

# **ANNUAL REPORT TO CONGRESS**

## **Efforts and Programs of the Department of Defense Relating to the Prevention, Mitigation, and Treatment of Blast Injuries**



**October 2008**

## **Executive Summary**

Section 256 of the National Defense Authorization Act (NDAA) for Fiscal Year 2006 (FY06), Public Law 109-163, requires the Secretary of Defense to submit a report on the efforts and programs of the Department of Defense (DoD) relating to the prevention, mitigation, and treatment of blast injuries (see Appendix A, Acronyms). The report is to include the following elements of information:

1. A description of the activities undertaken under this section during the 2 years preceding the report to improve the prevention, mitigation, and treatment of blast injuries.
2. A consolidated budget presentation for DoD biomedical research efforts and studies related to blast injury for the 2 fiscal years following the year of the report.
3. A description of any gaps in the capabilities of the Department and any plans to address such gaps within biomedical research related to blast injury, blast injury diagnostic and treatment programs, and blast injury tracking and monitoring activities.
4. A description of collaboration, if any, with other departments and agencies of the federal government and with other countries during the 2 years preceding the report in efforts for the prevention, mitigation, and treatment of blast injuries.
5. A description of any efforts during the 2 years preceding the report to disseminate findings on the diagnosis and treatment of blast injuries through civilian and military research and medical communities.
6. A description of the status of efforts during the 2 years preceding the report to incorporate blast injury effects data into appropriate programs of the DoD and into the development of comprehensive force protection systems that are effective in confronting blast, ballistic, and fire threats.

Appendix B, Crosswalk Between NDAA-Required Information and the Fiscal Year 2008 Annual Report, shows the crosswalk between the required information from Section 256 of the NDAA for FY06, Public Law 109-163 and this FY08 Annual Report.

As presented in this report, during the previous 2 years the DoD has made significant progress in coordinating and advancing medical research programs focused on preventing, mitigating, and treating blast-related injuries (see Appendix C, Taxonomy of Injuries from Explosive Devices). The Blast Injury Research Program Coordinating Office, on behalf of the Executive Agent, has developed a consolidated budget for FY09, FY10, and FY11 for DoD biomedical research efforts and studies that address validated blast injury knowledge gaps and capability needs. Numerous collaborative efforts with other departments and agencies of the federal government and with other countries have enabled the Department to optimize scientific growth and productivity in this area, as well as resource sharing. The Department's efforts to disseminate findings on the prevention, diagnosis, and treatment of blast injuries and on the rehabilitation of blast-injured servicemembers through civilian and military research and medical communities have resulted in significant improvements in the way blast injuries are prevented and in the way we care for blast-injured servicemembers. Finally, the Department has incorporated blast injury effects data into "end user" programs focused on the development and implementation of comprehensive force health protection systems.

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## Chapter 1 Introduction

**Background.** Section 256 of the National Defense Authorization Act (NDAA) for Fiscal Year 2006 (FY06), Public Law 109-163, directed the Secretary of Defense to designate an Executive Agent (EA) to coordinate and manage the medical research efforts and programs of the Department of Defense (DoD) relating to the prevention, mitigation, and treatment of blast injuries (see Appendix B, Crosswalk Between NDAA-Required Information and the Fiscal Year 2008 Annual Report). The DoD issued DoD Directive (DoDD) 6025.21E, “Medical Research for Prevention, Mitigation, and Treatment of Blast Injuries” on July 5, 2006. The Directive designates the Secretary of the Army as the DoD EA, assigns responsibilities governing coordination and management of the Blast Injury Research Program, and directs the Armed Services Biomedical Research Evaluation and Management (ASBREM) Committee to facilitate coordination and prevent unnecessary duplication of effort within DoD biomedical research and development and associated enabling research areas. The Secretary of the Army delegated authority and assigned responsibility to execute EA responsibilities to the Assistant Secretary of the Army (Acquisition, Logistics, and Technology) [ASA(ALT)] on January 4, 2007, and the ASA(ALT) delegated authority and assigned program responsibility to the Commander, U.S. Army Medical Command (USAMEDCOM) on January 16, 2007. The Commander, USAMEDCOM established the Blast Injury Research Program Coordinating Office (PCO) at the U.S. Army Medical Research and Materiel Command (USAMRMC) in a charter dated, June 5, 2007 (see Chapter 2, DoD Blast Injury Research Program Coordinating Office).

**Defining “Blast Injury.”** The term “blast injury” creates much confusion. Simply stated, “blast injury” includes the entire spectrum of injuries that can result from exposure to an explosion. The DoD Blast Injury Research Program uses the Taxonomy of Injuries from Explosive Devices as defined in DoDD 6025.21E to characterize such injuries. This taxonomy assigns blast injuries to five categories—Primary, Secondary, Tertiary, Quaternary, and Quinary—based on the mechanism of injury. Primary blast injuries result from the high pressures created by the blast itself. These high pressures, known as blast overpressure, can crush the body and cause internal injuries. Primary injuries are the only category of blast injuries that are unique to blast. Secondary blast injuries result when the strong blast winds behind the pressure front propel fragments and debris against the body and cause blunt and penetrating injuries. The strong winds and pressure gradients also can accelerate the body and cause the same types of blunt force injuries that would occur in a car crash or a fall. These are known as tertiary blast injuries. Quaternary blast injuries are the result of other explosive products, such as heat, light, and toxic gases, that can cause burns, blindness, and inhalation injuries. Finally, quinary blast injuries refer to the clinical consequences of “post-detonation environmental contaminants,” including bacteria, radiation (dirty bombs), and tissue reactions to fuel and metals (see Appendix C, Taxonomy of Injuries from Explosive Devices).

**Key Program Features.** The Blast Injury Research program is addressing critical medical research gaps for blast-related injuries and will fully address traumatic brain injury (TBI) and post-traumatic stress disorder (PTSD) research. The program is leveraging new extramural blast research partnerships with DoD medical research laboratories to achieve a cutting-edge approach to solving blast injury problems. Medical research products include medical standards for enhanced personal protective equipment (PPE). The program is addressing the new concept of “reset” for Warfighters in redeployment, ensuring return-to-duty readiness (or healthy return to civilian life for citizen Soldiers). One of the program’s major areas of focus is the improvement of battlefield medical treatment capabilities to mitigate neurotrauma and hemorrhage. Finally, the program is modernizing military medical research by bringing technology advances and new research concepts into DoD programs.

**Key Research Topics.** The Blast Injury Research Program is focused on filling gaps in the blast injury knowledge base. Key research topics by program area include:

- **Injury Prevention.** Determining if a nonimpact, blast-related mild traumatic brain injury (mTBI) exists and understanding the injury mechanisms; developing drugs to prevent and treat blast-related hearing loss; analyzing combat injuries and PPE performance; developing multi-effect blast injury models to improve protective equipment; and developing strategies that enhance psychological resilience and prevent PTSD and other psychological health problems.
- **Acute Treatment.** Developing diagnostic tools and neuroprotectant drugs for TBI; developing hemorrhage control and blood products; developing treatments for psychological trauma; developing medical procedures for damage-control orthopedics; and devising innovative strategies for improved pain management.
- **Reset.** Advancing tissue engineering and prosthetics; improving recovery of function; and developing return-to-duty standards.

**Key Program Accomplishments.** The Blast Injury Research Program has achieved great success during the past 2 years as illustrated by key accomplishments reported by DoD organizations, other federal agencies, academia, and industry. Chapter 4 provides a comprehensive listing of these key blast injury research accomplishments.

## Chapter 2

# DoD Blast Injury Research Program Coordinating Office

**Background.** The Commander, USAMEDCOM established the Blast Injury Research PCO at USAMRMC in a charter dated June 5, 2007. The mission of the PCO is to assist the DoD EA in fulfilling the responsibilities and functions in accordance with DoDD 6025.21E by coordinating and managing relevant DoD medical research efforts and programs related to the prevention, mitigation, and treatment of blast injuries.

**The Need for a Coordinated Program.** The DoD medical research community has been conducting medical research on blast-related injuries for decades. These decades of research have produced tremendous advances in battlefield medicine that are responsible for preventing blast injuries and saving the lives of blast-injured servicemembers on today's battlefields. This research also has produced biomedically valid blast injury prediction models and performance standards that serve as the basis for crew and personal protection system designs, as occupational exposure standards for blast-producing weapon systems, and as survivability assessment tools and metrics for combat vehicle crew survivability assessments. In addition to DoD contributions to solving blast injury problems, researchers in academia and industry have also made significant contributions to the study of blast injury prevention, mitigation, and treatment. The DoD Blast Injury Research Program will take full advantage of the body of knowledge and expertise that resides both within and outside of the DoD to solve complex blast injury problems. Specific examples are provided in Chapter 5, Key Components of the Blast Injury Research Program.

**Key Activities.** Since its inception, the PCO has worked hard to establish and manage a coordinated Blast Injury Research Program. The following are examples of key activities that have contributed to the success of the program:

- 1. Identified Blast Injury Research Knowledge Gaps.** The PCO held the first DoD blast injury research planning meeting in July 2006, during which representatives from the DoD, federal agencies, academic institutions, and industry assessed the state of the science and identified knowledge gaps in blast injury research. These gaps, detailed in the January 2008 Annual Report to Congress, were used to develop a prioritized list of program funding requirements and prepare program announcements and solicitations for research proposals.
- 2. Developed a Research Program Management Taxonomy.** The PCO developed a research program management taxonomy comprising three main categories of blast injury research: Injury Prevention, Acute Treatment, and Reset.
  - *Injury Prevention* mitigates the risk of blast injuries by providing medically based design guidelines and performance standards for individual and vehicle crew protection systems; comprehensive injury surveillance systems that link injury, operational, and protection system performance data; tools to identify individual susceptibility to injury; and individual resilience training to mitigate or prevent injuries.
  - *Acute Treatment* mitigates injury by providing acute and definitive treatment across the spectrum of blast-related injuries through improved diagnostic tools, health care provider training, wound care, and medical treatment outcomes analysis.
  - *Reset* mitigates disability by providing a biomedically based performance assessment capability for return to duty in redeployment and following injury; restoring full performance capabilities in redeployed individuals; and restoring seriously injured servicemembers with prosthetics and regenerative medicine. The term "reset" acknowledges a concept that extends beyond

rehabilitation to include all activities necessary to return injured servicemembers to duty or to productive civilian life.

Subcategories within each of the major categories of the taxonomy address specific research thrust areas. The thrust areas within the Injury Prevention category are Injury Surveillance, Individual Resilience Training, Protection Standards, and Personalized Medicine. The Acute Treatment category includes Medical Treatment Outcomes Analysis, Health Care Provider Training, Wound Care, and Diagnostics. The Reset category includes Return-to-Duty Standards, Individual Retraining, Advanced Prosthetics, and Regenerative Medicine. The PCO uses these major categories and thrust areas to promote a comprehensive and balanced portfolio of blast injury research and related projects designed to prevent, treat, and mitigate blast-related injuries.

**3. Identified Program Funding Requirements.** The DoDD 6025.21E requires the EA to perform programming and budgeting actions for all blast injury research to maintain research programs based on Director of Defense Research and Engineering-approved priorities of the DoD components. The PCO worked closely with organizations across the DoD to develop and staff the funding requirements for the Blast Injury Research Program in the following critical areas:

- Health, readiness, and well-being of servicemembers
- TBI and psychological health
- Medical standards for enhanced personal and vehicle crew protection systems
- Improved battlefield medical treatments to mitigate neurotrauma and hemorrhage
- The newer concept “reset” for servicemembers in redeployment, ensuring return-to-duty readiness or healthy return to civilian life
- Transfer of critically important annual Congressional Special Interest-funded projects, such as the Military Amputee Research Program, to core funding
- Leveraging of new extramural partnerships to achieve a cutting-edge approach to solving blast injury problems

**4. Strengthened and Expanded Collaborations Between the Medical Research Community and the Protection Equipment Developers.** The medical research community has always played a critically important role in the development of individual and vehicle crew blast protection equipment and systems by providing materiel developers with biomedically valid injury criteria, performance standards, and testing methods. The PCO has continued to strengthen and expand this important relationship as illustrated in the following activities:

- Served as the medical lead for the Vice Chief of Staff of the Army’s helmet-mounted sensor system fielding initiative
- Helped shape and focus the Combating Terrorism Technology Support Office/Technical Support Working Group (TSWG) blast injury research Broad Agency Announcement by serving as a voting member on the TSWG Human Lethality Integrating Integrated Product Team
- Facilitated USAMRMC blast injury research support for the U.S. Army Tank-Automotive Research, Development and Engineering Center and the U.S. Army Natick Soldier Research, Development and Engineering Center’s (NSRDEC) “Future Combat Systems Armor Development,” “Tactical Wheeled Vehicle Survivability,” “Enhanced Performance – Personnel Armor Technology,” and “Soldier Blast and Ballistic Protective System Assessment and Analysis Tools”
- Facilitated USAMRMC support for the Navy Live Fire Test and Evaluation Program by identifying opportunities for the program to leverage existing USAMRMC blast injury research tools that will eliminate the need for new research programs

- Identified opportunities for the Army Research Laboratory (ARL) Weapons and Materials Research Directorate to apply its expertise in computational modeling to the difficult problem of modeling blast-related injuries
  - Organized meetings with blast injury researchers from other federal agencies, academia, and industry to explore possible collaborations with DoD researchers
  - Advised a panel of the Committee on Toxicology, Board on Environmental Studies and Toxicology, National Research Council, to consider the USAMRMC Toxic Gas Assessment Software as an assessment method for occupational exposures to low-level combined gases
5. **Established a Research Subjects Coordinating Cell.** Injured servicemembers should be the beneficiaries of the best available medical care. They may voluntarily participate in approved ethical research that is of high value and carries potential benefits to their care. The PCO established a coordinating cell to manage requests from researchers for access to volunteers. These requests are considered in terms of the importance of the research to improving the current care of wounded Soldiers, the suitability of alternate patient populations not involving wounded Soldiers, and the demands of the study on patients. After study data have been analyzed and key results reported, data will be made available to other researchers according to a data sharing plan approved by the appropriate human use committees. This ensures efficient use of research data and maximizes potential benefits from the tests conducted. The PCO transitioned this coordinating function to the Office of the Congressionally Directed Medical Research Programs (CDMRP) in FY08.

