Defense Science Board
Task Force Report on

Science and Technology Issues of Early Intercept Ballistic Missile Defense Feasibility

September 2011

This report is a product of the Defense Science Board (DSB). The DSB is a Federal Advisory Committee established to provide independent advice to the Secretary of Defense. Statements, opinions, conclusions, and recommendations in this report do not necessarily represent the official position of the Department of Defense.

The DSB Task Force on Science and Technology Issues of Early Intercept Ballistic Missile Defense Feasibility completed its information gathering in May 2011.

This report is UNCLASSIFIED and is releasable to the public.

OFFICE OF THE SECRETARY OF DEFENSE
3140 DEFENSE PENTAGON
WASHINGTON, DC 20301–3140

DEFENSE SCIENCE BOARD

13 September 2011

MEMORANDUM FOR UNDER SECRETARY OF DEFENSE FOR ACQUISITION, TECHNOLOGY, AND LOGISTICS

SUBJECT: Final Report of the Defense Science Board (DSB) Task Force on Science and Technology Issues of Early Intercept (EI) Ballistic Missile Defense (BMD)

I am pleased to forward the final report of the DSB Task Force on Science and Technology Issues of EI BMD. The task force was asked to study the feasibility of achieving "Early Intercepts" of regional-level, adversary ballistic missiles, with the presumption that, if feasible, it would lead to significant cost savings in regional missile defense.

In the context of a regional BMD system, the task force concluded that the Early Intercept concept is not a particularly useful organizing principal. The more traditional objectives of large battlespace, large defended areas, and high single-shot probability of kill are far more useful to achieving an effective regional BMD system. Pursuit of these traditional objectives potentially results in increased effectiveness and lower cost. The Missile Defense Agency's (MDA) current program addresses all of these traditional objectives.

In addition, the task force examined the potential contribution of forward-based regional assets to the defense of the homeland against ICBMs. The task force found that a regional intercept, early in the trajectory of ICBMs heading towards the U.S. homeland, could potentially reduce significantly the cost of our homeland defense. However, achieving this potential is highly dependent on the development of a very high-speed regional interceptor. As described in the report, MDA is currently pursuing this capability.

Overall, the task force finds the basic components of our inventory today, namely Aegis ships with radars and long-range interceptor missiles, is well suited as a foundation for the planned regional defense mission outlined in the Phased Adaptive Approach, including the defense of Europe. The Task Force also finds that current MDA advanced development efforts, addressing a number of critical enablers highlighted in the report, potentially contribute to and enhance a flexible and effective regional and homeland ballistic missile defense.

I fully endorse all of the task force's recommendations and urge you adopt their findings and recommendations.

Paul G. Kaminski

Dr. Paul Kaminski
DSB Chairman

DEFENSE SCIENCE BOARD

OFFICE OF THE SECRETARY OF DEFENSE
3140 DEFENSE PENTAGON
WASHINGTON, DC 20301–3140

07 September 2011

MEMORANDUM TO THE CHAIRMAN, DEFENSE SCIENCE BOARD

SUBJECT: Final Report of the Defense Science Board Task Force on Science and Technology Issues of Early Intercept Ballistic Missile Defense

The final report of the Defense Science Board Task Force on Science and Technology Issues of Early Intercept (EI) Ballistic Missile Defense (BMD) is attached. The Task Force considered both technology issues and architectural constructs to accomplish "Early Intercept" against regional-level adversary ballistic missiles. In addition, the Task force briefly examined the use of regional missile defense missiles in a homeland defense role.

The task force concluded that there is often confusion as to what EI means and concluded that EI per se is not a particularly useful goal or protocol for design of a regional BMD system. EI is not fundamental as an attribute of effective ballistic missile defense. Far more useful are the more traditional objectives:

- **Large battlespace** – to enable flexible firing doctrines such as shoot-assess-shoot (S-A-S) and to reduce the defense sensitivities to varying offense tactics and threat details;
- **Large defended areas** – to obtain the economic benefit of having to deploy only a few sites instead of many, thereby reducing the number of defense assets, required interceptor missile inventories, and basing requirements;
- **High single-shot probability of kill** – to minimize the number of interceptor firings required to achieve high probability of low leakage and also to guard against correlated errors minimizing the effectiveness of multi-shot firing doctrines.

The critical enablers to achieve the objectives are:

- High missile velocity — fundamental to almost everything else.
- The ability to launch defense interceptors early in the trajectory of enemy missiles requires improved radar capability. The current radar on the Aegis ships requires more substantial operating range for the full realization of a robust regional defense while modest improvements to current land-based radars also improve the defense capability against long-range regional threats. New-technology airborne and space sensors, capable of establishing high-accuracy tracks on offensive missiles early in flight, are promising.
- The efficient networking of sensor platforms and weapons is clearly mandated for the demanding European role.

- Although not analyzed in detail during the course of the study, it is clear that the successful operations of these components is predicated on an ability to discriminate (in the exo atmosphere) the missile warhead(s) from other pieces of the offensive missile complex, such as rocket bodies, miscellaneous hardware, and intentional countermeasures. The importance of achieving reliable midcourse discrimination cannot be overemphasized.

Forward-based regional assets potentially contribute to the defense of the U.S. against ICBMs. Developing an intercept capability early in the trajectory of incoming missiles potentially reduces the cost and increases the effectiveness of homeland defense. This potential, however, is highly dependent on the regional defense enablers discussed above and in more detail in the accompanying report.

The task force concluded that despite the confusion surrounding the concept of EI, the Missile Defense Agency is on the path to developing a robust and effective regional missile defense capability.

ADM William J. Fallon, USN (*Ret*)
Co-Chairman

Gen Lester L. Lyles, USAF (*Ret*)
Co-Chairman

Table of Contents

List of Figures

Introduction and Summary

The Defense Science Board Task Force on Science and Technology Issues of Early Intercept (EI) Ballistic Missile Defense Feasibility was convened in December 2009 and concluded its deliberations in May 2011.

The Terms of Reference (TOR) for the Task Force focused on defense against regional-level adversary ballistic missiles. It directed the Task Force to consider both technology issues and architectural constructs to accomplish "Early Intercept" (defined in the TOR as that interval in a ballistic missile's flight between thrust termination and final deployment of warhead(s) and/or countermeasures).

The complete terms of Reference are in Appendix A, and the Task Force membership is in Appendix B. A list of briefings to the Task Force is in Appendix C.

In February 2010, the Department of Defense issued a key document that comprehensively outlined the objective of the Nation's ballistic missile defense program (*Ballistic Missile Defense Review Report*, February 2010). This document clearly spelled out the top priority role of regional ballistic missile defense wherein the U.S. committed itself to defend not only our military assets overseas, but also to provide missile defense assistance to our "allies and partners." The U.S. has many allies and partners worldwide, so there is a wide range in the difficulty of achieving defensive coverage of their territories. The collection of allies in Europe represents the largest land mass to cover, and the Task Force devoted much of its analytics to this European theater. However, in examining the issues related to EI in the context of the Phased Adaptive Approach (PAA) in Europe (EPAA), the Task Force additionally considered a different kind of "EI" from that spelled out in the TOR, namely the issues related to using regional forward-based defenses to get an "early" shot at intercontinental ballistic missiles (ICBMs) heading to the U.S.

Chapter 1 of this report analyzes the benefits and shortfalls of the EI proposition. As a result of the analyses presented in Chapter 1, certain key attributes of effective Regional Defense became evident, as did some key enablers required to achieve an effective defense. Chapters 2 and 3 review those key attributes and technological enablers, respectively. The Task Force's principal findings and recommendations are in Chapter 4.

Overall, we conclude that EI per se is not a particularly useful goal or protocol for design of a regional BMD system. There is often confusion as to what EI means; moreover, it is not fundamental as an attribute of effective ballistic missile defense. Far more useful are the more traditional objectives:

- **Large battlespace** – to enable flexible firing doctrines such as shoot-assess-shoot (S-A-S) and to reduce the defense sensitivities to varying offense tactics and threat details;
- **Large defended areas** – to obtain the economic benefit of having to deploy only a few sites instead of many, thereby reducing the number of defense assets, required interceptor missile inventories, and basing requirements
- **High single-shot probability of kill** – to minimize the number of interceptor firings required to achieve high probability of low leakage and also to guard against correlated errors minimizing the effectiveness of multi-shot firing doctrines.

Each of these traditional objectives contributes to the robustness, quality, and affordability of regional defense, and they are fundamental to cost-effective ballistic missile defense.

The critical enablers to achieve the objectives mentioned above are:

- High missile velocity — fundamental to almost everything else.
- The ability to launch defense interceptors early in the trajectory of enemy missiles**.** Radars of much more substantial operating range than the current radar on the Aegis ships will be necessary for the full realization of a robust regional defense. Modest improvements to current land-based radars also improve the defense capability against long-range regional threats. New-technology airborne and space sensors, capable of establishing high-accuracy tracks on offensive missiles early in flight, are promising.
- The efficient networking of sensor platforms and weapons is clearly mandated for the demanding European role. We show in Chapter 1 the serious consequence of relying solely on organic operation.
- Although not analyzed in detail during the course of the study, it is clear that the successful operations of these components is predicated on an ability to discriminate (in the exo atmosphere) the missile warhead(s) from other pieces of the offensive missile complex, such as rocket bodies, miscellaneous hardware, and intentional countermeasures. The importance of achieving reliable midcourse discrimination cannot be overemphasized.

In our examination of the potential for forward-based regional assets to contribute to the defense of the U.S. against ICBMs, we find that such an intercept capability, early in the trajectory of incoming missiles, has the potential to both reduce the cost and increase the effectiveness of homeland defense. This potential, however, is highly dependent on the regional defense enablers discussed above, and in particular on achieving high velocity in our regional interceptors as well as on the ability to do effective kill assessment for the forward based intercepts. We also note that this potential is much less dependent on earlier interceptor launch (including even prior to enemy missile booster burnout) than from the other enablers such as high interceptor velocity.

Overall, the basic components in inventory now, namely Aegis ships with radars and long-range interceptor missiles, are well suited as the foundation of the regional defense mission, including the defense of Europe. The Task Force also finds that current efforts to place assets on land, where suitable geography and regional political relationships enable this option have the potential to contribute to and enhance a flexible and effective ballistic missile defense.

Chapter 1:

The Value of Early Intercept and the Ability to Achieve It

Possible Value of EI

After much discussion and a number of briefings by MDA and others, the Task Force identified three potential areas in which EI, if achievable, might have considerable value.

- **The ability to deny an adversary the use of penetration aids or early release of submunitions:** While boost-phase intercept (currently not feasible) is a fundamental counter to either of these offense tactics, there could be some value in a post-boost intercept, provided it wasearly enough.
- **The ability to achieve a S-A-S firing doctrine:** If the first shot by the defense could be made early enough in the ballistic missile trajectory, sufficient time might remain to assess the lethality of the first shot before firing an additional interceptor missile(s).As will be shown, a S-A-S firing doctrine offers the potential for cost savings by reducing required interceptors per enemy ballistic missile.
- **The ability to achieve a large defensive footprint or area of protection:** By a suitable combination of interceptor location and interceptor velocity, an intercept early in the offensive trajectory can cast a large defensive "shadow" – i.e., the azimuth and elevation spread of outgoing ballistic missiles heading to different targets will not have propagated very broadly, and thus a single defensive firing battery can protect a large ensemble of potential target areas.

In the sub-sections below we examine the requirements and caveats associated with each of these three possibilities, after which, using the EPAA as a representative situation, we examine the feasibility of realistic ballistic missile regional capabilities to achieve them.

Deny the Use of Penetration Aids or Early Release of Submunitions

One of the primary motivations for boost-phase intercept, despite our current inability to achieve it, is that the offense cannot either (a) confound the defense by releasing penetration aids or (b) create too many lethal targets for the defense to shoot at by releasing submunitions, until after the booster has burned out. This is fundamental, and no "trick" of the offense can violate this principle. Clearly the advantage to the defense of doing this does not disappear the instant burnout occurs, because it takes the offense some period of time to dispense whatever penaids or submunitions are to be released. So the question is, "What is this period of time?" In order to get a first-order estimate of this, i.e., is it seconds, tens of seconds, or hundreds of seconds, the Task Force reviewed dispense times for a variety of U.S. and foreign ballistic missiles, including both test articles and operational missiles. The results of this review are displayed in Figure RMS-1.

