11] with which they could reach SLBMs in boost that were launched up to ≈ 2,000 km away during boost.[12] SLBM acceleration and RV deployment could take 200-400s. If so, a 20 km/s sling could reach them from 20 km/s·200-400s ≈ 4,000-8,000 km, less time for warning, decision, acceleration, and divert. If so, they could arguably negate SLBM launches from a single base in the center of the U.S. without needing space basing or treaty-stretching deployments. Slings have apparently not been further developed.

2. Close-in Launches

Launches closer to shore are more stressing. Figure 3 shows their flight times vs launch angle and range. For a range of 1,000 km, e.g. from a ship 1,000 km away from a large city or a submarine 500 km offshore against targets up to 500 km inland, a minimum energy trajectory's total flight time is ≈ 450 s. The powered and deployment portion, during which the missile and weapon would be accessible to boost-phase destruction, is about half that, or ≈ 200 s. On a 25^{o} moderately depressed trajectory, however, those times would be about 300 and 150 s, respectively, the latter being about the shortest time shown on Fig. 2. For those times and the launch of a full boat load, the constellation size for a single engagement per missile is on the order of 800 SBIs, which approaches the deployments sought for SBI defenses against large scale ICBM launches.[13]

The main differences between short-range launches and the long-range launches discussed earlier are the point-like nature of SLBM launches and the shorter engagement time for short, close-in trajectories, both of which contribute to reduce the fraction of the constellation from which SBIs can reach the missiles. Such short warning times could defeat systems requiring strategic warning. The impact of fast SLBMs depends on the ability to use short boost and deployment times. The applicability of fast burn booster technology to SLBMs is unclear, as is the application of fast buses. The ≈ 100s/5 RV ≈ 20 s/RV deployment time assumed in the example above is short compared to the ≈ 30s/RV for current MIRV buses. Against value targets with nonnuclear defenses simpler, however, faster, less precise multiple warhead releases could be used effectively. The hope would be that such explicitly counter-value weapons would not be put on SLBMs, particularly those close-in, since the launcher's advantages would be lost on them.

The impact of missile burn and deployment time on the number of RVs released is explored further in Fig. 4, which gives the number of RVs released before SBI impact for varying number of SBIs in the constellation. The top curve is for 125 s burn and an equal time for deployment, or a total SBI engagement time of 250 s. The bottom curve is for an engagement time of 400 s. Figure 2 shows that for 250s engagements, or ≈ 500s trajectories, the missile or bus would be destroyed before RV deployment was completed for constellations of > 40 SBI; for 400 s that occurs at > 20 SBI. While the missile and bus are destroyed, some RVs can be deployed before impact. Figure 4 shows that for a 250s engagement time and 40 SBIs 4 RVs would be deployed successfully before impact and that for 400s and 20 SBIs about 3 RVs would be deployed. While the deployment times per RV are again shorter than current values, these leakages are too large to be tolerated.

Given the difficulty of successfully intercepting decoyed RVs further downstream, it is useful to minimize leakage by oversizing boost phase constellations. The bottom curve of Fig. 4 shows that for a 400 s engagement time, increasing the number of SBIs from 20 to 30 would decrease the number of escaping RVs to ≈ 2, and that 50 SBIs would decrease it to about 1 RV, the limit set by single intercepts for the 0.9 kill probability assumed. Reducing the number further would require increasing the number of SBIs on each missile and bus.

Simply doubling the number targeted on each would increase the 400s constellation to about 100 SBIs per missile, or ≈ 2,000 per boat load, although SBI characteristics could support roughly a more efficient shoot-look-shoot strategy. For 250s about 5,000 SBI would be needed per boat, which would reach the envelope of the number of SBIs needed against current heavy ICBMs.[14] Significant leakage is therefore expected from close in SLBM launches, though not necessarily from third country launches, which would involve much smaller numbers of missiles.

3. Undecoyed Launches

Close-in SLBM launches are, after breakwater, analogous to third country launches from off-shore ships or barges. Both trajectories are short and fast. Interestingly, neither would be expected to have penaids. Decoys are currently stressing for defenses against minimum energy or lofted trajectories, but they are of limited utility for short, depressed trajectories. The dense air below ≈ 150 km strips them out rapidly, so unless the trajectory causes the RV to spend a good deal of its time higher, decoys are of limited utility, particularly on the shallow reentry angles of depressed trajectories. That means that RVs from close in launches should be essentially undecoyed.[15] Since they are also relatively slow, a number of interceptor concepts could be brought to bear on them in the latter part of their trajectories.

SBIs probably could not be brought to bear. Current designs are limited by their structures, controls, and sensors to intercepts above about 100 km altitude. The depressed trajectories under discussion here lie below that. Figure 5 shows the apogees of various short range trajectories. For a 1,000 km minimum energy trajectory the apogee is ≈ 250 km, which SBIs could readily reach. For a 25^{o} trajectory, however, the apogee drops to ≈ 100 km, which SBIs could not reach. For short trajectories the offensive penalties for that amount of depression are not great, perhaps ≈ 0.5 km/s. Thus, both close-in SLBMs and third country launches could apparently underfly the SBIs effectively. That observation also applies to short-range intra-theater launches, as discussed further below.

Figure 6 shows these limitations graphically. The top curve shows the number of SBIs needed for 1 intercept against missiles on short-range trajectories depressed to 25^{o}. The constellations range from ≈ 40 SBIs for 2,000 km range to ≈ 70 SBIs at 1,000 km. For shorter ranges SBIs cannot reach such depressed trajectories at all. The middle curve shows that they can engage minimum energy trajectories down to about 500 km range. Unfortunately, neither propulsion nor guidance gives much reason for the launcher to use minimum energy trajectories at such short ranges, so SBIs could probably again be underflown.

The bottom curve is for lasers to meet those trajectories. Space chemical laser (SCL) and free electron laser (FEL) beams can essentially reach all the way down to the ground. No trajectory can escape them altogether. The lasers assumed have the modest power levels that could be available in the limited numbers implied in the next decade.[16] The curve shown is for 25° missile trajectories; the curve for a minimum energy trajectory lies about a factor of two lower. Their numbers are adjusted by the ratio of their estimated costs relative to those of the SBIs to give SBI cost "equivalent" lasers.[17]

For current cost estimates lasers would appear to be a factor of ≈ 2 less expensive than SBIs for long missile ranges. The main issue is not, however, cost. The important distinction is that lasers can reach short-range endoatmospheric targets, which SBIs cannot do at all. The laser's costs do increase moderately at short range due to the shorter irradiation times permitted, but the number of platforms remains manageable. The issue is how the resulting costs compare with those of alternative ways of negating missiles at those ranges.

The competition for short ranges is the terminal interceptors. Against undecoyed targets HEDI should be effective, although it seems a bit wasteful to have the interceptors fly out twice as fast as the RV, particularly since doing so restricts the lower end of its operating envelope, which would be stressed by depressed trajectories. An alternative is the use of the FLAG-E class of interceptors, which fly somewhat lower and slower and have demonstrated good intercept probabilities and lethality with all-weather sensors in this altitude-velocity regime.[18]

These results, while couched in terms of SLBM and third country launches close-in to the U.S., are also relevant to other theaters.[19] Mideast conflicts have had characteristic dimensions on the order of a few hundred kilometers; they now have the capability for delivery over ranges of ≈ 500 km. Extra-theater trajectories from there to Europe have dimensions on the order of a 1,000-2,000 km. So do the main trajectories in the Pacific rim, Korea. The Sino-Soviet border territories involve somewhat longer ranges. All could apparently benefit about equally from the deployment of current or improved SBIs, modest lasers, and simple endoatmospheric interceptors to address the short-range nuclear, chemical, and precision conventional missiles that could be deployed there in the next decade.[20] The constellations and deployments follow precisely the numerical results discussed above.