**Blast Injury Research PCO Objectives.** In the coming months, the PCO will focus its efforts on the following objectives:

1. **Establish a Review Process for Medical Standards for Individual and Combat Vehicle Crew Blast Protection Systems.** Under the DoDD, the Assistant Secretary of Defense for Health Affairs is responsible for approving blast-related medical standards for the DoD. These medical standards include medically based performance standards and testing methods for combat vehicle crew and personal protection systems, occupational exposure standards for weapon system occupational health risk assessments, and injury and performance prediction tools for combat vehicle crew survivability assessments. The PCO will develop an impartial process that critically evaluates blast injury prediction tools, protection system performance testing methods, and health hazard and survivability assessment methods. The PCO will present the best tools and methods to the Assistant Secretary of Defense for Health Affairs with a recommendation for approval as DoD medical standards.
2. **Establish a Brain Injury Modeling Working Group.** One of the key knowledge gaps in the Blast Injury Research Program is determining whether a nonimpact, blast-related mTBI exists and understanding the injury mechanisms. To address this gap, many researchers have developed advanced computational models of brain injury. Several of these models are highlighted in Chapter 4. Simulations produced by biomedically valid computational models may help elucidate the precise mechanisms of brain injury that are critically important in the development of improved protection equipment, diagnostic tools, and treatments. As an extension of the current efforts and as biomedical data become available, outcome measures such as performance testing and other aspects of normal mental functioning will also be mapped to modes of injury. To coordinate brain injury modeling efforts and make the best use of computational modeling expertise and resources, the PCO will establish a brain injury modeling working group composed of subject matter experts from the DoD, other federal agencies, and academia. This working group will be charged with assessing the state of the art in computational modeling and evaluating the scientific quality and biomedical validity of available models.
3. **Establish a Blast Injury Research Web Site.** One of the most important components of any successful, coordinated program is the ability to easily share information. The PCO is in the final stages of developing a blast injury research Web site that will be the venue for sharing information

across the DoD, other federal agencies, academia, and industry. This Web site will provide users with access to critically important historical information on blast bioeffects (e.g., what has been learned from decades of blast bioeffects research) and on information about ongoing and planned blast injury research projects. A password-protected program management portal will provide a venue for conducting data calls from the DoD organizations and agencies conducting blast injury-related research and for reporting progress of ongoing research projects, identifying program funding requirements, and soliciting research proposals that address specific knowledge gaps. This Web site will be launched in the first quarter of FY09.

## Chapter 3 Consolidated Budget Presentation

A consolidated budget presentation for DoD biomedical research efforts and studies related to blast injury for the two fiscal years following the year of the report is presented in **Table 1**. These figures do not include any additional Congressional Special Interest appropriations.

Table 1 shows the consolidated fiscal budget for funded DoD biomedical research efforts and studies related to blast injury for FY09 through FY11 by program category. These fiscal values are consistent with the planning, programming, and budgeting guidance of the Department and reflect alignment of the program plan with Congressional items and Guidance for Development of the Force Program and Budget Assessment A4.16, Medical Research and Development Investments

**Table 1. Identified Funding by Fiscal Year and Program Management Category**

Funded (\$K)	Fiscal Year			
Program Category	FY09	FY10	FY11	Total
Injury Prevention	57,659	52,019	31,527	141,205
Acute Treatment	26,482	35,118	28,868	90,468
Reset	17,270	17,105	20,585	54,961
Total	101,411	104,243	80,980	286,634

## Chapter 4

# Key Program Accomplishments

### **Pad-Type Fitting Systems Improve the Blunt Impact Protection Level in the Army's Advanced Combat Helmet and the Marines' Lightweight Helmet**

Researchers at the U.S. Army Aeromedical Research Laboratory assessed the blunt impact protection provided by sling- and pad-type fitting systems in the Army's Advanced Combat Helmet (ACH) and the Marines' lightweight helmet. They determined that pad-type fitting systems provided better blunt impact protection but that the properties of pad-type fitting systems are influenced by temperature, which alters the blunt impact protection provided by the pad-type fitting systems. Based on these results, the U.S. Marine Corps altered its combat helmet configuration to include a particular pad-type fitting system, and the Army modified the ACH performance specification to improve the blunt impact protection level for the temperature extremes experienced in current areas of operation.

### **New Concept for Combat Helmet Padding System May Reduce Risk of mTBI from Blast Exposure**

The Office of Naval Research (ONR), USAMRMC, and L-3 Communications/Jaycor (under a contract with the ONR) collaborated to develop a concept design for a fluid cushion-based padding system, the Anti-Blast Shock Optimal Reduction Buffer (ABSORB) system. Testing at simulated blast levels comparable to improvised explosive device (IED) exposures shows significant performance improvements over currently fielded foam pad systems. In addition, the ABSORB system will allow more open ventilation to reduce heat buildup and does not degrade when wet. Field blast testing of prototypes and human use testing are planned. If successful, the ABSORB concept integrated into future advanced helmet designs is likely to provide increased protection against mTBI.

### **Body Armor Prevents Blast-Related Lung Hemorrhage**

Scientists associated with the Defense Advanced Research Projects Agency (DARPA)-funded Preventing Violent Explosive Neurologic Trauma (PREVENT) Program, in collaboration with the Walter Reed Army Institute of Research (WRAIR) and the Marine Breacher Training Program at Quantico, discovered that in an animal model (swine), protective equipment reduced mortality from lung hemorrhage without adversely increasing pressure in the brain. Further, they learned that the body activates an inflammatory response within the first hour following a blast exposure. Work continues as investigators examine the effects of inflammation and test additional strategies designed to prevent blast-related injury and mortality.

### **Assessment of Health Risks Following Repeated Low-Level Blast Exposures**

The Office of Naval Research, DARPA, TSWG, and the Military Operational Medicine Research Program (USAMRMC) sponsored an ongoing collaborative project among the U.S. Army Aeromedical Research Laboratory, Applied Research Associates, Inc. (under a contract with the ONR and TSWG), the University of Virginia, the Naval Medical Research Center, and the U.S. Marine Corps. Conducted at the U.S. Marine Corps Dynamic Entry School that trains Marines in the art of urban breaching, this is the first military volunteer study to characterize individual responses to repeated low-level blast exposures. Instruments within protective helmets and vests captured individual exposure data from blast events. Environmental data were collected through air sampling, surface particulate collection, and atmospheric readings. To identify potential health deficits, cognitive, hearing, balance, neurologic, and magnetic resonance imaging data were collected before and after exposure. Once all data have been collected and analyzed, the information will be used to guide standoff distances for military breachers, predict health outcomes following exposure to a known blast intensity, improve field exposure assessment equipment, and recommend medical assessments for Warfighters exposed to a blast.

### **Enhanced “QuadGard” Adopted by the U.S. Marine Corps**

The Army Research Laboratory contributed to the development of “QuadGard,” an arm and leg body armor protection system that is protective, lightweight, flexible, comfortable, and nonrestrictive. QuadGard is a protection option for mounted and dismounted Marines who may be exposed to blast munitions or devices during operational activities. ARL conducted a series of human factor evaluations for fit, configuration, and articulation at its small-arms, live-fire range and mobility portability course. ARL’s contributions led to an enhanced version of QuadGard, which the Marines adopted and currently use in Iraq and Afghanistan.

### **Development of a Lower Extremity Injury Criterion for Military Vehicle Occupants Involved in Explosive Blast Events**

Using funds from the U.S. Army Research, Development and Engineering Command Tank-Automotive Research, Development and Engineering Center, and data, modeling, and simulation information and real-world blast event scenarios from two North Atlantic Treaty Organization (NATO) task forces, researchers at Wayne State University exposed postmortem human specimens to a controlled antivehicular blast to quantify the velocity at which lower extremity fractures occur. These results led to the development of a lower extremity injury criterion for military vehicle occupants involved in an explosive blast event. The criterion can now be used to assess the probability of lower extremity injury to vehicle occupants under various blast threats and quantify the protection provided by armor or other blast mitigation designs. In addition, these data were used to evaluate vehicle hull structures in the High-Mobility Multipurpose Wheeled Vehicle Improvement Program and the Tactical Wheeled Vehicle Survivability effort. Recommendations were made to improve the hull structure so that kinetic energy from the blast would be better attenuated and thus reduce the probability of lower extremity injury. Dissemination included one publication, two abstracts, presentations at three conferences, and briefings to U.S. Army Research, Development and Engineering Command and NATO task forces. Two journal publications are pending. Information also was disseminated within the command through briefings and internal meetings and shared with NATO task forces.

### **Small, Wearable Blast Dosimeter Prototype Determines Potential Injury to Warfighters Exposed to Blast**

L3 Communications/Jaycor (under a contract with the USAMRMC) developed a prototype individual-worn dosimeter that can measure a blast event and predict the degree of injury to Warfighters. The prototype weighs approximately 1 ounce, is the size of a stack of 4 quarters, and can be read with a wireless reader. A small electronics package uses acquired output from the measuring device to compute the blast dose and USAMRMC’s INJURY model to predict blast lung injuries, and stores these data. The prototype has undergone laboratory testing over a range of blast exposures from exposures that cause no injury to those that are lethal. The value of this device is that data about a Warfighter’s blast exposure can be communicated to medical personnel to objectively quantify occupational safety and health risks. A self-contained unit suitable for field testing is under development.

### **Study Reveals That Soldiers Are Wearing Helmets Improperly**

The U.S. Army Aeromedical Research Laboratory contributed to a multi-institutional team led by the U.S. Army Infantry Center for the Vice-Chief of Staff of the Army that conducted an operational survey of helmet wear patterns and a laboratory study of helmet coverage. Photographic evidence showed that approximately 50% of Soldiers were wearing combat helmets improperly, exposing them to increased risk of injury due to fragments or concussion. The majority of improperly sized helmets were too small. The U.S. Army Program Executive Office (PEO) Soldier created and disseminated helmet sizing and fitting guidelines, graphical training aids, training videos, a maintenance advisory message, and a safety of use message to the field.

### **Enhanced Toxic Gas Assessment Software Assesses the Hazards of Toxic Gas Exposure**

The Toxic Gas Assessment Software is a series of software tools used to assess the hazard of exposure to toxic gases generated by blast or fire. Previous versions allowed estimates of the probability of immediate, total incapacitation and of immediate or delayed lethality from the seven most common combustion gases. An enhanced version (TGAS 2.0P) was developed that estimates the deleterious effects of an additional 21 gases. This software is used military-wide to assess the hazards of toxic gas exposure. The DoD Blast Injury Research PCO disseminates information about the software to all military organizations.

### **Dynamic Blast Simulations Quantify Helmet Protection Capability for Reducing TBI Due to Blast Loading**

This collaborative project among the Office of Naval Research, NSRDEC, and ARL established an analytical model for a helmet/head system, including skull and brain. Preliminary simulations on shock waves propagated through two head/helmet systems under various blast conditions were conducted, and pressures exerted on the head were computed. Pressure-enhancing effects were studied by comparing head pressure time histories between cases with and without helmet wear. Results indicated that wearing a helmet may increase pressure within the brain due to a tunneling effect. Information will be incorporated into the Individual Lightweight Protective System Future Naval Capability Program and was provided to DARPA as additional technical justification for developing a high-fidelity head/brain fluid shell model.

### **Techniques Developed to Predict and Visualize Injuries in a Threat Environment**

Together, the ARL Survivability/Lethality Analysis Directorate and the ARL Weapons and Materials Directorate developed new techniques to estimate fragment velocity based on injury patterns of personnel wearing body armor and in military vehicles. Additionally, a casualty assessment simulation model was used to predict wounds in a threat environment, and the model's depiction of injuries was improved. Information from the model regarding survivability and vulnerability was used to support acquisition decisions by the DoD. Reports and briefings were given to the test and evaluation community. Further, the Commanding General of the Army Test and Evaluation Command accredited the verification and validation of the threat, armor, interaction, and injury models for several DoD systems.

