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Reactive Armor Tiles for Army and Marine Corps Armored Vehicles

An Independent Report to the Department of Defense and the United States Congress

John D. Pinder

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Preface

This document provides an independent report on the results of a congressionally mandated study of reactive armor tiles for U.S. Army and Marine Corps armored vehicles. The study included an assessment of the existing operational requirements for reactive armor tiles and an analysis of the benefits and costs associated with their acquisition and use. This report was prepared for the Secretary of Defense in fulfillment of the *Strom Thurmond National Defense Authorization Act for Fiscal Year 1999* (HR Report 105-736; Public Law 105-261 Section 114). It will be submitted to the congressional defense committees by 1 April 1999, together with the comments of the Secretary of the Army and the Secretary of the Navy, and the recommendations of the Secretary of Defense as to the types and number of vehicles to be equipped with reactive armor tiles.

This study was conducted as a quick response effort—it was initiated in December 1998 and completed in March 1999. At the request of the Army, RAND was involved from the outset, helping to shape the scope and methodology of the study, monitoring its progress, and reviewing the final results. The study took advantage of the considerable expertise and resources of the U.S. Army Research Laboratory (ARL) and the U.S. Army Materiel and Systems Analysis Activity (AMSAA); ARL characterized the reactive armor tile designs and performed detailed computer simulations of their performance, while AMSAA gathered the necessary data, reviewed existing vehicle protection requirements, and assessed the cost and effectiveness of selected reactive armor tile configurations. This report integrates the supporting analysis performed by AMSAA and ARL with other information to compare the overall benefits and costs of developing, acquiring, and using reactive armor tiles. The inferences and recommendations presented are drawn from an independent review and appraisal of the AMSAA/ARL effort, together with an analysis of additional operational issues.

This research was sponsored by the Assistant Secretary of the Army for Acquisition, Logistics and Technology, and was conducted in the Force Development and Technology Program of the RAND Arroyo Center. The Arroyo Center is a federally funded research and development center sponsored by the United States Army. This report provides an independent perspective that is primarily intended to assist the Secretary of Defense and the Congress in

making development and acquisition decisions about reactive armor tiles for Army and Marine Corps vehicles. While its main objective is to inform high-level policy decisions, this document should also be of interest to a wider audience, including armor technologists, acquisition executives, force structure planners, and land warfare strategists.

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Introduction

This report presents an independent assessment of the results of a study of reactive armor (RA) tiles for Army and Marine Corps vehicles. In compliance with the *Strom Thurmond National Defense Authorization Act for Fiscal Year 1999* (HR Report 105-736; Public Law 105-261 Section 114), this study included:

1. A detailed assessment of the requirements for RA tiles on Army and Marine Corps vehicles.
2. An analysis of the benefits and costs of acquiring RA tiles for those vehicles found to have a requirement for them, as compared to the costs and benefits of any existing upgrade programs for these vehicles.

An extensive supporting analysis was conducted for this study by the U.S. Army Materiel and Systems Analysis Activity (AMSAA), in cooperation with the U.S. Army Research Laboratory (ARL). This analysis assessed the existing requirements for increased vehicle protection, characterized the RA tile candidates that could meet these requirements, and evaluated the cost and effectiveness of several different tile configurations.

This report provides an independent appraisal of the supporting analysis and its results. It also integrates these results with other relevant information to compare the overall benefits and costs of alternative strategies for developing and acquiring RA tiles. Finally, this report synthesizes these results and findings into a series of specific policy recommendations.

Requirements

The study found two Army vehicles to have a need or requirement for better protection that could be met by new RA tiles: the M2/M3 Bradley Fighting Vehicle (BFV), and the M113 vehicle family. The BFV has a specific requirement for increased protection, while the M113 has a clear need for better protection during contingency operations.

There are no existing protection requirements for any Marine Corps armored vehicles that RA tiles could address. Also, the Abrams tank is not considered because its protection requirement is already satisfied.

Candidates and Configurations

Two types of RA tiles were evaluated for the BFV: the current "Production" tile, and a new enhanced "2–3 Year" tile that would require some further development but is designed to provide better protection against advanced anti-armor threats. Both of these RA options for the BFV would use an optimized tile configuration, which provides maximum coverage without interfering with functionality.

Two types of tiles were considered for the M113: a version of the 2–3 Year tile, and a generic "1–2 Year" design, which is similar to the Israeli and French designs that were recently evaluated for the M113.[1] A configuration of each tile type was considered for two versions of the M113: the current M113A3, which can only carry 4,000 pounds of tiles, and an upgraded M113(RE) that can carry a heavier maximum-coverage tile set. In all, a total of six configurations were considered: two for the BFV and four for the M113.

Benefits of RA Tiles

The analysis performed by AMSAA and ARL found that all six RA tile configurations substantially improve vehicle survivability against a range of 2005 threats,[2] including 30mm cannons, hand-held infantry weapons (HHIWs), and anti-tank guided missiles (ATGMs). The 2–3 Year tiles generally provide more robust protection against a full spectrum of threats than either the Production or the 1–2 Year tiles. The M113(RE) benefits the most, due to its larger maximum-coverage configuration. The weight-constrained 1–2 Year configuration, however, provided greater coverage for the M113A3 than the heavier, more capable 2–3 Year tiles, and would thus be favored against less advanced threats.

There are also other important, but less tangible, benefits associated with using RA tiles on these two vehicles. In general, extra protection tends to reduce casualties and expand mission capabilities. Having better-protected vehicles

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[1] See Chapter 2 for a brief discussion of the D650 Foreign Technical Test, which was conducted at Aberdeen Testing Center in 1998.

[2] These threats were approved for this time frame by the Deputy Chief of Staff of the Army for Intelligence (DCSINT).

could also improve the versatility and adaptability of a contingency force, raise its confidence and morale, and ultimately make it more effective. The M113 stands to gain the most from RA, and it might even be able to replace the BFV in some situations.

Costs and Other Burdens

The supporting analysis by AMSAA estimated both the development and life cycle costs for each tile configuration. These estimates are shown in Table S.1, along with the estimated weight of the associated tile sets (as provided by ARL). Two important aspects of these costs should be noted. First, developing the same 2–3 Year tile for both vehicles is less costly ($11 million) than developing two different tiles ($16–17 million), and only slightly more costly than developing a new tile for just one vehicle ($8–9 million). Second, the two maximum-coverage tile configurations for the upgraded M113(RE) are much more expensive than the other tile sets considered for the BFV and the M113A3, and they would require an extra $3 million to develop the necessary upgrade.

The findings of the study with regard to safety risks and logistics burdens were mixed. None of the RA tiles are expected to impose any added logistics burden for storage or guarding, but the transportation and installation of tile sets during a contingency operation could reduce strategic mobility. In addition, if RA tiles are used in combat, the need to replace damaged tiles may reduce sustainability. RA tiles may also pose some danger to nearby dismounted infantry, but the nature and extent of this danger is not well understood. Tests on an older RA tile technology indicate that this danger is tolerable in light of the improved vehicle protection, but this result may not apply to urban operations or future tile designs.

Coordination with Vehicle Upgrades

Both the BFV and the M113 have ongoing A2-to-A3 upgrade programs, but the costs and benefits of each upgrade are quite different. The BFV upgrade is very expensive ($2.3–2.6 million) and primarily electronic, while the M113 upgrade is almost entirely mechanical and much less expensive (just over $200,000). The benefits of these upgrades—digitization for the BFV and mobility for the M113—are more pronounced in high-intensity combat than in lower-intensity operations such as urban peacekeeping.

Table S.1

Weight and Cost Estimates for Each RA Tile Configuration

Tile Configuration	Weight [pounds]	R&D Cost [$ millions]	Life Cycle Cost [$ thousands]
BFV M2A3/M3A3			
Production	6,900	15.4 (sunk)	262[c]
2–3 Years	7,600	9[a]	288
M113(RE)			
1–2 Years	6,400	11[b]	564[d]
2–3 Years	9,200	11[a,b]	710[d]
M113A3			
1–2 Years	4,000	8	209
2–3 Years	4,000	8[a]	209

[a]If 2–3 Year tiles are developed for both the BFV and the M113 at the same time, the total R&D cost is estimated at $10–11 million.
[b]The total R&D cost for an M113(RE) tile configuration includes an extra $3 million for the vehicle upgrade.
[c]The LCC of the first 56 tile sets may be closer to the LCC of $290,000 for sets being produced under the current procurement contract.
[d]The LCC of these configurations includes the $230,000 cost of upgrading the M113A3.

The benefits of RA tiles tend to complement these vehicle upgrade programs. A RA tile set constitutes a modest investment of about 10 percent of the cost of a BFV upgrade; not much considering the value of an A3 on the battlefield. A mechanical A2-to-A3 upgrade for the M113 is comparable in cost to a RA tile set for the refurbished vehicle. In general, it would be prudent to invest in RA for those M113A3s that need better protection. Indeed, if mobility is not so important, as is the case in many low-intensity missions, then RA tile sets might be favored over more A2-to-A3 upgrades. In those missions where protection is extremely important, an additional upgrade to the M113(RE) may be worth the added cost.

Development and Acquisition Choices

There are six development options that would provide an RA tile configuration for the M113 while only developing one new type of tile: 1–2 Year tiles for M113; 2–3 Year tiles for M113 only; 2–3 Year tiles for both M113 and BFV; and each of

these three with an M113(RE) upgrade. In this order, these options offer gradually increasing protection, but also higher development and life cycle costs. The nature of future contingency operations, and the degree of protection they will require, determine the merits of each choice. Based on an analysis of familiar operational scenarios, joint 2–3 Year tile development is the most robust option. The M113(RE) upgrade has potential, but its real value is uncertain, especially in urban operations.

This finding is also reflected in a simple comparison of investment strategies. Outfitting a fixed number of BFVs with 2–3 Year tiles instead of Production tiles caused only a modest drop in the number of M113A3s tile sets that could be acquired with a fixed life cycle budget. Similarly, the cost of outfitting a fixed number of both types of vehicles was hardly affected by this shift to joint 2–3 Year tile development. Choosing to also develop and acquire a small contingent of highly survivable M113s, 10 percent of the total, increased the total cost by only 16 percent, which is a significant extra investment but not an exorbitant one.

Policy Recommendations

The analysis presented in this report yielded eight specific recommendations, which address three important policy issues: the development of new RA tiles and configurations, the acquisition of RA tile sets for current Army vehicles, and further research into the application of RA technology.

A new universal enhanced 2–3 Year RA tile should be jointly developed for both the BFV and the M113. In addition, an optimal tile configuration should be designed for the 4,000-pound M113A3 tile set. Enough additional Production tile sets should be procured to equip a substantial portion of the BFVs in the Army's Contingency Response Forces. When they are ready, a sufficient number of the new enhanced tile sets should be procured to outfit an additional brigade of BFVs. At least this many M113A3 sets should also be procured, and then enough additional sets should be acquired shortly thereafter to meet identified needs.