C. Accidental and Unauthorized Launches

Protective measures against accidental or unauthorized launches of ICBMs scale strongly on the time available to engage them. Figure 7 shows the number of defenders that might be needed for times ranging from the ≈ 600 s of current SS-18 and -24s to the 100 s of faster missiles, buses, or singlets. The top curve is for a single heavy missile intercepted by current SBIs. For long engagement times ≈ 30 SBI/missile are required; for short times over 100 SBI/missile are required.

For reference, the bottom curve shows the number of SBIs required to defend against a missile launched from the current distributed launch area, which ranges from ≈ 5 to 20. The main difference is point versus distributed launch. The bottom curve assumes that the missiles are launched from the current ≈ 10^7 km^2 launch area, which lessens the kinematic requirements on each SBI. The difference is about a factor of 6 for current missiles; by the time their engagement time fell to 300 s it would approach a factor of 10.

1. SBI Engagement

It is not possible to anticipate the type of missile launched, so the defensive constellation would have to plan for a combination, possibly the worst. A fast singlet would be the most stressing kinematically because of its shorter burn times, but it could be negated by a single intercept. For a 250 s burn time that might require a constellation of ≈ 100 SBIs. A heavy, current 600 s missile might require ≈ 30 SBI for partial negation. As discussed above for SLBM buses, more complete negation could take 2-3 times that number. Destroying all of its RVs requires that it be intercepted during the 300 s of boost, which would require ≈ 80 SBI/missile. Thus, a singlet, mobile or not, poses a larger problem than a heavy missile.

The distinction between accidental and unauthorized launches at this level is their likely size. A group capable of effecting one heavy missile launch might be able to launch all of the missiles in a complex. If so, the launch of ≈ 10 missiles would increase the requirements above to ≈ 1,000 SBIs, whether the missiles were heavy or singlet, mobile or fixed.

2. Laser Engagements

The two intermediate curves are for directed energy defenses. The second curve down is for lasers against the point launch of a single missile. As in Fig. 6, it lies about a factor of 2 below the curve for SBIs. For this discussion the most important points are that the curve remains flat to much lower engagement times than SBIs. It only reaches 100 equivalent defenders at engagement times of about 100 s; SBIs reach that value at engagement times of about 300 s. The apparent 50% advantage in costs at long times is not significant, but the leakage that goes with them is. As noted above, the SBI numbers would have to be multiplied by a factor of ≈ 4 to reduce leakage below 10%. The laser could drive leakage far below that with 10% increases, since its agility and speed of light flight make reengagements simple and fast.

3. NPB Engagements

The third curve is for NPB kill of missile electronics or explosives. Alternatively, the NPB could repeatedly disrupt the bus's electronics so that its RVs and decoys are not deployed, leaving a single, unitary target for the GBIs.[21] The energy required to do that is not known with certainty, but could be an order of magnitude or more below that for kill. While this mechanism is indirect, it has the potential of locking up all of the RVs, not just a fraction of them, and could be executed with a small number of modest platforms. In short engagement time situations where the number of SBIs or lasers could grow to hundreds per missile, that capability together with the essentially speed of light flight of the NPB beam could be quite useful. Protective constellations of that size could be perceived as defenses by the Soviets.

4. Decoys

An essential element of successfully addressing accidental and unauthorized launches is providing margin against the many decoys that heavy missiles could deploy. SS-18s could provide 10 decoys per RV by offloading one RV per missile; offloading fuel could provide several times that many decoys without offloading RVs or restricting targeting significantly. Figure 8 shows what that means in terms of the objects per missile and hence the GBIs required per missile, the ordinate, as a function of the number of decoys per RV, the abscissa. The top curve is for no discrimination, the second is for 30%, the third for 60%, and the bottom for 90%. For no discrimination, even 30 decoys per RV could provide > 3,000 objects per missile, which could overwhelm practical protective systems.

For accidental launches radars could be used to discriminate the objects. There should be no overt attempt to suppress the radars, which should be effective against simple penetration aids. If, however, the missiles deployed a full set of decoys, it is likely that radars would only be partially effective.

There might not be any decoys. That is the current, and arguably likely, deployment. Unfortunately, the attacker controls that decision, and the Soviets have in the past been relatively conservative in assessing the likely effectiveness of countermeasures to their missiles. Discrimination, particularly measures that are explicitly linked to technologies intended to be used later in actual defenses, could tend to undercut their confidence. If the counters were perceived as militarily significant, that would argue for their deployment of at least partial means of overcoming them. That makes the sensors' task even harder. Against improved, deployed decoys the sensors would face diminishing returns. Then sensor deployments would become even larger--and hence more threatening to the attacker. The interaction has the potential of spiraling towards ever larger deployments of ever less effective defenses.

Against accidental or unauthorized launches there appears to be a solution. This potentially unstable interaction only comes about if the potential attacker assesses the discrimination sensors to have enough capability to be effective against actual attacks. The solution is a sensor that has significant effectiveness against small accidental or unauthorized attacks, but little against large, intentional launchers. That can be achieved through a built-in Achilles' heel: vulnerable sensors. It should be possible to use radars to reduce the number of objects in small launches to manageable levels. Against current decoys they should have some reasonable capability; against deliberate attacks they could be destroyed and should have little capability. They are manifestly non-survivable, and hence pose little danger of being confused with actual defenses. The unstable feedback is eliminated.

For just the same reasons, however, radars are not on the path to useful defenses, for which reason their development or deployment are opposed by those who want defense rather than protection. The point is not academic. The attempt to develop sensors that could grow to the levels required for defense could induce the deployment of penetration aids that could negate sensors deployed for protection. The net result could be a significant defensive expenditure on sensors that did not reduce the threat and left the configuration less stable.

D. Limited Attacks and Strategic Exchanges

Limited attacks differ fundamentally from both accidental or unauthorized launches and from strategic exchanges in both their intent and the means needed to deter them, although they could involve similar numbers of missiles. Limited attacks lie along the main progression in the numbers of missiles launched and in targeting strategy. They differ from the latter in that they are deliberate and fundamentally military. They differ from those at higher numbers of launches and objects in that they are deliberately limited in numbers and disposition to attempt to achieve limited military aims without doing the levels of damage to value or overall strategic systems that could trigger retaliation. The fact that they are deliberately not escalatory must be used in seeking counters to them.

Discussions of limited attacks preceded the Strategic Defense Initiative (SDI) and could survive it since they are a natural adjunct of the rational use of offensive strategic nuclear forces. Surprisingly, discussions of such flexible responses have not been enhanced by the gradual erosion of offensive force stability. The tendency has instead been to leap over this intermediate set of applications and concentrate on the restoration of defenses at the high end of threats. The justifications cannot and need not be explored here in depth; they are discussed at length elsewhere.[22] Only the defensive counters to limited attacks are discussed below.