### **Models Used to Predict Battlefield Injuries Integrated, Verified, and Validated**

The Survivability/Lethality Analysis Directorate of ARL collaborated with the USAMRMC Military Operational Medicine Research Program, WRAIR, the U.S. Army Aeromedical Research Laboratory, and the Air Force to examine and validate software models that predict risk of (1) blast-induced lung injury, (2) injury and performance decrements due to inhaled fire gases, (3) penetrating injury from fragments to personnel wearing body armor and in military vehicles, and (4) acceleration-induced injuries. Together these injury models were incorporated into the DoD Operational Requirement-based Casualty Assessment (ORCA) model that represents a combat casualty and the effect of that casualty on operational readiness. ORCA is embedded in other DoD vulnerability models that evaluate the lethality and effectiveness of munitions and the vulnerability of aircraft, missiles, and ground-mobile systems. Reports and briefings were disseminated to the test and evaluation community, and survivability and vulnerability information from ORCA was used to support acquisition decisions. Finally, the Commanding General of the Army Test and Evaluation Command accredited the verification and validation of the threat, armor, and injury models for several DoD systems.

### **Wound Ballistics Database Created**

The ARL's Survivability/Lethality Analysis Directorate created an Army Wound Ballistics database for archiving historic wound ballistics notebooks and associated data. Approximately 200 of the nearly 600 notebooks have been digitized. Indices have been developed for some notebooks to aid in searches. Accessibility to this information has helped researchers and developers improve injury models for various

insults. Information has been disseminated to Army research and development partners in the U.S. Army Research, Development and Engineering Command.

### **Refinements to INJURY Software Improve Prediction of Lung Injury from Exposure to Blast Overpressure**

INJURY software is used to predict lung injury from exposure to blast overpressure. A team from L-3 Communications/Jaycor (under a contract with the USAMRMC) re-examined injury patterns from animal test data collected between 1980 and 1996. Refinements and corrections to the injury scoring were made to produce consistent scoring for 15 years of testing. The analysis provided a quantitative ranking of occurrence and severity of injury, and the results were used to refine the INJURY model. The analysis of injury patterns was documented in a paper. An updated version of INJURY was distributed through the Military Operational Medicine Research Program of USAMRMC. The INJURY software is used military-wide to assess occupational risk and survivability related to blast injury.

### **Novel Eye and Face Criteria Enhance Evaluation of Protection Systems**

In response to increases in face and eye trauma, the U.S. Army Aeromedical Research Laboratory partnered with the Virginia Polytechnic Institute and State University (VT)-Wake Forest Center of Injury Biomechanics and Denton ATD, Inc. (under contract with VT), to develop and validate a model that can predict facial trauma such as eye rupture, jaw fracture, and facial fractures due to blunt trauma. The model and injury criteria will be incorporated into a suite of test devices and test standards under development by the Natick Soldier Research, Development and Engineering Center under the Soldier Blast and Ballistic Protection effort. This will enable materiel developers to assess whether new face and eye protection strategies can prevent catastrophic eye injury and facial fractures under blast and ballistic loading conditions. This work was presented at the Stapp Car Crash Conference, briefed at several conferences, and published in the *Journal of Biomechanics* and the *Stapp Car Crash Journal*.

### **Review of Past Blast Injury Modeling Research Helps Focus Future Efforts on Known Gaps**

A review of past blast injury modeling research conducted for the Military Operational Medicine Research Program was prepared for publication in the *Textbooks of Military Medicine* series. The review was written to provide the DoD Blast Injury Research PCO with a comprehensive summary of blast injury modeling. The information will help researchers and program managers take advantage of previous work and focus future efforts on known gaps. In addition to the book chapter, the review was released online by the Borden Institute.

### **Modeling and Simulation Tool Set to Link Mechanical Deformation and Damage with Biological Function and Ultimately Soldier Incapacitation**

This ARL-funded project, in collaboration with the Defense and Veterans Brain Injury Center, Purdue University, and the Massachusetts Institute of Technology (MIT), provides the foundation for creating a robust physics-based modeling and simulation capability used to describe how fragment impact, blast loading, and blunt trauma affect the individual Soldier. Using the results of laboratory experiments on various tissues, researchers created a computer model that will enable them to predict survivability. Results from this research will be used by the NSRDEC for its Soldier Blast and Ballistic Protective System Assessment and Analysis Tools Program, U.S. Army Project Manager Soldier Equipment (PM SEQ) for its helmet development program, Project Manager Maneuver Ammunition Systems for its small-caliber ammunition program, and the general Soldier incapacitation community. Research results were documented in a journal paper and an ARL technical report and presented at the Society for Experimental Mechanics Annual Conference, the 4th Symposium on Mechanics of Soft Materials and Tissues, and the American Society for Mechanical Engineers International Congress and Exposition.

### **Characterization of Shrapnel and Blast from Two Common IED Types in Support of Survivability Modeling and Armor Development**

ARL, the Army Test Center, and the Air Force Research Laboratory collaborated to characterize surface and shallow-buried types of artillery shell-based IEDs in terms of blast and fragment characteristics (e.g., size, shape, velocity, and spatial distribution). Results quantify the threat to personnel from blast and fragments. Using these findings, more accurate models can evaluate armor capabilities in response to two of the most common fragmenting IEDs encountered by deployed forces. This understanding of threat characteristics is necessary to support survivability modeling, supply requirements and/or standards for equipment development, and analyze the results of live-fire testing. ARL published two technical reports from these studies, and the results have been shared with the DoD testing and materiel development communities. The results of these studies were applied in the mine-resistant ambush-protected vehicle testing, are informing the Joint Light Tactical Vehicle Program, and provide valuable information to the armor research and development community on expected threats to be countered.

### **Assessment of the Joint Strike Fighter Transparency (Canopy) Removal System Shows Acceptable Risk of Auditory and Blast Lung Injury**

The Battlespace Acoustics Branch of the Air Force Research Laboratory (AFRL) studied the risk of hearing damage and lung injury associated with the blast overpressure created during the ejection sequence of the F-35 AA-1 Transparency Removal System. Collaborative partners included the Joint Strike Fighter (JSF) program office, USAMRMC, L3 Communications/Jaycor (under a contract with the USAMRMC), and the French-German Research Institute of Saint-Louis (under contracts with the JSF program and AFRL). Results indicated that risk of injury from the exposure was acceptable. The results of this effort were incorporated into the JSF safe-to-fly assessments and flight qualification procedures for the Transparency Removal System. Risk assessment, risk mitigation, and potential treatment information was disseminated to the flight test centers, the associated medical facilities, and the JSF program office.

### **Joint Trauma Analysis and Prevention of Injury in Combat Incident Analysis Network Project Develops Forensic Storyboards That Integrate and Analyze High-Profile Combat Events**

The Joint Trauma Analysis and Prevention of Injury in Combat (JTAPIC) Incident Analysis Network project integrated and analyzed more than 45 high-profile combat events and developed forensic storyboards. The forensic storyboards were developed by a multidisciplinary, multi-community team of JTAPIC partners, including the Office of the Armed Forces Medical Examiner, the U.S. Army National Ground Intelligence Center Anti-Armor Task Force, the ARL Survivability/Lethality Analysis Directorate, Naval Health Research Center, and the JTAPIC program office, and disseminated to various service materiel developers, U.S. Army Training and Doctrine Command, and Army and DoD leadership. Actionable information derived from the forensic storyboards has led to direct feedback to combatant commanders on tactics, techniques, and procedures, confirmed the presence of weapons of interest, and guided program managers as they make modification and upgrade decisions.

### **JTAPIC Analysis of PPE Shared with Service Materiel Developers and PEO Soldier**

The JTAPIC PPE Analysis Network received and analyzed more than 900 pieces of PPE from those killed-in-action and more than 60 pieces from those wounded-in-action. This work was made possible by member organizations of the JTAPIC partnership, to include the Office of the Armed Forces Medical Examiner, the Navy Health Research Center, PM SEQ, and the JTAPIC program office. Analyses were conducted to characterize any damage to the PPE from the wounding incident, and information was captured in a database for statistical and epidemiological analyses. Results were shared with the appropriate service materiel developers and U.S. Army PEO Soldier.

### **Network of DoD Operational, Intelligence, Materiel, and Medical Communities Provides Integrated Analyses Regarding Combat Injuries**

The Injury Prevention Analysis Network was established by the JTAPIC program under USAMRMC in FY07. To provide integrated analyses of combat injuries and their causes in support of Warfighter

survivability, this partnership links DoD operational, intelligence, materiel, and medical data and communities, including the Office of the Armed Forces Medical Examiner, the U.S. Army National Ground Intelligence Center's Anti-Armor Task Force, the U.S. Army Institute of Surgical Research, the Naval Health Research Center, and the PM SEQ. Through a Request for Information (RFI) process, customers across DoD are provided timely and actionable information to drive their decision-making processes. The comprehensive process can provide analyses at all levels, ranging from an individual combat incident to a full-scale epidemiological evaluation. More than 60 RFIs have been answered and the information provided to requirements developers and equipment and vehicle program managers across the DoD. The Injury Prevention Analysis Network and the JTAPIC program seek to increase Warfighter survivability by promoting effective information sharing and analysis.

### **Casualty Blast Injury Data Mapped to Significant Tactical Events**

Personnel at the Naval Health Research Center provided injury profiles to the National Ground Intelligence Center for 220 casualties who were injured by blast. Profiles included a clinical description of each injury, severity of injury, protective equipment worn, and drawings detailing the anatomical location of injuries. These clinical data were then mapped to intelligence reports of significant blast events. For the first time, intelligence agencies could link casualty data with a specific insurgent activity. Prior to this effort, the intelligence community lacked sufficient injury data because casualties are generally medically evacuated before military scene investigators arrive. Although classified, the findings afford information about the effectiveness of PPE, identify strengths and vulnerabilities of tactical transport vehicles, and are used to monitor the evolution of insurgent activities so that effective countermeasures can be developed and executed.

### **Characteristics of TBI Among Personnel Serving in Operation Iraqi Freedom May Improve Clinical Care and Suggest Strategies for Primary Prevention**

The Office of Naval Research and the Naval Health Research Center used data in the Navy-Marine Combat Trauma Registry that were collected during the second phase of Operation Iraqi Freedom (OIF) to study the extent and characteristics of TBI among military personnel (primarily Marines) from early in the medical chain of evacuation through care at Landstuhl Regional Medical Center in Germany. Battle casualties were more likely than noncombatant casualties to have multiple TBI diagnoses, more overall diagnoses, more severe TBIs, and to be medically evacuated from theater. Concussion was the most common TBI, and IEDs were the most common cause of TBI. Patients with more severe TBIs had higher mortality rates and used more medical resources. The incidence of mental health conditions was higher for patients with more mTBIs. These results may improve clinical care for those affected and suggest strategies for primary prevention. The findings were published in the *Journal of Neurosurgery* in May 2008.

### **Sensor Measures Pressure Waves in Brains Exposed to Blast Overpressure**

Scientists at the Navy Medical Research Center aimed to distinguish between two mechanisms of brain damage—direct transfer of pressure waves to the brain versus whole-body exposure to pressure waves. More specifically, they sought to determine whether an increase in intrathoracic pressure in subjects wearing chest armor influences the spread of a pressure wave to the brain. A miniature optic fiber sensor was placed in the brain of rats exposed to blast overpressure. Short-pressure waves lasting several milliseconds were detected inside the brain. The findings can be used to study blast-induced energy transfer to different parts of body, lead to a better understanding of the blast-related mechanisms of injury, and contribute to the development of better protective measures against blast-induced TBI. This information was presented at regional and national scientific conferences and published in the *Journal of Neuroscience Methods*.

### **Dynamic Behavior of Brain Tissues Under Impact Loading Conditions Advances the Understanding of Tissue-Level Mechanisms of Brain Injury**

This Joint Improvised Explosive Device Defeat Organization (JIEDDO)-funded collaboration between the Defense and Veterans Brain Injury Center, Purdue University, and MIT advanced the basic science

underlying blast-induced TBI by describing how various types of brain tissue respond differently to compressive loading conditions. These results form a critical part of the database that is needed to develop accurate brain tissue models for realistic simulations of TBI. Results were presented at regional and national scientific conferences and submitted for publication.

### **Studies of Blast-Exposed Soldiers to Evaluate the Potential Link Between Primary Blast and mTBI**

JIEDDO funded the Mid-Atlantic Veterans Integrated Service Network Mental Illness Research, Education, and Clinical Center and MIT to compare brain images and neurobehavioral test results of blast-exposed OIF/Operation Enduring Freedom (OEF) veterans with and without symptoms of TBI. This may help determine whether primary blast (e.g., the individual neither fell nor was hit) alone can cause mTBI. In collaboration with Task Force Troy, the team developed a self-report screening tool, adapted from the Department of Veterans Affairs (VA) TBI examination, that can capture blast effect data for each Soldier following a blast exposure. This tool is being used in Iraq to gather blast effect data. In addition, the team published a paper in the *Journal of Computer Assisted Tomography* and educated health care providers, researchers, and decision makers in DoD, VA, academic, and community venues about identification and treatment of TBI.

