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Introduction

Since Operation Desert Shield/Desert Storm, Gulf War veterans have expressed concerns about the health effects of possible hazardous exposures during their deployment. The Defense Science Board Task Force on Persian Gulf War Health Effects (DoD, 1994), the National Institutes of Health Technology Assessment Workshop, the Institute of Medicine Committee to Review the Health Consequences of Service during the Persian Gulf War, the Presidential Advisory Committee on Gulf War Veterans' Illnesses, and others (e.g., Lebowitz, 1998) have all conducted extensive reviews and published reports on the health of veterans. The focus of most of these reports has been on the current health of veterans, appropriate evaluation and care of veterans, and the connections between veterans' health status and their service in and specific exposures during the Gulf War. These expert bodies have also recommended improvements in Department of Defense (DoD) policies, procedures, and technologies for protecting the health of military personnel during deployments.

Two types of health concerns are related to hazardous exposures. First, exposures to chemical and/or biological (CB)[1] warfare agents and other harmful agents can degrade troop performance and interfere with the fulfillment of their mission. Second, low-level exposures to multiple toxic agents could have long-term health effects. Thus, there has been a

[1] In this report, the acronym CB refers to chemical and/or biological agents that can be used as weapons.

growing demand for both the collection and management of information on potential exposures (at all levels) to a large number of harmful agents and for better monitoring and control of exposures.

In public statements, the Special Assistant to the Deputy Secretary of Defense for Gulf War Illnesses has stressed the need for a better understanding of exposures that occurred during the Gulf War to facilitate the treatment of illnesses affecting Gulf War veterans and other deployed troops and support personnel (DoD, 1998a; Rostker, 1997a, 1997b, 1999); the same information will be necessary for future deployments. Moreover, the chronic health effects must be understood in the context of lifelong exposures to harmful agents in military and nonmilitary situations.

CHARGE

DoD requested that the National Academies conduct an independent, unbiased evaluation of its current and planned efforts to protect deployed forces and recommend a long-term strategy for protecting the health of military personnel deployed to unfamiliar environments. The evaluation is focused on four areas: (1) risk assessments; (2) technologies and methods for detecting and tracking exposures to harmful agents; (3) physical protection and decontamination; and (4) medical protection, health consequences and treatment, and medical record keeping.

Scope of This Study

This study, which is one component of the overall evaluation, addresses the second area, DoD's approaches to detecting and tracking exposures of deployed military personnel to potentially harmful agents, including CB agents, toxic industrial chemicals (TICs), environmental and occupational contaminants, and endemic, disease-causing organisms. This study also includes an evaluation of current policies, doctrine, and training and identifies opportunities for modifying strategies to provide better protection in future deployments. The study evaluates the following:

- methods of monitoring and characterizing CB agents present in, or released or dispersed into, the deployed theater
- use of the global positioning system (GPS) and other technologies to track troops and characterize locations and time-activity patterns of deployed military personnel, including high-risk subpopulations
- fixed-site and mobile methods of detecting and monitoring concentrations of potentially harmful agents
- computational methods and biological markers for estimating

exposure concentrations and patterns of exposure for individuals or groups
- implementation procedures, including tactical and administrative processes, for detecting, monitoring, and documenting exposures

Definitions of Terms

CB agents and other harmful agents is assumed to include all chemical agents (those that may be used as warfare agents, as well as TICs and environmental and occupational contaminants) and all biological agents (those that may be used as warfare agents as well as those that cause endemic disease). Traditionally, the agents of concern were primarily agents that could be weaponized and used against U.S. deployed forces (referred to by DoD as CB warfare agents); TICs, environmental and occupational contaminants, and agents of endemic disease were considered lesser concerns. Since the Gulf War, DoD has attempted to redress this gap. Although this study includes agents other than the traditional weaponizable warfare agents, a distinction between CB agents and other harmful agents is made to be consistent with the terminologies used by DoD and the other three concurrent studies.

Potentially harmful agents, a subcategory of chemical agents, includes TICs and environmental and occupational contaminants. *Inventories* refers to a category, class, or type of CB agent and its concentration in the local environment. The term does not refer to the amount or numbers of agents stored in stockpiles.