Further research should be done on two important issues over the next few years: the need for RA tiles on M113s in their typical roles and missions; and the appropriateness of enhanced RA tiles for urban operations. The Marine Corps should also reevaluate its protection requirements to see if the new universal RA tile would be appropriate for any of its vehicles. Similarly, the Army should consider whether its Army After Next vehicles could use the new universal tile.

Acknowledgments

I wish to thank the following people for their efforts in coordinating the study: Mr. Andrus Viilu and Mr. Al Soobert at the Office of the Secretary of Defense; and Dr. Herb Fallin, COL Michael Lavine, and Mr. John Ferguson of the Office of the Assistant Secretary of the Army for Acquisition, Logistics and Technology. I also want to thank AMSAA and ARL for their hard work on the supporting analysis for this study, and recognize the following people for their assistance and input: Wilbert Brooks, Philip Beavers, William Yeakel, John Connolly, Thomas Havel, Michael Zoltoski, Annie Young, Joseph Ploskonka, and especially Irene Johnson, who led the AMSAA analysis effort.

I want to express my appreciation to my RAND colleagues who reviewed and commented on various aspects of this report: Randy Steeb, Russ Glenn, Jerry Sollinger, John Matsumura, Robert Uy, and John Stillion. The efforts of Kenneth Horn in overseeing this effort were also greatly appreciated. I especially want to thank my secretary Linda Weiss for her diligence, patience and support. Finally, I want to thank the RAND Publications Department for their responsiveness in editing and formatting this document on such short notice.

1. Introduction

This report provides an independent appraisal of the results of a study of reactive armor (RA) tiles for U.S. Army and Marine Corps armored vehicles. This report is the product of a quick response study requested to assist the Secretary of Defense and the Congress in making development and acquisition decisions about RA tiles for these vehicles. As mandated by the *Strom Thurmond National Defense Authorization Act for Fiscal Year 1999* (HR Report 105-736; Public Law 105-261 Section 114), the RAND study included a detailed assessment of the existing operational requirements of these vehicles for RA tiles, and an analysis of the benefits and costs of acquiring RA tiles for several specific vehicles with an identified need for extra protection. This report will be submitted as part of a package to the congressional defense committees by 1 April 1999. It will be accompanied by the comments of the Secretary of the Army and the Secretary of the Navy, and the recommendations of the Secretary of Defense as to the types and number of vehicles to be equipped with RA tiles.

Impetus for the Study

RA tiles have been in use on both U.S. and foreign armored vehicles since the 1980s. Recent improvements in RA technology have made it possible to apply this type of protection to lighter vehicles. Although RA tiles have been in use on the Bradley Fighting Vehicle (BFV) for several years, they have not yet been developed for the M113 vehicle because of cost, weight, and safety considerations. However, a foreign technology test[3] performed last year led to a re-examination of the possibility of applying RA tiles to the M113 family of vehicles. M113 variants perform many different roles for the Army, and various elements within the Army have disagreed about whether RA tiles would be worthwhile for their particular variants. M113 users were also concerned about whether the acquisition of RA tiles would compete with a program for upgrading M113A2 vehicles to the A3 version. This upgrade program is important because it would give the M113A3 enough mobility to keep up with other vehicles, such as the BFV. In the end, $5 million was designated by

[3]See Chapter 2 for a brief discussion of the D650 Foreign Technical Test, which was conducted at Aberdeen Testing Center in 1998.

Congress to fund the development of RA tiles for the M113, but this money is frozen pending the completion of this study.

The acquisition of new RA tiles for the BFV was also affected by the law that mandated this study. In addition to the original 178 tile sets now on order, the current procurement contract included an option to purchase another 56 sets to round out the total to 234: enough for two brigades under the new leaner Army force structure. The $16.5 million designated for this procurement is also frozen until the study is received by Congress.

The perceived intent of the requirement for this study is as follows. Before spending any more money on either effort, the Congress needs to know if RA tiles are really needed for the M113, and if so, what the costs and benefits of buying those tiles would be as compared to doing more A2-to-A3 upgrades. Congress asked for a broader study to give the Department of Defense the opportunity to consider a more comprehensive acquisition strategy that would include both the M113, the BFV, and any Marine Corps vehicles with a need for RA. The Abrams M1 tank was not perceived to be an intended target of this study; no major acquisition decisions are pending because the Future Armor Tile (FAT) is already being acquired for this vehicle.

Structure of the Study

RAND Arroyo Center, a federally funded research and development center sponsored by the United States Army, was asked by the Assistant Secretary of the Army for Acquisition, Logistics and Technology to provide an independent assessment of the results of this study. In performing this role, the author attended all of the Study Advisory Group (SAG) meetings and interacted extensively with the various study participants to help shape the scope and methodology of the study, monitor its progress, and review its results.

Both the U.S. Army Research Laboratory (ARL) and the U.S. Army Materiel and Systems Analysis Activity (AMSAA) also played an important role in the study. They provided analytical and subject matter expertise across all aspects of the effort. ARL provided detailed information about RA technology trends, helped select the RA tile candidates and characterize their capabilities, and then used high-resolution computer simulation to estimate the performance of each RA tile configuration. AMSAA gathered data for the study from a wide range of sources and researched the existing requirements for vehicle protection. Based on this information, AMSAA assessed the effectiveness and cost of each candidate RA tile configuration, and it evaluated the extent of other related burdens, such as the safety, transportation, and storage of the tiles.

Study Objectives

The supporting analysis had two preliminary objectives: determine which armored vehicles in use by the Army and Marine Corps have a requirement or a need for RA tiles, and identify and characterize the types of RA tile packages that these vehicles could be equipped with. Once these two objectives had been achieved, the analysis then aimed to answer the following questions about each tile package considered:

- How effective is it at improving vehicle survivability?
- What is its total weight?
- How much would it cost to develop, procure and install?
- What safety risks and logistics burdens would it incur?

This analysis also compared the benefits and costs associated with each RA tile option, and determined the number of candidate vehicles in each force package that could be outfitted with RA tiles at different investment levels.

On the basis of the information generated by this analysis, this report will address three key questions:

- How do the tile packages that could be procured for each vehicle compare overall in terms of their benefits and costs?
- Which, if any, of the new tile designs should be developed?
- How many sets of each tile package should be acquired for each type of vehicle?

In answering the first of these three questions, the RA tile options are also compared to vehicle upgrades, in terms of their relative costs and benefits. The motivation for specific policy recommendations to address the last two questions is provided by a brief scenario analysis, in which various development and acquisition strategies are evaluated in the context of three different operational environments.

Limitations of the Analysis

Because of the fast response required by Public Law 105-261 Section 114, this study was conducted in less than four months. The scope of the analysis was limited accordingly, while still attempting to provide reliable results that address the study's objectives.

- *Time frame.* Only near-term RA tile options were considered: tile designs that would require no more than three years for research and development (R&D), so that procurement could start in fiscal year 2002. With this schedule in mind, various tile packages were evaluated against a spectrum of 2005 threats.[4]
- *Candidate vehicles.* The analysis only considered two vehicles—the Bradley and the M113 vehicle families—both of which are only in use by the Army. No Marine Corps vehicles were considered because none of them had a requirement for extra protection that could be met by RA tiles. An improved protection requirement exists for the Abrams tank, but this vehicle was not considered because the impetus for the study was light armored vehicles, rather than heavy tanks.
- *Operational context.* Only officially documented protection needs and requirements were considered. Differences in these requirements related to operational context (e.g., urban peacekeeping versus high-intensity combat) were not taken into account in the AMSAA analysis. Such contextual considerations will, however, be included in the scenario analysis segment of the policy discussion in this report.

Organization of this Report

The remainder of this document consists of seven chapters. Chapter 2 provides some background with a brief overview of the nature and history of RA. Chapter 3 presents the operational requirements for RA tiles on current armored vehicles. This is followed in Chapter 4 by a discussion of the scope of the analysis performed by AMSAA in support of the study. Chapter 5 then highlights the most important nuances of the methodology used in this analysis and discusses the reliability of its results. Chapter 6 summarizes these results and discusses the benefits and costs of the various RA options considered. This chapter also explains how the results of the study should be interpreted, given inherent limitations of the analysis. Chapter 7 compares the costs and benefits of RA tiles and vehicle upgrades and then evaluates a range of development and acquisition strategies. Chapter 8 makes some specific policy recommendations and suggests possible directions for further research on the application of RA technology.

The text of the authorization act that mandated this study is included in Appendix A. Appendix B provides a summary of the analysis conducted by

[4]These threats were approved and characterized by DCSINT.

AMSAA in support of the study. A separately bound classified annex to this report is also available.

2. Background

Nature and Origins of Reactive Armor

Reactive armor (RA) was first developed during the 1970s as a means of protecting armored vehicles against shaped-charge anti-armor weapons, including Hand Held Infantry Weapons (HHIWs) and Anti-Tank Guided Missiles (ATGMs). The same concept can also be applied to protect vehicles against kinetic energy penetrators (KEPs), such as armor-piercing, fin-stabilized, discarding-sabot (APFSDS) projectiles. The essential feature of most RA designs is a layer of explosive material sandwiched between two metal plates. When the hot jet of a shaped-charge (or a KEP) hits this sandwich, it ignites the explosive layer in the middle, causing the two metal plates to fly apart. These "flyer plates" erode and destabilize the jet (or KEP) as it slices through them, thereby reducing its ability to penetrate the base armor of the vehicle.[5]

The first patent for RA was registered in Germany in 1970 by a Norwegian, Dr. Manfred Held, who later worked with the Rafael Armament Development Authority to develop the "Blazer" RA design for Israeli tanks, which first appeared in combat in 1982. The Soviet Union had also been working on its own RA concept and followed suit with its first generation of RA about a year later.[6] Since then the Soviets, and later the Russians, have developed and fielded a variety of improved RA designs for their tanks, including Kontact-5, which is purported to be effective against a depleted uranium KEP fired from the 120mm gun of a U.S. M1 tank.[7] The United States also developed RA during the 1980s, acquiring RA tiles for Marine Corps M-60 tanks, which were used during Desert Storm in 1991.

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[5]A detailed overview of RA technology was provided by ARL.

[6]R.M. Ogorkiewicz, "Future tank armors revealed: Developments in electric and explosive reactive armor," *Jane's International Defense Review*, Vol. 30, No. 5, pp. 50–51, May 1997.

[7]See Jane's Information Group, "Impenetrable Russian tank armor stands up to examination," *Jane's International Defense Review*, Vol. 30, No. 7, p. 15, July 1997.