### **Blast Pressure Waves May Damage Neurons in the Brain**

Investigators at JIEDDO, MIT, and Boston University developed a method to deliver pressure waves to two-dimensional cultures of brain neurons. Neurons exposed to higher pressures had a reduced number of synapses, suggesting that blast pressure waves may alter the form or structure of the synapses before other signs of brain damage are apparent. These findings were presented at the Soldier Nanotechnology Workshop on blast and TBI and have been incorporated into an ongoing study that aims to characterize blast-induced injury at the cellular level.

### **New Simulated-Blast Testing Products Will Improve Experiments Used to Predict TBI**

JIEDDO partnered with researchers at the Defense and Veterans Brain Injury Center, MIT, and Purdue University and developed a method to direct small-scale explosives at specific targets, designed a shock tube that better simulates full-scale blasts, and produced a systematic way to monitor blast severity, pressure, and blast load. In addition, they began to develop a three-dimensional model of the skull. Collectively, the results and products will be used in a series of experiments designed to validate computer-simulated models used to predict TBI. The results will provide new insight into the overall understanding of TBI and provide a way to test possible mitigation techniques. A poster was presented at the Gordon Research Conference meeting for Energetic Materials. Further, an abstract was submitted to the Society of Engineering Science for presentation at its 45th Annual Technical Meeting later this year.

### **Model Assesses the Dynamic Response of Brain Tissue to a Blast Injury**

Researchers at JIEDDO, ARL's Weapons and Materials Research Directorate, Defense and Veterans Brain Injury Center, Walter Reed Army Medical Center, MIT, and Purdue University established cell cultures of brain neurons and developed a model to assess the dynamic response of brain tissue during a simulated blast injury. These products may enable the team to characterize the brain's response to a blast at the tissue and cellular levels and develop diagnostic tests for injury to central nervous system cells. Results were published in *Experimental Mechanics* last year and presented at several national scientific meetings. Two additional papers are undergoing peer review by other journals. In addition, these scientists participate on DoD task forces that address helmet instrumentation and identify gaps in blast injury research.

### **Consortium Characterizes Neurotrauma from an Explosive Blast**

The DARPA-funded Preventing Violent Explosive Neurologic Trauma (PREVENT) blast research program is composed of researchers from Yale University, Harvard University, the Safar Center within the University of Pittsburgh Medical School, WRAIR, the Uniformed Services University of the Health Sciences, and ORA, Inc (under a contract with the Space and Naval Warfare Systems Center

[SPAWAR]). The team synthesized existing data regarding blast magnitude, Soldier proximity to blasts, wear of PPE, time interval between blast exposure and medical intervention, and injury severity. Further, the team developed and used a swine model of explosive blast to describe how the physics of a blast may cause injury. Thus far, the scientists discovered three principal consequences of blast exposure: (1) vasospasm of major vessels in the head, (2) significant pressure transients in the brain, and (3) an inflammatory response occurs early after injury. The team published its work in the *Journal of Neurotrauma* and briefed the House Armed Services Committee about the program and its findings.

### **Vulnerability of the Brain to Injury by Primary Blast Forces**

JIEDDO partnered with the research staff at the Defense and Veterans Brain Injury Center, Walter Reed Army Medical Center, and Raytheon to conduct and analyze a series of coupled simulations comparing blast and impact conditions under a variety of blast conditions. Researchers found that threshold blast injury conditions led to intracranial conditions corresponding to or below concussive impact levels, whereas lethal blast loads led to intracranial conditions above those produced by concussive impact. Their efforts were reported in a front page article in *Technology Review Magazine* and in briefings to medical leaders within the DoD. This program is incorporated within the Medical Panel of the Defense Science Board Task Force on IEDs.

### **Development of Blast Test Devices, Mathematical Models, and Methodology for the Evaluation of Body Armors and Add-On Systems for Mitigation of Primary, Secondary, and Tertiary Blast Injuries**

The U.S. Army Natick Soldier Research, Development and Engineering Center, which is responsible for armor development, funded a collaborative effort with USAMRMC and L-3 Communications/Jaycor (under a contract with the USAMRMC) to develop test devices and models to assess body armor systems and designs for protective ability against blast. Using a combination of blast and injury models and large-animal field tests, these data are extrapolated to humans. Testing to date has shown that the current body armor provides some small primary blast mitigation; however, the injury patterns for the solid organs have changed. This finding is of significant value to the center, and model refinement is underway. Information gained from this research will guide future body armor and add-on protection design. The test device and injury/lethality models are used by the DoD armor development community and internationally with United Kingdom, Australian, and Canadian counterparts to evaluate material and armor design concepts.

### **Characterization of Blast Waveforms and Physiological Parameters Associated with Blast Injury**

The Uniformed Services University of the Health Sciences in collaboration with ORA, Inc. (under a contract with the SPAWAR), is characterizing blast waveforms and physiological parameters associated with blast injury to extend predictive models of injury. Generally, the effort will evaluate what characteristics of a blast cause what kind of injury. This effort is incorporated into DARPA's Blast Injury Research Program with Ora's study of blast injury in animals. The results of this effort may inform protective equipment and medical response developments. Preliminary results outlining quantitative procedures for characterizing animal behavior following blast exposure were presented at the First International Conference on Cognitive Neurodynamics in Shanghai, and a related paper was published in the journal *Cognitive Neurodynamics*.

### **New Discoveries Will be Used to Create Treatments for Lung and Tissue Injury After Blast Exposure**

The CDMRP funded a study in which WRAIR scientists, in collaboration with researchers at USAMRMC, University of Pittsburgh, University of Connecticut, and George Washington University, built on previous work to advance the basic science regarding biochemical disruptions resulting from blast injury. The team discovered a mechanism that limits production of a substance, called nitric oxide, previously shown to injure the lungs and other organs after blast injury. When scientists expanded earlier work to examine how iron may cause inflammation, they found an unexpected source of iron in lymph

fluid. New information will be used to create potential treatments designed to prevent or ameliorate lung and tissue injury after blast exposure. Scientists at USAMRMC laboratories will test potential treatments for their effectiveness with the ultimate goal of producing clinical therapies that reduce morbidity and mortality from blast injuries. The researchers published a paper in *Shock*, published three abstracts, presented at three scientific meetings, and briefed DoD RDT&E program managers.

### **Morphine Use After Traumatic Combat Injury May Protect Against PTSD**

Using data from the Navy-Marine Corps Combat Trauma Registry Deployment Health Database, investigators at the Naval Health Research Center found that combat casualties who received morphine shortly after injury were less likely to be diagnosed with PTSD than those who did not receive morphine. This evidence suggests that morphine or similar medications administered for the immediate control of pain and anxiety after trauma also may protect against PTSD. These findings can be implemented in practice now, at little cost, and with minimal provider training. A paper describing these findings has been submitted for publication.

### **Comparison of High-Frequency Oscillatory Ventilation and High-Frequency Percussive Ventilation**

Funded by the Air Force Surgeon General's Office, investigators at the 59th Medical Wing compared two artificial respirators that provide respiratory support at fast breathing rates, but through distinctly different mechanisms, to patients with lung failure. The purpose of the study was to evaluate oxygenation and ventilation and the ability to interchange the devices. The high-frequency percussive respirator ventilated and oxygenated as well as the high-frequency oscillatory respirator at equivalent ventilator settings. The high-frequency percussive respirator tended to require a higher pressure to deliver a correct-sized breath than did the high-frequency oscillatory respirator. The percussive respirator was designed for the transport environment and may be suitable for the transport of patients who cannot be ventilated during flight with a traditional respirator. The investigators presented their findings at a medical conference and are writing a paper for publication.

### **Hemeoxygenase-1 Induction May Protect Against Severe Respiratory Impairment After Pulmonary Trauma**

Researchers at the Naval Medical Research Center's Undersea Medicine Department advanced knowledge about the basic mechanisms of blast- and hyperbaric oxygen-induced lung trauma. Although current treatment is limited to supportive therapy and mechanical ventilation with an artificial respirator, findings from this study indicate that induction of a protein called hemeoxygenase-1 may protect against severe respiratory impairment and improve recovery after pulmonary trauma. These data will now be used in additional studies to investigate if this protection is due to the specific effects of hemeoxygenase-1 or whether it involves other antioxidative drugs or substances. Information was presented at regional and national scientific conferences and published in the *Journal of Trauma*.

### **Antioxidants May Prevent Hearing Loss After Exposure to Loud Noise**

The Office of Naval Research sponsored collaborative research with the Oklahoma Medical Research Foundation in which researchers discovered that, in animals, the administration of certain antioxidants and combinations of antioxidants following exposure to loud noise substantially reduced hearing loss and prevented hair cells in the ear from killing themselves. The team determined dosing information for the antioxidants, identified potential side effects, and quantified treatment efficacy by time point of treatment post-noise exposure. Work is ongoing to further clarify how these antioxidants work. Discussions are underway regarding the production and licensure of the antioxidant combination products. The goal is to conduct clinical trials in humans in the near future. The findings were presented at two national meetings and in five journal articles that were published in *Hearing Research*, *Audiological Medicine*, and *Acta Oto-Laryngologica*.

### **Stable Manufacturing Process Developed for Cryopreserved Platelets**

Until recently, manufacturing of frozen (cryopreserved) platelets has been limited to laboratory experimentation and bench-top processes. Researchers at WRAIR and Dartmouth Hitchcock Medical Center established a stable manufacturing process for frozen platelets that allows continued clinical development and lays the necessary groundwork for deployment of the product to clinical test sites. This work is a prerequisite for further development of a good manufacturing process that meets U.S. Food and Drug Administration requirements for licensure of cryopreserved platelets.

### **Resuscitation Requirements Are Complicated by Explosion-Induced Trauma**

Preliminary results of research conducted by investigators at WRAIR revealed that air blast from a compression-driven shock tube to rats diminished cardiovascular resilience, hastened cardiac decompensation and death following hemorrhage, and altered fluid volumes required to restore blood pressure. Blast-induced brain injury was observed, and, serendipitously, protective vests were shown to reduce brain injury and improve survival. Information from these basic science mechanism studies will be used to design resuscitation strategies and resuscitation fluids best suited for blast casualties. Information was presented at regional and national scientific conferences, including the Advanced Technology Applications for Combat Casualty Care and the International Shock Meeting.

### **Expansion of Automated Neuropsychological Assessment Metrics System's Diagnostic Capability**

The Uniformed Services University of the Health Sciences in conjunction with the Naval Aerospace Medical Research Laboratory is evaluating whether the diagnostic capability of the Automated Neuropsychological Assessment Metrics can be increased. These metrics are used by the DoD for assessing cognitive performance and/or cognitive status using a variety of automated standardized cognitive tests and can target specific processes (e.g., memory, attention, and switching from one task to another). This study considers whether further analysis of response time may be diagnostic for mTBI. Additionally, such metrics may prove useful for assessments over time. The results of this research are being provided to the DoD mTBI assessment effort, and discussions have been initiated with the Defense and Veterans Brain Injury Center. An invited lecture on quantifying choice task behavior in neuropsychiatric patients was presented at the First International Conference on Cognitive Neurodynamics.

### **Contributions of Blast and Impact Exposure to Military TBI**

Researchers at the Defense Centers of Excellence (DCoE) for Psychological Health and Traumatic Brain Injury and the Defense and Veterans Brain Injury Center conducted experiments to elucidate how the intensity and duration of high-strain rate blast exposure and low-strain rate impact contribute to brain injury. The team used magnetic resonance images to create a one million finite-element mesh with 11 types of brain tissue. Following blast exposure, tensile, compressive, and loading stresses were measured. These data were compared to the stresses generated within the brain from an impact deceleration injury typical of an NFL football concussion. The researchers concluded that exposure to a high-strain blast (fatal to 50% of those not wearing PPE) would result in a less serious "football concussion" if PPE is worn.

### **Link Found Between Head Injury and PTSD**

Using data collected after the bombing of the Alfred P. Murrah Federal Building in Oklahoma City, Defense and Veterans Brain Injury Center and DCoE scientists found clear evidence that head injury is associated with subsequent PTSD. This knowledge informs caregivers regarding which physical injuries may lead to psychological disorders. Further, these data may guide development of an injury profile that can predict which survivors of a terrorist attack or wartime operations are at highest risk for PTSD. A research paper has been submitted for publication to the *Journal of Trauma*.

## Chapter 5

# Key Components of the Blast Injury Research Program

The Blast Injury Research PCO was established to coordinate the large number of relevant efforts that can contribute solutions to the problems associated with blast threats. Within the DoD, blast injury research is conducted by Army, Navy, Air Force, and Defense organizations. In addition to these DoD organizations, many other federal agencies as well as academia and industry are playing key roles in solving blast injury problems. This chapter summarizes key components of the DoD Blast Injury Research Program and highlights collaborations among diverse organizations that are committed to providing Soldiers, Sailors, Airmen, and Marines with the very best blast injury prevention, mitigation, and treatment solutions.