Presumably, these attacks, though limited, would deploy the most effective combination of launchers equipped with maximum effective numbers of penetration aids. They would presumably use the proper complement of SLBM and airbreathing weapons as well. Those combinations, and in particular the latter launchers, lie outside the current discussion and indeed the SDI itself. These qualitative issues are discussed in the companion note; the discussion below only treats the quantitative requirements for denying the success, or increasing the price, of these combinations.

1. Boost Phase Interceptors

Figure 9 shows the number of SBIs and lasers needed to meet varying attacks by intercepting the missiles in the boost phase. The abscissa is the number of missiles launched; the ordinate is the number of SBIs, or equivalent lasers, required. In the near term the number of SBIs and equivalent lasers are comparable. At 100 missiles each is at ≈ 500 SBIs. At 400 missiles, perhaps the rough upper boundary of the limited attacks, lasers are on paper cheaper by perhaps a factor of 2. The real distinction, however, is not cost, but that SBIs exist while lasers don't. SBIs in test could arguably meet both the performance and ≈ $1 M/SBI cost levels assumed in constructing the figure.

The numbers shown are for a single intercept per missile. Depending on the amount of leakage allowed they could be multiplied by a factor of 2-3. If good GBIs were available, one intercept per missile could be used and the leakage would be ≈ 30%. If the GBIs were poor or compromised, twice as many SBIs could be used to drive leakage to 10%. The number of SBIs required against a near term 400 missile attack would then be ≈ 10,000. That number could encounter production constraints. Other defenses could be useful.

2. Directed Energy

The directed energy concepts are not quite as immature as is sometimes thought.[23] While lasers of the optimal sizes would not be available in large numbers initially, numbers of smaller ones could be.[24] If so, those smaller lasers could apparently perform quite effectively, particularly if they were introduced in a phased manner to absorb the overflow from SBIs that were deployed earlier.[25] The two upper curves are for 10-20 years after the initial deployment of defenses. The number of SBIs grows linearly with the threat, reaching ≈ 10,000 SBIs for ≈ 200 missiles. That number is perhaps at the borderline of cost effectiveness, the proper criteria to be imposed on deployments this large. For $ 200 M heavy missiles and $ 1 M SBIs, the exchange ratio would be about 2:1, which is down by a factor of 20 from near term values.

Laser costs increase less than linearly with the threat. Thus, their scaling becomes favorable relative to SBIs in the mid term. At midterm levels lasers have an advantage of ≈ 3:1

relative to SBIs and hence ≈ 6:1 relative to the threat. In the long term it would appear that FELs, because of their continuous, effective scaling to higher power levels, could have an order of magnitude advantage over SBIs.[26] The scaling for NPBs could be even more favorable, although they face more severe altitude limitations against faster missiles.[27]

3. Midcourse Interceptors

GBIs should be effective against undecoyed ICBM launches, less so against missiles with modest numbers of decoys, which could significantly reduce the effectiveness of the discrimination capability expected in the near to mid term. Credible decoys could essentially eliminate the GBIs' contribution to the defense. SLBMs, particularly those launched close in, would be more stressing, although in a different dimension. Depressed trajectories could underfly all but the terminal defenses, which could be overwhelmed. Endoatmospheric interceptors' contribution would face nuclear effects and footprint limitations, particularly if faced by a large, unattrited attack.

GBIs could be effective against limited attacks, although distributed basing and good discrimination would be essential. Passive discrimination measures could be useful in the near term, but should fade against improved decoys in the midterm. Active radars would then also have little of substance upon which to discriminate. Lasers probe more fundamentally, but would still have low discrimination rates and known countermeasures.[28]

"Dust" discrimination, i,e. detecting decoys' velocity change on the impact of millimeter sized particles, looks adequate for silo defense, and perhaps feasible for moderately hard targets, but would not be applicable to the defense of value, since the mass required increases with the total area defended.[29] NPBs appear to be the best suited but least developed discriminators.[30] It would appear that keeping them on the ground and popping them up on efficient sounding trajectories on warning could provide the capability needed to fully discriminate limited attacks with a single platform and complement of detectors.[31]

4. Depressed Threats

Deliberate attacks would certainly be accompanied by SLBMs, which should be used in most stressing manner possible--close in. Their performance and defensive requirements would again be determined by Fig. 6. From short ranges their missiles would be hard to intercept and leave little time to respond. Since SLBMs are apparently gaining a hard target capability as well, they could produce a whole new class of instabilities, i.e. they could destroy hardened command, control, and communication links and attack missiles directly rather than just pinning them down.

Unfortunately, land-based radars, which from a kinematic standpoint would be useful acquisition and tracking sensors, would probably not survive long enough to contribute. Interestingly though, densely proliferated SBI platforms could provide excellent geometries and signal to noise ratios for SLBM detection and track, even for trajectories that they could not themselves attack directly. They could also house other sensors such as small radars, which could profit greatly from the SBI platforms' improved geometry, shorter ranges, and survivability.

Airbreathing threats, bombers and cruise missiles, would almost certainly be used in limited attacks, and should be particularly stressing in them. At present the main counters to them are airborne radars and interceptors, but both of them have performance and survivability limitations. Lasers could address airbreathing threats all the way down to the ground. The main problem is detection. Advanced radars such as the OTH-B could see many of the targets, as long as they survived. It is fair to say that the community is somewhat between ideas on detection, but the highly proliferated and closely spaced SBIs again offer convenient platforms for further development.

E. Strategic Exchanges

Strategic exchanges have been widely discussed.[32] There is no need to repeat the main results here, which are largely agreed upon in the absence of unquantified counter measures. According to the bulk of the analyses, kinetic energy interceptors could be quite favorable, particularly in the near term.[33] Lasers could be cost effective, once available.[34] Together they could be extremely effective, with lasers catching the overflow from a SBI boost phase and providing a very effective second layer to it.[35]

One issue, however, remains. At high threat levels, very good discrimination is essential. For limited attacks enough interceptors may be available to shoot a large proportion of decoys. That is not desirable, but is feasible if other components fail. For strategic exchanges it is not feasible to buy excess interceptors; each must be used to good effect.

Figure 10 shows the sensitivity of life cycle costs for phase 1 deployments to offensive decoy modernization.[36] Without decoys a threat of 1,000 missiles would require about 5,000 SBIs costing ≈ $ 5B, plus ≈ 1,000 GBIs costing ≈ $ 2B to handle the leakage. That would give a hardware cost per intercept of ≈ $ 10B/1,000 missiles ≈ $ 10M/missile, for a cost effectiveness of ≈ 10:1.

If, however, this defense induced the attacker to deploy 10-100 decoys per RV, the midcourse requirements would be expanded 10-to 100-fold. The total costs would increase proportionally. If the boost phase defense was unchanged, without good discrimination the GBIs required would jump to 10,000-100,000 and their cost to $ 20-200B, which would dwarf the cost of the SBIs. The cost impact on the defense would be unacceptable. That is true whether the costs are actual in the form of the interceptors bought, or simple the shadow cost of buying an inadequate number of interceptors and not meeting the threat. The cost for the offense would only be that for the decoys.