Application to Light Armored Vehicles

The earliest forms of RA were only appropriate for heavy tanks because of the structural strength needed to bear the weight of the tiles and endure their exploding force. But as the technology improved during the 1980s, the prospect of applying it to protect lighter vehicles became more feasible. In particular, the use of better explosive materials made relatively lightweight RA tiles more effective and less susceptible to unintentional ignition. In the late 1980s, the U.S. Army acquired Rafael-designed RA tiles for its Bradley Fighting Vehicle (BFV). About 50 vehicle sets of these first-generation, or A0, BFV tiles were deployed for use in Somalia in 1993. The Army is now in the process of procuring a total of 178 sets of an improved A1 version of these tiles from General Dynamics Ordinance Systems (GDOS), which is in partnership with Rafael. As of March 1999, 74 sets of the new A1 tiles have already been delivered, with the remaining 104 expected by the end of 1999.

Some of the U.S. Army's M113s—its aged but numerous armored personnel carrier (APC)—perform operational roles that might expose them to attack by shaped-charge weapons, so these vehicles could also benefit from the added protection that RA tiles could provide. The BFV A0 and A1 tiles are not ideal for the M113, as the modifications necessary to apply these tiles to the vehicle would add significant extra weight. In particular, extra backing armor would be required to adapt these tiles for use on the M113. More generally, there are serious concerns about the relatively heavy weight of RA tiles, due to the M113's limited payload capacity.

In 1998, to explore the potential benefits of applying RA to U.S. M113s, two possible M113 tile candidates were tested in the D650 Tank Automotive-armaments Research, Development Engineering Center (TARDEC) Foreign Technical Testing program, which was conducted by the U.S. Army Test and Evaluation Command (TECOM) at its Aberdeen Test Center (ATC).[8] One of the tiles evaluated was a design developed by Rafael for an Israeli M113 variant.[9] The other tile evaluated in the D650 test was a design developed by the French firm Societe Nationale des Poudres et Explosifs (SNPE), which is also marketing a similar design for the French AMX-30 light tank and the Russian BMP-3 APC. Both of these options are similar to current BFV tiles in terms of weight and performance, and they would include extra passive backing armor to reinforce the base armor of the M113.

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[8]Detailed information on the D650 test was provided by ARL.

[9] A photograph of an Israeli M113 with Rafael RA tiles is shown in Ogorkiewicz, 1997.

Changes in the Threat Environment

Not surprisingly, new anti-armor weapons are emerging that are designed specifically to counteract RA by using a "tandem" warhead, which includes a smaller precursor in addition to the main shaped charge. The precursor charge detonates the explosive layer of the RA early to enable the main shaped charge to penetrate more easily. Tandem warheads have already begun to appear on both ATGMs and HHIWs.[10] As these advanced threats become increasingly prevalent, armored vehicles will need greater protection against them.

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[10]A large selection of existing tandem HHIW designs are discussed in T.J. Gander, "Shouldering the burden of last-ditch defense," *Jane's International Defense Review*, Vol. 30, No. 4, pp. 57–62, April 1997; for a similar discussion of ATGM designs, see Jane's Information Group, "Keeping up with the tank hunt," *Jane's Defence Systems Modernisation*, March 1997.

3. Operational Requirements

This chapter will summarize the study's assessment of existing operational requirements of Army and Marine Corps armored vehicles for improved survivability that could be met by RA tiles. Before discussing these findings it is necessary to point out a subtle but important distinction between an official *requirement* and a perceived *need* for a particular level of protection. A need merely identifies a deficiency or vulnerability that should be addressed if a cost-effective means of doing so can be found, while a requirement amounts to a formal request for equipment to alleviate a specified need. In both cases the desired performance (level of protection, in this case) is usually described in general terms, without reference to any particular technological solution. For example, a desired level of armored vehicle protection could be achieved using a number of technological means, including both reactive and passive armor, and even some type of active protection system (APS).[11] This study, because of its mandate, focused exclusively on RA options for improving armored vehicle protection.

Army

The AMSAA analysis found that a need or requirement exists for increased protection of two types of Army armored vehicles:

- *Bradley Fighting Vehicle (BFV).* The infantry (M2) and cavalry (M3) variants of the BFV both require some protection against HHIW and ATGM threats in contingency operations. This requirement was initially met by the first-generation Bradley A0 tile, which was developed for the A1 version of the M2/M3. The new second-generation A1 tile that is now in production will meet the current protection requirements for the A2 and A3 versions of the BFV. A need also exists, however, to maintain this level of protection against increasingly capable HHIW and ATGM threats, especially for those vehicles involved in contingency operations. An enhanced RA tile could be developed within two to three years to meet this need.

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[11] See M. Hewish and L. Ness, "Shoot first, ask questions later: smart tanks learn to fend for themselves," *Jane's international Defense Review*, Vol. 29, No. 3, March 1996.

- *M113 armored vehicles.* The study also identified a need for increased protection of the M113 in contingency operations. This need is greatest for those M113s that would be in the armor and infantry elements of a contingency force. This need has not yet led to an official requirement, but an RA tile package could be developed in one to two years to meet this need. An enhanced RA tile, like the one discussed above for the BFV, could be developed in two to three years. In either case, the added protection would have to be traded off against the extra cost and weight.

The study also found that there are a total of 349 BFV and 554 M113 variants in the armor and infantry segments of Force Package 1, which would be used for contingency response. Both the BFV and the M113 were found to have a need or requirement for added protection in contingency operations, and the armor and infantry forces are the most likely to be exposed to significant threats, so the BFVs and M113s in this portion of Force Package 1 should probably be given first priority for RA tile acquisition. These numbers can be considered as a baseline for calculating the magnitude of the acquisition investment needed to outfit all or part of a contingency force. If vehicles in other types of units, such as engineer vehicles, are also found to have a need for RA, some of the sets already acquired could be reassigned to those vehicles, or more sets could be procured.

Marine Corps

No requirement or need for improved protection was found to exist for Marine Corps armored vehicles that could be met by RA in the near term. In the future, however, the threat environment that Marine Corps armored vehicles will face may change. If this happens and a need for greater protection emerges, then RA tiles could be developed to meet that need. Moreover, while the Marine Corps does not use the BFV or the M113, any RA technology developed in the near term for these vehicles could, with further development, be adapted for use on lightweight Marine Corps armored vehicles like the Advanced Amphibious Assault Vehicle (AAAV) or the Light Armored Vehicle (LAV). Thus, many of the issues discussed in this report with regard to future RA tiles may be of interest to the Marine Corps from a long-term planning perspective.

4. Scope

This chapter briefly describes the scope of the analysis that was performed in support of the study in terms of: the types of vehicles considered, the candidate tile designs, and the tile configurations evaluated for each vehicle.

Vehicles Considered

The study examined RA tile options for two armored vehicles: the M2A3/M3A3 BFV and the M113A3 APC. The M2A3/M3A3 was selected because RA tiles can address this vehicle's requirement for improved survivability. While the M2A2/M3A2 can also be equipped with RA tiles, only the later A3 version was evaluated because, as the more valuable asset, it is more likely to be equipped with RA tiles. In any case, the A2 and A3 versions are not that different structurally, so the degree of protection provided by RA tiles would be similar.

The M113A3, the latest version of the M113, was found to have a need for better protection in contingency operations that could be met by RA tiles, but there is no official requirement for this extra protection at this time. The engine of the earlier version of this vehicle, the M113A2, is not powerful enough to bear the extra weight of a substantial set of RA tiles. In fact, even the current M113A3 can only carry up to 4,000 pounds of tiles; any more extra weight would cause a significant drop in mobility and reliability. Because of this weight limit, two versions of the M113A3 were evaluated in the study: the M113(RE), which would have to be upgraded with a new power train and chassis to enable it to carry the weight of a full set of RA tiles; and the current M113A3, with its 4,000-pound capacity. While only the M113A3 APC variant was evaluated for the study, other A3 variants in the M113 family are, in most cases, similar enough to the APC for the findings of the study to be applicable.

Reactive Armor Tile Candidates

Three different RA tile designs were selected and characterized for the study:

- *Production.* This tile design is the second-generation Bradley A1 tile, which is currently being produced for the A2 and A3 versions of the BFV. Because it already exists, the characteristics and performance of this tile design are

fairly well understood. This year the A1 tile is undergoing live-fire testing on the M2A3/M3A3 as part of the Bradley live-fire testing program.[12]

- *1–2 Year.* This is a new tile that could be developed specifically for the M113 in one to two years. This generic tile design is very similar, in terms of weight and performance, to the Rafael and SNPE tiles evaluated in the D650 tests last year. This tile design includes extra backing armor to augment the thin base armor of the M113 and protect it from being damaged if the tile is activated.
- *2–3 Year.* This design represents a new tile that could be developed within two to three years. This enhanced tile is designed to provide greater protection against a broad range of HHIW and ATGM warheads. This tile design could be developed specifically for the BFV or for the M113. It should also be possible to develop a universal version of this tile for both vehicles.

Tile Configurations Evaluated

A total of six different tile configurations were evaluated: the M2A3/M3A3 with Production tiles and with 2–3 Year tiles; and the two M113 versions, the current A3 and the upgraded (RE), each with 1–2 Year and with 2–3 Year tiles. Table 1 shows these six vehicle-configuration combinations. Each RA tile configuration was designed to give the vehicle the maximum protection possible, while still permitting normal movement and operation. This means that the four tile configurations for the two different versions of the M113A3 are all different. The two configurations for the M113(RE) cover the same surface area, but have different total weights since the individual 1–2 Year and 2–3 Year tiles differ in

Table 1

Reactive Armor Tile Configurations

Vehicle	RA Tile Design
Bradley M2A3/M3A3	Production 2–3 Year
M113A3	1–2 Year 2–3 Year
M113(RE)	1–2 Year 2–3 Year

[12]The author attended a live-fire test of the Bradley A1 RA tiles at ATC on February 9, 1999.

areal density.[13] In the case of the M113A3, the two tile configurations are constrained to be the same weight, 4,000 pounds, so the 2–3 Year configuration will cover less surface area than the 1–2 Year configuration because its tiles are heavier.

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[13]The areal density of any type of armor is the weight per unit of surface area, in units such as lbs/ft^2 or kg/m^2. It can be expressed in two different ways: normal to the surface, or for a particular line of sight (e.g., horizontal if the surface is tilted).

5. Methodological Considerations

This chapter highlights several important methodological issues that should be considered when interpreting the results of the study. The discussion is organized around the RA tile attributes targeted by the study's four research questions: effectiveness, weight, cost, and safety and logistics. The chapter concludes with a qualitative reliability assessment of the attribute estimates made for each tile configuration.