### **FY07 Psychological Health and Traumatic Brain Injury Research Program Update**

The Psychological Health and Traumatic Brain Injury (PH/TBI) Research Program, previously called the Post-Traumatic Stress Disorder and Traumatic Brain Injury (PTSD/TBI) Research Program, is a Defense Health Program medical research development test and evaluation program administered by the USAMRMC CDMRP. This program was established to manage the \$300 million (M) FY07 War Supplemental funding aimed at promoting a better standard of care for PTSD and TBI in the areas of prevention, detection, diagnosis, treatment, and rehabilitation. This includes research to benefit servicemembers, their family members, veterans, and other beneficiaries of the Military Health System. Of the \$300M funded, \$45M was assigned to the DCoE for Psychological Health and Traumatic Brain Injury for investment.

The CDMRP held a stakeholders meeting on June 11–12, 2007, to assess the state of the science and to identify gaps in the areas of PTSD and TBI research. Participants included representatives from the four services, Office of the Secretary of Defense for Health Affairs, VA, National Institutes of Health, private industry, and academia. Six PTSD and five TBI research gaps were identified by these stakeholders. A vision setting meeting followed on June 13, 2007. The purpose of the vision setting meeting was to prioritize research gaps (**Tables 2 and 3**), establish program goals and objectives, and develop an investment strategy (**Table 4**) for the \$255M assigned to the CDMRP for management. Vision setting was conducted by a Joint Program Integration Panel (JPIP), which consisted of representatives from the four services, Office of the Secretary of Defense for Health Affairs, Uniformed Services University of the Health Sciences, the VA, and National Institutes of Health

**Table 2. Prioritized PTSD Research Gaps by Percentage of Available Funds**

Treatment and Intervention	50%
Prevention	15%
Measures in Screening, Detection, and Diagnosis	10%
Epidemiological Studies	10%
Families/Caregivers Projects	10%
Neurobiology/Genetics	5%

**Table 3. Prioritized TBI Research Gaps and Percentage of Available Funds**

Treatment and Clinical Management	40%
Neuroprotection and Repair Strategy	22.5%
Rehabilitation/Reintegration Strategies	15%
Field Epidemiology	15%
Physics of Blast as It Relates to Brain Injury	7.5%

**Table 4. PTSD/TBI Funding Mechanisms**

Mechanism	Key Features
Intramural Investigator-Initiated Research	<p>To accelerate ongoing basic and clinically oriented DoD and VA research that supports (1) substantial improvements over today's approach to the treatment and clinical management of PTSD, (2) the development of novel preventive measures, and (3) the implementation of processes and procedures to enhance the quality of life of persons with PTSD and/or TBI.</p> <p><b>Maximum Direct Cost: \$600K Duration: Up to 4 years (additional with justification)</b></p>
Intramural Advanced Technology – Therapeutic Development	<p>Targets ongoing DoD and VA demonstration studies of pharmaceuticals (drugs, biologics, and vaccines) and medical devices in preclinical systems and/or testing of therapeutics and devices in clinical studies. The intent is to accelerate ongoing DoD and VA research on PTSD therapeutics and devices for prevention, detection, diagnosis, and treatment of PTSD and/or TBI into the clinical setting.</p> <p><b>Maximum Direct Cost: \$4M Duration: Up to over 4 years (additional with justification)</b></p>
Concept	<p>To spark new ideas, innovative technologies, and groundbreaking concepts that will drive the field of PTSD and/or TBI research forward.</p> <p><b>Maximum Direct Cost: \$150K Duration: Up to 18 months</b></p>
New Investigator	<p>To increase the number of established PTSD and/or TBI researchers.</p> <p><b>Maximum Direct Cost: \$300K Duration: Up to 3 years</b></p>
Investigator-Initiated Research	<p>To support basic and clinically oriented research that will (1) result in substantial improvements over today's approach to the treatment and clinical management of PTSD and/or TBI, (2) facilitate the development of novel preventive measures, and (3) enhance the quality of life of persons with PTSD issues and/or TBI.</p> <p><b>Maximum Direct Cost: \$600K Duration: Up to 4 years</b></p>
Advanced Technology – Therapeutic Development	<p>Targets demonstration studies of pharmaceuticals (drugs, biologics, and vaccines) and medical devices in preclinical systems and/or the testing of therapeutics and devices in clinical studies. The intent is to assess therapeutics and devices for the treatment, prevention, detection, and diagnosis of PTSD and to accelerate the introduction of improved therapies, treatments, devices, or technologies for PTSD and/or TBI into the clinical setting.</p> <p><b>Maximum Direct Cost: \$4M Duration: Up to 4 years</b></p>
Multidisciplinary Research Consortium	<p>To optimize research and accelerate the solution of a single critical major overarching problem in PTSD and/or TBI research relevant to the prevention, detection, diagnosis, and/or treatment of PTSD issues and/or TBI.</p> <p><b>Maximum Direct Cost: \$25M Duration: Up to 5 years</b></p>
PTSD/TBI Clinical Consortium	<p>To escalate development and marketing of novel military-relevant PTSD and TBI treatments and interventions.</p> <p><b>Total Cost: \$60M Duration: Up to 5 years</b></p>

Program Announcements for the 4 intramural and 12 extramural award mechanisms were released in July 2007. These mechanisms challenged the scientific community to design innovative research that will foster new directions, address neglected issues, and bring new investigators into the fields of PTSD- and TBI-focused research. A total of 640 PTSD- and 1,052 TBI-focused proposals were submitted in response to the FY07 PH/TBI Research Program Intramural and Extramural Program Announcements. Additionally, the DCoE solicited proposals focused on Complementary and Alternative Medicine (CAM) at the request of Dr. S. Ward Casscells, the Assistant Secretary of Defense for Health Affairs, and received several submissions through the USAMRMC Broad Agency Announcement (BAA).

Proposal review for all submissions was conducted according to the USAMRMC two-tier review model recommended by the National Academy of Sciences Institute of Medicine. This model received high praise from the scientific community, advocacy groups, and Congress. The first tier is a scientific peer review of proposals against established criteria for determining scientific merit. The second tier, programmatic review, compares submissions to each other and recommends proposals for funding based on scientific merit and overall program goals. The first tier of review involved both scientist and consumer (individuals suffering from TBI and/or PTSD and family members) reviewers. Programmatic review was conducted by the JPIP. Following the first three rounds of programmatic review, 121 projects were recommended for funding by the JPIP and approved for funding by the final approval authority, the Deputy Assistant Secretary of Defense for Force Health Protection and Readiness (DASD[FHPR]). Additionally, 62 proposals recommended by the DCoE, including 10 CAM proposals and 1 BAA proposal, were approved for funding by the DASD(FHPR). The FY07 PH/TBI Research Program’s investment profile is provided in **Tables 5a** and **5b** by JPIP-prioritized research gap areas. The variance in the percent invested and the percent initially recommended by the JPIP in Tables 2 and 3 was due to the quality and number of proposals received to address the PH and TBI research gap areas.

**Table 5a. PH/TBI Research Program: PH Investment by Research Gaps (Total)**

PH Research Gaps	Funded/Received	Budget (M)	Percent Invested	Percent Recommended by JPIP*
Treatment and Intervention	43/225	\$101.4	76.1	50
Prevention	7/37	\$4.2	3.1	15
Screening, Detection, and Diagnosis	5/93	\$5.7	4.3	10
Epidemiological Studies	9/54	\$4.9	3.7	10
Families/Caregivers	5/29	\$2.9	2.2	10
Neurobiology/Genetics	20/180	\$10.3	7.7	5
CAM**	8	\$3.9	2.9	NA**
Broad Agency Announcement	1	\$65K	0	NA

\* Recommendation made by JPIP at the Vision Setting meeting on June 13, 2007, as shown in Table 2.

\*\*CAM was requested by Dr. Casscells.

Note: The \$60M budget for the Clinical Consortium Center and Study Sites was distributed between both PH and TBI gaps.

**Table 5b. PH/TBI Research Program: TBI Investment by Research Gaps (Total)**

TBI Research Gaps	Funded/Received	Budget (M)	Percent Invested	Percent Recommended by JPIP*
Treatment and Clinical Management	29/305	\$94.9	69.7	40
Neuroprotection and Repair Strategies	21/432	\$20.7	15.2	22.5
Rehabilitation/Reintegration Strategies	11/145	\$7.4	5.4	15
Field Epidemiology	9/66	\$4.2	3.1	15
Physics of Blast	13/73	\$8.0	5.9	7.5
CAM**	2	\$1.0	0.7	NA**

\* Recommendation made by JPIP at the Vision Setting meeting on June 13, 2007, as shown in Table 3.

\*\* CAM was requested by Dr. Casscells.

Note: The \$60M budget for the Clinical Consortium Center and Study Sites was distributed between both PH and TBI gaps.

For all projects approved for funding, award negotiation and funds obligation will be completed by September 30, 2008. Detailed information on all PH/TBI Research Program awards is posted at <http://cdmrp.army.mil> (under Search Awards) for each award at the time of completion of award negotiation. Eighty-five proposals remain on a prioritized alternate list. These projects will be funded in priority order, commensurate with cost savings.

### **FY08 War Supplemental Funding for Battle Casualty and Psychological Health Research**

Congress authorized \$273.8M in the FY08 War Supplemental to fund battle casualty and psychological health research. These funds, to be executed by USAMRMC in conjunction with the Navy and Air Force, are intended for research that addresses the following topics: medical devices (suction and electrocardiograms), blood safety and products, burns (tissue viability and fluid resuscitation), orthopedic and other trauma and rehabilitation (nerve damage and dental), suicide (counseling and nurse stress and fatigue), TBI and psychological health (PTSD), injury prevention, wound infection and healing, treatment for severe cutaneous leishmaniasis, and wound infection vaccines. The key features of the Execution Plan for these funds are: maximal acceleration of ongoing programs, optimal use of acquisition methods, significant funds available for open competition, peer review of all initiatives, and execution management through Joint Program Committees (e.g., Armed Services Biomedical Research Evaluation Management Board [ASBREM] and Joint Technology Coordinating Group).

### **Armed Forces Institute of Regenerative Medicine**

USAMRMC in partnership with the Office of Naval Research, the Air Force Office of the Surgeon General, the National Institutes of Health, and the VA established the Armed Forces Institute of Regenerative Medicine (AFIRM), a multi-institutional, interdisciplinary research network working to develop advanced treatment options for servicemembers who sustain multiple traumatic injuries. Conventional weapons and the destructive force of IEDs ravage the face, neck, head, and limbs, causing massive trauma and tissue loss. Although advances in body armor have improved protection of vital organs, thereby increasing survivability, survivors often have more serious injuries than in past military conflicts. For example, approximately 6% of those wounded in Iraq sustained a traumatic amputation. Treatment of these combat-related traumatic injuries is particularly complex, often requiring years of treatment and rehabilitation.

Regenerative medicine, which has achieved some success in the regeneration of human tissues and organs for repair or replacement, represents great potential for treating military personnel with debilitating, disfiguring, and/or disabling extremity injuries. Regenerative medicine uses bioengineering techniques that prompt the body to regenerate cells and tissues, often using the casualty's own cells in combination with degradable biomaterials. The ultimate goal is to deliver advanced therapies such as whole organs and engineered fingers and limbs.

AFIRM is composed of two research consortia. The U.S. Army Institute of Surgical Research in Fort Sam Houston, Texas, works closely with the consortia to provide guidance regarding military medical needs and conduct research trials of new therapies. Wake Forest University Baptist Medical Center and the McGowan Institute for Regenerative Medicine lead one consortium; Rutgers, the State University of New Jersey and the Cleveland Clinic lead the other. Each consortia is a multi-institutional network of civilian universities and medical centers. The consortia have received \$90M in Federal and \$80M in state and local funding. Further, contributing institutions have \$109M in existing funding (e.g., the National Institutes of Health) that support AFIRM-related projects.

During the next 5 years, the AFIRM team will focus its efforts on five clinical areas: (1) burn repair, (2) wound healing without scarring, (3) craniofacial reconstruction, (4) compartment syndrome, and

(5) limb reconstruction, regeneration, or transplantation. Operating as a nation-wide virtual enterprise, the institute also will train experts in treating trauma with regenerative medicine.

### **Defense Centers of Excellence for Psychological Health and Traumatic Brain Injury**

The DCoE for Psychological Health and Traumatic Brain Injury was established to lead a collaborative effort toward optimizing psychological health and TBI treatment for the DoD. Deputy Secretary of Defense, Gordon England, announced the opening of the DCoE on November 30, 2007. The Director of the DCoE serves as an advisor to the Assistant Secretary of Defense for Health Affairs. The DCoE establishes quality standards for clinical care; education and training; prevention; patient, family, and community outreach; and program excellence.