Detection and monitoring of agents refers to the detection and monitoring of CB and other agents that may be harmful to U.S. troops. Detecting and monitoring an agent, toxic cloud, or contaminated area includes discovering its presence and noting its location, identifying the agent, determining the size and boundaries of the cloud or contaminated area, measuring the concentration, and predicting its future path.

Tracking refers to identifying and monitoring troop locations. In the near term, tracking includes locating and following troops and keeping track of their contacts with harmful agents. Near-term tracking can be done at the unit or organizational level. Tracking also means following where individual service members are at particular times and determining whether or not they have been or could have been exposed to agents in a given location. For the purposes of this report, tracking includes gathering information on the levels and times of contact with the agents.

Detecting, *monitoring*, and *tracking* are defined as follows. *Detecting* is the process of finding the presence of agent(s). *Monitoring* is the process of collecting data for space and time profiles of agent concentrations. *Tracking* provides information on both the geographic locations of troops and

their specific activities at those locations (e.g., marching, operating inside a vehicle, sleeping in a tent, eating, wearing normal uniforms, or wearing protective clothing).

APPROACH OF THE STUDY

The National Academies Board on Army Science and Technology in the Commission on Engineering and Technical Systems, in collaboration with the Board on Environmental Studies and Toxicology in the Commission on Life Sciences, contracted a principal investigator, Thomas E. McKone, an expert in exposure assessment, to conduct this study. As part of the study, the principal investigator and National Research Council (NRC) staff assembled an advisory panel to provide supplementary information, review the report during development, and participate in planning and conducting workshops and commissioning papers.

The principal investigator worked with the NRC staff to collect and synthesize the data and information. Sources of information included reports and databases at DoD and regulatory and research organizations, as well as information provided by experts in relevant disciplines. Data was gathered at a series of meetings with DoD representatives, who made presentations on various topics related to the study. Individuals from the Soldier and Biological Chemical Command (SBCCOM) Edgewood Chemical Biological Center, SBCCOM Soldier Systems Center, the U.S. Army Chemical School, U.S. Army Medical Research Institute for Chemical Defense, the Joint Service Materiel Group (JSMG), and the JSMG Contamination Avoidance Commodity Area presented briefings at open meetings. Lessons from previous deployments, DoD field manuals, and other documents were also reviewed to provide a broad context for evaluating current and planned military doctrine and training.

Much of the DoD reference material cited in this report has been prepared by or for the Army. This is because the Army assumed the *de facto* role of executive agent for CB research and development (R&D) by virtue of its large and long-term investment in the development of chemical equipment and its extensive experience with chemical exposure on the battlefield. The Army controlled the production of chemicals, the development and production of defensive equipment, training, testing, basic research, and a chemical warfare unit. The Army, thus, has historically invested more resources than the other services in the area of contamination avoidance.

As operations became more and more integrated and cooperative (joint operations), both Congress and the military departments recognized the need for joint R&D programs and integrated procedures to improve joint operations and decrease logistical support burdens. This

resulted, in 1994, with passage of Public Law (P.L. 103-160), the National Defense Authorization Act for Fiscal Year 1994 (Title XVII) (U.S. Congress, 1994), which officially assigned the Army the role of executive agent for coordination and integration of the CB defense program. DoD reorganized its CB programs across the services, and each service was given responsibility for coordinating the R&D acitivities across all services in specific areas of the CB defense program. The Army was given lead responsibility for the contamination avoidance commodity area. Current and future work in this area will, therefore, continue to have much Army input and emphasis. Although the Army is the lead, there has been and continues to be related, ongoing activities in the other services (e.g., U.S. Air Force, 1999; U.S. Navy, 1999a, 1999b, 1999c).

ISSUES

This study is focused on technologies for detecting and monitoring concentrations of agents and for tracking the exposures of troops to those agents. The study also addresses the overall framework in which these technologies could be used. Because a comprehensive understanding of troop exposures requires many types of information, the study also focuses on DoD's procedures for collecting, managing, and using information. However, this study did not evaluate the many computing, information processing and storage, and communications technologies that would be associated with any large-scale attempt to detect and monitor many different harmful agent concentrations during deployments and to monitor, over an extended period of time, actual or potential exposures of deployed troops, as well as individual predeployment and postdeployment exposures. Computing, information processing, and communications technologies are being developed mostly by the private sector, and DoD's use of these commercial, off-the-shelf technologies has been evaluated in many other reports (e.g., National Defense Panel, 1997; NRC, 1995, 1997a).[2]

[2] It is widely agreed that future military systems for command, control, communications, intelligence, surveillance, and reconnaissance will require new technologies to meet the growing demand for sensor integration, high-speed data transport, more data storage, and distribution and analysis of data to achieve full, real-time, situational awareness on the battlefield and meaningful postdeployment assessments. If the recommendations of this study are implemented, they could add significantly to DoD's existing needs for improving computers, information processing and storage, and communications technologies.