Four sets of data are presented. Above the line are data for foreign vehicles, and below the line for U.S. vehicles. In each set of data, the red figures represent the time at which the first objects were released and the red figures indicate the last release of objects. The blue shaded area depicts the first release of the various objects considered.

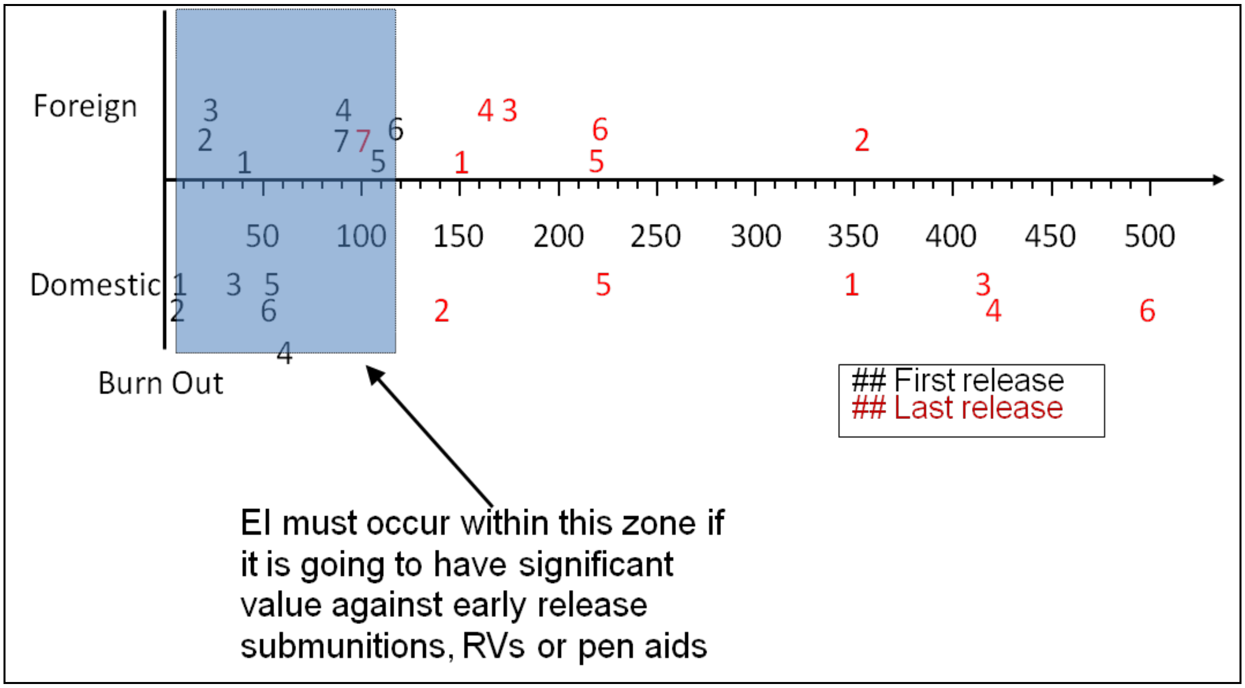

Figure RMS-1: Ballistic Missile Dispense Times in Seconds

If the benefit of the defense's EI in countering release of ballistic missile penaids or submunitions is to be realized, then the defense must achieve its intercept, at the latest, within the time after burnout highlighted in blue. Based on the above, we have used a canonical time of 100 seconds post-boost as the measure of whether an intercept is early enough to provide this defense benefit. We note that, as stressing as this may be on the defense, it is the longest time that is available, and in many cases will be too long, as indicated by the fact that most of the first releases occurred well inside this time. In the footprint analysis below, we will examine the conditions under which intercepts can be achieved within 100 seconds after enemy missile burnout.

Save defense missile assets with a S-A-S firing doctrine

In general, for realistic values of single-shot kill probability (Pssk), if the ballistic missile defense is to achieve low leakage, multiple shots will be required against each incoming enemy ballistic missile. For example, if the defense system can achieve a Pssk of 0.85 for each missile it shoots, and this statistic is independent shot-to-shot, achieving a 50% probability of no leakers against a raid of 30 tactical ballistic missiles (TBMs) will require the defense to shoot three missiles at each incoming TBM. In order to achieve a 90% probability of no leakers, four defense missiles must be devoted to each incoming offense missile. This obviously can become a very expensive requirement for the defense. If, as an alternative to simply firing salvos of defense missiles at each incoming missile, time is available to fire one missile, observe what happens from that engagement, and then fire the remaining missile(s) only if the assessment is made that the first shot was not successful, then the potential exists to save significant defense resources. For the Pssk of 0.85 that we used above, the probability that the first missile will not be successful is 0.15 (1-0.85) and thus only 15% of the time will the other missiles have to be fired. For the 0.5 probability of no leakage against the example of 30 TBMs, this would mean that instead of firing 3 missiles on average, the defense would have to fire only 1.3 missiles (the first one and then another two 15% of the time). This would represent a potential missile savings of 56%. For the 90% no leakage case above, the potential savings would be 64% (1.45 missiles instead of 4).

But none of these potential savings can be achieved unless two criteria are satisfied:

1. The ability to make the first shot early enough (or alternatively, to make the last shot late enough) to leave sufficient time to observe the results of the initial shot before launching the subsequent missile(s). We note that it is the time available before the first possible and the last possible shot that is important – not necessarily the ability to shoot "early," although this will certainly help. We call this time interval "battlespace," and it is the all-important attribute in having the time available to do S-A-S.
2. The ability to keep the errors we make in the assessment of whether or not the first shot was successful sufficiently low. There are two types of errors that are possible – the error that although the first shot was unsuccessful the target is assessed as dead (false positive), and the opposite error that although the first shot was successful, the target is assessed as still alive (false negative). We note that while the false negative wastes defense missile resources (we shoot when we don't have to), the false positive is far more critical – a live RV is still coming at us, and we let it come without further action. For this reason we generally set our decision criteria to minimize the false positive at the expense of the false negative (the two are linked by the physics and statistics of the phenomenology). Figure RMS 2 provides one example of how well we must be able to assess whether or not we killed the target with the first missile if we are to save significant missile inventory. It is evident that an error of only a few percent in the probability of false positive makes the effort to achieve sufficient battlespace to enable S-A-S, whether through EI or not, not worth doing. Unfortunately, the ability to make kill assessments with such small probabilities of false positive has yet to be demonstrated.

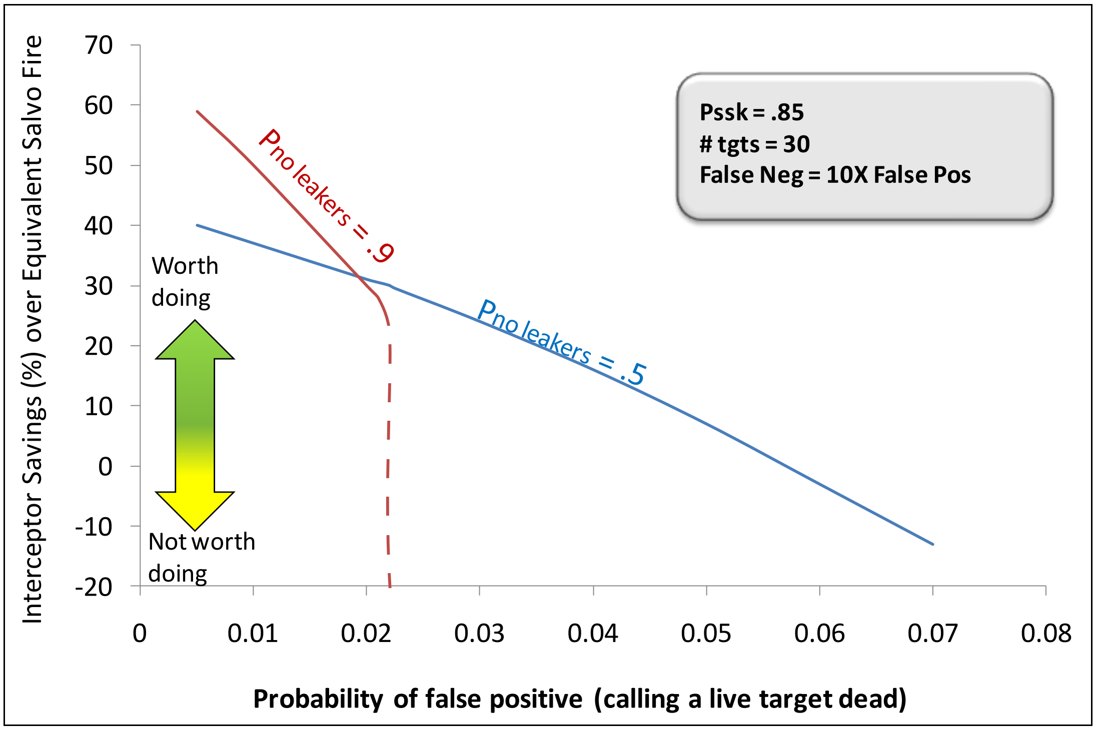

Figure RMS-2: Kill Assessment Errors Must be Very Low to Provide Payoff

Protect large defended areas by making intercepts early in the ballistic missile trajectory

This is sometimes called casting a large defended "shadow." It comes about from the fact that early in their trajectories RVs from the same launcher heading to widely separated targets will not have spread far, since the time over which their different velocity vectors have propagated is short. Thus, a single interceptor launch position – given that it is close enough to the offense launch position and contains defense missiles of sufficient velocity – can protect a large area behind it. This has a defended coverage benefit in and of itself. However, to also get the efficiency benefit of S-A-S discussed above, once again the real issue is battlespace – i.e., the ability to make intercepts both early and late.

In the remaining sections of this chapter we examine the ability to protect the large areas implied under the latter phases (Phases 3 and 4) of the EPAA. This will provide a means of examining both the difficulty of achieving EI in a regional context, as well as the value of achieving it in each of the three potential payoff areas discussed above.

Assessing the feasibility and actual payoff of EI in achieving penaid denial, S-A-S, and large defended areas in EPAA

The Task Force examined the area of protection that could be achieved in the latter phases of EPAA as a function of four different EI conditions, listed in order of decreasing difficulty:

1. Early enough to achieve denial of early release of submunitions or penaids – this was defined as intercepting no more than 100 seconds after threat burnout.
2. Early enough to provide sufficient battlespace to enable an S-A-S firing doctrine. We assumed that the assessment phase could be accomplished within 20 seconds after intercept
3. Early enough that a salvo firing doctrine (i.e., firing two or more missiles in close succession) could provide at least one intercept opportunity within the pre-apogee flight regime.
4. No EI constraint – ability to provide salvo intercepts unconstrained by the criterion of #3 above.

Surveillance Unconstrained, Kinematic Coverage in Europe

Figure RMS 3 represents one such examination. The map shows the defended area in five different colors (the fifth being "uncovered" or no defense coverage possible) as a function of each of the EI definitions above. The colors are ordered in terms of potential benefit to the defense.[1] The zones are constructed to be defense enforceable, i.e., we assume that the adversary can attack from any place within his country and an area is considered "defended" if and only if all of the attack trajectories can be intercepted prior to getting to their intended target area. Four defense sites contribute to the defense -- three on ships as shown and one on land in Eastern Romania. Each site contains generic advanced SM-3 missiles with a burnout velocity that we will characterize here as "slow." The assumption is made that the defense can launch missiles 100 seconds after threat booster burnout – this being a representative time to establish the threat state vectors with sufficient accuracy such that the initial missile heading errors can be taken out within the divert capability of the later stages of the interceptor. Using this definition regarding when the defense can launch, no surveillance sensor detection or tracking constraints are included- i.e., we assume a defense interceptor launch at enemy booster burnout plus 100 seconds without any regard to whether or not this is possible with realizable surveillance sensors -- we will examine the impact of real surveillance in association with figs RMS 6, 7 and 8 below...

[1] We include whether before or after apogee as a criterion as a matter of interest. However, we note that there is no identified specific advantage or disadvantage of intercepting before or after apogee respectively. It's an arbitrary measure.

.