The DCoE mission is to maximize opportunities for Warfighters and families to thrive through a collaborative global network promoting resilience, recovery, and reintegration for psychological health and TBI. The objectives of the DCoE are:

- Maximal resilience and integration of mind, body, and spirit for Warfighters, families, caregivers, and communities
- Actionable PH/TBI knowledge within all community sectors, including health care, employer, faith, education, and civic leadership
- Vibrant civilian–federal research partnership to focus on relevant knowledge gaps within the PH/TBI realm
- Innovative telehealth program to support clinical care, outreach, advocacy, surveillance, treatment, education, and research initiatives
- Consistent clinical standards of PH/TBI care, informed by DCoE/Walter Reed National Military Medical Center experience in both inpatient and outpatient domains as well as best practices identified throughout DoD/VA and beyond
- Responsive communication via 24/7 outreach call center/clearinghouse

The DCoE is part of the DoD’s Military Health System, which provides a “continuum of care” from initial accession to separation and discharge, for all of its servicemembers. The DCoE employs a “center of centers” concept. These centers include:

- **Defense and Veterans Brain Injury Center**  
The Defense and Veterans Brain Injury Center provides TBI-specific evaluation, treatment, and follow-up for military personnel, dependents, and veterans, and conducts clinical research, training, and education. Over the past 16 years, the center has made significant contributions to the knowledge of TBI. Its members serve as the DoD’s primary subject matter experts. There has been a robust research program including the first-ever randomized controlled study of rehabilitation therapies and the first-ever Institutional Review Board-approved prospective study in a combat zone. The center has a comprehensive network of clinical sites throughout the DoD and VA. Members created clinical practice guidelines for the management and treatment of brain-injured patients in theater, developed evidence-based guidelines for comprehensive care for severe injuries, and conducted surveillance of TBI in OIF/OEF servicemembers.
- **Center for Deployment Psychology**  
Established at the Uniformed Services University of the Health Sciences in mid-2006, the Center for Deployment Psychology trains military and civilian mental health professionals to provide high-quality deployment-related behavioral health services to military personnel and their families. The center recently expanded its training audience to include all caregivers within the Military Health System.

- **Deployment Health Clinical Center**  
Established in 1994, the Deployment Health Clinical Center developed the Specialized Care Program for Gulf War Veterans whose health concerns and symptoms presented unclear etiology. With OIF/OEF, the center's responsibilities expanded to include clinical care for veterans of all conflicts, deployment-related health research, and deployment-related health education and training for patients and families.
- **Center for the Study of Traumatic Stress**  
The Center for the Study of Traumatic Stress provides knowledge, leadership, and applications for preparing for, responding to, and recovering from the consequences of war, operations other than war, disaster, and trauma. The center focuses on translational research and knowledge, from the laboratory to the bedside, field, and clinic, as well as in operations and public policy. The center advances knowledge, health care, and preparedness through education, research, consultation, and training.
- **TeleHealth and Technology Center**  
The TeleHealth and Technology Center will serve as the principal resource for the DoD and other stakeholders for the application of technology in the areas of psychological health and TBI. It will operate a comprehensive program to evaluate, research, standardize, and deploy new and existing technologies for psychological health and TBI. The center leverages telehealth and other technologies to screen, educate, prevent, assess, and treat psychological health problems and TBI.
- **National Intrepid Center of Excellence**  
The National Intrepid Center of Excellence provides leading-edge services for advanced diagnostics, initial treatment plan/family education, introduction to therapeutic modalities, referral and reintegration support for Warfighters with PTSD, complex psychological health issues, and/or TBI. The center will conduct research, test new protocols, and provide comprehensive training and education to patients, providers, and families while maintaining ongoing telehealth follow-up care.

The DCoE is collaborating with organizations, defense activities, and other federal and civilian programs. The DoD and the VA collaborate extensively on psychological health and TBI issues. In particular, the DCoE is striving to increase the number of mental health providers working with wounded Warfighters and personnel returning from OIF/OEF, improve access to psychological health care, and jointly train to meet the needs of service personnel and veterans with psychological health and TBI issues.

### **Vision Center of Excellence**

The DoD is collaborating with the VA, academia, and other public and private entities to establish a Center of Excellence in the prevention, diagnosis, mitigation, treatment, and rehabilitation of military eye injuries. The Center of Excellence will develop, implement, and oversee a data registry for tracking ocular trauma and surgical intervention. It will lead advanced research that defines future clinical practice guidelines, expands rehabilitative programs, and offers new modalities to treat and prevent ocular disease and trauma.

### **Military Amputee Research Program**

The Military Amputee Patient Care Program, headquartered at the Walter Reed Army Medical Center, provides state-of-the-art treatment, rehabilitation of military amputee patients to the highest level of physical function, and return to active duty if possible. To support this program, the Military Amputee Research Program (MARP), managed through the Telemedicine and Advanced Technology Research Center (TATRC), was formed at the Walter Reed Army Medical Center and includes an organized research core at the Center for the Intrepid at Brooke Army Medical Center. MARP funding started with an FY04 Congressional Special Interest item (addition) and continued through FY07 but not in FY08.

Most patients want to return to their active lifestyles after recovery and continue to engage in activities such as running, hiking, biking, and "extreme" sports such as skateboarding and snowboarding. Current

prosthetic technologies are limited in this regard. Ongoing combat operations have resulted in major limb amputations in 2.4% of all combat wounded. With such a large group of young military personnel utilizing prosthetic devices, there is both a great need and an opportunity to conduct research that will lead to the development of more functional and comfortable prosthetic technologies and improved rehabilitative training strategies. MARP accepts proposals from internal DoD researchers for intramural research and from external non-DoD researchers from academic and private sectors for extramural research. The goal of the program is to support research that will optimize patient recovery after traumatic limb loss. Research is being conducted both within the DoD and through extramural partners in a number of areas, such as advanced prosthetics, rehabilitation, outcomes and program assessment, clinical management, and database development and management.

MARP research includes comparison studies of various technologies and rehabilitation methods. A good and comfortable prosthetic fit is critical to patient satisfaction and overall quality of life. Researchers are thus investigating various types of socket designs and suspension systems. Other studies examine the differences in a patient's functional performance when comparing the utility of mechanical versus electronically controlled prosthetic systems.

MARP is managed by TATRC as part of a larger research portfolio with a growing slate of projects aimed at providing advanced prosthetics, orthotics, and other assistive devices, treatments, and interventions for patients with major limb amputations, fractures, and other orthopaedic-related injuries. TATRC also cooperates with DARPA on the Revolutionizing Prosthetics program and also with the VA on various portfolio-related research efforts. There is significant overlap and collaboration between the TATRC portfolio and areas of research including neural prosthetics, TBI, spinal cord injury, tissue generation, and robotics to name but a few. Current research projects include: neural controlled lower limb prosthesis, powered and regenerative kinetics prostheses, advanced socket design, comfortable and dynamic sensing socket, over-ground body-weight support gait training system, limb trauma outcomes, quality of life surveys, orthotic and prosthetic education, pain management, metabolic cost studies, heterotopic osseointegration, and virtual reality/computer aided rehab environment.

Otto Bock Healthcare Products, Inc. (under a contract with USAMRMC) is funded by MARP for the development of the Advanced Hardened C-Leg. This is a microprocessor controlled prosthetic knee that will meet all user requirements from initial fitting through returning the user to the highest levels of function to include running, walking, and climbing. This prosthetic offers the potential of replacing up to six separate lower limb prostheses with one device, which will perform at levels equal to or higher than those it replaces. Ultimately, this will improve the quality of life and level of user functionality with the potential for overall cost savings to the government for prosthetic devices.

### **Uniformed Services University of the Health Sciences Center for Neuroscience and Regenerative Medicine**

The Uniformed Services University of the Health Sciences is establishing the Center for Neuroscience and Regenerative Medicine (CNRM). The CNRM will be built on a network model with the university providing a coordinating cell and linking the federal laboratories in the national capital region, including the National Institutes of Health, Walter Reed National Military Medical Center, the DCoE for Psychological Health and Traumatic Brain Injury, and USAMRMC and Navy laboratories. Secondary connections through collaborations and visiting scientist programs will expand the network to other universities and public/private entities to increase knowledge and technology sharing. Funding proposed to support the CNRM includes \$70M in the FY08 DoD Supplemental. The mission of the CNRM is to focus the network's research on protection, assessment, diagnosis, treatment, and rehabilitation of TBI.

The immediate challenges in TBI research are to develop more accurate and precise diagnostic tools, novel approaches to increase neuroplasticity, and when appropriate, use regenerative medicine to tackle brain injury at the organ, cellular, and molecular levels. The CNRM has five areas of proposed research: Regenerative Medicine; Improved Diagnostics Imaging, Neuroplasticity as a Treatment Tool,

Rehabilitation Medicine, and Animal Models, Biomarkers, and Neural Protection. Within these areas the following activities are planned by the CNRM:

- The Regenerative Medicine Program at the Uniformed Services University of the Health Sciences will be expanded by recruitment of a high-profile investigator with translational and clinical investigations in regenerative medicine expertise.
- A state-of-the-art research team will be established to investigate neuroimaging methods for brain injury. Novel biomarkers and neuroimaging strategies will be explored. This research is expected to result in new diagnostic capabilities using biomarkers that can be used as prognostic indicators and for monitoring.
- Clinical trials of neuroplasticity-based therapeutic strategies will be developed. Significant plasticity is known to occur in the adult brain, and a combination of transcranial magnetic stimulation, including magnetic resonance imaging and positron emission tomography, training paradigms, and pharmacological manipulations, have demonstrated functional improvements when therapy is focused on neuron-plasticity. These strategies are supported by results in stroke patients.
- Investigations using animal models will be conducted to better understand the nature of brain injuries. Studies also will look at ways to manipulate the endogenous neuro stem cells to repopulate damaged areas and to restore function to a normative state. These studies may lead to new understanding in the mechanisms of brain injury and the development of novel therapeutic strategies.

#### **U.S. Army Center for Health Promotion and Preventive Medicine**

The U.S. Army Center for Health Promotion and Preventive Medicine (USACHPPM) is a key partner in the DoD Blast Injury Research Program. USACHPPM's diverse preventive medicine, occupational health, and health promotion and wellness programs have made significant contributions to solving blast injury problems as described in the following paragraphs:

- **Metal Fragment Analysis Program.** The Directorate of Laboratory Services conducted x-ray fluorescence analysis, with follow-up analysis by inductively coupled plasma spectrometry as required, of all fragments removed from servicemembers in accordance with recent Assistant Secretary of Defense for Health Affairs- and USAMEDCOM-implemented policies, requiring laboratory analysis of all fragments removed from servicemembers. The x-ray fluorescence results provide a relative percent composition for the metals in the fragment. Metals of interest and subsequent risk assessments are reported to requesting health care providers as well as incorporated into a metal fragment database. The Armed Forces Institute of Pathology and the Air Force's laboratory (formerly AFIOH) also provide similar analyses.
- **Behavioral Health Program.** The Directorate of Health Promotion and Wellness works with the Resilience and Prevention Directorate of the DCoE for Psychological Health and Traumatic Brain Injury. The directorate also updated a guide to combat operational stress reaction and published a brochure dedicated to PTSD for Soldiers.
- **Hearing Conservation Program.** Investigators from the Directorate of Occupational and Environmental Medicine perform passive surveillance data mining for statistical analyses and time series reporting of selected International Classification of Diseases, 9th Revision (ICD-9) codes that may be markers for mTBI. Noise-induced hearing injury and blast ICD-9 injury codes include acoustic trauma, noise-induced hearing loss, perforated eardrums, tinnitus, dizziness/imbalance problems, TBI, and associated clinical outcomes from TBI, including central auditory processing disorder. The Disease Epidemiology Program, Directorate of Epidemiology and Disease Surveillance works with the Directorate of Occupational and Environmental Medicine on this project.
- **Tri-Service Vision Conservation and Readiness Program.** The Directorate of Occupational and Environmental Medicine responds to congressional and DoD queries on OIF/OEF eye injury

statistics. Data concerning theater eye injuries, many of which were blast related, were compiled and analyzed in coordination with the Injury Prevention Program, USACHPPM and the Army Surgeon General's Office (optometry consultant). This consisted of analysis of Patient Administration Systems and Biostatistics Activity, U.S. Transportation Command Regulating and Command and Control Evacuation System, Joint Medical Workstation, and Joint Theater Trauma Registry data, as well as data mining of Standard Inpatient Data Record and Standard Ambulatory Data Record data from the medical metrics database.

- **Deployment Injury Surveillance.** The Directorate of Epidemiology and Disease Surveillance, Injury Prevention Program conducts ongoing injury surveillance (battle and non-battle injuries) for deployed Soldiers using medical, air evacuation, casualty, and safety data systems. A primary objective of this project is to identify and classify the causes of injury. The combined database for this project includes more than 40,000 air evacuees from OIF and OEF since 2001. The directorate performed detailed casualty analyses for specific subgroups of deployed Soldiers, such as Soldiers assigned to the explosive ordnance disposal military occupational specialty. Periodic reports have been provided to the Assistant Secretary of the Army for Installations and Environment and to the Defense Safety Oversight Council. Four technical reports summarized various aspects of this project. The directorate also responded to more than 20 external requests for information.
- **Laser/Optical Radiation Program.** The Laser/Optical Radiation program provided the following support to the Army Research, Development and Engineering Center:
  - Developed novel measurement techniques to assess hazards to the eyes and skin from the optical radiation emitted by explosive devices (e.g., retinal injuries resulting in blindness or burns to the skin). The transient nature of the optical radiation emission from devices such as pyrotechnics, flash/bang grenades, infrared flares, defective ammunition, and shoulder-launched missiles make traditional radiometric measurements difficult. In addition, the large amount of acoustic energy and electromagnetic energy outside of the optical spectrum that is released can interfere with electronic equipment and make measurements unreliable. Inexpensive passive detectors have been designed and used for more than 20 years that can evaluate hazards to the skin and eye without the use of electronics, which are susceptible to acoustic and electromagnetic interference.
  - Devised a technique that can be used to make reliable radiometric measurements of optical radiation sources, including exploding devices, which limit the number of parameters that must be specifically measured. This method can be used to determine an effective source temperature that allows the evaluators to produce a simple hazard analysis. The results of this technique are similar to traditional spectroradiometric measurements.
  - Work is underway to model the source temperature of an exploding device from its chemical content. Measurements from exploding sources are being compared to the mass of the exploding material to determine if a precise theoretical hazard analysis is possible from knowledge of only the chemical composition and mass. The outcome looks favorable, but more measurements are needed to confirm the theory.

