QuadGard Arm and Leg Protection Against IED's

P. Matic,[1] G.K. Hubler,[1] J.A. Sprague,[1] K.E. Simmonds,[1] N.L. Rupert,[2] R.S. Bruno,[2] J.J. Frost,[3] D.H. Branson,[4] C. Farr,[4] and S. Peksoz[4]
[1]*Materials Science and Technology Division*
[2]*Army Research Laboratory*
[3]*FS Technology, LLC*
[4]*Oklahoma State University*

The Naval Research Laboratory (NRL) led a government-university-industry team that developed the "QuadGard" arm and leg body armor from initial concept to industrial production over a period of 17 months. QuadGard provides extremity protection against fragments from conventional munitions and improvised explosive devices (IED's) in an innovative flexible design, based on combat casualty trends. Weighing only 10 lb, it achieved a high level of acceptance during test and evaluation by warfighters for its flexibility and comfort. The first three design phases were performed under an Office of Naval Research program, from April to December 2004. The final design phase and preparation for production was performed for the Marine Corps Systems Command (MCSC) in the spring of 2005. More than 4800 sets of QuadGard were then procured by MCSC for use by 50-caliber turret gunners and shipped forward for operations in Iraq between October 2005 and January 2006. An additional 300 sets were purchased by the Joint IED Defeat Task Force. These were delivered in November and December 2005 for test, evaluation, and operational use in Iraq by additional Marine Corps, Army, and Air Force units. Finally, 100 sets were purchased by the Naval Facilities Expeditionary Logistics Center in January 2006 for the Navy's Seabees in Iraq.

INTRODUCTION

Improvised explosive devices (IED's), such as those in Iraq, are a challenging threat to U.S. military forces. These blast weapons, often rigged to detonate conventional munitions such as artillery shells, have caused fatalities and severe injuries to Marines and soldiers. The introduction of the outer tactical vest (OTV) with soft armor to protect the upper torso against fragments, along with the ceramic small arms protective insert (SAPI) plates, has shifted the injury patterns sustained by Marines and soldiers. The superb effectiveness of this armor protects soldiers who would otherwise have received fatal wounds to the chest, but produces significant numbers of casualties with arm and leg injuries. Now, as a result of this trend, one quarter of all injuries incurred affect the arms and one third affect the legs. Limb amputation rates have been more than twice as common as in previous conflicts. New lightweight and flexible limb protection options were needed for the Marines and soldiers.

After visiting amputees at Walter Reed Army Medical Center in late 2003, Secretary of the Navy Gordon England asked the Office of Naval Research (ONR) to assess the situation and develop new protective equipment options for the Marines in Iraq. The assignment was handed to the Naval Research Laboratory's Materials Science and Component Technology Directorate (Code 6000) in early 2004. NRL applied its expertise in materials and the biomechanics of blast injuries to understand the unique aspects of the IED problem. By April 2004, it had formulated a strategy for a rapid response program to develop extremity armor. A multidisciplinary team was organized that consisted of NRL as program lead, the U.S. Army Research Laboratory (ARL) Weapons and Materials Research Directorate, the ARL Human Research and Engineering Directorate, FS Technology, LLC (FST), and the Oklahoma State University (OSU) Design, Housing and Merchandising Department. ARL was particularly helpful in identifying team members who possessed world-class expertise. Each team member had primary responsibilities, listed in Table 1, while at the same time contributing to and supporting each task.

The QuadGard team was then funded by ONR to design, prototype, and test the system. Follow-on funding from the Marine Corps turned the prototypes into production items that were shipped to Iraq. The time from initial design to initial shipments for operational use in Iraq covered a period of 17 months. This article describes the development of the QuadGard extremity armor system.