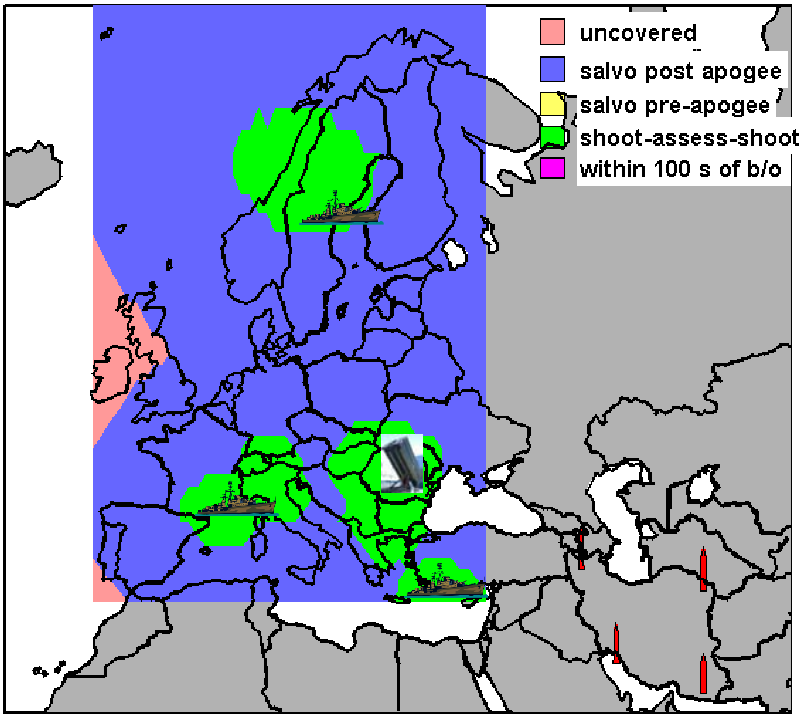

Figure RMS-3: EPAA Kinematic Coverage with Slower Missile

We see in RMS-3 that good coverage of most of Europe is achievable, and even some small pockets of S-A-S just behind each of the firing batteries is possible, although none of the three "EI" benefits is widely achievable. In particular, it is not surprising that the penaid benefit (intercept less than 100 seconds after burnout) cannot be achieved, since the defensive missiles are not launched until this time.

Fig RMS-4 shows the same case but with a significantly faster missile in the land-based site. The faster missile, even in the single land-based site, buys enough time to now enable S-A-S over nearly the entire region. Note that we also see a small area of pre-apogee salvo west of the UK, where there is not sufficient battlespace to achieve S-A-S, even though at least some of the salvo shots are sufficiently early to achieve intercepts prior to apogee[2]. This is the only case we saw in which pre-apogee salvos had a zone somewhat larger than the S-A-S zone. Thus, in general, achieving a pre-apogee intercept shrinks the coverage zone beyond the more beneficial S-A-S zone. This also underscores the fact that S-A-S is more a function of available battlespace than EI per se.

[2] See Footnote 1.

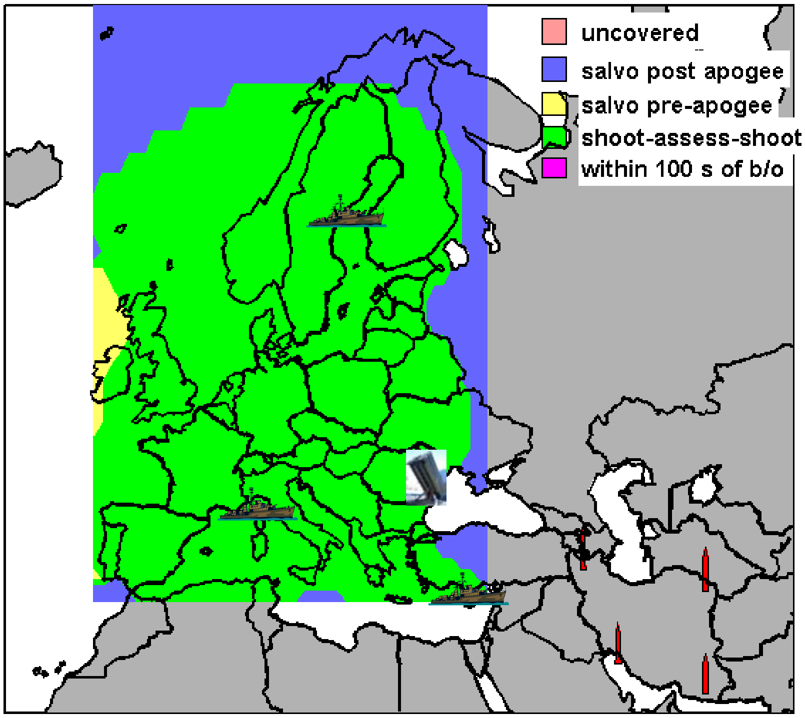

Figure RMS-4: EPAA Kinematic Coverage with Faster Missile

<u>The difficulty in achieving intercepts within 100 seconds of burnout</u>

We noted above our assumption that not launching the interceptor until 100 seconds after enemy booster burnout fundamentally eliminated any possibility of achieving intercepts inside this timeline. The Task Force explored the degree to which a more optimistic set of defense conditions might lead to at least some pre-100-second intercepts over the coverage region. Fig RMS-5 below is one example of what it might take to get even minor coverage in the region.

To achieve even the very limited pre-100-second coverage in the figure, a number of extremely optimistic defense assumptions were made – both on what could realistically be assumed with greatly advanced missile technology and with dramatic changes in the political environment in the region to allow the defense deployment to essentially surround the launch areas. These assumptions included:

- Deploying two sea-based (one in a land-locked body of water) and two land-based firing batteries sitting immediately outside the adversary's territory. All contain the very high velocity missiles described below.
- The ability to launch the defense interceptor immediately at enemy booster burnout. If possible at all, this would take significant effort, both in sensor technology and in deployment, as well as in the divert capability of the missile.
- Intercept burnout velocity nearly 70% greater than the "fast" interceptor used in RMS-4 above, together with an interceptor burn time about 1/3 that of the fast missile – again, taken together these are near-impossible conditions.

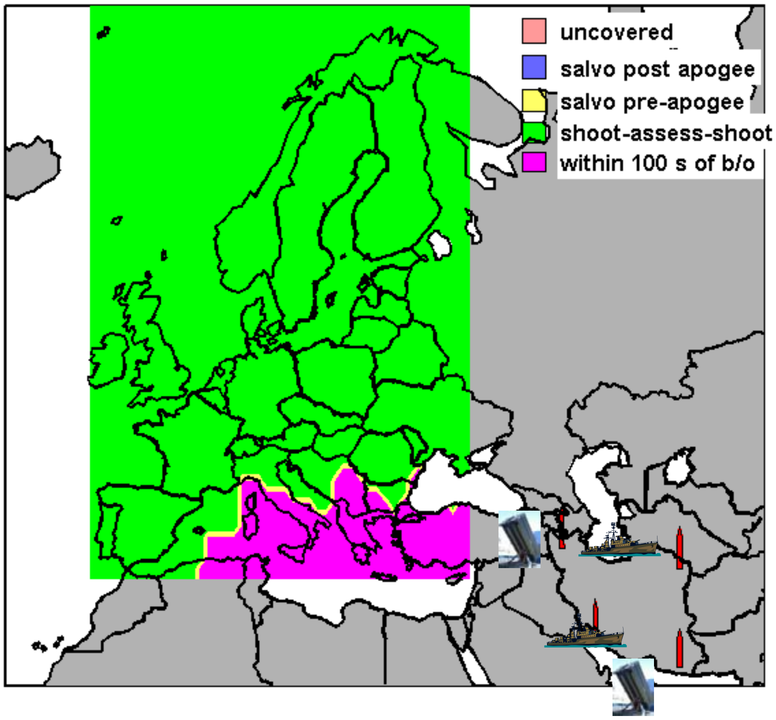

Figure RMS-5: Pre-100-second Intercepts with Overly Optimistic Assumptions

From these analyses, the Task Force concluded that achieving a useful area of protection over which intercepts could be made within 100 seconds after enemy booster burnout was essentially impossible. Again, from the missile data we reviewed, in most cases 100 seconds is too late – to effectively negate early release of penaids or submunitions, intercepts would have to be achieved well inside this timeline.

Surveillance Considerations in EPAA

The Task Force next investigated the required sensor capability to support the kinematic coverages achieved with the slower and faster missiles shown in Figures RMS-3 and RMS-4, respectively. Figure RMS-6 shows the defense coverage for the slower missile, including sensor limitations, for the sensor suites discussed below. The objective was to provide a "balanced" capability that matched the kinematic-only coverage in Fig RMS-3 – e.g., a construct in which the required sensor capabilities just support the kinematics of the missile.

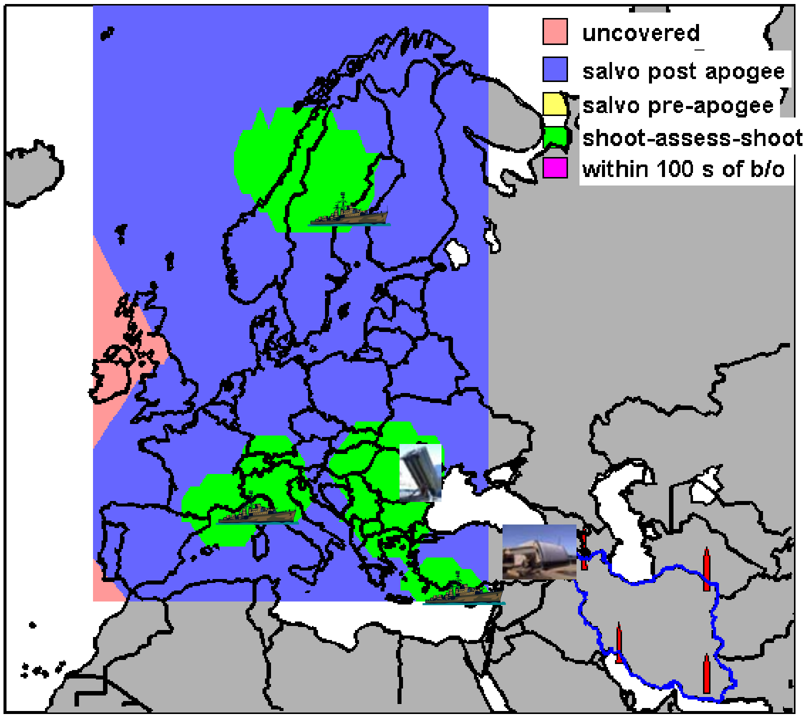

Figure RMS-6: Coverage Achievable with Slow Missile and Netted Local Surveillance and Tracking

With advanced local sensors at all four firing batteries, as well as a larger sensor forward based in Eastern Turkey, the kinematic coverage depicted in RMS-3 can be fully supported – i.e., the coverage shown in figure RMS-6, in which interceptor launch is dependent upon sensor detection and track, is essentially the same as that in RMS-3.

The shipboard radars were assumed to be of the type and size for which the Navy is currently conducting competitive concept formulation and risk reduction studies to support advanced Aegis surveillance and fire control. The radar supporting the land-based firing battery is identical to the existing Army fire control radar for THAAD. The larger forward-based early warning, detection, and tracking radar is similar to the land-based fire control radar, but is larger in the product of gain, aperture, and power by a factor of 3 (5 dB). This measure of radar capability is appropriate, since it is assumed that because satellite cueing is available to aid in detection, track rather than search is the dominant requirement. This 3X factor could be achieved with an array size about 40% greater in area than the current configuration. Whether this is feasible or not was not investigated by the Task Force, although it certainly seemed that an array that was about 20% greater in both dimensions was within the realm of feasibility. It is important to note the assumption that all of these radars were fully netted, including their connectivity to satellite surveillance for cueing purposes. This presumption that high-quality track data were available wherever and whenever it was useful enabled the employment of both launch-on-remote and engage-on-remote fire control. We will see in a subsequent discussion the significant sensitivity of these results to that oversimplifying assumption.

The Task Force further investigated whether these same sensor capabilities had the ability to support the kinematic coverage achieved with the faster missile depicted in Figure RMS 4. Figure RMS-7 below depicts the coverage obtained with the same local sensors as discussed above in relation to RMS-6, but with the addition of a second land-based firing battery in Poland. This additional firing battery was required to preserve the large kinematic S-A-S coverage area shown in RMS-4.. With interceptor launch at booster burnout plus 100 seconds, (the condition in RMS-4) the faster missile in the single land-based site in Romania was adequate to provide battlespace over the entire region sufficient to allow subsequent shots after the "assess" period from both that same site, as well as from the sea-based sites, with the slower missiles. But under the condition of launching 100 seconds after ballistic missile detection by the sea-based or land-based sensors in situations in which detection occurred after booster burnout, (i.e., interceptor launch could not occur until more than a hundred seconds after booster burnout), the single land-based site with the faster missile could not project enough battlespace for S-A-S over the entire region, even with the large forward radar in Turkey. For some adversary launch sites the Poland battery offered protection of the northern areas of Europe, unachievable without it.