That tradeoff is shown graphically in Fig. 10, in which the abscissa is the fraction of the decoys that can be discriminated initially. The ordinate is the cost of the initial deployment plus 20 years of operation of the defense against a threat that is modernized only in the number of decoys, which is only one component of the possible offensive modernization. The top curve is for light decoys, i.e. ones weighing about 0.5% of an RV. The middle is for 1%; the bottom is for 2%. The number of decoys is optimized for the level of discrimination expected.[37] For the heaviest decoys, the defense costs $ 20B for full discrimination; $ 50B for no initial discrimination. For the 1% decoys the range is up to $ 80B; for 0.5% up to $ 140B. The latter is 70-140% of $ 100-200M heavy missiles, which would mean that the defenses 10-fold advantage was compromised before the offense ever started its fundamental countermeasures.[38]

Thus, good discrimination is essential, and the key to minimizing costs is to have good discrimination at the outset of deployment. If discrimination is not available then, the cost of the additional interceptors required to replace it is very large. Since that cost is up front, at the very beginning of deployment, subsequent developments cannot fully offset its impact. With good initial discrimination, midcourse expenses are small throughout. With poor initial discrimination, it is not possible to recover from the large initial costs of the interceptors. Unfortunately, discrimination is not readily secured at high threat levels. Passive techniques are limited, and radars are not generally survivable. NPBs are promising but need development. That seems to be the largest issue in addressing strategic exchanges.

IV. CROSSCUTTING ISSUES

The previous sections discussed the numerical requirements for the defensive concepts to address the progression of applications indicated in Fig. 1. This section examines how the different concepts play across the threats. The main applications form a progression. There are four main steps: third country and subnational attacks, accidental and unauthorized launches, limited attacks, and strategic exchanges. The dominant defensive concepts are, in order of the missile's trajectory, SBIs, lasers, NPBs, GBIs, HEDI, and FLAG-E, which are discussed in order.

A. SBI Applications

SBIs are well suited to third country and subnational launches from abroad. Modest constellations should give global coverage--for all, not just the U.S. That, however, provides an incentive for such attackers to move closer. For intermediate, e.g. midocean, launches, SBIs could still be quite effective. By the time the platforms moved to within a few hundred kilometers of shore, however, depressed missiles could underfly the SBIs altogether. SBIs also provide good, global coverage for SSBNs, for which their relative autonomy could be quite useful. Even when oversized to achieve low leakage, their constellations are small. For in close SLBM launches, however, they could again be underflown.

SBIs are useful for accidental and unauthorized launches because their boost phase operation makes them insensitive to launcher location and missile MIRV and decoying. SBIs are directly and effectively applicable to limited and strategic exchanges. They are not necessarily the optimal way to prevent such attacks, but they do have the virtues of global coverage and insensitivity to decoys. That is particularly so for the near term, although it now appears that with brilliant pebble costs and performance they could remain the dominant interceptor into the long term as well.

Overall, SBIs are developed, affordable, flexible defenders that are uniformly effective for all but the closest in third country, subnational, or depressed SLBM launches.

B. Laser Applications

There are a number of lasers; only two are discussed here: SCL and FEL. Neither exists in the sense of SBIs, but of the two the SCL is clearly closer. The FEL is discussed because it has the potential to operate essentially inexhaustibly in a hybrid mode, which can apparently scale to arbitrarily high power levels. For third country and subnational attacks they both share the favorable scaling and coverage of SBIs. Moreover, they can reach any launch point, so they could protect all countries.

Their ability to penetrate the atmosphere prevents close in launches from them or SLBMs. It could also act to close the short range gap in theater ballistic and airbreathing launches. For accidental and unauthorized launches they share SBIs' useful insensitivity to decoys and they have the potential of acting as cheap second layers to provide very low leakage. FELs are potentially the cheapest and most flexible way to address strategic launches in the boost phase. They could also address airbreathing carriers, given detection.

Overall, lasers can close the gaps that exist in other defenders for short range missiles, which is important for third country launches, theaters, and SLBMs. Their speed of light flight makes them useful in the boost phase, particularly in providing a low-leakage second layer for limited or strategic engagements, for which they scale favorably. They are the only SDI concept that can address bombers, cruise missiles, and carriers.

C. NPB Applications

NPBs can kill missiles and buses. They would be extremely useful in doing so in the near to mid term, if available. They would have the minimum deployments for third country and subnational attacks. They could interrupt the operation of accidental or unauthorized launches. They are the best of the discriminators known. They scale favorably to limited and strategic exchanges. If their theoretical discrimination ability can be realized, GBIs with discrimination from NPBs could be the dominant defense against strategic attacks.

D. GBI Applications

GBIs provide good, relatively cheap lethality, especially when used as a second layer to an effective boost phase defense. GBIs are well suited to third country or subnational launches from long ranges. Very close in launches could underfly them. They should be very effective in limited attacks, if they have good discrimination. For strategic launches they could be the cheapest defense, if NPBs or other sensors could provide them with very good discrimination.

E. Terminal Applications

Terminal interceptors are cheap and simple, but have small footprints, and hence must be distributed for usefulness. HEDI would appear to be a useful second or third layer in protecting value against third country or subnational attacks from long ranges or from accidentally or unauthorized attacks from the Soviet Union that happened to attack value. In that role it would compete with or complement GBIs, which could address those launches from a single, treaty-compliant location. HEDI would appear to be limited against closer or SLBM attacks by its own aerodynamic performance. In limited or strategic exchanges it would provide essentially one more shot at RVs attacking silos.

The FLAG-E interceptors has flight characteristics well suited to defense against close in attacks. It could be valuable in protecting command, control, and communication from depressed attacks. It could provide limited protection of value targets from depressed attacks.

V. SUMMARY AND CONCLUSIONS

This paper has discussed the application of strategic defense concepts to a progression of applications that range in size and complexity from accidental or unauthorized launches, through third country or subnational threats, to limited or strategic exchanges. Based on the analysis above, the defenses discussed could perform reasonably well against each. Current SBIs and GBIs are in good states of development. They would at present and in the foreseeable future anchor defensive responses. Good discrimination is probably required at all levels above third country and subnational attacks; otherwise decoys could produce bothersome uncertainties at all levels of launches and attacks. The likely contributions from passive and active discriminants is still undecided. Lasers hold some promise for discrimination. Particle beams hold more, but need development.

Third country threats could develop within a decade. They could be stressing, and cannot be deterred. The technologies exist for long range launches, but launches from close to shore are feasible, stressing, and to the advantage of the attacker. Space and ground based defenses are applicable; combinations are preferable. In addressing these launches it is necessary to differentiate carefully between protection and defense, or one could undercut the other. It could be hard to develop defenses without inducing changes in strategic missiles that could make protection against their accidental or unauthorized launch more difficult. It is only possible to do so much within the ABM Treaty. The protection that can be developed is limited, and pertains mostly to long-range threats. But for those threats a surprising amount can be done.

Close in submarine launches stress protection and defenses much harder for the same reasons third country launches from ships near shore would. They give little time for decision or response, and they could in the limit screen out space-based interceptors. That is partially compensated for by their low speeds and lack of decoys, which makes intercepts with simple, developed interceptors possible. Similar short-range limitations also occur in theaters, where directed energy concepts could alleviate the constraints.

Protective measures against accidental or unauthorized ICBM or SLBM launches scale strongly on the number of missiles launched, the time available to engage them, and the number of decoys deployed. The requirements can approach the performance levels needed for strategic exchanges. Space based interceptors are best suited to meeting the bulk of the launch, but directed energy concepts have significant advantages in reducing the threat to manageable levels. Radar sensors could be effective and are manifestly non-survivable. As such they should pose little danger of confusion with actual defenses and hence minimal danger of inducing untoward countermeasures.