TABLE 1 — Major Tasks and Primary Responsibilities of the QuadGard Multidisciplinary Development Team

Expertise	Institute
Program coordination	NRL
Medical assessment	NRL
Threat assessment	NRL, ARL
Ballistic materials performance	ARL, FST
Extremity armor objectives	NRL
Extremity armor design	OSU, FST
Prototype design and fabrication	OSU, FST
Human factors assessment	ARL
Warfighter feedback	ARL, NRL
Transition to production	FST, OSU

DESIGN PHILOSOPHY

Arm and leg armor in the form of gauntlets for the arms and greaves for the lower legs has been used for thousands of years to protect against low velocity penetrating and blunt trauma. These were constructed from wood, leather, and bronze, culminating in the use of iron and steel by Asian and European armies in the Middle Ages. Body armor disappeared at the end of the Renaissance when rifles and artillery were introduced to the battlefield.[1]

Perhaps the first practical reappearance and use of modern body armor against higher velocity fragments was the "flak jacket" issued to aircraft crews during World War II. The use of fragment protection vests was extended to Marines and soldiers on the ground in Korea and Vietnam. The current OTV was issued in large numbers during the late 1990s, and its first widespread use in combat has been in Afghanistan and Iraq. The OTV is made of Kevlar and it provides blast fragment protection to the upper torso. The OTV with the addition of front and back ceramic SAPI plates provide protection against small arms fire using full metal jacket ammunition, such as used in the AK-47 rifle.

The convergence of the IED blast weapon threat, modern materials technology, and modern military medicine on today's battlefield has effectively reopened the possibility, for the first time in 400 years, of a full body armor ensemble to protect the torso, arms, and legs of today's warfighter.

The Challenge of Minimizing Added Weight

The IED threat is ever-present for the Marines and soldiers conducting ground operations, and it can come from any direction. Therefore, 360-deg protection for the extremities is highly desirable. A Marine is also already burdened with the weight of his body armor, helmet, weapon, ammunition clips, grenades, water, first-aid kit, pistol, knife, radio, extra batteries, and more, depending on the mission and function of his unit. This often amounts to a minimum load of 45 lb, although it can often increase to between 75 and 100 lb. Therefore, any armor for the arms and legs must be very lightweight. From preliminary estimates of weight, level of protection, and flexibility from available ballistic protection materials technologies, 10 lb of additional weight for arm and leg armor appeared to be acceptable and was adopted as a design goal.

Determining the Area of Coverage

To assess the relative vulnerability of different areas on the arms and legs, medical personnel were consulted from Walter Reed Army Medical Center in Washington, DC, the National Naval Medical Center in Bethesda, Maryland, and the Naval Medical Center in Portsmouth, Virginia. Together, their combat casualty care experience ranged from initial stabilization of casualties on the front lines in Iraq, to hospitals in Kuwait and Germany, and to long-term hospital treatment and rehabilitation back in the United States. They provided an early and unique perspective on the emerging casualty trends that was invaluable in the QuadGard design process.

In addition to these in-depth discussions, all available data on combat casualties from Operation Iraqi Freedom (OIF) and from Operation Enduring Freedom (OEF) in Afghanistan were reviewed for trends relevant to the armor design. Information was also obtained from the Naval Health Research Center, ONR-Human Systems Science and Technology Department; the United States Army Institute for Surgical Research; the Armed Forces Institute of Pathology; the Army Research Laboratory, Aberdeen Test Center (ATC); and others.

As might be anticipated, injuries to the extremities tracks quite well with the projected area of the extremities and constitute 60 to 65% of the debilitating injuries. Contained within the details of these gross percentages, however, were a number of valuable lessons learned from both the combat casualty care communities and the data analyses. The following design guidelines were generated from these lessons: protection against smaller fragments is both possible and valuable; protect the vulnerable areas where nerve and vascular bundles are concentrated and near the surface (i.e., behind the knee, inside the elbow, around the shoulder, under the arm); protect joints where prognosis for full recovery from injury is poor (i.e., knees, elbows, hips); protect the sciatic nerve in the lower back and buttocks (which is essential for leg function); protect the femoral arteries in the lower abdomen; and use "shadowing" by the armor on exterior surfaces to shield interior surfaces left uncovered for flexibility and comfort (such as inside surfaces of the upper arm, the torso under the upper arm, and the upper leg to facilitate major sweat gland ventilation and comfort).