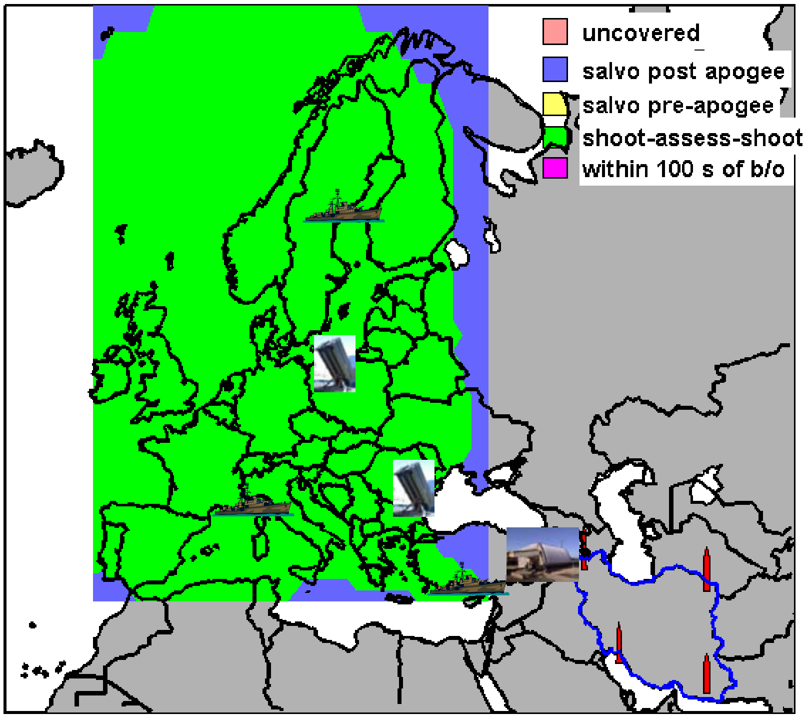

Figure RMS-7: Coverage Achievable with Fast Missile and Netted Local Surveillance and Tracking

The Criticality of the Robust Netting That Has Been Assumed

Throughout all of the above, the assumption has been made that the data collected by any sensor can be available with low latency and high quality to any other sensor, fire control function, or missile, whether on launch or in flight -- in other words, a perfectly netted regional BMDS system. It is therefore important to ask how critical this regional sharing of data is to obtaining the large defended areas shown in the preceding figures. The answer is "extremely." Fig RMS-8 shows the results of the same defense laydown as in Fig RMS-7 (three sea-based sites with the slower missile, two land-based sites with the faster missile, and a forward-based large radar in eastern Turkey). All of the individual radar and missile capabilities are the same as in the robust S-A-S coverage of RMS-7, but all networking has been disabled and each site is working organically – i.e., it cannot launch a missile or send updates to it in flight except based on data it collects with its organic radar. The result is startling – not only has all of the S-A-S coverage disappeared, but most of the salvo coverage has disappeared as well. The only areas of protection left are small defended areas behind each of the land-based firing batteries – i.e., those with the fast missiles. The slower ship-based missiles cannot provide any area of protection, because without cueing from some source, their on-board radars do not provide enough time to get to the RV either before the ship is overflown or before the RV gets to the ground. This is remedied to a degree with cueing, but without some kind of dependable real-time connectivity even timely cueing is not possible. Note this result occurs even *assuming* the organic radar upgrades previously described are implemented.

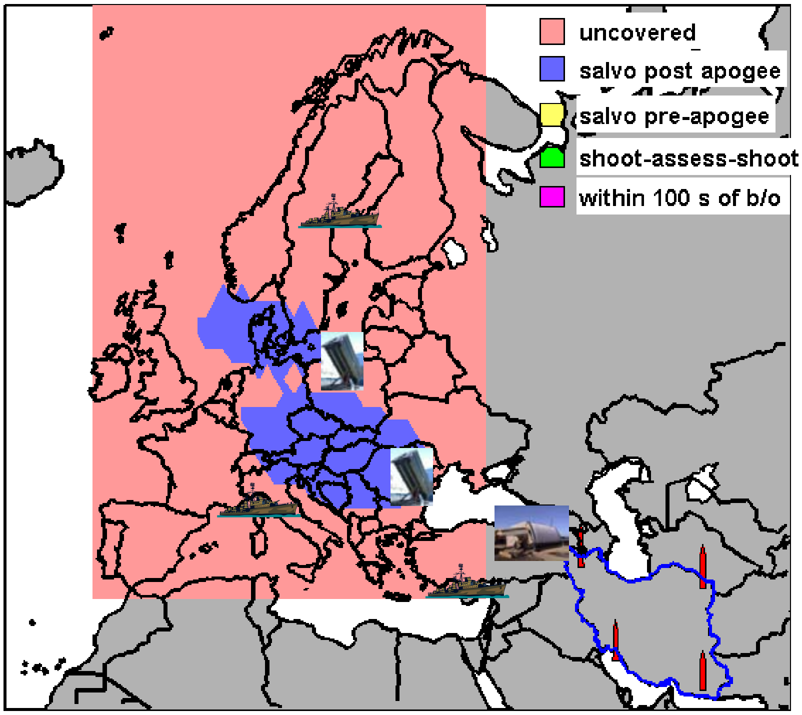

Figure RMS-8: Impact of Organic-only Operation

<u>Capabilities in Mid-East and South East Asia Theaters</u>

Figures RMS 9 and 10 indicate the defense coverage that can be obtained over Israel and Japan for attacks from potentially hostile neighboring countries. As is evident from the figures, country-wide coverage is much easier to obtain than in Europe, given the much smaller expanse of either of these countries as compared to all of Europe, and the relatively shorter range (lower velocity) of the attacking missiles. In both cases, complete coverage can be obtained with the slower advanced SM-3 family missile. In Israel, the single ship is aided by a sensor on land, about the size of the existing U.S. land-based radar supporting THAAD. Together they provide the salvo coverage shown. Because there is no opportunity to provide sensor basing closer to the shooter, a larger sensor (about +5 dB) is required to project S-A-S over the entire country.

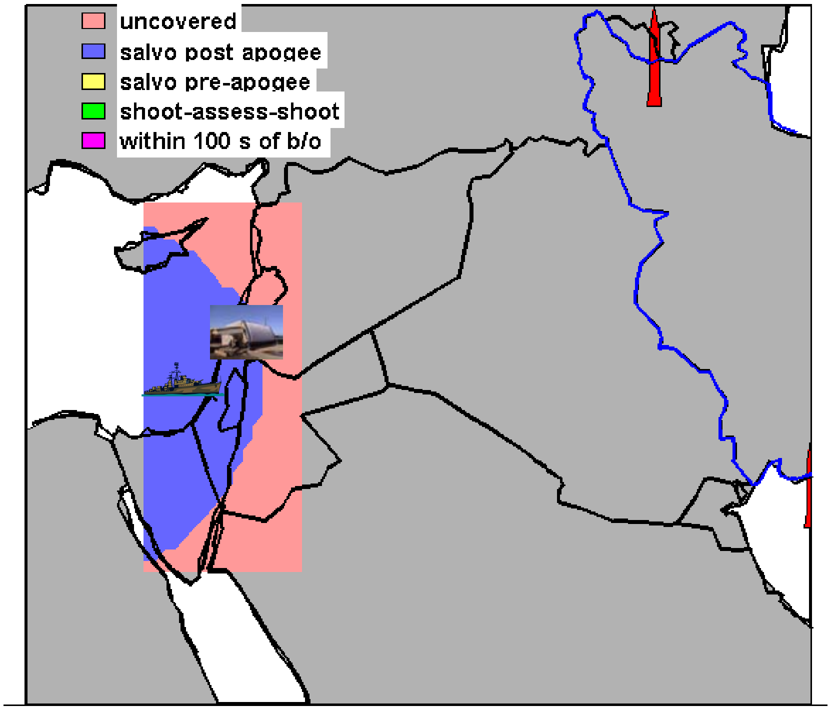

Figure RMS-9: Defense Coverage over Israel with Slower Missile

In Japan, two ships between the shooter and the area to be protected provide complete coverage, with S-A-S over the most populated area. If increased S-A-S coverage were desired over most of the country, a third ship would be required, with the two shown in the figure redeployed somewhat.

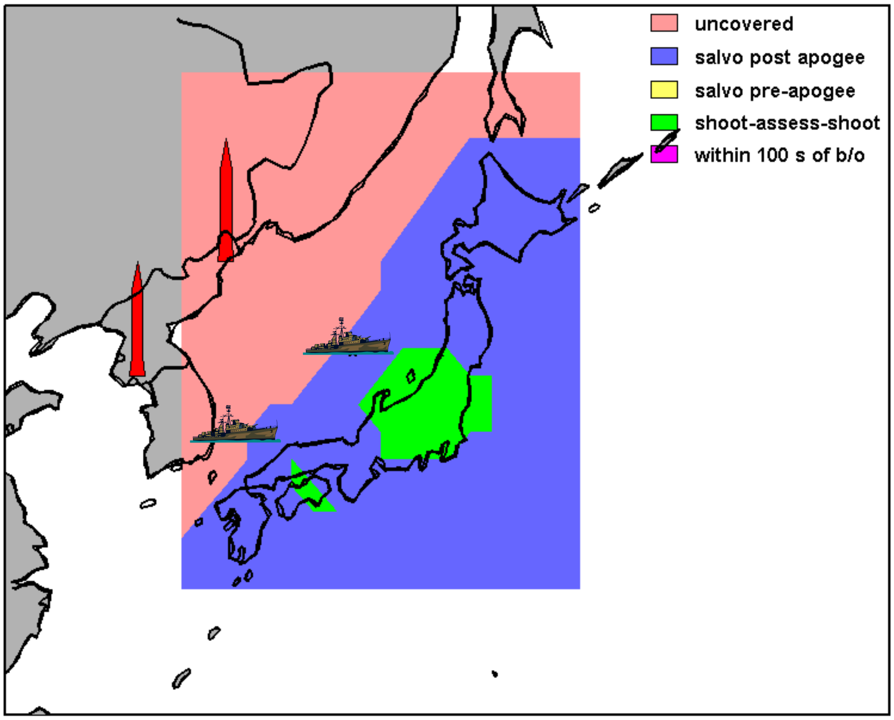

Figure RMS-10: Defense Coverage over Japan with Slower Missile

Potential Benefit of Forward-Based Regional Defenses in Supporting U.S. Homeland Defense

The Task Force also examined a somewhat different kind of "EI" than described in the Terms of Reference – the ability of forward-based regional defenses, as in Phase 4 of EPAA, to aid in the defense of the United States. The incentive for doing so is clear – not only does this present an opportunity for additional engagements beyond those possible with U.S.-based Ground-Based Interceptors (GBIs), but if the regional intercepts were early enough, there could be an opportunity to assess the results of the regional intercepts prior to committing the far-more-expensive GBIs. With a significant cost ratio between the GBI and the regional missile, this could provide a huge economic advantage. Fig RMS 11 quantifies this potential for the representative situation indicated in the figure.