Effectiveness

The performance of each type of tile was characterized by ARL, based on the details of its design. This information is precisely known for the Production tile and was estimated for the 1–2 Year and 2–3 Year tiles. The representative designs of these two near-future tiles are very well understood, so the estimates of their performance should be quite accurate.[14]

These tile characterizations were used in combination with high-resolution vehicle vulnerability simulations (conducted by ARL) to estimate the impact on vehicle survivability of the various tile configurations. The vulnerability of the M2A3/M3A3 was evaluated using ARL's Squash simulation, which is based on a very detailed component-level representation of the vehicle. A less detailed compartment-level model was used to estimate the vulnerability of the M113A3. This difference in detail and resolution makes the M113 vulnerability estimates slightly less reliable. This deficiency is not that important because the M113 has a much simpler interior structure than the BFV and usually has less flammable material inside.

Each RA tile configuration is intended to provide maximum protection by covering the most vulnerable areas on the vehicle. Due to significant structural differences, more surface area is available for tiles on the M113 than on the BFV. The BFV tile placement pattern, which is the same for both of its tile configurations, is already optimized to account for the vehicle's complex surface.

[14]The 1–2 Year tile design is based on the Rafael and SNPE tiles, which already exist and would only need some additional development and adaptation to be fitted onto U.S. Army M113s. Much of the necessary basic research has already been completed by ARL-WMRD on the 2–3 Year tile design, so that only the engineering development and implementation would still need to be done. Thus, both of these technologies are fairly mature and should be considered low-risk.

By contrast, the surface of the M113A3 is fairly simple and flat. The maximum protection tile placement pattern used for the two M113(RE) tile configurations simply covers all of the available surface area with tiles, so it is also very close to optimal.

The 1–2 Year and 2–3 Year tile sets for the M113A3 are a different case. Both configurations are assumed to provide maximum protection, but neither completely covers the vehicle, so some designated areas must be left uncovered. There was not, however, enough time for the study to determine the optimal tile placement pattern for these two configurations. Instead, the effectiveness of these weight-constrained M113A3 tile configurations was estimated by scaling down the simulation-based M113(RE) effectiveness estimates in proportion to the weight ratio between the two tile sets. This approach is roughly equivalent to scaling down by coverage area, since the weight and coverage area of a tile configuration are essentially proportional. This would likely result in an underestimate of the true effectiveness of both of the M113A3 tile configurations, as compared to the optimized placement pattern.

Weight

The total weight of each tile configuration was based on the detailed design of the tile, including any extra backing armor needed to protect the vehicle's base armor, as provided by ARL. The total weight of a tile configuration is roughly equal to the product of the areal density of the tile design and the surface area covered by the configuration.

Cost

There are two costs associated with outfitting an armored vehicle with RA tiles: R&D costs, which are fixed for a particular design and application; and life cycle costs, which are incurred for each tile set acquired. The cost of the necessary R&D for each RA tile configuration was estimated by AMSAA through discussions with ARL and the BFV Program Office, drawing on their knowledge of the tile designs and their A1 tile acquisition experience.

The life cycle cost (LCC) of an RA tile set consists of two components: the cost of procuring and installing the tile set, and all of the other related expenses, such as transportation and storage costs. Not surprisingly, the vast majority of the LCC of a new RA tile set is associated with its procurement. The procurement cost estimate for Production tile sets is very reliable, since it is based on the current procurement contract and the learning rate observed during the production of

these tiles. The procurement cost of the 2–3 Year BFV tile configuration was estimated by scaling up the Production configuration in proportion to weight; the 2–3 Year tiles are 10 percent heavier, so they were assumed to cost 10 percent more. The rationale for this assumption, which should be reasonable for small changes, is that most of the cost of an RA tile is associated with its constituent materials, such as metal plates and explosives. The M113 Program Office recently estimated the cost of procuring a 4,000-pound RA tile set for the M113, so the study used this estimate for the two M113A3 tile configurations and then scaled it up by weight to estimate the procurement cost of the two M113(RE) tile configurations. The weight differences in both cases are quite large, so although these estimates are reasonable, they are not as reliable as the other estimates.

Safety and Logistics

The safety and logistics burdens associated with RA tiles were estimated in a variety of ways. Most of the safety estimates are based on tests of either the A0 or A1 tiles for the BFV, and they are assumed to apply to the future tile designs as well. Similarly, the logistics burdens were estimated based on the procedures developed to handle the current BFV tiles, which are assumed to be the same for any future RA tiles. These assumptions are reasonable for those burdens incurred when the tiles are not in use, such as when they are stored or transported. However, they are not necessarily valid for situations where the tiles would be used in combat. Future tiles would need to be tested to assess their safety and logistics burdens. Even so, it seems reasonable to assume that these burdens will be similar to those incurred by current tiles, given that the technology and design of these new tiles are so similar.

Reliability of Study Estimates

Table 2 summarizes the implications of these issues for the reliability of the study estimates. Three levels of reliability are indicated on this table:

- *Extremely Reliable.* Attribute of the tile configuration has actually been measured or is known with certainty.
- *Very Reliable.* Estimate is based on a valid theoretical calculation or projection, and is expected to be quite accurate.
- *Fairly Reliable.* Estimate is based on reasonable assumptions but may be subject to some error.

Table 2

Reliability Ratings of Tile Configuration Attribute Estimates

Tile Configuration	Effectiveness	Weight	Cost	Safety and Logistics
BFV M2A3/M3A3				
Production	Extremely Reliable	Extremely Reliable	Extremely Reliable	Extremely Reliable
2–3 Year	Very Reliable	Very Reliable	Very Reliable	Fairly Reliable
M113(RE)				
1–2 Year	Very Reliable	Very Reliable	Fairly Reliable	Fairly Reliable
2–3 Year	Very Reliable	Very Reliable	Fairly Reliable	Fairly Reliable
M113A3				
1–2 Year	Fairly Reliable	Extremely Reliable*	Very Reliable	Fairly Reliable
2–3 Year	Fairly Reliable	Extremely Reliable*	Very Reliable	Fairly Reliable

*Weight is constrained to be 4,000 pounds.

The estimates for the BFV Production tile configuration are all known, and therefore extremely reliable, since these tiles are already being procured.

The estimated effectiveness of both of the M113(RE) tile configurations and the 2–3 Year BFV configuration are rated as very reliable because they were based on very accurate high-resolution vulnerability simulations. The effectiveness estimates for the two M113A3 tile configurations are only fairly reliable because they are based on a weight-based extrapolation from the M113(RE) estimates.

The weight estimates for the 2–3 Year BFV and both M113(RE) configurations are very reliable because the designs of both future tiles are well understood. The weight of the two M113A3 tile configurations is constrained to be 4,000 pounds, so these estimates are rated as extremely reliable. Any uncertainty in the weight of the future tiles in these configurations is reflected in the coverage they provide and captured by the lower reliability rating on their effectiveness.

The cost estimate for the 1–2 Year M113 A3 tile configuration is rated as very reliable because this type of configuration was the basis of the M113 Program Office's cost estimate. The 2–3 Year BFV and M113 A3 configurations received the same rating because the scaling of these costs by weight was reasonable, since the difference in weight was relatively small. The M113(RE) cost estimates

also relied on weight scaling, but they were rated as only fairly reliable because the weight differences were much more significant (a factor of about 1.5 for the 1–2 Year tiles, and more than 2 for the 2–3 Year tiles).

The safety and logistics estimates were rated as fairly reliable for all the future tile configurations. This rating reflects the fact that these estimates are all based on the assumption that future tiles will be essentially the same as current and past RA tiles with regard to safety and logistics. This will probably be true, but it cannot be confirmed until these new tile designs are developed and tested.

6. Results

This chapter summarizes the results of the AMSAA analysis and discusses how they should be interpreted, taking into account the methodological considerations highlighted in Chapter 5. A summary and discussion of these results, prepared by AMSAA, is also included in Appendix B.

Effectiveness

The results of the AMSAA analysis indicate that all of the RA tile configurations significantly improve vehicle survivability. In general, the results show that the 2–3 Year tiles provide more robust protection against the full spectrum of 30mm APFSDS, HHIW and ATGM threats than either the Production or the 1–2 Year tiles. The 2–3 Year BFV tile set provided better overall protection than the current Production tile set, and the 2–3 Year configuration for the upgraded M113(RE) was superior to the 1–2 Year alternative. In these two cases the same tile placement pattern was used for both configurations, so it is not surprising that the enhanced 2–3 Year RA tile prevailed. Also, because the BFV placement pattern covered only about 35 percent of the vehicle's surface, while the M113(RE) pattern covered 65 percent, the upgraded M113 tended to gain more added protection from the addition of RA tiles than the BFV did.

The situation is more ambiguous for the M113A3 configurations, which were constrained to a total weight of 4,000 pounds and did not use the same placement pattern. The 2–3 Year tile set included fewer tiles than the 1–2 Year set and hence would cover less surface area: about 40 percent coverage for the 1–2 Year configuration, but only 30 percent for the 2–3 Year configuration (as compared to about 65 percent for a maximum coverage configuration). As a result, there is a tradeoff between quantity and quality in this weight-limited case—more robust protection but less coverage (45 percent of the maximum), or more coverage (60 percent of the maximum) but less robust protection.

The reliability of these effectiveness estimates should also be taken into account. The BFV and M113(RE) estimates are all very reliable since they are based on detailed vulnerability simulations, so the finding that the 2–3 Year tile configuration is the more effective option in these two cases is strongly supported by the results. The relative effectiveness of the two M113A3 configurations is less certain because of the weight-scaling method used to make

these estimates. This method also introduces a bias that affects how the estimates should be interpreted.

The placement patterns are not optimal, so the absolute level of effectiveness is probably underestimated and too much emphasis is placed on coverage relative to protection. An optimal placement pattern would take maximum advantage of the extra protection provided by the RA tiles by placing them where they are needed most. Reducing the coverage would have a less than proportional impact on overall survivability because the tiles providing the least extra protection would be eliminated from the pattern first. Thus, the upward bias on effectiveness in the study results for the M113A3 is larger for the 2–3 Year configuration than for the 1–2 Year configuration.

Weight

The total weight of a complete set of the Production tiles for the BFV is 6,900 pounds. The 2–3 Year tiles for the BFV are about 10 percent heavier than the Production tiles, so a set of these tiles should weigh about 7,600 pounds. Both tile configurations for the unimproved M113A3 are constrained to a total weight of 4,000 pounds. A 1–2 Year tile set for the upgraded M113 would weigh 6,400 pounds, and the 2–3 Year tile configuration would weigh 9,200 pounds. For perspective, it should be noted that the weight of these tile sets would add 27 percent and 39 percent, respectively, to the base weight of the vehicle. The source of this large weight difference is the extra backing plates incorporated into the 2–3 Year tile to protect the base armor of the M113. These tile configuration weights are summarized in Table 3.