- Ergonomics Program. This program used the Blast Overpressure (BOP)-Health Hazard Assessment software, developed by USAMRMC to characterize injury risk to the lung associated with exposures to blast from U.S. weapons or explosive devices. Assessments typically focused on the injury risk incurred by Soldiers who operate weapons occupationally but, on occasion, have included injury risk to nonoperators such as individuals incidentally exposed to nonlethal weapons such as stun grenades. This work is typically performed to support BOP analyses required for health hazard assessment reports coordinated by the USACHPPM Health Hazard Assessment Program. Systems being analyzed within this calendar year include:
  - Anti-Tank4-Confined Space-Reduced Sensitivity, HESCO. Analysis of data representing exposures to gun crews firing the Anti-Tank4-Confined Space-Reduced Sensitivity from inside a HESCO structure.
  - Non-Line-of-Sight Cannon (NLOS-C) for Future Combat System’s (FCS) Manned Ground Vehicle. Input on BOP requirements for the NLOS-C was provided in response to an inquiry from the FCS Program Manager.
  - Screening Obscuration Device – Visual Restricted (SOD-VR). Analysis of data representing blast exposures to hostages from the SOD-VR.
  - XM1167 Gunner Protection Kit. Analysis of data representing blast exposures to the gunner firing a tube-launched, optically tracked, wire-guided missile and the occupants inside a high-mobility multipurpose wheeled vehicle.
  - Excalibur weapon system. Analysis of BOP data collected from testing the Excalibur weapon system.

### **Joint Trauma Analysis and Prevention of Injury in Combat Project**

A critical component and one of the most notable success stories from the DoD Blast Injury Research Program is the JTAPIC program. The JTAPIC program is a joint partnership among the intelligence, operational, materiel, and medical communities with a common goal to collect, integrate, and analyze injury and operational data. These analyses improve the understanding of our vulnerabilities to threats and enable the development of improved tactics, techniques, and procedures and materiel solutions that will prevent or mitigate blast-related injuries. Prior to the establishment of the JTAPIC program, the DoD did not have a mechanism established to systematically analyze and integrate information across these communities, and these communities had focused on improving Warfighter survivability from their individual perspectives.

The JTAPIC program was established at USAMRMC in October 2006. The list of JTAPIC partners includes the U.S. Army National Ground Intelligence Center Anti-Armor Task Force, Office of the Armed Forces Medical Examiner, PM SEQ, ARL, U.S. Army Aeromedical Research Laboratory, U.S. Army Institute of Surgical Research, Naval Health Research Center, U.S. Marine Corps Systems Command, and the Air Force Surgeon General’s Office.

To adequately analyze a combat event, JTAPIC linked cause (incident operational data and analysis), effect (injury and combat casualty care data and analysis), and mitigation (materiel performance data and forensic equipment analysis) factors—information from disparate sources with varying levels of classification and restricted access, and effected a culture shift among partner organizations from “need to know” to “need to share.” Critical capability gaps that JTAPIC addressed included data collection and standardization, materiel recovery and analysis, data sharing and integration, and the timeliness and responsiveness of comprehensive analyses. Three key components of the JTAPIC are:

- Materiel Recovery and Analysis

A combined effort by PM SEQ, the Office of the Armed Forces Medical Examiner and ARL provides for the collection of PPE (individual helmet and body armor) from wounded-in-action servicemembers in Iraq and identification and analysis of foreign bodies (fragments) removed from killed-in-action servicemembers during postmortem examination. PPE can be analyzed for damage and performance, and retrieved fragment material properties can be characterized. Fragment data can provide clues to the threat weapons involved in an incident, and modeling by ARL can then provide kinetic energy data that is useful to PPE and armor developers.

- Incident Analysis Network

The Incident Analysis Network generates detailed forensic storyboards of combat incidents that tie together key information from several disparate sources related to a specific combat event. The U.S. Army National Ground Intelligence Center Anti-Armor Task Force provides operations and intelligence data, the Office of the Armed Forces Medical Examiner provides information on killed-in-action servicemembers, JTAPIC provides information on wounded-in-action servicemembers, ARL provides analysis on any fragments collected from the incident and models the event, and PM SEQ provides analysis of the PPE involved in the incident. A multi-community analysis of the storyboard provides the “so what” take-home message. The storyboards have been used by JTAPIC customers to guide survivability models and analyses and support vehicle/equipment development and milestone decisions.

- Injury Prevention Analysis Network

The Injury Prevention Analysis Network provides actionable medical analysis on both a push-and-pull basis. The push system is based on the data collected and information generated internally by JTAPIC partners. The pull system is driven by an RFI process. JTAPIC developed its RFI process as a way for its customers to submit questions or requests to support and guide decisions. When an RFI is submitted, JTAPIC works with its partners to collect and analyze the required data.

The JTAPIC program has already made a difference in the way we protect our Warfighters from blast-related injuries. For example, the program established an effective, near-real-time process for collecting and analyzing data from blast-related combat incidents. Using this process and sophisticated fragment analysis procedures, the program confirmed the presence of prominent threat weapons of interest to the intelligence community. Using incident, injury, and virtual autopsy data, the program identified potential vulnerabilities in operational procedures and rapidly conveyed those vulnerabilities to commanders in theater. The JTAPIC program provided actionable information to combat vehicle Project Managers that led to the modification of vehicle equipment to prevent or mitigate blast-related injuries. The program is currently analyzing performance data related to specific modifications to the up-armored high-mobility, multipurpose wheeled vehicles to determine the effectiveness of those modifications. To date, the JTAPIC program has processed approximately 125 RFIs from various customers throughout the DoD. Finally, the JTAPIC program has begun to collect damaged PPE, such as body armor and combat helmets, for analyses that will provide PPE developers with the information they need to develop improved protection systems.

The JTAPIC partnership provides relevant information to its customers by having the appropriate service component subject matter experts work together to analyze the data “in context.” The JTAPIC paradigm represents a new generation of Joint Services informatics sharing and collaboration for the analysis and prevention of injuries in combat. The program has received personal endorsements from the Commanding Generals of the Army Materiel Command, U.S. Army Medical Command, and U.S. Army PEO Soldier.

## Chapter 6

# Key Blast Injury Research Issues

### JIEDDO FY08 Funding for High-Priority Blast Injury Research Projects

In the FY08 NDAA Conference Report 110-477, the conferees directed, “...that JIEDDO fund, through interagency transfer of resources as appropriate, blast-related research, training, and programmatic activities which have been identified as high priorities by the DOD executive agent and the centers of excellence established under section 1621 of this Act, at a level of not less than \$50.0 million in fiscal year 2008. These include, but are not limited to: research and development of diagnostics, training, and treatment for traumatic brain injury and post-traumatic stress disorder; collection, storage, and integration of operational, medical, and protective equipment performance data associated with wounding and non-wounding events; body surface wound mapping for investigation of wounding patterns to be included in body armor design; research and training to prevent traumatic eye injury and cranial-facial injury; research to enhance prevention, healing, and quality of life relating to burns; advanced prosthetics; and enhanced research on hemorrhage control.”

The PCO responded to this Conference Report by compiling a list of high-priority blast injury research projects that meet the congressional intent and help to fill critically important, recognized knowledge gaps in the DoD Blast Injury Research Program. These blast injury research projects address a wide range of key blast injury problems and include:

- Mining more than 40 years of blast bioeffects research data to develop a blast knowledge database where medical researchers and protection system developers can readily access data and information to help solve current and future blast injury research problems
- Expanding the capabilities of the JTAPIC program to include analysis of dismounted incident data and development of tools, such as body surface wound mapping tools, that can provide protection system developers with the information they need to develop more effective protection systems
- Sustaining MARP, which provides state-of-the-art prosthetic devices and optimized rehabilitation for wounded Warfighters
- Developing objective criteria using advanced neuroimaging technologies for clinical classification of TBI and PTSD that will help guide and monitor the progress of neurorehabilitation

The PCO transmitted this list of projects to JIEDDO in April 2008 through the Commander, USAMEDCOM who has the delegated authority to act on behalf of the EA.

In April 2008, JIEDDO reported to Congress that it had budgeted \$25.7M in FY08 for, “...blast injury research with the goal of preventing or mitigating injuries from the most lethal attacks, underbelly and Explosively Formed Projectiles (EFP).” These research projects included sustainment of JTAPIC, explosively formed projectiles defeat, protection against advanced underbody threats, measurement of soil properties to enable IED defeat, IED blast and shrapnel characterization, micro-structurally engineered armor systems, and tissue-level mechanisms of blast injury.

The JIEDDO has advised the PCO to submit the EA’s high-priority blast injury research projects to JIEDDO’s multitiered panel review process to compete for funding. The JIEDDO review panels historically favor projects that demonstrate tactical utility with a narrow focus on counter-IED technology and rapid fielding. The PCO is currently preparing the necessary documentation for the JIEDDO review panels.

## **Improving Impact Protection for Combat Helmets**

The medical research and protection equipment development communities have a long-standing and effective working relationship focused on providing our servicemembers with the very best protective equipment available. This relationship is illustrated by the Army ACH Pad Suspension System Assessment Program. This program is assessing commercial helmet pad technologies to increase nonballistic impact protection for the current-generation ACH. Organizations contributing to this program include the U.S. Army Institute of Surgical Research, Defense and Veterans Brain Injury Center of the DCoE for Psychological Health and Traumatic Brain Injury, the U.S. Army Aeromedical Research Laboratory, the Blast Injury Research PCO, and the U.S. Army Infantry Center Directorate of Combat Developments.

Modifying the ACH pad suspension system appears on the surface to be a relatively simple task—retrofit the ACH with available pads, such as those produced by the commercial sporting goods industry. However, in reality, this task is anything but simple because the ACH is a system that is designed to meet many performance requirements. It must protect Warfighters from ballistic and blunt impact threats without compromising fit and comfort that can seriously impact performance and place the Warfighter at risk of serious injury. Any changes made to one component of the helmet system are likely to impact the performance of other components and of the system as a whole.

For the combat helmet to provide better impact protection, the pads either have to be harder or thicker, or a combination of both. Harder pads compromise comfort, and an uncomfortable helmet compromises Soldier performance. Thicker pads compromise fit and helmet coverage, which compromise protection. Pad configurations can compromise compatibility with other head-worn systems like communications systems. Some padding systems require additional holes to be drilled in the helmet shell, and additional holes compromise the shell's ballistic protection performance. Pad configurations that reduce airflow inside the helmet increase heat stress and compromise Soldier performance. The list of all potential impacts from a seemingly simple change to the combat helmet pads is quite long.

To accomplish the task of improving ACH impact protection, the Product Manager, Soldier Survivability issued an RFI in FedBizOpps from November 13, 2007 to February 15, 2008, seeking candidate systems capable of increasing the current ACH blunt impact protection (150g) at the impact velocity of 10 ft/sec to 17.3 ft/sec (objective) or 14.1 ft/sec (threshold) without compromising other ACH protective capabilities. Nine vendors were determined to have sufficiently mature systems to present to the Army Criteria Review Board. Board members represented the medical research, equipment development, and operational communities. The Army allowed vendors 45 days to fabricate and test their candidates prior to the board's review. The Army conducted the review on April 10, 2008, and selected systems from five vendors for further evaluation.

Impact testing is being conducted on the systems from the five selected vendors using three independent laboratories. Suspension systems are being tested on all ACH sizes at three velocities (10, 14.1, and 17.3 ft/sec) in hot, ambient, and cold temperatures utilizing a Department of Transportation head form. Human factors testing will be conducted at Fort Benning, Georgia, in August 2008 using Soldiers from the Officer Candidate School company over a 5-week period to evaluate Soldier comfort, weapon/equipment compatibility, and anthropometrics evaluations. The results of the impact tests and human factors engineering will allow the Army to field an improved pad suspension system in FY09, increasing Soldier protection during combat operations.

## **Determining the Existence and Possible Causes of Nonimpact, Blast-Induced mTBI**

Nonimpact blast exposures occur when Warfighters are close enough to an explosion to experience the high pressures created by the blast itself but far enough away to avoid penetrating injuries caused by fragments and blunt impact injuries caused by debris or by whole-body translation. The existence and mechanism of a nonimpact, blast-induced mTBI remains a key knowledge gap in the DoD Blast Injury Research Program. This gap consists of two questions: (1) Does nonimpact, blast-induced mTBI exist?

and (2) If it does exist, what is the injury mechanism? Understanding the mechanism of any injury is the key to developing effective prevention, mitigation, and treatment strategies.