At the assumed 0.8 Pssk effectiveness of the homeland defense GBI-like interceptor, three shots in salvo provide about a 90% probability of no leakers against a 10-missile attack[3]. If we now introduce a regional missile system, forward of the GBI, that takes two early shots against each ICBM heading toward the U.S., two things happen:

1. Some fraction of the time the forward missiles kill the target and, given time to assess the results, only they are fired. The GBI missiles are not fired, thereby reducing the number of GBIs required;
2. For the remaining cases, the regional missiles do not kill the target and the homeland defense missiles are fired.[4]

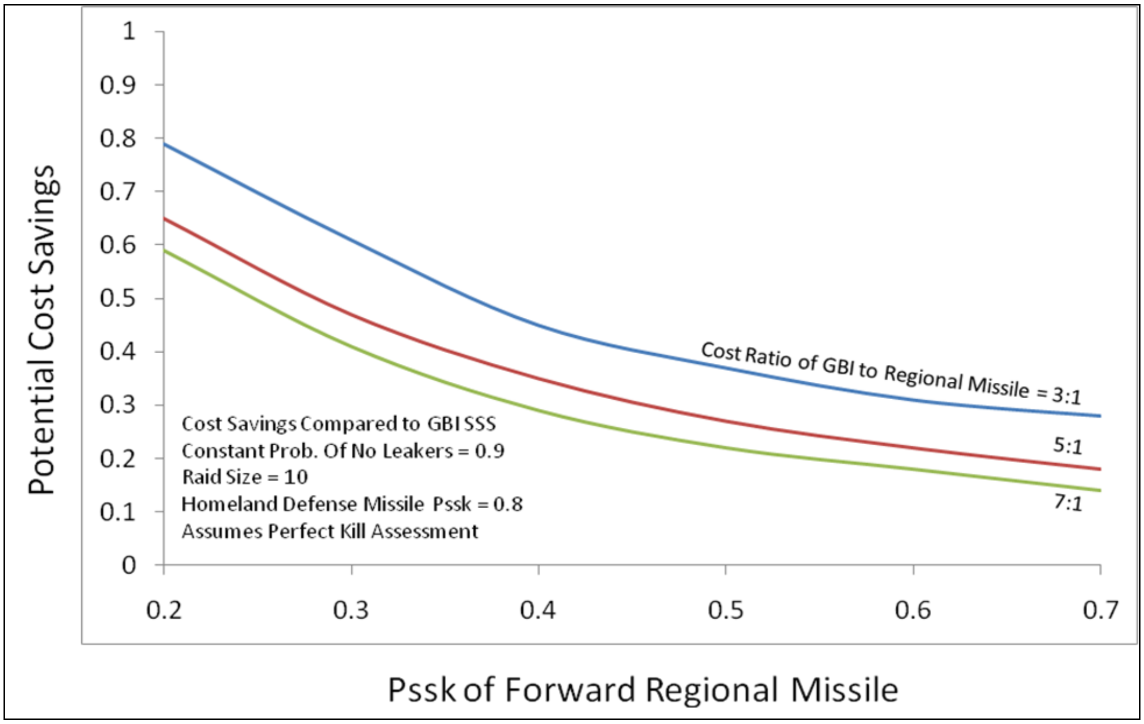

Figure RMS-11: Potential Value of Regional Defenses in Contributing to Homeland Defense

[3] We assume that a regional adversary has fewer ICBM class missiles than the shorter range ones useful in regional conflicts. Thus, although in the earlier part of this section we analyzed 30 missile regional attacks, here we believe 10 missile attacks are more representative of the ICBM situation.

[4] The specific number of homeland defense missiles fired is a function of the Pssk of the forward based regional missile. In the curves, the number is chosen to maintain a fixed 0.9 probability of no leakers.

This results in an overall savings of missile expenditures, the specifics of which depend upon two variables – the single shot kill probability of the regional missile and the ratio of unit cost between the rearward GBI missile and the forward regional missile (the blue, red and green curves in the figure). What is significant is that even the combination of a relatively low regional defense effectiveness (e.g., 0.4) against ICBMs and a relatively low cost ratio between the two kinds of missiles (e.g., 3:1) has the potential to cut the missile expenditure cost in approximately half. Two questions, of course, remain: can we achieve the very low kill assessment errors required to enable these kinds of cost savings? And can the regional defense system, and in particular the missile, provide this early shot capability? Figures RMS-12, 13 and 14 provide some insight into this latter question.

Each of the figures color-codes CONUS with five different defense capabilities: pink - no forward (i.e., EPAA) or rear (i.e., GBI) intercepts are possible; blue - only the forward regional intercepts can be made; yellow - only rear GBI intercepts can be made; light green - both forward and rear intercepts can be made, but only in a salvo (this situation did not occur in any of the three charts below); and dark green - the most favorable situation in which the forward regional missile can intercept with sufficient time to allow an assessment before launching the GBIs. We are interested, of course, in obtaining as much dark green as possible. As can be seen in Figure RMS-12, regional intercepts can take place only for those missiles heading into a small area in the northeastern U.S. This occurs because those trajectories travel closest to the regional defense land-based launch sites in Eastern Europe. As the target areas move southwesterly across the U.S., their corresponding trajectories over Europe move more northerly – trajectories from Iran into southern California go almost due north over the interior parts of Russia. These are too far from the regional land-based fast-interceptor launch locations to be intercepted. We also notice that the small bit of joint coverage over Maine that does occur provides sufficient time for the GBI launches to wait until after the regional missile intercepts have occurred – i.e., there is no significant light green area outside of the dark green Thus, at least in this limited case, if the forward intercepts can occur at all, they occur with sufficient time to enable S-A-S. We shall see below what is required to get joint coverage over the entire CONUS land mass and whether or not the conclusion holds up that wherever the regional missiles can get a shot at all, they can provide S-A-S capability.

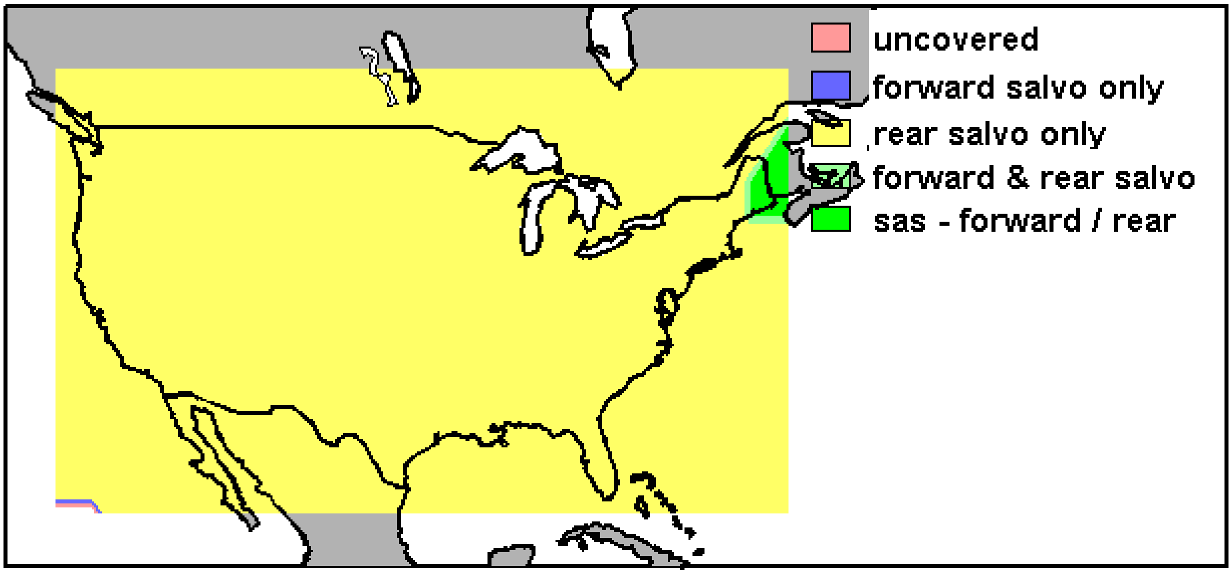

Figure RMS-12: Regional System Participation in Defense of CONUS with Nominal Fast Missile

Figure RMS-13 shows the S-A-S joint coverage that can be obtained with a slightly greater than 40% increase in the Vbo of the regional land-based missiles in Romania and Poland. As the Vbo of the land-based missiles increases from the nominal "fast" missile to the 40% increase discussed here, the S-A-S coverage over CONUS increases from that depicted in Figure RMS-12 to that shown in Figure RMS -13. The southwestern edge of the green area moves linearly with velocity in a southwest direction across the country until, at a 40% increase, all of CONUS is covered. We also examined the sensitivity of the required velocity to assumptions about when a defensive launch could take place (i.e. sensor effectiveness). The required velocity turned out to be relatively insensitive to launch timing. Over the range of 50 seconds before enemy missile burnout to 100 seconds after burnout, the interceptor velocity required varied only by about 0.3 km/sec, for a sensitivity of 0.1 km/sec per 50 seconds of launch timing. Thus, advanced search-and-track sensor technology, although useful for other purposes, cannot significantly ease the regional interceptor kinematics required to participate in this homeland defense mission.

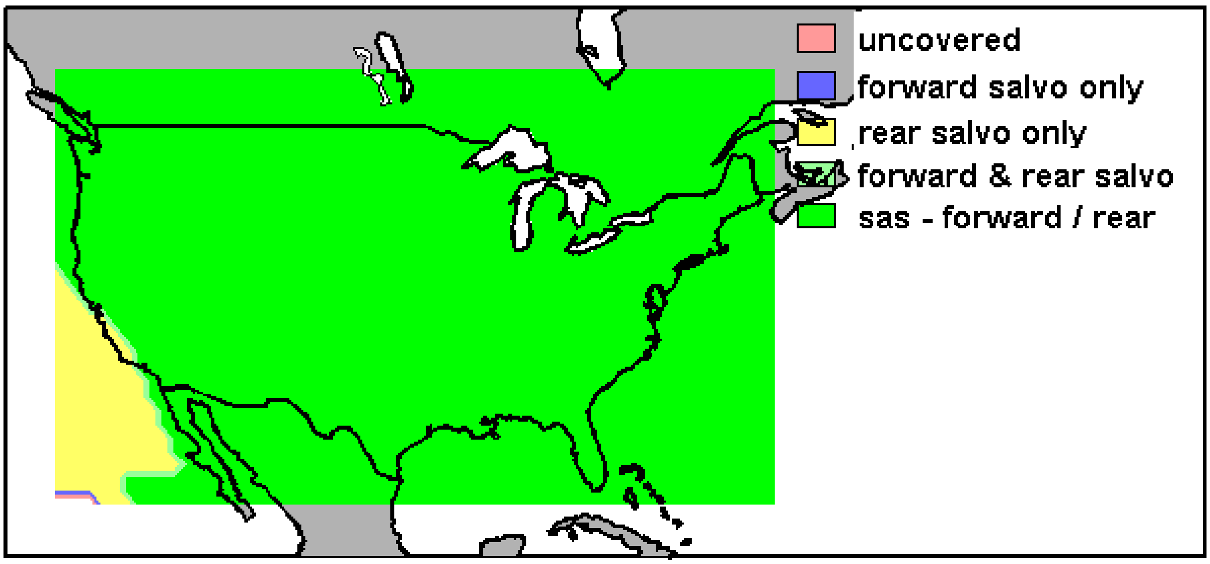

Figure RMS-13: Full Regional S-A-S Coverage over CONUS with 40% Faster Missile in Land-Based Sites Only

If, instead of restricting the faster missile to land-basing only, the faster missile is based on both sea and land (all of the five locations shown in Figure RMS-7: Baltic, northern Mediterranean, eastern Mediterranean, Romania, and Poland) the required increase in Vbo over the nominal fast regional missile can be cut in half to about a 20% increase in Vbo, a more realistic option.[5] The S-A-S coverage provided with this missile in all European locations is shown in Figure RMS-14, almost duplicating that shown in Figure RMS-13 with the 40% faster missile. Note that in both cases, no forward and rear salvo-only coverage is provided – in other words, the general condition holds that if the forward regional missile can get a shot at all, the shot is early enough to provide sufficient time for an S-A-S doctrine, potentially saving considerable missile resources, provided that robust kill assessment is feasible. In addition, we

[5] In fact, the required missile velocity is quite sensitive to basing. For instance, if instead of a 3rd site on a ship in the Baltic, the basis for figure RMS-14, the 3rd site were on land further north and west in Europe, such as in Vardo, Norway, the 20% additional velocity could be reduced to about 14%.

found the same interceptor velocity sensitivity to launch timing as in the land-based-only situation – namely about 0.1 km/sec Vbo per every 50 seconds of pre- or post-boost launch timing.