Cost

The cost of R&D for the BFV Production tile was $15.4 million, which is now sunk. The cost of additional R&D to develop the enhanced 2–3 Year tile for the BFV was estimated to be $9 million. The cost of developing either a 1–2 Year or a 2–3 Year tile for the M113 was estimated to be $8 million. If, however, a 2–3 Year tile is developed simultaneously for both the BFV and the M113, the total cost is expected to be about $10–11 million, which is only slightly more than it would cost to develop this tile for just one vehicle. Also, an additional $3 million would be needed to reengineer the M113A3 to carry a RA tile set of more than 4,000 pounds without a sharp drop in mobility and reliability. (This vehicle is designated as an M113(RE).)

Table 3

Weight and Cost Estimates for Each RA Tile Configuration

Tile Configuration	Weight [pounds]	R&D Cost [$ millions]	Life Cycle Cost [$ thousands]
BFV M2A3/M3A3			
Production	6,900	15.4 (sunk)	262[c]
2–3 Years	7,600	9[a]	288
M113(RE)			
1–2 Years	6,400	11[b]	564[d]
2–3 Years	9,200	11[a,b]	710[d]
M113A3			
1–2 Years	4,000	8	209
2–3 Years	4,000	8[a]	209

[a]If 2–3 Year tiles are developed for both the BFV and the M113 at the same time the total R&D cost is estimated at $10–11 million.
[b]The total R&D cost for an M113(RE) tile configuration includes an extra $3 million for the vehicle upgrade.
[c]The LCC of the first 56 tile sets may be closer to the LCC of $290,000 for sets being produced under the current procurement contract.
[d]The LCC of these configurations includes the $230,000 cost of upgrading the M113A3.

The life cycle cost (LCC) of an individual BFV A1 Production tile set is about $290,000 under the current GDOS contract, which includes an option for the Army to purchase 56 more sets at this price. (This is the $16.5 million that is on hold.) The LCC of additional A1 tile sets, beyond the next 56, would be $262,000. The estimated LCC of a 2–3 Year enhanced RA tile set for the BFV is $288,000. This estimate is based on a 10 percent increase in cost, in proportion to the increase in weight from the Production tile design. According to this estimate, a 2–3 Year BFV tile set would cost roughly the same amount as one of the next 56 Production tile sets.

For an M113A3 that has not been upgraded, the estimated LCC of either a 1–2 Year or a 2–3 Year tile set is about $209,000. This estimate is based on a projected procurement cost of $200,000 for a 4,000-pound tile set. This value is scaled up by weight to estimate the LCC of the upgraded M113 tile configurations: $334,000 for the 1–2 Year tiles, and $480,000 for the 2–3 Year tiles. These weight-scaled cost estimates are a reasonable projection, but they could be off by tens of

thousands of dollars. Also, some learning effects are likely to occur if large numbers of tiles are produced, and this would tend to lower costs, so these cost estimates may be too high. In addition to the cost of the tile set itself, the total LCC should include the cost of upgrading the chassis and powertrain of the M113, which is about $230,000 per vehicle. Thus, the total LCC of a 1–2 Year tile set for an upgraded M113(RE) is $564,000, and $710,000 for a 2–3 Year set.

Safety and Logistics

The study found that all the RA tile configurations would be as safe to store as ammunition, so they should not incur any significant added logistics burden for storage or guarding. These results were implied from the characteristics of current tile designs, but there is no reason to expect that future tiles would not be similar in this respect because their explosives are expected to be just as insensitive. This characteristic of both current and future tiles also means that they would not be ignited by small arms fire or even APC cannon rounds.

RA tiles pose a significant danger to soldiers (or civilians) who are near a vehicle when its RA is activated by a HHIW or ATGM, but it is not clear whether the danger is any greater than it would be if the vehicle being hit had no RA. On the whole, the increased protection provided to mounted troops by RA tiles appears to justify the added danger posed to those soldiers when they are dismounted. These findings are somewhat speculative, however, as they are based solely on tests of the old A0 tile for the BFV. These tests did not consider the danger to dismounted infantry who are closer to the vehicle than 25 meters, so while they may be valid for most open battlefield situations, they would not apply to urban contexts where soldiers are likely to be much closer than 25 meters. Clearly, the balance between protection inside and safety outside depends on a variety of factors—such as the likelihood of an attack when soldiers are dismounted—which are determined by the operational and tactical circumstances. Thus, the particular role and mission of a vehicle should be considered when deciding whether to install RA tiles.

There is also some possibility that the actual use of RA tiles in combat operations would impose some additional logistics burdens. If a vehicle with RA tiles is hit and one or more of the tiles is ignited, then any tiles that were activated or damaged will eventually need to be replaced. Thus, even if RA is effective at

improving survivability, frequent extra maintenance may be needed in high-intensity operations, which could reduce overall sustainability.[15]

Insights on Benefits and Costs

Bradley Tile Configurations

The two tile configurations available for the BFV, the Production tile set and the 2–3 Year enhanced tile set, differ in effectiveness and in cost and weight, but they are assumed to be roughly equivalent in terms of safety risks and logistics burden. Both tile configurations provide the maximum coverage possible, but the 2–3 Year configuration provides more robust protection across the spectrum of possible threats. This enhanced 2–3 Year tile configuration is only 10 percent heavier than a Production tile set, which should not result in a significant change in the vehicle's mobility or reliability. The new 2–3 Year tiles would, however, require additional R&D and would not be ready for procurement until at least FY02. Also, the LCC of the 2–3 Year configuration would be about the same as that of the Production tile sets currently being produced, but 10 percent higher than that of any additional Production sets.

M113 Tile Configurations

No RA tiles are currently in production that could be applied to the M113 family of vehicles, but a need does exist for added protection on some portion of these vehicles. Some expenditure on R&D would, of course, be necessary to develop a RA tile configuration to meet this need for the M113. There are two choices that would need to be made with regard to this development: first, will the tile be based on the 1–2 Year or the 2–3 Year technology, and second, will an upgraded version of the M113 be developed that can accommodate a full-coverage tile configuration. Developing the upgrade would require extra R&D, and the tile sets for this upgraded vehicle would be heavier and more expensive, because they would include the maximum possible number of tiles. In fact, the 2–3 Year M113 tiles are much heavier than the 1–2 Year tiles, and as a result they are expected to cost over 40 percent more per set for the M113(RE). This substantial weight difference also has important implications in the case of RA tiles for the current version of the M113A3. Because the total weight of a tile configuration for this vehicle is limited to 4,000 pounds, the cost of the 1–2 Year and 2–3 Year

[15]These concerns are based on observations made by the author at a live-fire test of the BFV with Production RA tiles on February 9, 1999.

configurations is about the same, but the coverage provided by a set of the heavier 2–3 Year tiles would be 25 percent lower than that of a 1–2 Year tile set. Thus, when considering which type of tile would be better for the M113, the real operational value of the robust protection provided by a 2–3 Year configuration must be compared to the increased coverage (current M113A3) or lower cost (upgraded M113(RE)) of a 1–2 Year configuration.

7. Policy Discussion

This chapter addresses three important policy issues: the tradeoffs between RA tiles and vehicle upgrades, the merits of different RA tile development options, and the acquisition investments necessary to outfit contingency force vehicles with RA. The first section discusses the benefits of RA tiles and vehicle upgrades, and compares them in light of the cost associated with the various RA options considered. The second section summarizes the RA tile development options that could be pursued in the near term. The next section presents three scenarios based on familiar operational environments, and explains which RA development options are favored in each scenario. The final section of the chapter describes and compares the acquisition investments associated with each development option.

Reactive Armor versus Vehicle Upgrades

Benefits of Reactive Armor

There are a variety of advantages to increasing armored vehicle protection by using some type of RA tile configuration. At the strategic decisionmaking level, an increase in vehicle protection improves force survivability—both directly and through deterrence—and expands the range of contingency operations that can be undertaken. However, increased vehicle weight due to the addition of RA tiles, or having to transport the tiles separately for installation in theater,[16] may decrease the strategic and operational mobility of the force. At the tactical level, vehicles with more protection can exploit opportunities that would otherwise be too dangerous. In addition, the presence of extra protection on a vehicle will tend to improve the confidence and morale of its crew, especially when they are in dangerous situations, which should enable them to fight more effectively. These benefits must, of course, be weighed against the potential logistics burden associated with the tiles, and any dangers the RA may pose to dismounted infantry or civilians. Overall, these benefits appear to be greater for the M113 than for the BFV, since it has much less protection to start with.

[16]It is estimated that a vehicle crew can install an entire tile set on the BFV in three hours.

Benefits of Vehicle Upgrades

The A3 version of the BFV incorporates a wide range of improvements over the A2. Most of these improvements involve sensor and computer systems that are designed to make it a fully "digitized platform." These systems are expected to improve many different capabilities, including target acquisition, fire control, communications, and navigation. The current A1 Production tile set on the BFV A3 is also an improvement over the older A0 tile set on the A2 version of the BFV.[17] This increased lethality and mobility of the A3, together with its "digitization" features, are most advantageous during normal combat operations on a fast-moving battlefield. With the exception of the navigation and communications improvements, the features of this upgrade are less useful in urban and peace enforcement operations.

Upgrading an M113A2 to an M113A3 is primarily a mechanical improvement. It involves strengthening the vehicle chassis and increasing the power of its engine. The intent of this upgrade is to increase the mobility of the M113 to the point where it can keep up with other vehicles, like the BFV and the M1 tank, during combat operations. This improved mobility is extremely important in coordinated battlefield maneuvers, but is far less vital in urban and peace enforcement operations.

Cost Comparison

The study found that, based on previous estimates, it costs around $2.3 to $2.6 million to upgrade a BFV from an A2 to an A3 version.[18] The LCC of either type of BFV RA tile set is only about 10 percent of the cost of an A2-to-A3 upgrade for the BFV. This modest extra cost appears to be well worth it, considering the high value of an A3 version of the BFV and its improved battlefield capabilities.

The cost of upgrading an M113A2 to an M113A3 is more than an order of magnitude smaller than a BFV upgrade; only $222,000 per vehicle for a standard APC, and about the same for most other variants. Thus, a weight-constrained RA tile set for a current M113A3 would be comparable in cost to an A2-to-A3 upgrade. Upgrading an M113A3 to accommodate a heavier tile set—creating, in essence, an "A4" version—would also be about the same cost as an A2-to-A3 upgrade, since it would involve similar mechanical improvements. Of course,

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[17]LTC William Riker, "Executive Overview: Bradley M2A3/M3A3," briefing presented at Aberdeen Testing Center, Aberdeen Proving Ground, MD, on February 9, 1999.

[18]These BFV upgrade cost estimates are based, respectively, on information from the BFV Program Office and a recent study by the Center for Army Analysis (CAA-MR-97-11).