Limited attacks would present large, competent mixes of missile and airbreathing carriers. Deliberate attacks would certainly be accompanied by SLBMs, which should be used in most stressing manner possible--close in. They would differ from strategic exchanges in that they are susceptible to intra-level deterrence. If defenses could extract a large enough price, their execution could be rationally deterred. Adequate kinetic energy lethality exists, although the favorable scaling of directed energy becomes important at this level. Interceptors and sensors for the airbreathing part are demanding.

Strategic exchanges are the most demanding, since they would involve intelligent mixes of all of these threats. For them current interceptor concepts are adequate, but discrimination is pivotal and delayed. The key to minimizing cost is having good discrimination at the outset of deployment. The current mixes of kinetic and directed energy appear appropriate for extracting good attrition across the spectrum of threats. For low costs it is necessary to balance boost and midcourse contributions; for cost effectiveness, capable and survivable sensors are essential. The interceptor and sensor concepts described above are potentially very effective against all of the threats discussed. With development they could within this decade progress to the levels required to deter or defeat them.

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Fig.1. Requirements for defenses

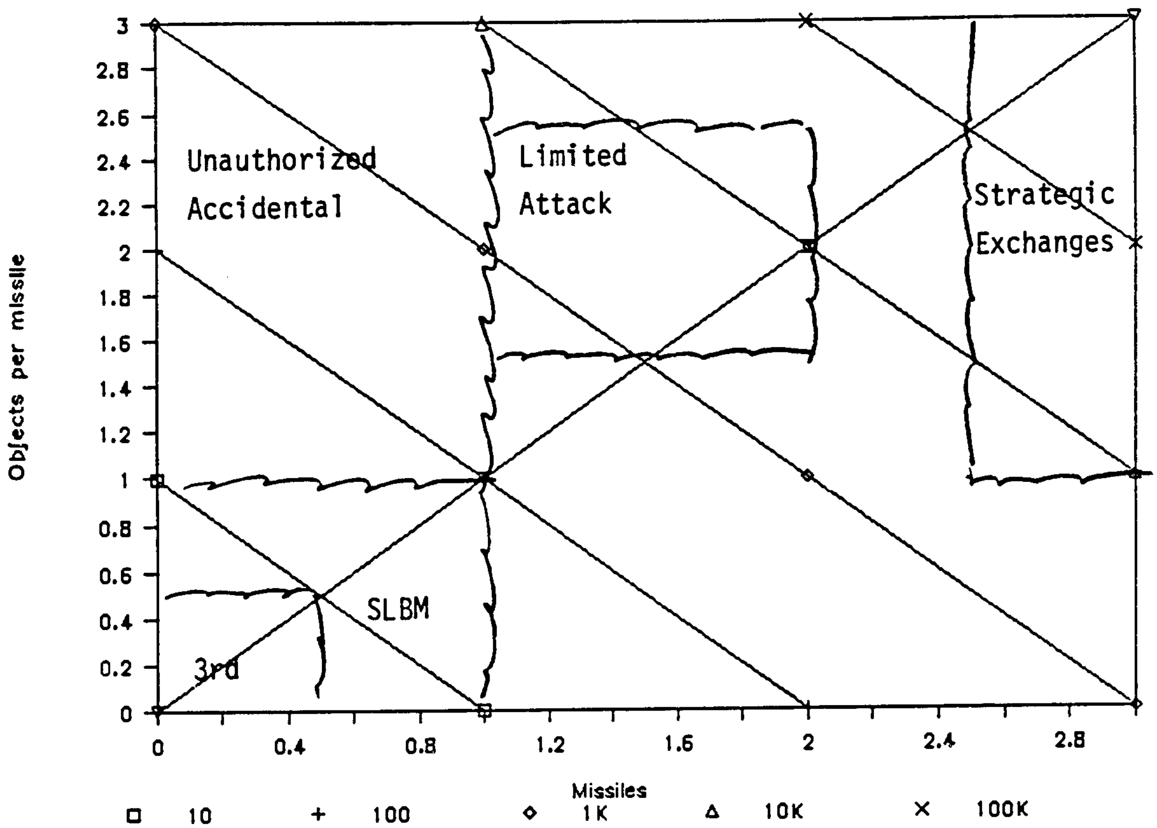

Fig.2. SBI for third country launch

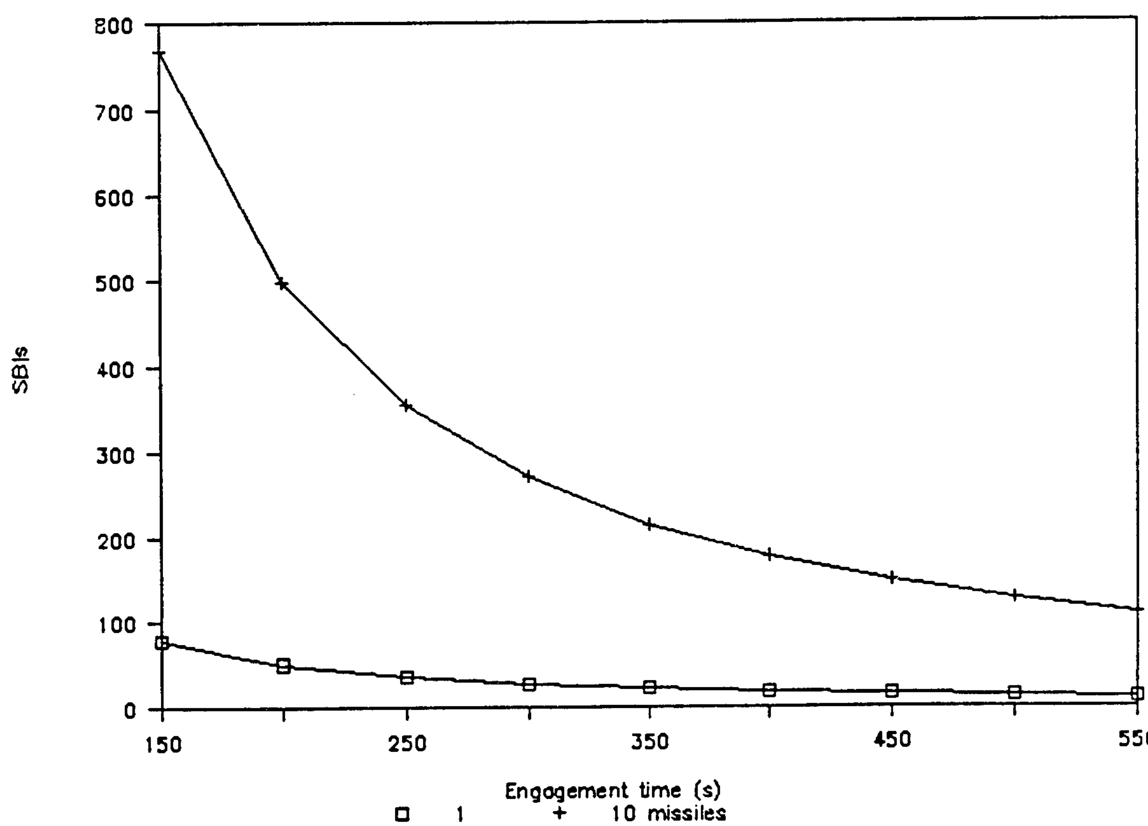

Fig. 3. SLBM flight times

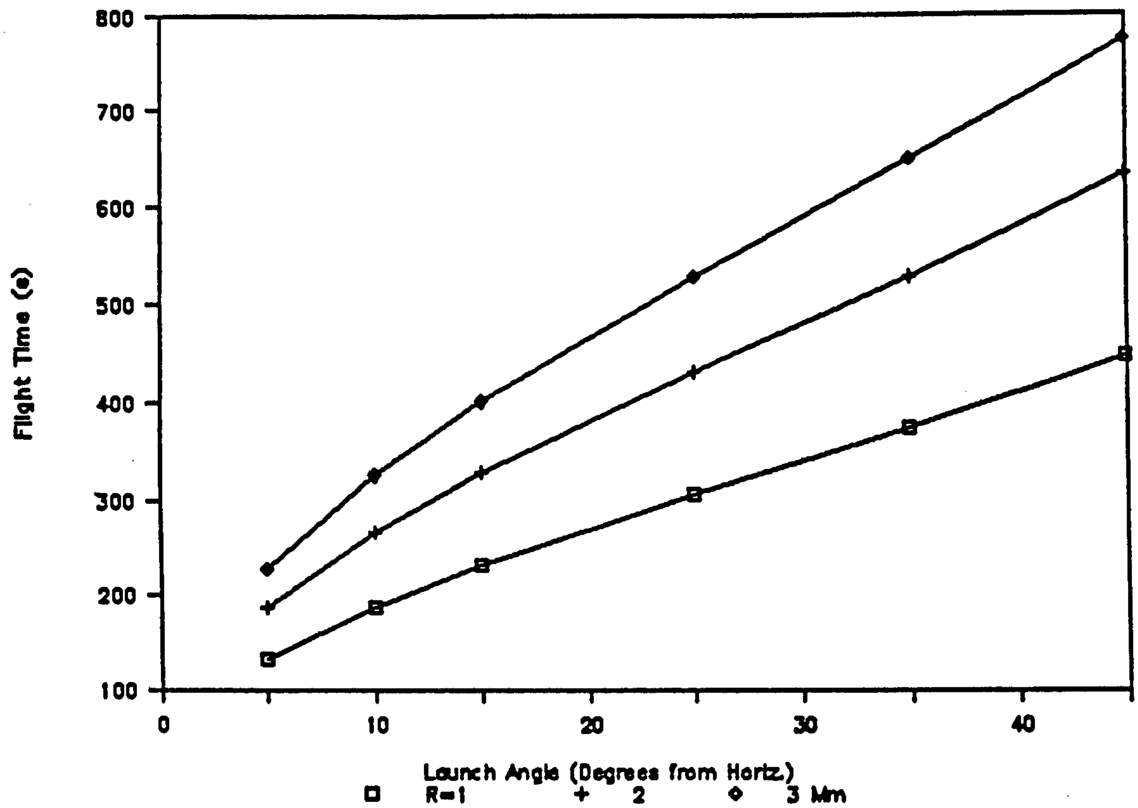