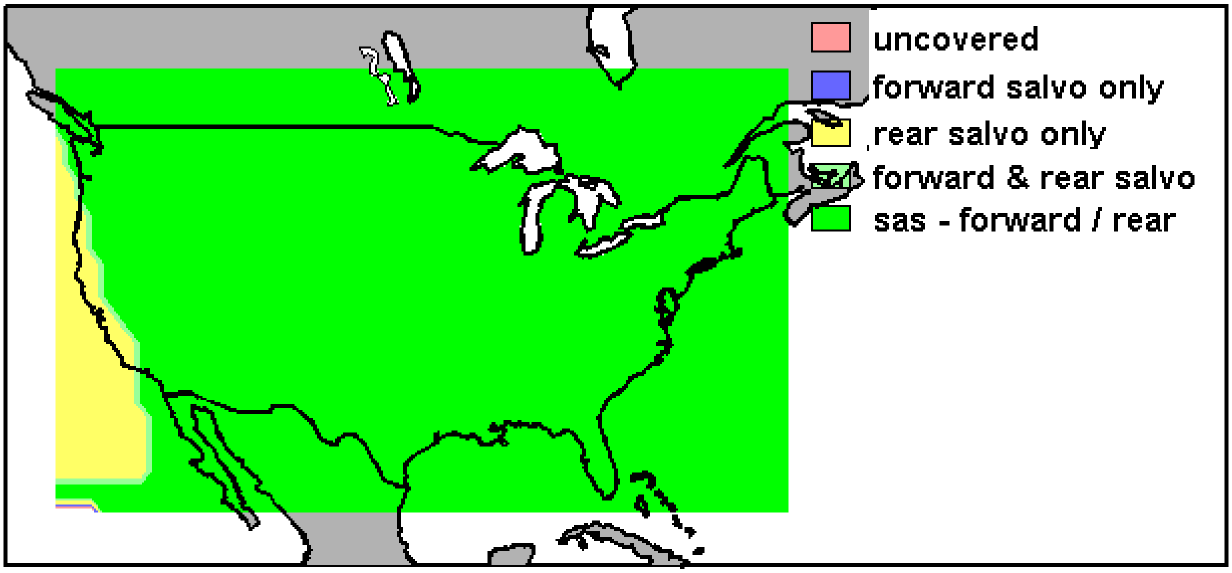

Figure RMS-14: Full S-A-S Coverage over CONUS with 20% Faster Missile in Both Sea-based and Land-based Sites

Conclusions Regarding the EI Value Proposition

Based on the analyses reviewed in this chapter, some summary conclusions emerge:

1. In a regional context there is little measurable value in achieving EI per se.
    a. A determined adversary can deny the potential benefit of intercepting missiles before they can dispense their lethal munitions or penaids.
    b. Although there is potential value in enforcing a S-A-S firing doctrine, the ability to do so is dependent on large battlespace, not EI. Further, the value is dependent on performing robust kill assessment, and the ability to do so has yet to be established.
    c. There is value in achieving large defended areas, but doing so is a function of scenario geometry, fast missiles, capable sensors, and robust networking. The imposition of an "EI" on top of these actually reduces the area of protection over the non-constrained case (see discussion of pre-apogee salvo zone in association with Figure RMS 4).
2. In a homeland defense context, there is a significant potential cost and effectiveness advantage of achieving an intercept by forward-based regional assets prior to having to commit rearward homeland protection assets such as GBIs. However, just as in the regional case, robust kill assessment is a crucial enabler. In addition, the feasibility of achieving the very high regional missile burnout velocity, depending upon siting, far in excess of what has currently been achieved, to provide this benefit over a large portion of the U.S. is uncertain. Finally, the performance benefit of earlier forward based intercept launch of the interceptor (e.g. even prior to booster burnout) in this scenario was minimal compared with the benefit of achieving a very high regional missile burnout velocity.
3. Aside from these negative or qualifying comments on EI as a fundamental performance goal, it would appear that the feasibility of achieving the basic objectives of the PAA has been well established by the current and planned MDA program – no fundamental roadblocks or major technical barriers to success were uncovered by the Task Force.

Chapter 2:

Key Attributes of Regional Ballistic Missile Defense

Certain characteristics of BMD systems have long been held as very important measures of overall effectiveness. Among these are large defended areas, high single-shot probability of kill (Pssk), and large battlespace (that is, a long time over which target complexes can be observed and evaluated and during which successive engagements can be made). The analyses performed by the Task Force – summarized in Chapter 1 and based on European regional defense and the potential regional contribution to U.S. homeland defense, with basic analyses of the defense of Israel and defense of Japan – confirm these beliefs.

Figure RMS-15 illustrates the benefits of these characteristics for the EPAA scenario discussed in Chapter 1. This analysis computes the number of defensive interceptor missiles required to enforce a 0.9 probability of no leakers against a raid of 30 offensive missiles. We assume perfect exo-atmospheric discrimination of warheads from other objects, and, in the case of a S-A-S firing doctrine, an S-A-S error probability of false positive of 1% and false negative of 10%.

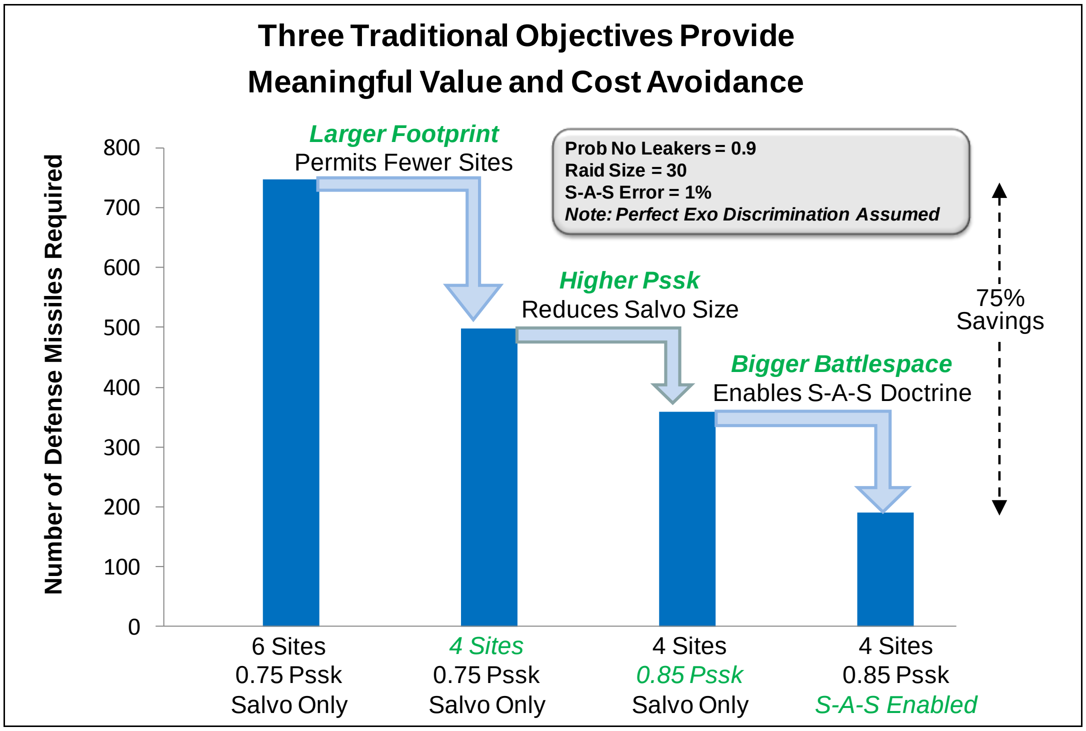

Figure RMS-15: Traditional Ballistic Missile Defense Objectives

Four hypothetical cases are considered. In the first case we assume the defense consists of six sites, each containing interceptor missiles with a 0.75 Pssk and with insufficient battlespace to enable an S-A-S firing doctrine. In order to achieve a 90% probability of no leakers with a 0.75 Pssk interceptor, statistically 4.1 interceptors must be salvo'd against each incoming missile. Since the defense must be able to withstand a 30-missile attack on whatever targets or critical areas the offense chooses to shoot at, the total number of interceptors required at each interceptor location is slightly over 120 (30 potential incoming missiles times 4.1 interceptors per missile). Because we don't know how the adversary may distribute his attack (spread over 30 different targets, all allocated to one high-value target, or anything in between), we must stock this number of missiles at all 6 launch locations, for a total of 738 interceptor missiles as shown in the bar.

In the second case we assume that each site can defend a 50% larger area on the ground. Other assumptions remain unchanged from Case 1. In Case 2 only four sites are necessary, and, although the number of interceptors required at each launch location remains the same (slightly over 120), they are required at only four locations instead of six, for a total of only about 492 interceptor missiles.

In the third case we assume that each interceptor missile is of a higher quality and is characterized by a Pssk of 0.85. Other assumptions remain unchanged from Case 2. The higher Pssk reduces the size of the salvo required to enforce the 0.9 probability of no leakers from 4.1 interceptors per incoming missile to 3. Thus, only 90 interceptors are required at each launch location for a total of only 360.

In the fourth case we assume that the defense systems have both the kinematics and the long-range sensing to provide a significantly larger battlespace, which in turn enables the defense to employ an S-A-S firing doctrine. Other assumptions remain unchanged from Case 3. On average, only 1.6 interceptors are required for each incoming missile, instead of the 3 required in the salvo case, and the larger battlespace and associated S-A-S firing doctrine reduces the number of interceptor missiles almost in half, to about 190.

Thus, the combination of these three fundamental factors or measures of effectiveness – larger defended area per site, higher Pssk, and battlespace sufficient to permit an S-A-S firing doctrine – combine to provide a 75% reduction in the number of missiles that are required in the defense laydown.

What is important here is not necessarily the particular numbers and assumptions used in this section, but rather the fact that these three traditional measures of defense "goodness" provide a powerful impact on one of the most important affordability factors in missile defense – the number of interceptor missiles that must be procured for a given level of effectiveness. Thus, they provide meaningful and measurable objectives and should remain high in the focus of missile defense requirements vice the broad goal of achieving "EI".

Chapter 3:

Critical Enablers for the Regional Defense Mission

The performance results described in Chapter 1 are predicated on four main defense system attributes:

- Fast missiles
- Long-range radars with precision tracking
- Reliable defense discrimination of threat objects
- Effective networking of defense assets across wide areas.

1. Fast Missiles

The planned progression in development of the SM-3 family interceptor missiles involves higher speed as a continuing improvement over subsequent generations of the missile. The value of higher speed in terms of regional defense area coverage and the ability to achieve the large battlespace required for S-A-S is illustrated in Figure RMS-7 (in comparison with Figure RMS-6) of Chapter 1. This evolution toward faster missiles is a key element of the European regional defense mission. In addition, the ability for regional defenses to participate in the defense of the U.S. homeland by forward engagement of adversary ICBMs is also critically dependent on high speed interceptors. This is illustrated in Figures RMS-12 and RMS-13. Importantly, the requirement for fast interceptor speed is not significantly reduced by Herculean efforts to launch close to, or even prior to, ballistic missile burnout; as discussed in Chapter 1, there is minimal performance gain in earlier regional interceptor launch for the S-A-S U.S. homeland scenario.

2. Long-Range Sensors

The current Aegis shipboard radar is inadequate to support the objective needs of the EPAA mission. For this reason, the TPY-2 land-based radars and the future Navy ship-based Air and Missile Defense Radar (AMDR) upgrade become critical components of the European defense scenarios (Section 1 Figure RMS-6 and associated discussion). In some situations, even the TPY-2's superior tracking range is not adequate for a robust defense, and a moderate increase in sensitivity would be very useful (Chapter 1, Figure RMS-7, and associated discussion).

Radar technology has progressed significantly since the design of the Aegis radar in the 1960's. The current development of a replacement for the Cobra Judy ship-based radar is clear evidence that shipboard radars of much longer range capability are feasible. The challenge for an advanced missile defense shipboard radar will be to accommodate the long-range detection and tracking needs to support a robust PAA, wherever it may be required in the world, while fitting within the volume, weight, and power constraints of both back-fit and new Navy combatant platforms. The Navy's AMDR program is the only program solely focused on that challenge. Continued effort must be made in the years ahead to continue to develop advanced missile defense shipboard radar.

Currently, the MDA is engaged in development of the Airborne Infrared (ABIR) sensor for ballistic missile threat detection, tracking, and possibly discrimination. This concept, although potentially promising as a component that would fit in well with a variety of missile defense architectures and regional situations, is in early development and not ready for inclusion in near-term plans for PAA architectures. At the time of this writing, the technical challenges include achieving highly accurate angular accuracy for the sensor as well as the packaging (e.g. form factor) to employ on an operational (unmanned) air platform. The Task Force notes the great potential of this capability.