Selecting a Level of Ballistic Protection

Determining the level of ballistic protection is the most challenging part of limb armor design. There is no definitive model to predict the injury level or severity caused by a fragment of a given size and strike velocity. There also is no definitive model that predicts the ballistic performance of soft armor, where the problem is complicated by the lack of high shear rate mechanical property data, fabric denier effects, and fiber-to-fiber interactions that are difficult to model. Therefore, quantitative methods to predict the effect of arm and leg body armor on blast injury severity from the IED threat do not currently exist.

Information on the blast-weapon and IED threat was assessed from background information provided by ARL, ATC, the Navy explosive ordnance disposal community, National Ground Intelligence Center, and OIF and OEF briefs. Many types of devices and methods are used against the Marines and soldiers in OIF and OEF, and no "typical" IED exists.

The general consensus from these sources was that IED's were based on conventional munitions such as artillery shells. These were generally devices of varying explosive yield deployed in nonoptimal fashion (e.g., buried in the ground or positioned above the ground in nonoptimal orientations). The IED designs evolve over time to use available materials and current operational tactics employed by the insurgent forces. The lethal radius of these devices for persons without armor is estimated to be from 10's to 100's of feet.

Although IED's can generate larger fragments, smaller fragments often dominate the fragment yield. Conventional artillery munitions produced by NATO or Warsaw Pact sources generate large numbers of 100 to 250-mg engineered fragments. IED's are often augmented with nails, washers, and bolts. Grenades and antipersonnel mortars also generate relatively small fragments. Gravel and sand are also entrained by blast weapons, and become part of the fragment yield. These smaller fragments are aerodynamically inefficient, meaning their velocity drops rapidly over a shorter distance from the blast and they are less effective as penetrators of body armor.

Consistent with the recommendations from combat casualty care communities and practical concerns about added weight, the QuadGard design focused on stopping the smaller fragments with soft armor at a level of protection slightly below that of the soft OTV. Standards developed by the National Institute of Justice (NIJ)[3] were used to quantify the level of protection during the materials selection process, prior to testing using Marine Corps production testing standards. This level of protection is both medically relevant, meets the 10-lb weight limit, and allows full coverage of all limbs and joints. Design options at higher levels of protection were also examined to match 100% of the OTV level of protection, with the same area of coverage. This was done for comparative purposes and future options, with a projected total weight of under 15 lb.

Designing for Human Factors and Warfighter Acceptance

In addition to considerations of coverage, ballistic protection level, and weight, the "human factors" that govern warfighter acceptance and use are just as important as physical performance of the armor. Armor is not useful if a Marine or soldier does not wear it. Conversely, a high rate of acceptance maximizes the potential range of uses in the field. By paying special attention to flexibility, mobility, heat management, appearance, and overall comfort, the QuadGard design has tried to maximize acceptance and use by Marines and soldiers. Table 2 summarizes key design objectives and solutions.

Based on the above considerations, the QuadGard design that evolved covers most of the arms and shoulders, while the pants cover the entire lower torso beneath the OTV, the hips, the buttocks, and the legs. The decision was made to design QuadGard to be compatible with the groin protector currently issued to all Marines and soldiers as part of their OTV ensemble.

Figure 1 shows features of the QuadGard arms. The arms are attached to the OTV by using three straps, one of which connects the arms together across the back. The arm length is adjustable up and down to ensure that the flexible elbow joint is aligned properly with the wearer's elbow. The arms are open along the inside of the upper arm for ventilation and do not impede arm motion in any way, while maintaining 360-deg armor protection around the elbow. Velcro straps at the cuff allow expansion of the sleeve circumference for donning and for increased ventilation when needed. Shoulder pads protect the shoulder joints. The lower arm portion resembles ancient Roman gauntlets.