RA tile sets for this "A4" version (i.e., the M113(RE)) are more expensive because they include more tiles; the cost rises to 150 percent of an A2-to-A3 upgrade for the 1–2 Year set, and over 200 percent for the 2–3 Year set. To put these cost comparisons in perspective, the $0.7 million cost of turning an ordinary M113A3 into a much more survivable "A4" with a full set of 2–3 Year RA tiles is about a quarter of the cost of an A2-to-A3 BFV upgrade. The resulting "A4" vehicles may even be able to take over some of the missions now assigned to BFVs.

Reactive Armor Development Options

There are a dozen conceivable near-term options for developing new RA tiles, plus a "zero" option that would involve no new development. This list was reduced to six by eliminating those options that violated one of two constraints. First, because the M113 was found to have a definite need for added protection in at least some circumstances, only those options that include an RA tile for the M113 are considered viable. This constraint eliminates the zero option, and the option of only developing a 2–3 Year tile for the BFV. The second constraint required that only one type of new tile be developed—either the 1–2 Year tile or the 2–3 Year tile, but not both.[19] Table 4 lists the remaining six options in order of total development costs (not including procurement), and indicates the combination of tile types and required upgrades involved.

Options 1 and 2, which only develop a tile for the M113 with no upgrade, are the least costly options. Not only do they have the lowest development cost, but their associated tile configurations have the lowest LCC of all the configurations considered in the study: just over $200,000 each. Of course, these tile configurations do not provide the maximum possible coverage, but they do still provide considerable increased protection. While these two options are equal in cost, their overall value depends on the nature of the anticipated threat environment. Because its configuration provides greater coverage, the 1–2 Year tile (option 1) would be preferred against "low-tech" threats, consisting of older types of HHIWs and ATGMs. The 2–3 Year tile (option 2), on the other hand, would be preferred in a "high-tech" threat environment that includes more advanced HHIWs, ATGMs, and 30mm cannons.

[19]This is a sensible constraint, given that this study was limited to short-term decisions; a second type of tile could always be reconsidered later.

Table 4

Viable Near-Term Options for the Development of New Reactive Armor Tiles

Option Number	1–2 Year for M113	2–3 Year for M113	2–3 Year for BFV	Upgrade for M113	Total R&D Cost
1	√				$8 million
2		√			$8 million
3		√	√		$11 million
4	√			√	$11 million
5		√		√	$11 million
6		√	√	√	$14 million

Similar reasoning can be applied to options 4 and 5, which add an M113 upgrade to options 1 and 2, respectively. Here there is a full coverage tile configuration, where the advantage of the 1–2 Year tile is cost rather than coverage; the cost difference is almost $150,000 per set, but the 2–3 Year tiles do still offer superior protection. The advantage that options 4 and 5 have respectively over options 1 and 2 is that the M113 upgrade provides the flexibility of outfitting a small contingent of M113s with maximum-protection tile sets. While these specialized high-survivability M113 variants would be very expensive, they might prove to be very valuable in certain situations where HHIW or ATGM attacks are likely. In an urban setting, for example, a vehicle like this could be used to rescue soldiers (or even hostages) that have been isolated and pinned down, provided that the added danger to dismounted soldiers from the RA is considered tolerable.

Option 3, which costs about the same as options 4 and 5, takes advantage of economies of scale by developing the same 2–3 Year enhanced tile for the BFV as well as the M113, but it does not include an M113 upgrade. This option is appealing because it provides more robust protection for the BFV, while also meeting the need for improved M113 protection. Only the weight-constrained low-coverage configuration would be available for the M113, but an optimized configuration should still provide a substantial increase in protection at a fairly low cost per vehicle. This option would be especially attractive if the objective is to improve BFV survivability while also equipping as many M113s as possible with some RA tile protection without severely impacting their mobility or reliability.

Option 6 offers a more robust, but somewhat more expensive, alternative to options 3, 4, and 5. It is, however, the least expensive RA development option that can provide all three of the specific benefits that new RA tiles have to offer:

(A) Inexpensive, substantially improved protection for the M113A3

(B) More robust protection for the BFV

(C) A highly survivable M113 variant

Options 1 and 2 only provide A; option 3 provides A and B, but not C; and options 4 and 5 provide A and C, but not B. Which option is preferred thus depends largely on the importance of these three potential benefits, which in turn depends on the operational context.

Scenario Analysis

Three different scenarios, each representing a familiar operational environment, are presented in Table 5. Each scenario is characterized in terms of its terrain, threat environment, maximum intensity, and overall size. The descriptions of these exemplary scenarios are very general because their intent is only to illustrate that different RA tile development options may be favored in different operational situations.

- *Nation Building*. Development options 1 and 4, which both include a 1–2 Year tile for the M113, are favored because of the low-tech nature of the threat in this scenario. Advanced HHIW and ATGM threats would be rare, so there is no need for a new 2–3 Year tile for either the BFV or the M113. Moreover, the weight-constrained 1–2 Year tile configuration for the M113A3 is preferred in this scenario because it provides more coverage than 2–3 Year tiles could. Option 4, which adds an M113 upgrade to the 1–2 Year tile, might also be worthwhile if RA is found to be safe enough to use in urban operations. In addition, high mobility is not so important for the M113 in this scenario; surprise HHIW attacks could be a major concern, however, so RA tile sets would generally be favored over A2-to-A3 upgrades.
- *Peace Enforcement*. Development options 2, 3, 5, and 6 are all contenders for this scenario. In the purest version of this scenario, where M113s would be used more widely for patrolling than BFVs, option 2 would be preferred. If there is also a substantial chance of urban operations where RA would be appropriate, option 5 might be preferred over option 2. But if there is less urban terrain and high-tech threats are more prevalent, more BFVs would need to be involved and option 3 would be better. Of course, if all these factors are present, then option 6 would be a more robust choice, provided

Table 5

Operational Characteristics of Illustrative Scenarios

Scenario	Nation Building	Peace Enforcement	Regional War
Examples	Haiti, Somalia	Bosnia, Kosovo	Persian Gulf[a]
Terrain	Urban ◊ Mixed	Urban ◊ Mixed	Mixed ◊ Open
Threat	Low-tech	Medium-tech	High-tech
Intensity	Low	Medium	High
Size	Small	Medium	Large
Preferred RA Tile Development Option	1 (possibly 4)	2 (possibly 3, 5, 6)	3 (possibly 6)

[a]This scenario refers to a major theater war; smaller engagements, like those that took place in Khafji and Kuwait City in 1991, would be closer in nature to the Peace Enforcement scenario.

that there is a role for RA in urban settings. If there was a significant chance that this scenario could escalate, then more A2-to-A3 upgrades might be favored over RA tile sets for the M113 (if the upgrades are needed) because mobility would become very important.

- *Regional War*. In this scenario option 3 is clearly preferred because it would provide robust protection for both the BFV and the M113 and would equip the M113s with an economical tile configuration that will not impact its mobility. There is less need for a high-survivability version of the M113, because low-intensity urban operations are not a central feature in this large, high-intensity scenario. (If they were, and RA could help, then option 6 might be worth considering.) The need to outfit as many vehicles as possible with extra protection is probably more important than the specialized capability this M113 variant would provide. This scenario also requires excellent communications and high mobility, so A2-to-A3 upgrades for the BFV and the M113 are both attractive. Detailed force-on-force analysis of the need for upgrades versus better protection would have to be conducted to resolve this tradeoff.

All three of these scenarios are realistic, as evidenced by the recent examples shown in Table 5, so it is safe to assume that the Army may be involved in these types of future operations. Thus, the RA tile development option selected should be robust

across all three scenarios. The Regional War scenario is the most important, and option 3 is preferred in this case. The Peace Enforcement scenario is also very important, especially in light of current events, and option 3 is also preferred in this case under some circumstances. However, for a fairly modest increase in development costs, option 6 could cover all three scenarios, provided that a high-survivability M113 variant would be valuable in an urban setting. The challenge with option 6 is to design a prudent acquisition strategy that balances the various benefits this option could provide against the higher costs associated with it.

Acquisition Strategies

Many different approaches to RA tile acquisition could be taken after implementing any of the six development options discussed above. As we move through these options from 1 to 6, the degree of protection provided by the resulting RA tile configurations generally goes up. To illustrate the types of acquisition tradeoffs associated with these options, we will walk through two examples: number of vehicles versus degree of protection (i.e., development option) for a fixed budget, and total cost versus degree of protection for a fixed number of vehicles.

For simplicity, it is assumed that just enough new BFV tile sets are procured for all the BFVs in Force Package 1 to be outfitted with RA tiles; 171 additional sets to bring the total to 349. If the development option includes a 2–3 Year tile, then the additional sets consist of 56 Production tile sets and 115 new 2–3 Year tile sets, otherwise all 171 are Production tile sets.[20] Figures 1 and 2 show the resulting acquisition strategies for each of the six development options in the fixed budget and fixed vehicle number cases, respectively.

In Figure 1, a total LCC budget of $100 million is allocated to new tile sets for the BFV (in the manner described above) and for the M113. There are no upgraded M113(RE) variants in the first three development options, so in these cases all the money not used for new BFV tiles is allocated to outfitting M113A3s with 4,000-pound tile sets. In the second three development options, where an M113(RE) is available, 25 of these specialized high-survivability variants and their tile sets are acquired, and the remaining money is invested in standard M113A3 sets. Figure 1 shows that between a third and a little less than half of the armor and infantry

[20]The 56 additional Production tiles have a LCC that is about the same as enhanced tile sets will have later ($290,000 versus $280,000). After the first 56 sets, each Production set has a LCC of only $262,000. In determining how many additional Production sets to purchase if a 2–3 Year tile is developed, a tradeoff must be made between some protection for more vehicles now and more robust protection in a few years.