Space also plays an important role in the process of detecting and tracking adversary missiles prior to launching an interceptor. While ground-, air-, and sea-based sensors provide the current tracking capability, their performance is often limited by geography and political constraints. Overhead Persistent Infra Red (OPIR) sensors can provide the initial detection capability when connected to a robust Command and Control, Battle Management and Communication (C2BMC) infrastructure. These sensors support and enable the BMDS to initiate the engagement process early and to cue downstream sensors to the missiles' position and velocity. The sensors on the Space Tracking and Surveillance System (STSS) demonstration satellites have demonstrated fire-control quality tracking data for engagement of threat reentry vehicles and when combined with radar data, will provide improved threat object discrimination. Once fielded, the Precision Tracking Space System (PTSS) should provide a persistent, near-global tracking capability.

In order to take full advantage of the OPIR cueing capability, additional elements of the space architecture must be completed. The highest precision cues can be accomplished by fusing Space Based Infrared System (SBIRS), other OPIR sensor data and radar data together; though this has been demonstrated in test environments, the BMDS Overhead Architecture ground system needs to be implemented in order to provide this capability in the operational system. Also, the Joint OPIR Ground architecture initiatives are needed in order to fully collect, process and integrate the data provided by the OPIR sensors. Finally, OPIR supports missions other than missile defense to include missile warning, battlespace awareness, and tactical intelligence; a community-wide OPIR concept of operations needs to be developed that addresses all stakeholders' needs.

3. Threat Discrimination Capability

The analysis of European regional defense in Chapter 1 and the missile resources analysis in Figure RMS-15 in Chapter 2 were both predicated on a robust ability for the U.S. defender to identify the offensive warhead in a background of missile booster bodies, separation hardware, and possible countermeasure objects such as decoys. These analyses accounted for defense interceptor reliability failures and the statistical probability of an interceptor miss; they did not account for interceptors launched at non-warhead bodies. If the defense should find itself in a situation where it is shooting at missile junk or decoys, the impact on the regional interceptor inventory would be dramatic and devastating!

In the previous chapter we discussed the fact that large protected area and large battlespace were important attributes of robust missile defense. Unfortunately, those two attributes require intercepts outside the atmosphere, and if high single-shot probability of kill (the third important attribute in section 2) is going to be realized, then exo-atmospheric discrimination is necessary. Yet discrimination in the exo-atmosphere is still not a completely solved problem. Robust research and testing of discrimination techniques must remain a high priority.

4. Effective Networking

All of the Task Force analysis of future regional missile defenses was predicated on the effective networking and low-latency transfer of information among the various components of the defense – components that are deployed on land, on sea, in the air, and in space and spread over a continent-size, and in some cases, multi-continent-size, and piece of the earth's surface.

Without low-latency networking, the defense capability would be sorely restricted, and the large areas of protection depicted in Chapter 1 in Figures RMS 6 and 7 would be reduced to the small local areas of protection shown in Figure RMS 8. Lacking effective networking, the only way the defense could compensate would be to increase the range of sensors and the speed of missiles, as well as their associated inventory on both land and sea, to unrealistic and impossible-to-afford levels.

Thus, robust networking is the only realistic protocol to achieve operationally useful, large-area defense coverage, effectiveness, and fire power for regional missile defense. In terms of future technology needs, adversary efforts to defeat, disrupt, and/or deny such networking need to be anticipated, mitigated, and protected against.

Chapter 4

Costs and Cost Effectiveness

While the Task Force did not conduct a comprehensive review of BMDS costs, our analyses nevertheless reveal the potential for EI to provide more cost-effective BMD insofar as it can contribute to reducing the number of interceptors needed/expended in both regional and homeland defense scenarios.

We will use these two defense scenarios—regional and homeland defense--to illustrate the potential cost savings that could be achieved. In Chapters 1 and 2, we identified opportunities for relative cost savings measured in reduced numbers of interceptors which might be achieved through enabling effective opportunities for S-A-S[6] in the context of EPAA. In particular, in Figure RMS-2 we analyzed the results for using a higher $V_{BO,}$ land-based missile for the first shot(s) with the potential of saving missiles for subsequent shots. The cost advantage of this approach will depend on a number of parameters, as shown in Figure RMS-2. Key among these parameters, is the relative cost of high V_{BO} missiles employed in a S-A-S firing doctrine (figure RMS-4) compared to slower missiles, that could cover the same defended area, employed in a salvo firing doctrine (figure RMS-3). In Figure RMS-11, we analyzed the potential value of using regional missiles against threats to CONUS prior to committing the more expensive homeland defense missiles in cases in which the regional missiles failed to kill their targets. The savings result from a comparison of the "Shoot Regional – Assess – Shoot Homeland Defense" firing doctrine to a salvo engagement with homeland defense missiles alone. As seen in Figure RMS-11, the savings are a function of the P_{SSK} of the regional missile and the cost ratio of the homeland defense to the regional missile.

Focusing on differences in interceptor costs is appropriate because, to counter multiple missile raids with a high probability of no leakers, large numbers of interceptors will need to be expended. We anticipate that differences in interceptor costs will dominate differences in the costs of other components of the total BMD system.

In order to develop estimates of absolute savings (versus the relative cost savings in figures RMS-2 and RMS-11), we need to convert differences in numbers of missiles fired into dollars saved (or costs avoided). This is difficult for two reasons, especially in the context of later phases of the EPAA. First, significantly higher V_{BO} missiles are in the initial stages of competitive development, and only very rough cost estimates for them are available. Second, missiles such as the GBI 3.0 were developed in the context of an integrated Ground-based Mid-course BMD system, and it has been difficult to estimate the cost of individual interceptors, which comprise one part of the system. MDA has, however, provided an approximate estimate of $70 million per GBI.

Using these rough cost estimates in conjunction with estimates for the cost of other interceptors in the Standard missile family, we are able to develop estimates of potential cost savings from effective employment of S-A-S in the context of EPAA.

[6] Some clarification of the two firing doctrines, S-A-S and salvo, that we discuss may be useful. A salvo firing doctrine is one in which all of the missiles fired against a target are launched in relatively rapid sequence, normally before the first one reaches the target. A S-A-S firing doctrine is one in which a single shot or initial salvo is fired but further shots are not made until the results of the initial shot or salvo are assessed – i.e., further shots are launched only if it is determined that the first engagement did not kill the target. As indicated, that first engagement could be a single shot or it could be a salvo, depending upon the Pssk of the missile, the desired probability of no leakage, etc.

To structure this cost information, we used the current plans for the four phases of the EPAA. These are outlined in table 4.1 below.

Table 4.1 General Description of EPAA[7]

Phase	Time frame	Planned (cumulative) capabilities
1	2011	Deploy existing missile defenses to defend against short- and medium-range ballistic missiles. Planned BMD assets include the deployment of: • An existing sensor (the AN/TPY-2 radar) • BMD-capable Aegis ships (Aegis BMD) and the currently fielded Standard Missile-3 interceptor (SM-3 Block IA)
2	2015	Field enhanced capability to defend against short- and medium-range ballistic missiles. Planned BMD assets to include: • One Aegis Ashore – a land-based version of the Aegis BMD weapon system – in Romania and the more advanced SM-3 Block IB interceptor
3	2018	Field enhanced capability to defend against medium- and intermediate-range ballistic missiles. Planned BMD assets to include: • One additional Aegis Ashore in Poland and the upgraded SM-3 Block IIA interceptor
4	2020	Field enhanced capability to defend against potentially longer-range threats, including intercontinental ballistic missiles. Planned BMD assets include: • Further upgraded SM-3 Block IIB interceptors

Table 4.2 displays cost estimates provided by MDA of the standard missile family and GBI 3.0. Only a rough cost estimate is available for the SM-3 Block IIB interceptor because it is still in the concept phase. The estimates show increases in unit interceptor cost as seeker systems and V_{BO} improve.

[7] Source: GAO Report 11-220, *Ballistic Missile Defense: DoD Needs to Address Planning and Implementation Challenges for Future Capabilities in Europe*, Jan 2011

Table 4.2. Cost estimates for selected EPAA interceptors[8]

Interceptor	Unit cost estimate (BY10 $ millions)	Characteristics
SM-3 Block IA	9.6	Engage SRBM and MRBM mid-course.
SM-3 Block IB	9.4	Improved seeker and optics compared to IA.
SM-3 Block IIA	15.7	Increased V_{BO} to engage IRBMs. Limited capability against ICBMs
SM-3 Block IIB	15 (+/- 5)	Increased V_{BO} for improved capability against ICBMs
GBI 3.0	70	Land-based, CONUS defense against ICBMs

In chapter 1, we noted that employing an effective S-A-S doctrine with a P_{SSK} of 0.85 per missile against a raid of 30 missiles, a BMD system would need to fire 1.3 interceptors per threat missile for a 50% likelihood of no leakage compared to three on average without S-A-S; or 1.45 missiles compared to four on average for a 90% likelihood of no leakage. We can use these ratios to estimate absolute savings provided we know the unit cost of individual interceptors. For these cases, the potential cost savings per intercepted missile would be the difference between the cost of 3 salvo missiles and 1.3 S-A-S missiles for the 50% no leakage case or 4 salvo missiles and 1.45 S-A-S missiles for the 90% no leakage case. Using information from table 4.2 for a regional case, where the salvo missile is an SM-3 Block IIA ($15.7 million per missile) and the S-A-S missile employed is an SM-3 Block IIB (upper end cost is about $20M), the potential savings by employing effective S-A-S against a 30-missile raid amount to between $630 million and $1 billion depending on the desired probability of no leakers.[9] It should be further noted that these savings represent savings in missiles fired against the 30 missile raid. In actuality, the savings would be significantly greater, because, not knowing a priori the area in which the attack would be directed, missile stockage at all interceptor locations would have to reflect this potential difference in required defense missile expenditure.

For the homeland defense case, in which the salvo-only missile is the GBI (~$70 million per missile) and the S-A-S missiles are regional (initial shots at $20M per missile) and homeland defense (later shots at $70 million per missile), the savings will reflect this greater disparity between the two types of missiles – i.e., homeland defense interceptor is 3.5 times greater than the forward-based regional interceptor. For this case, the potential savings against a 10 ICBM-class missile raid against CONUS, for a probability of no leakers of 0.8, is between $0.8 and $1.2 billion depending on the Pssk of the SM-3 Block IIB missile

[8] Cost estimates provided by MDA. For SM-3 Block IA, IB, and IIA estimates reflect buy sizes of 128, 371, and 78, respectively. Because of learning curve effects, the relatively higher quantity of Block IIB missiles somewhat lowers the apparent cost of these missiles in comparison to the others. A cost estimate range is provided for SM-3 Block IIB, which is still in development.

[9] The calculation is straightforward. For a 50% likelihood of no leakers, the cost of successfully engaging a missile employing S-A-S would be 1.3 times the cost of an SM-3 Block IIB missile or $26 million. The cost of defeating the same missile employing an SM-3 Block IIA using salvo fire would be 3 times the cost of the SM-3 Block IIA or $47 million. The implied cost savings employing S-A-S is therefore about $21 million per attacking missile or $630 million for a 30-missile raid. A similar approach holds for a 90% likelihood of no leakers comparing the cost of 1.45 S-A-S interceptors with 4 salvo interceptors.

against ICBMs (here we assume the range of 0.4 to 0.7 as in figure RMS 11). If the P_{SSK} for this missile is higher, e.g., 0.8, and the objective of no leakers is a more aggressive 0.95 probability, the potential savings are significantly greater, in the order of $2 billion. As in the regional defense case, all of these potential savings would have to be multiplied up by a factor of two or three, to account for the number of widely separated regional missile firing locations, i.e., those that are required to protect different areas of CONUS against attack to ensure that the necessary numbers of first shot regional missiles are available for firing, regardless of where the attack is directed.

Thus, although the specific details of defense objectives, regional missile Pssk, and relative costs between the homeland defense and regional missiles are somewhat uncertain at this point in time, this analysis indicates that there are substantial opportunities for savings in defense of CONUS through employing an early intercept against ICBMs from EPAA forward based regional missiles enabling a S-A-S firing doctrine in conjunction with more costly rearward based homeland defense missiles.