The QuadGard legs are actually pants held up by suspenders that cover most of the lower torso, buttocks, hips, and legs (Fig. 2). The unique knee design covers the back of the knee, with a hinged flap of the armor material attached to the pants above and below the knee joint. In the standing position, the flap covers a small area behind the knee designed without armor to make the knee joint flexible. When the knee flexes, the flap folds, slides down the calf, and allows a

TABLE 2 — The QuadGard Design was Based on a Set of Key Objectives and Solution Strategies that Balanced Weight, Ballistic Protection, Flexibility, and Comfort

Functional Parameters	Design Strategy
Area of coverage	Cover medically vulnerable areas
Level of protection	Small fragments at moderate velocity
Thermal management	Segmented and vented design
Weight	10 lb maximum (<OTV with SAPI plates)
Comfort	OTV attachments and suspenders
Flexibility	Innovative elbow and knee joints
Mobility	Consistent with dismounted activities
Appearance	Consistent with warfighter image
Compatability	Helmet, OTV, weapon, equipment
Environmental durability	Comparable to OTV
Cost	Comparable to OTV w/SAPI plate

(a) Front view (b) Back view

FIGURE 1
QuadGard arms attached to the Outer Tactical Vest.

(a) Front view (b) Back view

FIGURE 2
QuadGard pants.

complete crouch by the wearer. Nonballistic kneepads protect the knee from bumps.

Zippers along the outside of the legs open from either the top or bottom for ventilation and as an aid in donning and doffing the pants. Flaps at each hip can be folded open for maximum ventilation or fastened down with Velcro straps for maximum protection. The design of the flaps allows ready access to the Marine's side pockets on his combat utilities worn under the QuadGard pants. A carry strap was included at belt level on the rear of the pants for rescue and evaluation. The QuadGard armor is shipped with wicking undershirts that have been proven to increase the comfort of the OTV in hot weather.

Operational Benefits and Uses

In operational terms, the QuadGard extremity body armor provides ballistic protection that can increase nonlethal and safe operating areas around an IED by reducing these minimum standoff distances from the warfighter to the device. An associated reduction in injury severity can mean quicker return to duty for relatively minor injuries (e.g., hours or days instead of weeks), reduced time need for intensive medical treatment and rehabilitation for severe injuries (e.g., weeks instead of months), or the difference between injuries producing or not producing fatalities, amputation, or disability.

Potential operational uses of QuadGard were gleaned from discussions and feedback with warfighter communities in the Marine Corps, Army, and Navy. These include

- vehicle occupants/convoy crews,
- sentry and checkpoint duty,
- security and support operations,
- roadside patrols,
- explosive ordnance reconnaissance,
- forward-deployed medical personnel,
- military operations in urban terrain,
- combat engineers, and
- aircraft crews and passengers.

Although ballistic protection was the primary goal, additional secondary benefits of QuadGard were identified as protection against blunt trauma from direct exposure to blast pressure waves, and protection against flash burns beyond that provided by the blouse and trousers of the standard combat utility uniform.

BALLISTIC MATERIALS TESTING AND PERFORMANCE

The selection of a lightweight, soft ballistic material system to provide fragment protection was based on the ballistic testing of a series of candidate material systems. Candidate systems were chosen from experience with the newer commercially available products having the best potential for increased performance, on a unit weight basis, over the ballistic materials currently used in protective equipment. Sixteen different ballistic material combinations, including both homogenous and hybrid systems, were tested at ATC according to Marine Corps production standards. The monolithic materials were found to perform better than the hybrid systems. The material systems are tested using standard 18 × 18-in. square shoot packs, freely suspended on the ballistic test range, subjected to multiple impacts in a specified geometric pattern. Steel right circular cylinders of 2-, 4-, 16- and 64-grain weights, and 9-mm 124-grain full metal jacket (FMJ) ammunition were used to evaluate candidate armor material performance. V_{50} testing is used to determine level of ballistic performance where V_{50} is defined as the velocity at which 50% of the projectiles are stopped and 50% penetrate the armor. The specification requires that the statistics of the measured spread in V_{50} velocities not exceed a specified small value for the test to be valid.