There are currently 40 projects in the DoD blast injury research portfolio totaling \$34M that are addressing these questions. Among these projects are the DARPA “PREVENT” program and the MIT/Institute for Soldier Nanotechnology project on “Tissue-Level Mechanisms of Blast Injury.” The performers of these research projects include DoD laboratories, other federal agencies, academia, and industry.

These projects are investigating many possible causes for a nonimpact, blast-induced mTBI, including a blast-induced surge in the vascular system, direct effects of the blast pressure wave on the brain tissue, head acceleration, electromagnetic pulse, thermal effects, and inhaled toxic gases. So far, there are no conclusive data from any of these ongoing projects that confirm the existence or mechanisms of this type of injury. Without conclusive data, it would be unwise to modify existing protection systems, such as body armor and combat helmets, because uninformed modifications of protection systems can have disastrous results.

The Blast Injury Research PCO will continue to closely monitor these ongoing research projects to ensure that conclusive findings are quickly shared with the developers of individual and vehicle crew protection systems.

#### **Helmet-Mounted Sensor System and Event Data Linkage to Injury in Theater Study**

In support of the U.S. Army Product Manager, Soldier Survivability, the JTAPIC program (USAMRMC) is coordinating a medical research project to analyze data from helmet-mounted sensors that are being worn by Soldiers in Iraq and Afghanistan. The medical research team includes the U.S. Army Aeromedical Research Laboratory, L-3 Communications/Jaycor (under a contract with the USAMRMC), and the Naval Health Research Center. The U.S. Army National Ground Intelligence Center Anti-Armor Task Force, another key JTAPIC partner, is facilitating the collection of sensor data and event data in theater through a contract with R4 Inc (under a contract with the USAMRMC). This medical research project has three phases: Phase 1 (3rd Qtr FY08 – 1st Qtr FY09), conduct laboratory tests to assess the reliability and accuracy of the sensor systems and establish a method for correlating helmet acceleration with head acceleration; Phase 2 (3rd Qtr FY08 – 2nd Qtr FY09), analyze sensor data from the field to determine if we can confidently discriminate data generated during blast or other serious and potentially injurious impact events from data generated during normal operations where helmets may be dropped or bumped; and Phase 3 (3rd Qtr FY09 – 4th Qtr FY10), link the sensor data with injury and event data when it is expected that the subject matter expertise of other organizations, such as the Defense and Veterans Brain Injury Center of the DCoE, will be brought to focus on this clinical translation. This phase will require a human research protocol and appropriate human subjects research approvals. Phase 3 will not begin until defined criteria and statistical significance are achieved in Phases 1 and 2.

#### **Automated Neuropsychometric Assessment Metric Use for TBI Diagnostics**

The Automated Neuropsychometric Assessment Metrics (ANAM) is a DoD method for assessing cognitive performance and/or cognitive status using a variety of automated standardized cognitive tests and can target specific processes (e.g., memory, attention, and switching from one task to another). On July 24–25, 2008, a meeting was held to consider the potential utility of the ANAM4<sup>TM</sup> testing system for the in-theater assessment of mTBI. Participants included ANAM developers, military and civilian neuropsychology researchers and clinicians, civilian researchers who have studied mTBI using the ANAM (e.g., effects of concussion on ANAM performance in athletes), a civilian expert on the pathophysiology of mTBI, as well as representatives from the Defense and Veterans Brain Injury Center, the U.S. Army Office of the Surgeon General, USAMRMC, DCoE for Psychological Health and Traumatic Brain Injury, and TATRC. An in-theater study is needed to determine whether for initial mTBI screening the ANAM4<sup>TM</sup>, with its automated test battery, could replace a trained neuropsychologist using other standard neurocognitive measures. In combination with a pre/post-deployment study to be

executed at Fort Campbell, the utility or limitations of the in-theater study will quickly determine the value or limitation of the ANAM4™ for mTBI management.

Further, the Defense and Veterans Brain Injury Center, with oversight by the National Academy of Neuropsychology, is conducting a head-to-head study of five routinely available automated psychometric tests (CogSport, Impact, CNS Vital Signs, HeadMinder, and ANAM) so that evidence-based decisions may be made about fielding. This study will consist of an “in-theater” component together with a component based at Fort Bragg, North Carolina, allowing correlation and corroboration of these automated psychometric indices.

## Appendix A Acronyms

ABSORB	Anti-Blast Shock Optimal Reduction Buffer
ACH	Advanced Combat Helmet
AFIRM	Armed Forces Institute of Regenerative Medicine
AFRL	Air Force Research Laboratory
ANAM	Automated Neuropsychological Assessment Metrics
ARL	Army Research Laboratory
ASA(ALT)	Assistant Secretary of the Army for Acquisition, Logistics, and Technology
ASBREM	Armed Services Biomedical Research Evaluation and Management
BAA	Broad Agency Announcement
BOP	Blast Overpressure
CAM	Complementary and Alternative Medicine
CDMRP	Congressionally Directed Medical Research Programs
CNRM	Center for Neuroscience and Regenerative Medicine
DARPA	Defense Advanced Research Projects Agency
DASD(FHPR)	Deputy Assistant Secretary of Defense Force Health Protection and Readiness
DCoE	Defense Centers of Excellence
DoD	Department of Defense
DoDD	Department of Defense Directive
EA	Executive Agent
EFP	Explosively Formed Projectile
FCS	Future Combat Systems
FY	Fiscal Year
ICD-9	International Classification of Diseases, 9th Revision
IED	Improvised Explosive Device
JIEDDO	Joint Improvised Explosive Device Defeat Organization
JPIP	Joint Program Integration Panel
JSF	Joint Strike Fighter
JTAPIC	Joint Trauma Analysis and Prevention of Injury in Combat
M	Million
MARP	Military Amputee Research Program
MIT	Massachusetts Institute of Technology
mTBI	Mild Traumatic Brain Injury
NATO	North Atlantic Treaty Organization
NDAA	National Defense Authorization Act
NLOS-C	Non-Line-of-Sight Cannon
NSRDEC	U.S. Army Natick Soldier Research, Development and Engineering Center's
OEF	Operation Enduring Freedom
OIF	Operation Iraqi Freedom
ONR	Office of Naval Research
ORCA	Operational Requirement-Based Casualty Assessment
PEO	Program Executive Office
PCO	Program Coordinating Office
PH	Psychological Health
PM SEQ	U.S. Army Project Manager Soldier Equipment
PPE	Personal Protective Equipment
PREVENT	Preventing Violent Explosive Neurological Trauma

PTSD	Post-Traumatic Stress Disorder
RFI	Request for Information
SOD-VR	Screening Obscuration Device – Visual Restricted
SPAWAR	Space and Naval Warfare Systems Center
TATRC	U.S. Army Telemedicine and Advanced Technology Research Center
TBI	Traumatic Brain Injury
TSWG	Technical Support Working Group
USACHPPM	U.S. Army Center for Health Promotion and Preventive Medicine
USAMEDCOM	U.S. Army Medical Command
USAMRMC	U.S. Army Medical Research and Materiel Command
VA	Department of Veterans Affairs
VT	Virginia Polytechnic Institute and State University
WRAIR	Walter Reed Army Institute of Research

## Appendix B

### Crosswalk Between NDAA-Required Information and the Fiscal Year 2008 Annual Report

The following table shows the crosswalk between the required information from Section 256 of the National Defense Authorization Act (NDAA) for Fiscal Year 2006 (FY06), Public Law 109-163 and this FY08 Annual Report.

Required Information from Section 256 of the NDAA for FY06, Public Law 109-163	Crosswalk with FY08 Annual Report
1. A description of the activities undertaken under this section during the 2 years preceding the report to improve the prevention, mitigation, and treatment of blast injuries.	<ul style="list-style-type: none"> <li>• Chapter 2, pages 2-1—2-3: <b>Blast Injury Research Program Coordinating Office (PCO) Key Activities</b> section lists key Blast Injury Research PCO accomplishments during the preceding 2 years.</li> <li>• Chapter 4: <b>Key Program Accomplishments</b> describes specific accomplishments during the preceding 2 years.</li> <li>• Chapter 5: <b>Key Components of the Blast Injury Research Program</b> describes the significant activities of eight major blast injury research-related programs during the preceding 2 years. These programs are the FY07 Post-Traumatic Stress Disorder/Traumatic Brain Injury Research Program, the FY08 War Supplemental Funding for Battle Casualty and Psychological Health Research, the Armed Forces Institute of Regenerative Medicine, the Defense Centers of Excellence for Psychological Health and Traumatic Brain Injury, the Military Amputee Research Program, the Uniformed Services University of the Health Sciences Center for Neuroscience and Regenerative Medicine, the U.S. Army Center for Health Promotion and Preventive Medicine, and the JTAPIC program.</li> </ul>
2. A consolidated budget presentation for DoD biomedical research efforts and studies related to blast injury for the 2 fiscal years following the year of the report.	<ul style="list-style-type: none"> <li>• Chapter 3: <b>Consolidated Budget Presentation</b> shows the consolidated budget for research efforts and studies related to blast injury for FY09–FY11.</li> </ul>
3. A description of any gaps in the capabilities of the Department and any plans to address such gaps within biomedical research related to blast injury, blast injury diagnostic and treatment programs, and blast injury tracking and monitoring activities.	<ul style="list-style-type: none"> <li>• Chapter 1, pages 1-1—1-2: <b>Key Program Features and Key Research Topics</b> sections describe major capability and knowledge gaps and research focus areas that will address the gaps.</li> <li>• Chapter 2, page 2-2: <b>Identified Program Funding Requirements</b> section describes the FY10–FY15 programmed funding request for research projects that address recognized capability and knowledge gaps.</li> <li>• Chapter 2, pages 2-3—2-4: <b>Blast Injury Research PCO Objectives</b> section describes five specific Blast Injury Research PCO program management process objectives focused on addressing recognized capability and knowledge gaps.</li> <li>• Chapter 6: <b>Key Blast Injury Research Issues</b> describes five ongoing programs of research designed to address gaps related to the prevention, diagnosis, treatment, and rehabilitation of blast-induced injuries.</li> </ul>
4. A description of collaboration, if any, with other departments and agencies of the federal government and with other countries during the 2 years preceding the report in efforts for the prevention, mitigation, and treatment of blast injuries.	<ul style="list-style-type: none"> <li>• Chapter 4: <b>Key Program Accomplishments</b> describes specific accomplishments during the preceding 2 years. Each accomplishment description identifies the primary performers and collaborators. Collaborators cited in this section include DoD organizations, federal agencies, other countries, academia, and industry.</li> </ul>

Required Information from Section 256 of the NDAA for FY06, Public Law 109-163	Crosswalk with FY08 Annual Report
<p>5. A description of any efforts during the 2 years preceding the report to disseminate findings on the diagnosis and treatment of blast injuries through civilian and military research and medical communities.</p>	<ul style="list-style-type: none"> <li>Chapter 4: <b>Key Program Accomplishments</b> describes specific accomplishments during the preceding 2 years. Each accomplishment description identifies the dissemination of information from the research effort. Examples include the presentation of research findings at workshops and conferences and the publication of research findings in technical reports and in the open scientific literature.</li> </ul>
<p>6. A description of the status of efforts during the 2 years preceding the report to incorporate blast injury effects data into appropriate programs of the DoD and into the development of comprehensive force protection systems that are effective in confronting blast, ballistic, and fire threats.</p>	<ul style="list-style-type: none"> <li>Chapter 4: <b>Key Program Accomplishments</b> describes specific accomplishments during the preceding 2 years. Each accomplishment description identifies the incorporation of research findings and products into DoD programs and into force protection systems. Examples include the incorporation of research findings into materiel development programs, follow-on research efforts, and blast injury prevention, mitigation, and treatment practices and policy.</li> </ul>

## Appendix C

# Taxonomy of Injuries from Explosive Devices

- *Primary.* Blast overpressure injury resulting in direct tissue damage from the shock wave coupling into the body.
- *Secondary.* Injury produced by primary fragments originating from the exploding device (preformed and natural [unformed] casing fragments and other projectiles deliberately introduced into the device to enhance the fragment threat) and secondary fragments, which are projectiles from the environment (debris and vehicular metal).
- *Tertiary.* Displacement of the body or part of body by the blast overpressure causing acceleration/deceleration to the body or its parts, which may subsequently strike hard objects causing typical blunt injury (translational injury), avulsion (separation) of limbs, stripping of soft tissues, skin speckling with explosive product residue and building structural collapse with crush and blunt injuries, and crush-syndrome development.
- *Quaternary.* Other “explosive products” effects—heat (radiant and convective) and toxic toxidromes from fuel and metals—causing burn and inhalation injury.
- *Quinary.* Clinical consequences of “post detonation environmental contaminants” including bacteria (deliberate and commensal, with or without sepsis), radiation (dirty bombs), and tissue reactions to fuel and metals.

Source: DoDD 6025.21E, Medical Research for Prevention, Mitigation, and Treatment of Blast Injuries, July 5, 2006.