Fig.4. Reentry vehicles remaining

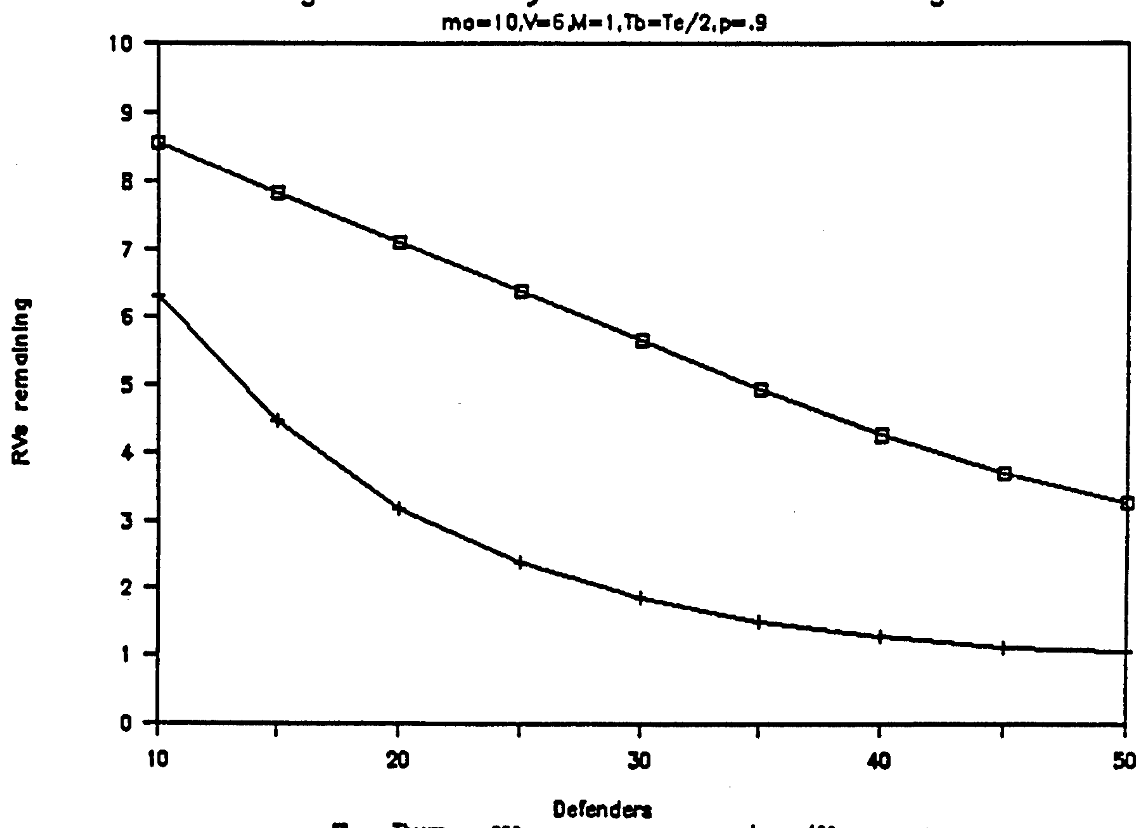

Fig. 5. SLBM RV apogees

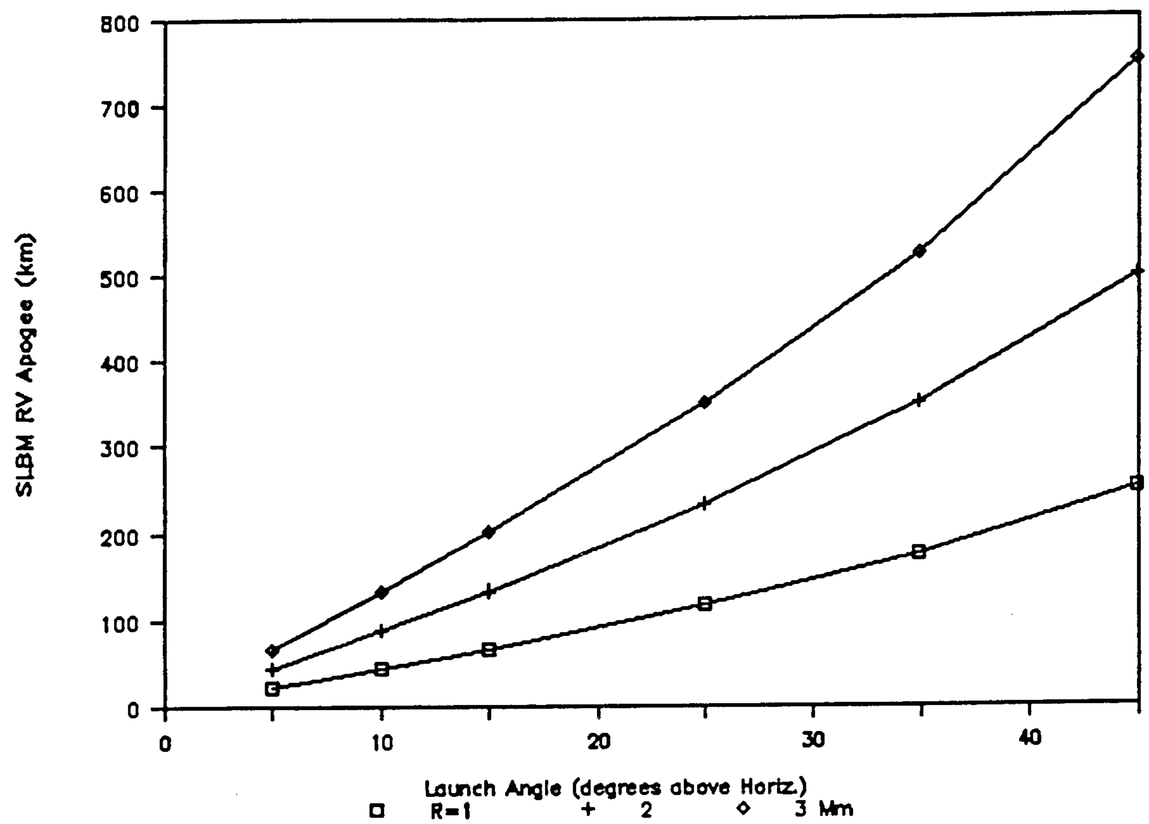

Fig.6. SBI vs DEW for third country

V=6km/s,M=1,hmin=100/125

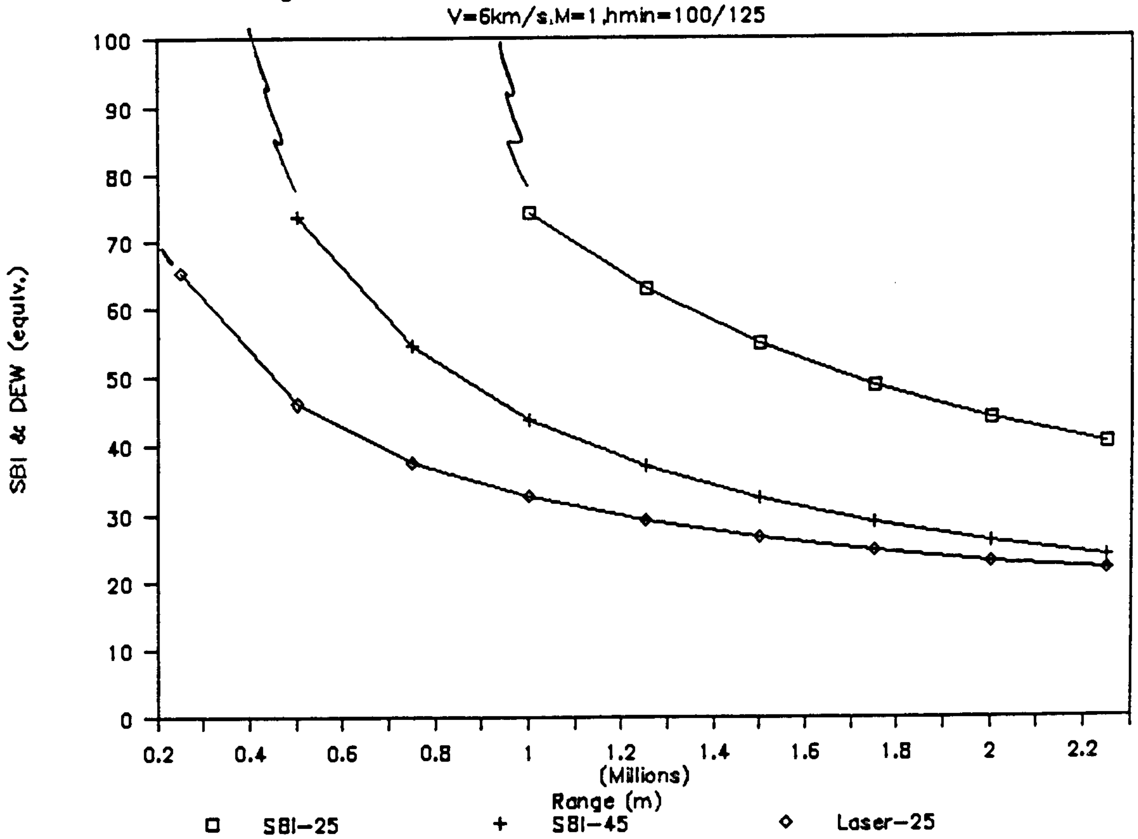

Fig.7. Accidental/unauthorized launch

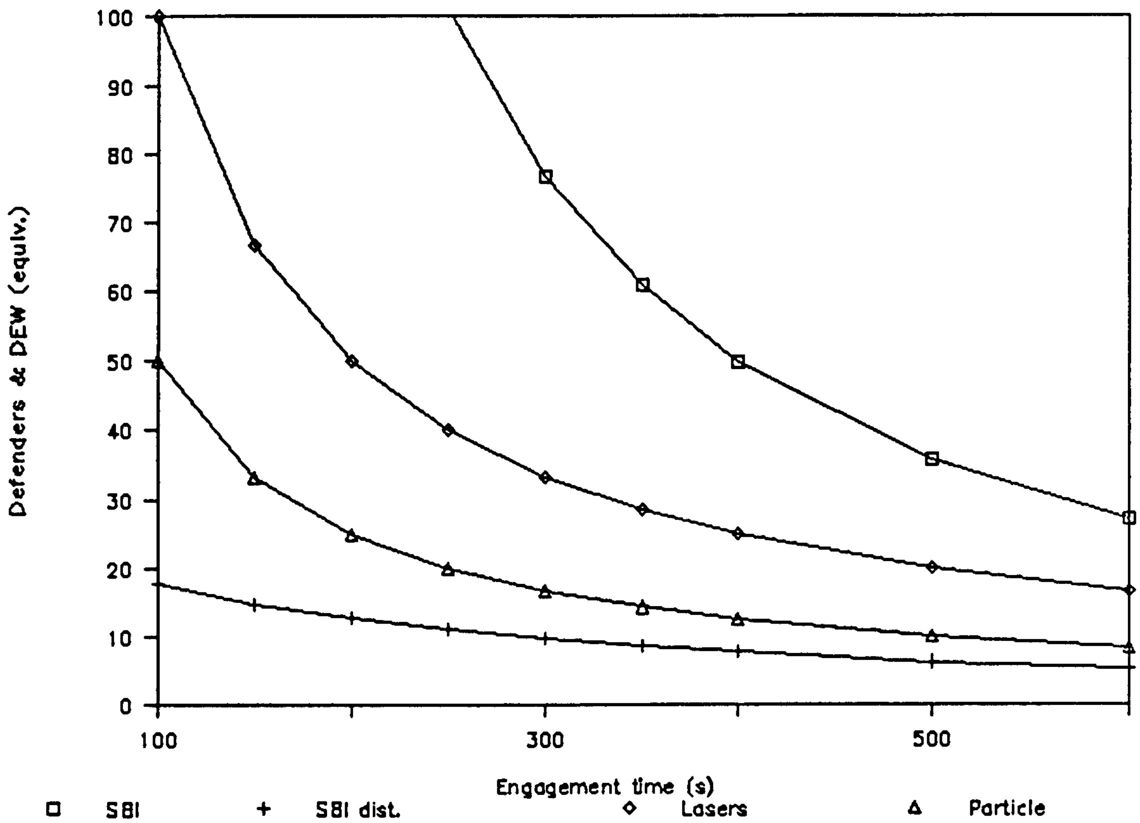

Fig.8. GBI for unauthorized launch

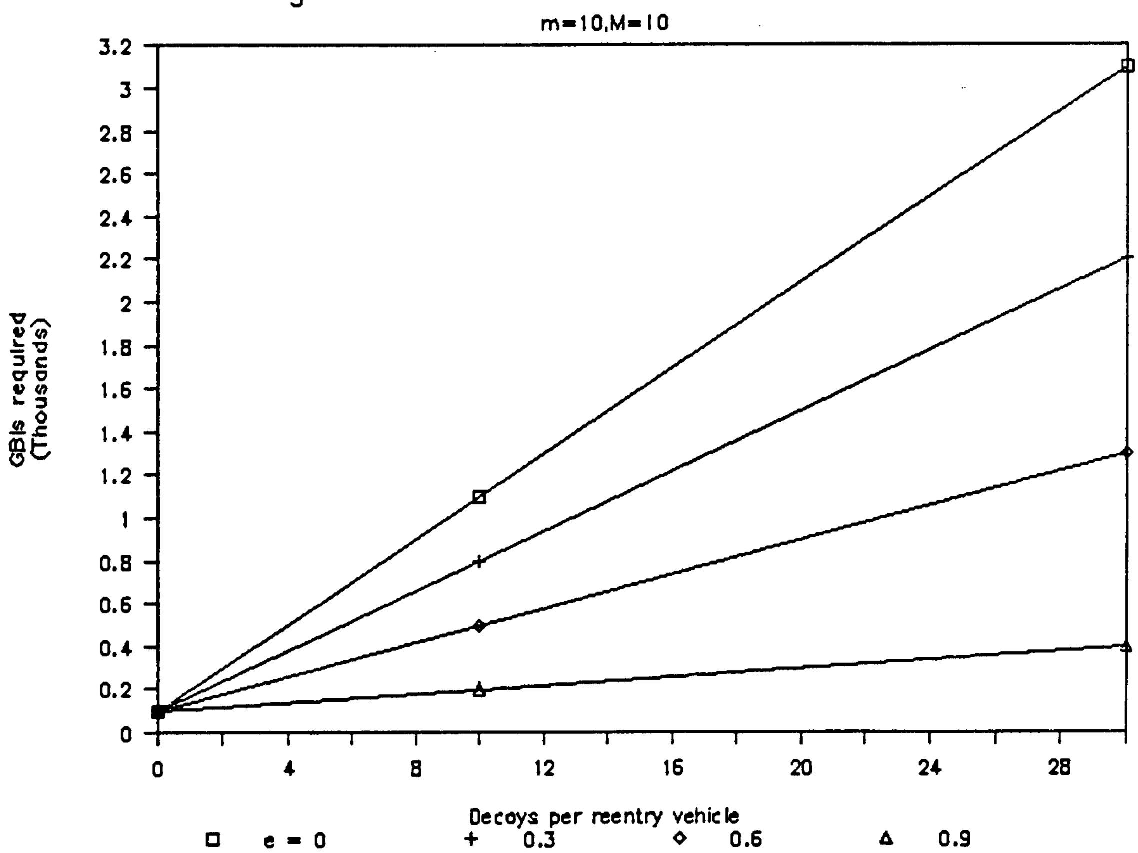

Fig.9 SBI & lasers: limited & strategic

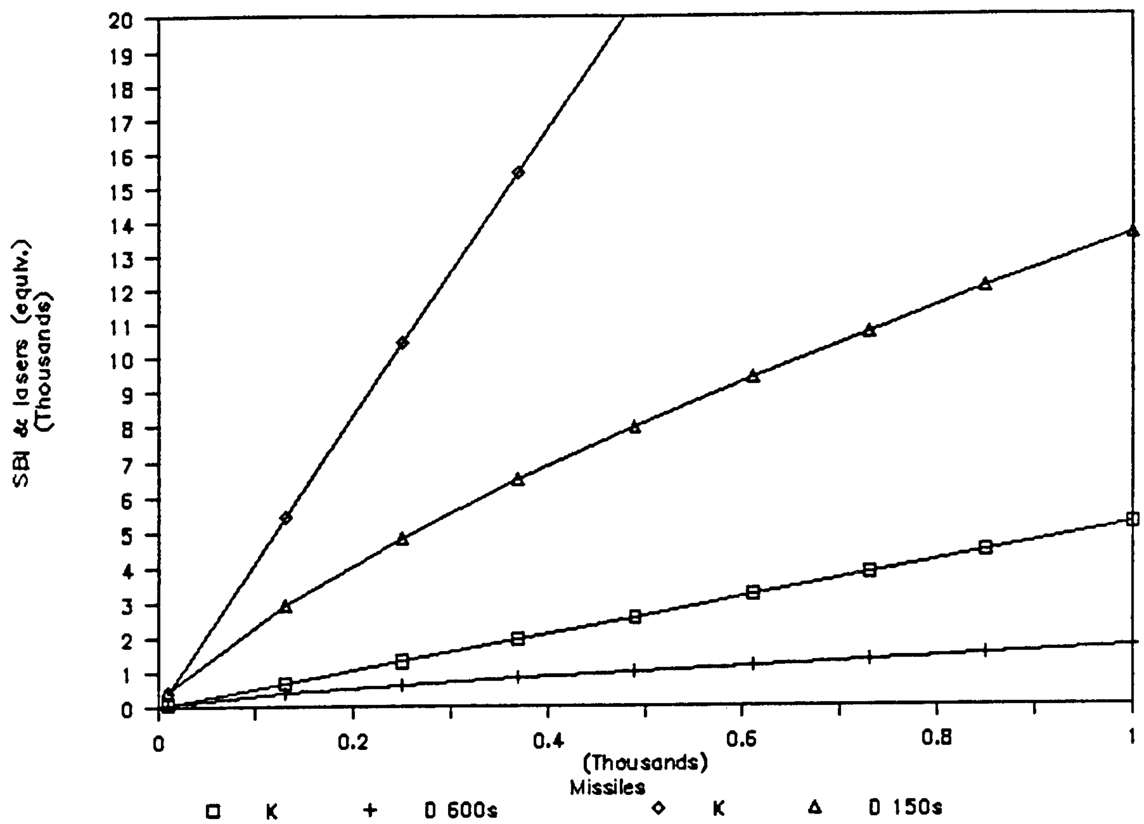

Fig.10. Cost vs decoy mass

f=0.2,Ck=1,Ci=2,m=10,p=0.9,g=7,t=20