The ballistic material system found to provide the best desired ballistic performance, by weight, was unidirectional DSM Dyneema in a cross-ply lay-up. Dyneema is a relatively new product that consists of high molecular weight polyethylene fibers in a flexible fabric. It has demonstrated 20% improvement in ballistic performance by weight compared to Kevlar, a fact that is very useful for body armor applications. It is also more environmentally stable than Kevlar, resistant to environmental factors such as water, chemicals, and ultraviolet radiation.

PROTOTYPE TESTING AND EVALUATION

Using the protection, material, and weight guidelines previously discussed, the design team produced a series of prototypes in four phases through an iterative design cycle. Funding from ONR was received in mid-April 2004 to support a three-phase design effort. In one month, five sets of the Phase I concept design prototypes were produced to demonstrate the essential features of coverage and flexibility.

By the end of July 2004, 20 sets of Phase II prototypes were fabricated and feedback was being obtained from Marines, Army, and Navy warfighter communities who provided feedback on wearability, flexibility, and comfort. ARL also conducted static exercises to assess range of motion, ease of movement, and overall compatibility with the basic fighting load ensemble including the OTV (with groin and neck protectors), helmet, and rifle while wearing the QuadGard system. The static exercises included arm and leg movements, various standard rifle firing postures, climbing, and a short distance run. No major problems were identified related to the QuadGard system. A number of recommendations for functional refinements and improvements were noted and implemented during the next design iteration.

By December 2004, 20 sets of Phase III prototypes were completed and ready for ARL evaluations using static exercises; the 500-m "known distance" mobility/portability obstacle, also known as the KD-range; and the small arms firing range, also known as M-range, both at ATC. Figure 3 is a collage of photographs showing QuadGard undergoing testing on the ATC ranges.

The KD-range consists of an open course interrupted by a series of obstacles designed to measure essential physical performance skills associated with a combat environment. The course consists of 20 individual obstacles spread over a twisting course of about 500 m. The course requires the participants to perform maneuvers that test their running, jumping, climbing, crawling, and balancing skills, and their ability to negotiate buildings, stairs, and windows. Incompatabilities between new equipment and existing equipment or weapons will be most evident during obstacle course runs. The time to run the course was measured. When weight and bulk is worn or carried, especially by the lower extremities, course completion time increases and performance degrades. When QuadGard is added to the base system of the OTV, helmet, and rifle, the time to complete the course increased by 34%. This performance falls in the range expected for the added weight according to data taken for many studies of various types of equipment on the KD-range.

The M-range is a fully instrumented and automated facility to assess individual marksmanship performance. Participants fired a commonly zeroed M4 carbine and M240 machine gun, with and without the QuadGard limb protection system, while wearing the OTV and helmet. Eighteen targets appeared in a random sequence, at ranges from 50 to 300 m, to the participant who fired in semiautomatic mode. Participants used the foxhole supported, basic prone unsupported, kneeling unsupported, and standing firing positions. The participants said they were comfortable wearing the QuadGard system while firing their weapons, and no compatibility issues were identified. Target scoring with QuadGard was consistent or slightly better than without QuadGard. One expert marksman noted that the QuadGard system provided more support and was more comfortable than his personal shooting jacket.