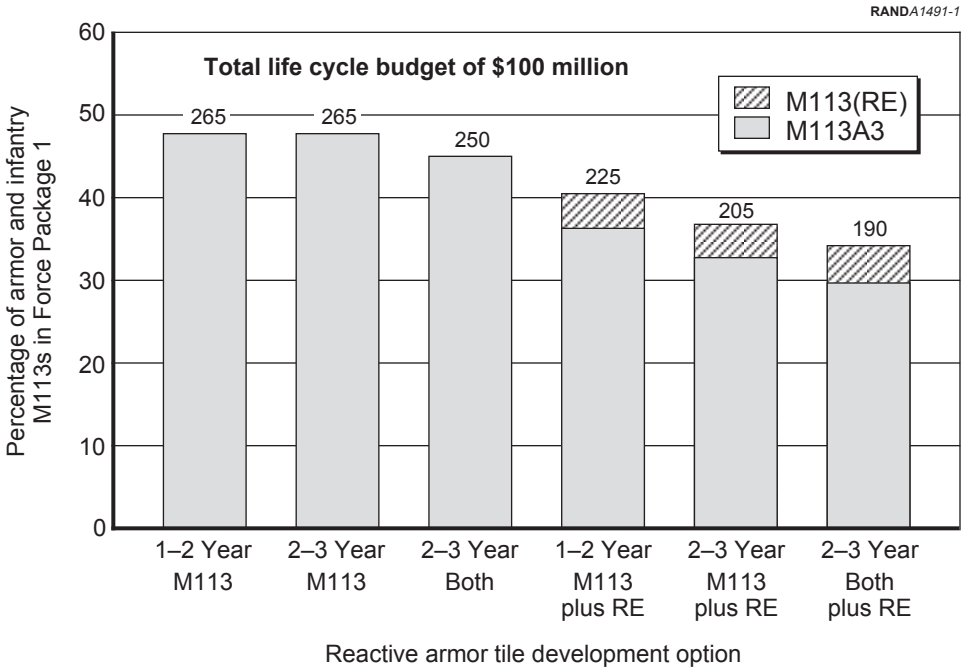

Figure 1. Percentage of Armor and Infantry M113s in Force Package 1 Outfitted with RA Tiles with a Fixed Life Cycle Cost Budget.

M113s in Force Package 1 could be outfitted with tiles given this budget. This graph also indicates how the number of vehicles that can be outfitted with RA tiles decreases as the degree of protection on those vehicles increases.

Figure 2 illustrates the second tradeoff by assuming that enough tile sets are procured for all 554 of the armor and infantry M113s in Force Package 1. For the second three options, 55 of these sets (10 percent) were for the upgraded M113(RE), and the other 499 for the M113A3. The total LCC associated with each of these RA tile acquisition strategies is shown in the figure. The graph shows that every BFV and M113 in the armor and infantry units of Force Package 1 could be outfitted with RA tiles for about $160–165 million in total LCC, over 95 percent of which would be for procurement. This total cost might be even lower because of cost reductions due to learning and economies of scale, which are likely to occur if this many tiles are produced. If, for example, these effects result in an 85 percent learning curve,[21] which is what was used to calculate the cost of additional Production tile sets, the total would be only about $130 million. Figure 2 also shows the impact on total cost of converting 10 percent of the

[21]This means that the average cost per unit would be reduced by 15 percent every time the cumulative number produced was doubled. For example, if the first 100 units cost $100 each, then a total of 200 units would cost $85 each, and 400 would cost $72.25 each, and so on.

M113s to high-survivability variants under the last three R&D options. Developing this variant and buying the extra tiles for it increases the total LCC by only 16 percent, or about $30 million, in the case where 2–3 Year tiles are developed for both vehicles.

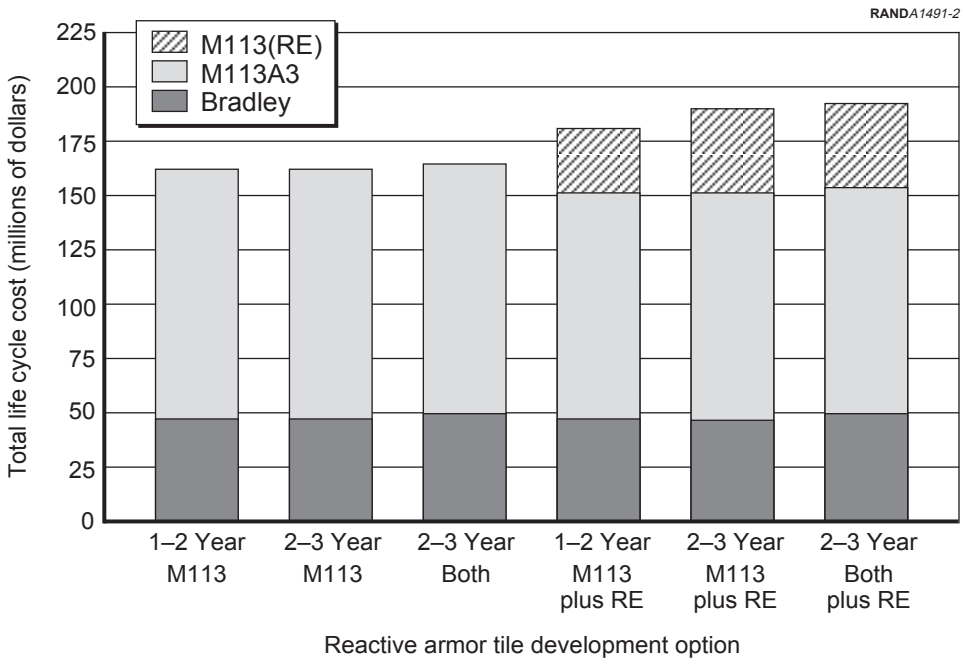

Figure 2. Total Life Cycle Cost of Outfitting Every Armor and Infantry BFV (349) and M113 (554) in Force Package 1 with an RA Tile Set

8. Policy Recommendations

This chapter presents several specific policy recommendations on the development and acquisition of RA tiles for armored vehicles currently in use by the Army, and on further research into the application of this technology. Each recommendation is accompanied by a description of the funding implications, the motivation, and some additional comments.

Development Recommendations

- **Develop a universal enhanced RA tile, based on the 2–3 Year design, for both the BFV and the M113.**

Funding Implications: This is a moderate-cost option that should involve a total of about $11 million in R&D.[22] This is consistent with AMSAA's conclusion that this approach is the most cost-effective RA tile development option (see Appendix B).

Motivation: The M113 has a clear need for improved protection when used as part of a contingency response force. Without more protection, the usefulness of the M113 is very limited because it is too vulnerable to HHIW and ATGM threats. Therefore, some type of RA tile must be developed to meet this need and expand the range of missions that the M113 can contribute to. And even though a tile design is already in production for the BFV, this vehicle would benefit from a new tile that would provide better protection against advanced threats in the future. The enhanced 2–3 Year tile design provides robust protection from a range of 30mm cannon, HHIW, and ATGM threats, which improves survivability in the future threat environment. The development of a universal enhanced RA tile for both the M113 and the BFV should result in a savings of $6 million, as compared to separate development. This approach also creates the potential for greater savings during procurement due to economies of scale and learning.

Comments: This tile design should be applicable to both the BFV and the M113, and future vehicles should also be able to use it. The installation mountings

[22] This could be funded in FY99 with the $5 million currently on hold for M113 RA tile R&D. Another $6 million would be required in FY00 and FY01.

should be the same for all vehicles, so that the same tile can be removed from one type and then installed on another. This means, for example, that any extra backing armor needed for the M113 tile should be removable.

- **Design an optimal enhanced RA tile configuration for the M113A3.**

Funding Implications: Appropriate additional funding to the enhanced tile development effort in FY00–FY01 to cover this extra work.

Motivation: This tile set is constrained to a total weight of 4,000 pounds, so it only includes enough tiles to provide about 45 percent of the maximum possible coverage. An optimized coverage pattern for this tile configuration would significantly improve its overall effectiveness by covering only the most vulnerable areas.

Comments: The optimization process would also determine the relative vulnerability of different parts of the surface of an M113A3. This information would indicate where additional tiles should be installed in an emergency where extra protection is much more important than mobility and reliability, or if the weight capacity of the M113 were improved.

Acquisition Recommendations

- **Procure an additional BFV A1 Production tile sets now.**

Funding Implications: Release FY99 funds now on hold in order to equip a substantial portion of the Army's Contingency Response Forces.

Motivation: The original order for these tile sets is already being procured and will be completed by the end of FY99. With the additional procurement, there should be enough RA sets to equip two brigades under the new Army force structure, which would be about two-thirds of the BFVs in the armor and infantry portions of Force Package 1.[23] This should meet the Army's current requirement for increased protection of the BFVs that are a part of its Contingency Response Forces.

Comments: If more BFVs need better protection in the next couple of years because of ongoing contingencies, then additional Production sets should be procured to meet this need.

[23]This option could cost as much as $16.5 million, based on the current cost estimate for 56 additional sets.

- **Procure enough sets of the new enhanced RA tiles for the BFV to outfit at least one brigade.**

Funding Implications: Based on the study's cost estimate for the new enhanced tiles, $35 million in FY02–FY03 would be required to procure enough tile sets for one BFV brigade.

Motivation: These tile sets will provide more robust protection for an entire brigade of BFVs, while the other two brigades would still have adequate protection from current Production tiles.[24]

Comments: Existing Production RA tile sets should be used in peace operations, while the enhanced tile sets should be saved for situations where advanced threats are more common. Consider procuring more enhanced tile sets over time to gradually replace the Production tile sets on contingency force BFVs.

- **Procure enough M113A3 tile sets to outfit at least one brigade.**

Funding Implications: According to the study cost estimates, it would cost approximately $25 million in FY02–FY03 to equip one brigade of M113A3s.

Motivation: This procurement should provide enough tile sets to outfit the same number of M113A3s as there will be in a BFV brigade. These M113s will be able to keep up with the force, due to their A3 upgrade, and will have protection comparable to a BFV with enhanced tiles.

Comments: More of these M113A3 tile sets should be procured if additional contingency force M113s are perceived to have a need for improved protection.[25]

Further Research Recommendations

- **Perform mission analyses to determine the most appropriate use of enhanced RA tiles on M113s during contingency response operations.**

Funding Implications: Appropriate funds for this research in FY00–FY02.

Motivation: The M113 and its variants play many different roles in the Army. In some of these roles RA tiles may be of great value, while in others RA may be

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[24]A total of 115 new enhanced RA tile sets would bring the total number of BFV sets to 349, which is the number of armor and infantry BFVs in Force Package 1.

[25]For example, a total investment of $50 million would be enough for about 240 tile sets, which would be over 40 percent of the armor and infantry M113s in Force Package 1.

unnecessary or inappropriate. More importantly, the better protection afforded by RA may expand the range of roles and missions that M113s can contribute to. These issues must be studied carefully to understand where RA would be most valuable for the M113. This information would enable the Army to plan how to allocate its new M113 RA tile sets more effectively during a contingency operation.

Comments: A variety of operational contexts, ranging from humanitarian relief and peace enforcement to major theater war, should be considered in this research, and the findings should be used to determine the exact number of RA tile sets needed for the Army's M113s and which units they should be assigned to for different contingencies.

- **Study the benefits and safety implications of using enhanced RA tiles on armored vehicles in urban peace enforcement operations.**

Funding Implications: Appropriate funds to perform initial research and conduct tests of enhanced tile prototypes in FY00–FY02.