Chapter 5:

Findings and Recommendations

Findings

EI in and of itself is not a useful objective for missile defense in general or for any particular missile defense system. Intercept prior to the potential deployment of multiple warheads or penetration aids – the principal reason often cited for EI – requires Herculean effort and is not realistically achievable, even under the most optimistic set of deployment, sensor capability, and missile technology assumptions.

Nor does EI itself provide the capability to defend a large area. Rather, it is the forward basing of interceptor assets and high interceptor speeds that facilitate large defended areas. In fact, requiring even a modestly EI, e.g., before apogee, can often take away much of the benefit that forward deployment of interceptors can provide.

EI can facilitate a S-A-S firing doctrine, which, if successful, has the potential to make the defense much more cost-effective. But it is not EI itself that makes this possible; rather it is large battlespace, however obtained, that enables it. Key contributors to battlespace are forward-based, long-range sensors; properly placed interceptors; interceptor velocity; and low-latency command and control, battle management, and communications, with robust networking of sensor-to-sensor and sensor-to–shooter communications. The other necessary component of S-A-S is very-high-quality kill assessment, without which there can be no effective S-A-S. The Task Force saw no analysis that indicated whether or not such very low error rates are achievable. We believe that such analyses, if not already available, need to be performed, given the potential of S-A-S to achieve large savings in missile inventory and cost.

We found that, kinematically, S-A-S is feasible for regional defenses within the currently planned capabilities of interceptor velocities and advanced sensors. A different application of "EI," namely the use of forward-deployed regional missile defense assets to contribute to the homeland defense of the U.S. against rogue states, appeared to have large potential benefit. The geometry of European regional defense and potential adversaries in the Mid-East are such that if any intercept by regional defense assets of an ICBM targeted against the U.S. homeland from a regional adversary were possible, that intercept would occur before rearward-based GBIs had to be fired. Given the anticipated large cost difference between GBIs and regional defense interceptors, this would enable a firing doctrine of: (1) shoot a salvo of regionally based interceptors, (2) assess the result, and (3) shoot GBIs only at the surviving warheads. However, the Task Force also found that this forward-based intercept of ICBMs from regional defense deployments would require a significant increase of velocity beyond that currently planned for advanced regional interceptors. There could be some reduction in this additional requirement if advanced missiles could be deployed both on land and at sea. More optimistic assumptions on launching soon after or even before enemy missile burnout do not have a significant impact on required missile velocity.

Other indispensible characteristics of an effective missile defense system are the ability to dependably discriminate reentry vehicles from penetration aids and other objects, and interceptors with high single-shot kill probability. These both are fundamental attributes of cost-effective missile defense.

In summary, pursuit of the current plans for regional ballistic missile defense, such as envisioned in the PAA, if pursued to completion, will provide an effective regional defense capability – those plans are technically feasible, are making good progress, and enjoy broad political support. The fact that the Task Force does not believe EI, as defined in its TOR, is either a realistic or useful missile defense objective does not detract from the beneficial position that regional missile defense now occupies. We endorse current efforts within MDA to bring this to fruition.

Recommendations

The Task Force finds that the Missile Defense Agency is on a path to achieve effective regional defense. We recommend that MDA:

- Reduce the emphasis on EI per se.
- Increase the emphasis on system and element advances that contribute to expanded battlespace, larger defended area, and improved single-shot kill probability. These objectives are fundamental, are easily measureable, and have high payoff.
- Increase emphasis on research and development to:
  - Understand the fundamental contributors to non-kills, understand the ability and timing for assessing non-kills, and improve kill assessment methods and techniques, key to a useful S-A-S firing doctrine;
  - Provide robust networked operations of sensors, shooters, and command and control, ensuring robust connectivity, high quality of service, and low latency. Ensure that potential adversary techniques to deny such capabilities can be defeated or mitigated, should the need arise; and
  - Improve capabilities for the exo-atmospheric discrimination of warheads from penetration aids, debris, and other objects. Ensure that the use of all observables from the ensemble of sensors available to missile defense are used to the extent possible.
- Develop future plans and capabilities, both within MDA and in coordination with current service efforts, for:
  - Growth of shipboard and land-based RF sensors beyond the currently planned capabilities;
  - More advanced technology for regional missiles with the proper balance between higher velocity, lateral movement capability, payload weight and shorter burn time and with the potential to be deployed both on land and at sea.
- Continue the development of an airborne infrared sensor, and conduct systems analyses to better understand its potential benefits and limitations as part of the BMD architecture.
- Continue development of space based infrared sensors as part of the BMD architecture for both regional and homeland missions.

Appendix A: Terms of Reference

OFFICE OF THE SECRETARY OF DEFENSE
3010 Defense Pentagon
Washington, DC 20301-3010

ACQUISITION,
TECHNOLOGY
AND LOGISTICS

DEC 04 2009

MEMORANDUM FOR THE CHAIRMAN, DEFENSE SCIENCE BOARD

SUBJECT: Terms of Reference - Defense Science Board (DSB) Task Force (TF) on Science and Technology Issues of Early Intercept Ballistic Missile Defense Feasibility

The DSB study of Missile Defense considered Ascent Phase Intercept in 2002. Since then, many aspects of the Missile Defense architecture and underlying science and technology have matured. I request the DSB study the feasibility of ballistic missile defense in engaging regional-level, adversary ballistic missiles (large raid sizes greater than 30) in the early intercept phase (i.e., from thrust termination to final deployment of reentry vehicles and countermeasures) of the ballistic missiles trajectory. Engaging ballistic missiles during this phase of the missile's trajectory could provide some advantages leading to significantly increased cost effectiveness of missile defense.

The TF should consider unwarned regional level adversary launch scenarios including large raid size, land-based ballistic missiles (BMs) (focused on short, medium and intermediate BMs) and clandestine sea-launched (e.g., from merchant vessels) missiles.

The entire command, control, communications, computers, intelligence, surveillance and reconnaissance sequence, including communication latency issues, should be considered. Alternative early intercept phase system architectures, which incorporate current air-, sea- and land-based systems (e.g., Airborne Laser, Standard Missile-3 (land based and sea based variants IB, IIA, IIB)), should be considered as well as science and technology efforts to increase the effectiveness of the different architectures. To the maximum degree practical, legacy assets including space-based sensor systems (e.g., the Space-Based Infrared System and other Overhead Persistent Infrared Sensors) and incorporation of new components (e.g., Unmanned Airborne Platforms) should be incorporated in the analysis. The purpose of listing specific components is to explore a wide range of solutions and is not meant to direct a review of the listed platforms as a particular matter. Concepts of operation for technical alternatives should also be identified.

This TF shall have access to all levels of classified information needed to develop its assessment and recommendations.

The study will be sponsored by the Under Secretary of Defense for Acquisition, Technology and Logistics, the Vice Chairman of the Joint Chiefs of Staff, and the Commander, U.S. Strategic Command. General Les Lyles, U.S. Air Force (Retired), and Admiral William Fallon, U.S. Navy (Retired), will serve as Co-chairmen of the Task Force.

Colonel Stan Stafira, U.S. Air Force, of the Missile Defense Agency, will serve as Executive Secretary and Lieutenant Colonel Karen Walters, U.S. Army, will serve as the DSB Secretariat Representative.

The TF will operate in accordance with the provisions of Public Law 92-463, the "Federal Advisory Committee Act," and DoD Directive 5105.4, the "DoD Federal Advisory Committee Management Program." It is not anticipated that this TF will need to go into any "particular matters" within the meaning of title 18, U.S. Code, section 208, nor will it cause any member to be placed in the position of acting as a procurement official.

Ashton B. Carter

Appendix B: Task Force Membership

CO-CHAIRMEN

ADM William J. Fallon, USN (Ret)	NeuralIQ
Gen Lester L. Lyles, USAF (Ret)	Private Consultant

EXECUTIVE SECRETARIAT

Col Stanley Stafira, Jr., USAF	Missile Defense Agency

MEMBERS

Dr. Wanda Austin	Aerospace Corporation
GEN Paul Kern, USA (Ret)	Private Consultant
Dr. William LaPlante	MITRE Corporation
Dr. Mark Lewellyn	John Hopkins University Applied Physics Laboratory
VADM Rodney Rempt, USN (Ret)	Private Consultant
Dr. George Schneiter	Private Consultant
Mr. Robert Stein	Private Consultant
RADM Brad Hicks, USN (Ret)	Private Consultant
Brig Gen Mark Owen, USA(Ret)	Northrop Grumman Corporation

SENIOR REVIEWER

Mr. William Delaney	MIT Lincoln Laboratory

GOVERNMENT ADVISOR

Dr. Spiro Lekoudis	OSD, AT&L

DEFENSE SCIENCE BOARD

Mr. Brian Hughes	Defense Science Board
LTC Karen Walters, USA	Defense Science Board
CDR Doug Reinbold, USN	Defense Science Board

SUPPORT

Mr. Chris Grisafe	SAIC
Ms. Tammy-Jean Beatty	SAIC

Appendix C: List of Briefings

ABIR	MDA
Advance Laser Research Program	MDA
Advanced Directed Energy Technology	Lawrence Livermore National Laboratory
Aegis and Aegis Ashore	MDA
Aerospace Corporation	Aerospace Corporation
Air Launch Hit-to-Kill	MDA
Applied Physics Laboratory	Johns Hopkins/APL
Architectural Needs and Potential Airborne Laser System Concepts	MDA
Arrow Weapon System	MDA
BMDS Architecture	MDA
C2BMC and Early Intercept	MDA
Countermeasures	Lincoln Lab
Directed Energy: ALTB	MDA
Early Intercept Overview	MDA
Ground Sensors	MDA
High Frame Rate IR Staring Sensor Systems	USAF
Joint Integrated Air and Missile Defense Organization	Joint Integrated Air and Missile Defense Organization
LB SM-3 Study	MDA
Lockheed Martin Company	Lockheed Martin Company
Northrop Grumman	Northrop Grumman
Policy Briefing	OSD-Policy
Raytheon	Raytheon
Sandia National Laboratory	Sandia National Laboratory
SM-3 Block IIB	MDA
Space Architecture	MDA
The Boeing Company	The Boeing Company
Threat Brief	MSIC/NASIC
UHF Radar	Lincoln Lab

Appendix D: Briefers

Ms. Kari Anderson
Mr. Bill Delaney
Mr. Neil Doar
Col Laurence Dobrot
Mr. Eric Forrest
Ms. Alison Fortier
Mr. Conrad Grant
Dr. Greg Hyslop
Mr. Michael Jacobs
Mr. Larry Jones
Mr. Michael Kelly
Mr. John Kirk
Dr. Mark Lewellyn
RADM Archer Macy
Mr. Richard Matlock
Capt Dennis Murphy
Mr. Kevin O'Brien
Dr. Daniel O'Connor
Mr. John O'Pray
Mr. Scott Perry
Mr. Steve Post
Mr. Richard Ritter
Dr. Brad Roberts
Mr. Kevin Robinson
Dr. Will Roper
Dr. Will Roper
Mr. John Rowe
Ms. Lauree Shampine
Mr. Kirk Shawhan
Mr. Benny Sheeks
Dr. Craig Siders
Mr. Bob Stein
Mr. Edward Taylor
Mr. Stan Thomas
Mr. Gabe Watson
Dr. Lou Weiner
Ms. Lora Wirth
Mr. Kevin Zondervan

Appendix E: Acronyms

ABIR	Airborne Infrared Program
AMDR	Air and Missile Defense Radar
AN/TPY-2	Army-Navy Transportable Radar Surveillance
BMD	Ballistic Missile Defense
BMDR	Ballistic Missile Defense Review
BMDS	Ballistic Missile Defense System
BOA	BMDS Overhead Architecture
CONUS	Continental United States
C2BMC	Command, Control, Battle Management & Communications
EI	Early Intercept
EPAA	European Phased Adaptive Approach
GBI	Ground-Based Interceptor
ICBM	Intercontinental Ballistic Missile
IR	Infrared
JOG	Joint OPIR Ground
MDA	Missile Defense Agency
MRBM	Medium Range Ballistic Missile
PAA	Phased Adaptive Approach
PSSK	Single-Shot Kill Probability
PTSS	Precision Tracking Space System
RF	Radio Frequency
RV	Reentry Vehicle
S-A-S	Shoot-Assess-Shoot
SM	Standard Missile
SRBM	Short Range Ballistic Missile

Defense Science Board
The Pentagon
OUSD (AT&L) Room 3B888A
Washington, DC 20310
(703) 695-4157