Questionnaires were filled out by the participants to solicit their ratings, comments, and suggestions on QuadGard features and their ability to perform while wearing the system. The quantitative portion of the questionnaire requested ratings on a numerical scale of 5 = Excellent, 4 = Good, 3 = Acceptable, 2 = Poor, and 1 = Unsatisfactory. An example of results for a group of 17 participants shows that the majority regarded the system fit, task performance, system features, movement, fasteners, and closures as "Acceptable to Good." Figure 4 shows an overall "Good" rating regarding one's ability to move while wearing the system. Figure 5 shows that while concerns about additional heat and bulk of QuadGard were noted by the participants, which were comparable to historical concerns about the OTV and other comparable equipment, the armor is still viewed as comfortable and compatible. Overall, the ratings were exemplary considering the historical trend for body armor evaluations.

The Phase III testing at ARL was instrumental in showing that the QuadGard concept was meeting the design goals and maturing as a system. This generated new interest and support at the Marine Corps Warfighting Laboratory (MCWL), which evaluates new concepts and equipment, and at the Marine Corps Systems Command (MCSC), which develops and procures equipment for the Corps. In early 2005, MCSC initiated support of QuadGard Phase IV development with the goal of a production-ready system. Phase IV incorporated more than 20 improvements and refinements over Phase III that were suggested by the results of testing at ARL. Twenty sets of QuadGard Phase IV were delivered in April 2005. Final testing on the KD-range and M-range began at ARL, with assistance of personnel from the Army's 16th Ordnance Battalion and the Marine Corps Detachment at Aberdeen Test Center.

In early 2005, in parallel to the development effort being conducted for the Marine Corps, the Joint IED Defeat Task Force became interested in evaluating QuadGard along with other arm and leg protection systems. Twenty sets of QuadGard prototypes were provided to the Rapid Equipping Force, who conducted wearability and warfighter acceptance testing for the Task Force between July 2005 and January 2006, with the Army's 14th Engineers at Fort Lewis in Yakima, Washington; with the Marines at the Marine Corps Air/Ground Combat Center in Twentynine Palms, California; and the Air Force 820th Security Forces Group at Moody Air Force Base in Georgia. Figure 6 shows QuadGard Phase IV being worn during training exercises at Twentynine Palms.

In these exercises, QuadGard was evaluated against two other arm and leg protection systems. This testing was consistent with the results of the ARL human factors testing. Participants deemed QuadGard more desirable than two other competing systems. In late 2005, 300 sets of QuadGard were purchased by the Task Force for evaluation and use in Iraq by Army, Marine Corps, and Air Force units.

FIGURE 3
QuadGard testing by Army Research Laboratory at Aberdeen Test Center obstacle course and marksmanship range demonstrates the flexibility of the design and its compatability with existing body armor and infantry equipment.