Motivation: Events during recent urban operations in Somalia, Haiti, and Bosnia indicate a potential need for improved vehicle protection in certain situations. For example, a vehicle with RA tiles could be used to rescue isolated or pinned-down soldiers when HHIW threats are present. It is not clear, however, that RA is appropriate for use in urban operations, even in a rescue situation, because of legitimate concerns about the safety of nearby soldiers and civilians. More research and testing is needed to clarify both the potential benefits and the safety implications of using RA on armored vehicles during urban peace enforcement operations.

Comments: A variety of RA applications and missions should be explored as a part of this research. For example, there are some common nation building or peace enforcement missions, such as escorting truck convoys, where having RA tiles on BFVs and M113s would provide valuable HHIW protection during an ambush. In addition, a maximum-coverage set of enhanced RA tiles could be used to protect an armored vehicle from dangerous HHIW threats during special rescue missions. This type of specialized survivable urban rescue vehicle (SURV) might benefit from a roof version of the enhanced 2–3 Year tile that could protect it from HHIWs fired down at it from above, as is likely in an urban context.

- **Explore the possibility of applying the enhanced universal RA tile to other Army and Marine Corps armored vehicles in the future.**

Funding Implications: Encourage the Army and the Navy to allocate some of their long-term R&D funds to this effort.

Motivation: The universal enhanced RA tile design should be applicable to other light armored vehicles. The procurement of significant numbers of these tiles for the BFV and the M113 in FY02–FY04 will probably reduce their cost to some extent. The Army and Marine Corps could take advantage of this lower cost to procure enhanced RA tile sets for other types of armored vehicles. Two current Marine Corps armored vehicles that might benefit from RA tiles are the AAAV and the LAV-3. RA tiles could also be used to increase the survivability of the lightweight vehicles that are being considered for the Army After Next.

Comments: Obviously, no tiles should be procured unless a need for improved protection has been identified. It would, however, be prudent to consider the merits of applying RA to plausible candidates, so that if a need did emerge in the future it could be addressed quickly.

Summary of Recommendations

Development

Only one new RA tile design should be developed in the near term: a universal enhanced tile based on the 2–3 Year design. This tile should be jointly developed for both the BFV and the M113. At this time, no additional upgrade should be developed for the M113, although this option should not be ruled out for the future. Additional effort should also be placed on designing an optimal configuration for the M113A3 that would maximize the protection provided by a 4,000-pound set of enhanced tiles.

Acquisition

Enough additional sets of the A1 Production tiles should be procured to equip a substantial portion of the Army's Contingency Response Forces. When the new enhanced tile is ready, enough sets of the new tiles should be procured to outfit an additional brigade. At least this many M113A3 sets should also be procured initially. If, as these initial sets are allocated, it becomes apparent that more M113s need extra protection, then additional sets should be acquired shortly thereafter to meet this need.

Further Research

The roles and missions of M113s should be studied further in the next few years to determine which and how many of them need RA tiles. Such research, which might include mission analysis and force-on-force simulation, will improve future M113 tile acquisition decisions. The benefits and safety implications of using enhanced RA tiles in urban peace enforcement operations should also be studied to determine if vehicles with RA can play a role in this environment. In addition, the Marine Corps should reevaluate its protection requirements to see if the new universal RA tile would be appropriate for any of its vehicles. Similarly, the Army should consider whether its future vehicles for Army After Next could benefit from using the new enhanced universal RA tile.

Appendix

A. Text of Public Law 105-261 Section 114

SEC. 114. REACTIVE ARMOR TILES.

(a) LIMITATION.— None of the funds authorized to be appropriated under section 101(3) or 102(b) may be obligated for the procurement of reactive armor tiles until 30 days after the date on which the Secretary of Defense submits to the congressional defense committees the matters specified in subsection (d).

(b) EXCEPTION.— The limitation in subsection (a) does not apply to the obligation of any funds for the procurement of armor tiles for an armored vehicle for which the Secretary of the Army or, in the case of the Marine Corps, the Secretary of the Navy, had established a requirement for such tiles before the date of the enactment of this Act.

(c) STUDY REQUIRED.— (1) The Secretary of Defense shall contract with an entity independent of the Department of Defense to conduct a study of the operational requirements of the Army and the Marine Corps for reactive armor tiles for armored vehicles and to submit to the Secretary a report on the results of the study.

(2) The study shall include the following:

(A) A detailed assessment of the operational requirements of the Army and the Marine Corps for reactive armor tiles for each of the armored vehicles presently in use, including the requirements for each vehicle in its existing configurations and in configurations proposed for the vehicle.

(B) For each armored vehicle, an analysis of the costs and benefits of the procurement and installation of the tiles, including a comparison of those costs and benefits with the costs and benefits of any existing upgrade program for the armored vehicle.

(3) The entity carrying out the study shall request the views of the Secretary of the Army and the Secretary of the Navy.

(d) SUBMISSION TO CONGRESSIONAL COMMITTEES.— Not later than April 1, 1999, the Secretary of Defense shall submit to the congressional defense committees—(1) the report on the study submitted to the Secretary by the entity carrying out the study;

(2) the comments of the Secretary of the Army and the Secretaryof the Navy on the study; and

(3) for each vehicle for which there is a requirement for reactive armor tiles, as indicated by the results of the study, the Secretary's recommendations as to the number of vehicles to be equipped with such tiles.

B. AMSAA Study Summary and Investment Strategy Proposal

In Public Law 105-261 Section 114, Congress directed the Secretary of Defense to conduct an independent study of the Army and Marine Corps armored vehicle operational requirements for RA tiles and a cost-benefit analysis of the procurement and installation costs. By 1 April 99, the Defense Secretary will submit to Congress the independent study report, the Secretaries of the Army and Navy (Marine Corps) comments, and a recommendation on the quantity of vehicles to be equipped with RA.

The approved RA Tile Study assessed the operational requirements for RA tiles for the M113 and Bradley family of vehicles: the effectiveness of two RA tiles on M113 and Bradley against the 2005 Hand-Held Infantry Weapon (HHIW), Antitank Guided Missile (ATGM), and 30mm APFSDS threat; life cycle cost; cost of equipping Force Package I; cost-benefit; safety; and storage. The Army has a requirement for RA for Bradley and a need for RA for the M113 for contingency operations.

Two RA tile configurations were evaluated for the Bradley: current production RA and a 2–3 Year notional developmental RA. The Army has 74 Bradley RA tile sets stored in depot. An additional 104 sets are on contract to be produced.

Two RA developmental tiles were evaluated for the M113A3: 1–2 Year developmental tile and 2–3 Year developmental tile. The M113A3 1–2 Year developmental tile will provide protection comparable to Bradley current production RA. The M113A3 2–3 Year developmental tile will provide protection comparable to Bradley 2–3 Year developmental tiles.

Bradley and M113RA configurations evaluated represent maximum vehicle protection (coverage) permitting unobstructed vehicle operation. The M113 power train and chassis would have to be redesigned (M113(RE)) to handle the increased weight for both RA tile configurations with maximum vehicle protection. Since an M113 redesign would double the cost of an M113A3 vehicle, the M113 was also evaluated with maximum vehicle protection that could be achieved without requiring a vehicle redesign (M113A3).

There is a significant percent reduction in vulnerability for all RA configurations on the Bradley, M113(RE), and M113A3). The 2–3 Year developmental tiles provide robust protection against the spectrum of threats.

Current vehicle costs without RA tiles are: Bradley (M2A2/M3A2—$1.38M; Bradley (A2-to-A3 upgrade)—$2.62M; M113A3 (A2-to-A3 upgrade—$0.2M. RA costs and weights are summarized in Table B.1. Providing maximum M113(RE) protection will cost at least twice as much per vehicle as providing maximum Bradley protection. Providing maximum M113(w/o RE) protection will cost about 20 percent less than providing maximum Bradley protection. Putting 2–3 Year RA tiles on the M2A3/M3A3 will increase the cost of the vehicle about 10 percent. Putting RA tiles on the M113(RE) will increase the cost of the vehicle about 275–375 percent. Putting RA tiles on the M113A3 will increase the cost of the vehicle about 100 percent. RA tiles R&D costs are comparable for Bradley 2–3 Year tiles and M113 1–2 Year and 2–3 Year tiles.

Materiel Safety and Storage: Based on previous Bradley and Abrams RA testing, RA is safe to use, install, store, maintain, and transport. RA tiles are classified as explosive and treated like ammunition. RA would be packed in barrier bags and stored in ammunition-type sheds or igloos which are guarded. However, given that RA would be stored near ammunition that already requires active guarding, no additional burden is assumed.

Table B.1

Vehicle and Tile Concepts Costs and Weights

Vehicle System	Tile Concept	R&D Tiles	LCC Less R&D Per Tile Set	R&D Chassis	Chassis Upgrade Per Vehicle	Tile Weight (lbs)
Bradley (Maximum Protection)	Production	Sunk $15.4M	$262K	None	None	6,900
	2–3 Year	$9M	$288K	Assume None	Assume None	7,600
M113 (RE) (Maximum Protection)	1–2 Year	$8M	$334K	$3M	$230K	6,400
	2–3 Year	$8M	$480K	$3M	$230K	9,200
M113 (w/o RE) (Maximum Protection w/o Redesign)	1–2 Year	$8M	$209K	None	None	4,000
	2–3 Year	$8M	$209K	None	None	4,000

Safety to Soldiers: Dismounted troops accompanying the Bradley or M113 with RA will have a slightly higher average vulnerability to the blast and fragment from a munition impacting the vehicle. However, dismounted troop increased vulnerability is more than offset by the significant reduction in the vulnerability of the Bradley vehicle and crew/squad while mounted.

What additional investments should the Army make beyond the 178 current production Bradley RA tile sets? The Army needs a robust RA tile to increase Bradley fleet protection and to provide M113 protection against fielded threats. This will require RA R&D. The most cost-effective RA R&D investment is a 2–3 Year RA tile that provides designs for both the Bradley and M113. This would cost about $10–11M (a little more than the cost of Bradley 2–3 Year RA R&D).

Given 2–3 Year RA tile design for Bradley and M113, how many tile sets should be procured? For $234M, it would be possible to buy enough tile sets to provide significant survivability enhancements to armor and infantry forces in Force Package I (349 Bradleys, 554 M113s). If one assumes that the number of Bradley current production RA tile sets is the amount necessary for contingency operations, this could be provided for $84M (178 Bradleys, 178 M113s).

The funding challenge is to start the RA R&D as soon as possible. This will require reprogramming $10–11M. There is $5M for M113 RA investigations that is currently frozen by Congress, pending the outcome of the RA study. These funds could be used to start the RA R&D. ARL could start RA R&D in FY99. This leaves $5–6M to be reprogrammed in FY00 and FY01. Assuming RA R&D funds could be reprogrammed, the procurement needs to be put into the POM for execution starting in FY02. The only question is how many RA tile sets the Army wants to procure for Bradley and M113.

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