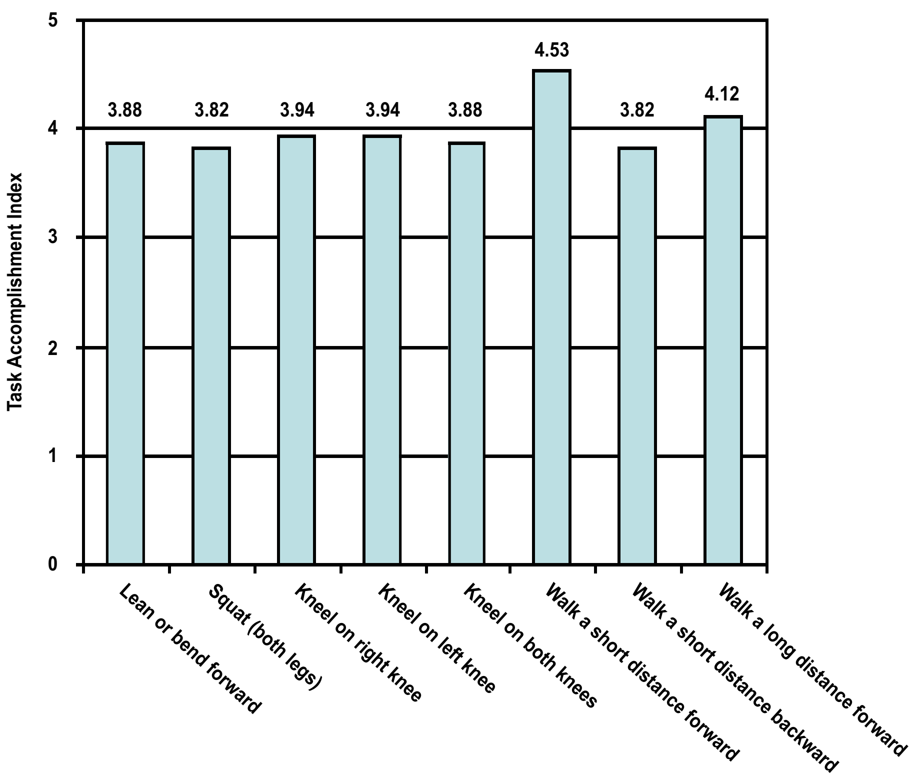

FIGURE 4
QuadGard task accomplishment data, obtained from warfighter testing and evaluation. High scores reflect the flexibility of the QuadGard design and compatability with the OTV, helmet, and rifle.

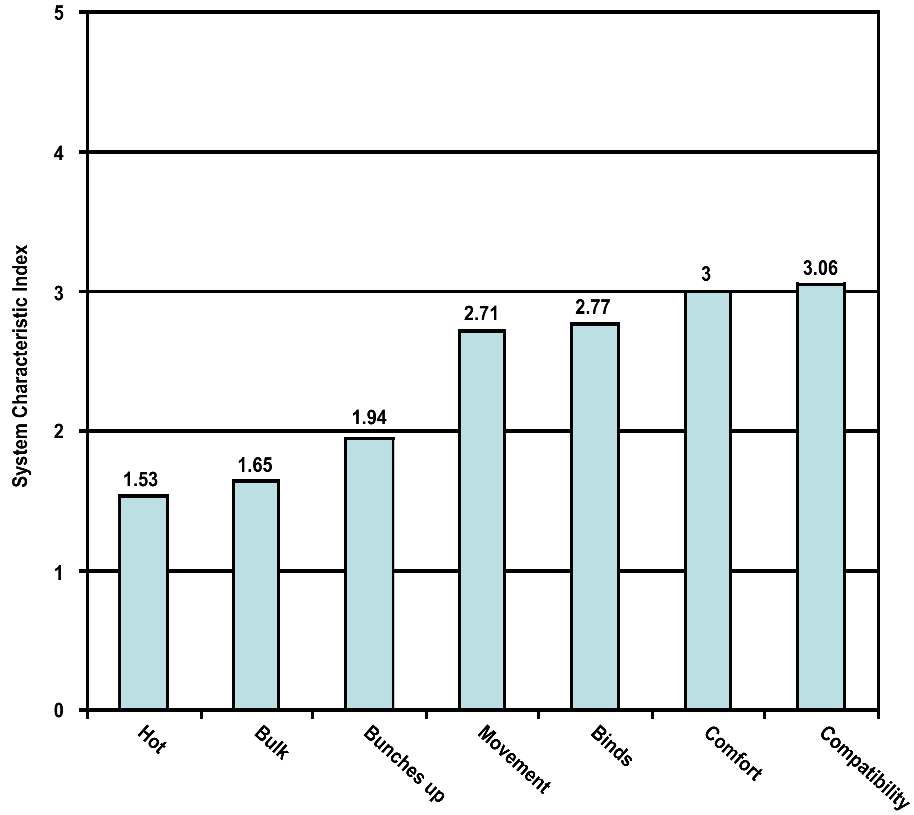

FIGURE 5
QuadGard system characteristics data while under movement, obtained from warfighter testing and evaluation. QuadGard scores are excellent compared to historical values for new body armor. The values show some heat and bulk concerns, but overall satisfaction including comfort and compatability.

FIGURE 6
Testing and evaluation of QuadGard during training exercises by the Marine Corps at the Air/Ground Combat Center in Twentynine Palms, California.

QUADGARD TO IRAQ

In July 2005, the Marine Corps Systems Command received an urgent Universal Needs Statement (UNS) from Iraq for protection for 50-caliber turret gunners. MCSC ran a standard set of more extensive preproduction ballistic tests of the Dyneema material system to certify the level of protection against fragments. MCSC also had independent analyses performed to predict the effect of QuadGard's armor materials and area of coverage on casualties and fatalities. This analysis was conducted using the Casualty Reduction (CASRED) simulation program with a standard set of ballistic fragment characteristics and data closest to the IED threat. The results of the CASRED analysis predict a 35% reduction in casualties and 10% reduction in fatalities. Based on these results, MCSC immediately ordered 4,800 sets of QuadGard for deployment in response to the UNS. The first sets of QuadGard were delivered to the Marines Corps in early October 2005. The order was completed in January 2006.

In August 2005, the Joint IED Defeat Task Force ordered 300 sets of QuadGard Phase IV for use in Iraq by the Army, Marine Corps, and Air Force units. This order was met from production in November and December 2005.

Finally, in December 2005, the Navy Facilities Logistics Center made inquiries about the QuadGard system for Seabee units deployed to Iraq. They purchased 100 sets, which were delivered in January 2006.

SUMMARY

The development effort and progress to date on the QuadGard arm and leg armor for Marines and soldiers covers an integrated effort involving the synthesis of combat casualty trends, blast weapon threats, soft ballistic armor materials, equipment design, human factors, and warfighter feedback into fully functional and accepted equipment. The armor design is lightweight, flexible, compatible with the OTV and other infantry equipment, and provides the needed protection against blast fragments.

The effort went from initial concept to the first delivery, for operations in Iraq, in 17 months. Production runs over the following four months met requests for a total of more than 5,000 sets of QuadGard from the Marine Corps Systems Command, Joint IED Defeat Task Force, and the Naval Facilities Expeditionary Logistics Center. QuadGard is presently manufactured by CoverCraft Industries at their production facilities in Pauls Valley, Oklahoma, and Wichita Falls, Texas. Following the initial costs of transitioning the design to production, the cost of QuadGard is presently $1,520 per set. It is listed under a National Stock Number.

MCSC has funded the QuadGard team for development for a Phase V version that offers added features including modular area of coverage with detachable lower arm and leg segments, removable soft armor packs allowing laundering of the carrier garment, options for increased protection level options in the soft armor packs, and design for quick doffing. Prototypes of QuadGard V have been produced for human factors testing and warfighter feedback in preparation for production.

ACKNOWLEDGMENTS

The authors thank the military participants from the Army Research Laboratory, the Army 16th Ordnance Battalion, and the ARL Marine Corps Detachment for their support in evaluating the QuadGard system as documented in this paper. The authors acknowledge the support received from RADM Jay Cohen of the Office of Naval Research and from Major Wendell Leimbach and Capt. John Gutierrez of the Marine Corps Systems Command.

[Sponsored by MSCS]

References

[1] R.C. Woosnam-Savage and A. Hall, *Brassey's Book of Body Armor* (Brassey's, Dulles, VA, 2001).

[2] Casualty Reduction (CASRED) is a deterministic model that calculates lethal areas for fragmentation weapons engaging personnel targets. For more information see http://www.msrr.army.mil/index.cfm?top_level=ORG_A_1000023&taxonomy=ORG.

[3] The National Institute of Justice (NIJ) Ballistic Standard 0101.04 for testing of ballistic protection materials and vests uses a 124-grain 9-mm bullet. This standard is found at www.ojp.usdoj.gov/nij/welcome.html. The Army and Marine Corps test procedures to determine the V_{50} performance of soft ballistic materials and vests use 2-, 4-, 16-, and 64-grain right circular steel cylinder fragment simulators.

★