No attempt was made to assess the budgetary impact on DoD of adopting some or all of the recommendations developed in this report. This report assesses techniques for detecting and monitoring agents, tracking troop activities, and characterizing exposures, as well as DoD's implementation of these techniques, according to the following criteria:

- applicability of the technology to the CB agents of concern
- technical feasibility of using the technology in theaters of deployment
- value of the technology for assessing physical protection, health risks, or medical follow-up
- usefulness of the technology for setting priorities for detecting and monitoring agents and tracking troops
- contribution of the technology to an understanding of the full range of exposures, including low-level and high-level exposures
- cost effectiveness of the technology

The utility of the information in DoD's decision making (i.e., whether the information is likely to make a difference) was an important consideration. The types and extent of exposure information needed during a deployment depend largely on the military mission, the deployment environment, and how the information will be used. Although DoD is putting forth a great deal of effort to develop technologies for detecting CB agents and for tracking military personnel during deployments, it is not yet clear how these technologies and the information they provide will be used to assess potential exposures to harmful agents or to make operational decisions. Decision analysis would be one method of identifying the most useful exposure information and the best ways of collecting it and preventing data overload. For example, a taxonomy of exposure information could be developed to prioritize various kinds of information. Appendix A contains a more detailed discussion of the decision framework and the elements of decision analysis.

MILITARY DOCTRINE AND TRAINING

This study should be seen in the context of doctrine and training related to CB attacks. For many years, the U.S. military has adhered to the doctrine of contamination avoidance, which involves four steps: (1) implementing passive defense measures (e.g., camouflage, dispersion) to reduce the probability of a CB attack; (2) warning and reporting a CB attack to protect others who might be affected; (3) locating, identifying, tracking, and predicting CB hazards so commanders can decide whether to operate in or around them; and (4) limiting the exposure of personnel if operation

in a contaminated area is necessary (U.S. Army, 1992). Military doctrine states, "If the mission permits, avoiding CB hazards completely is the best course of action. This is not always possible" (U.S. Army, 1992, p. vi). Since contamination may not always be avoided, military personnel are trained to use protective gear (e.g., masks and suits). Although operating in a CB environment is extremely difficult, the military believes that well trained troops can survive and fight on a contaminated battlefield.

DoD recognizes that its current detection equipment has many limitations. The basic manual of the Army Chemical Corps and the Marine Corps, which describes the principles of operating in a contaminated environment, reiterates the importance of avoiding contamination (U.S. Army and U.S. Marine Corps, 1996). If a unit is contaminated or must enter a contaminated area, protection becomes very important. The manual, which offers substantial guidelines for protection against chemical attacks, includes the following statement on protection against biological attacks: "Personnel should treat a suspected biological attack just as a chemical attack. *The protective mask provides protection against all known biological and military chemical agents. However, current detector systems will not react to biological agents*" [emphasis added] (U.S. Army and U.S. Marine Corps, 1996, p. 4-7). In the *Annual Report to Congress on Nuclear/Biological/Chemical (NBC) Defense* (DoD, 1999a), DoD identified nine projects under way, managed by the Joint Program Office for Biological Defense, to improve its detection technology.

The Army's training program emphasizes contamination avoidance but also includes protocols for training troops to conduct effective combat operations in a CB environment with protective equipment (U.S. Army, 1993). One objective of the program is "to ensure that all soldiers, leaders, and units achieve and maintain proficiency in combat operations under NBC conditions" (p. 20). Monitoring for CB hazards is designated as a unit responsibility, and the planning and control of chemical surveys and biological sampling are assigned to the battalion or squadron and higher levels.

However, some evidence indicates that actual training does not always meet these goals. In 1998, the DoD Office of the Inspector General conducted an audit of unit CB readiness training. The audit results are summarized in the following paragraph.

> Except for Navy surface ships, at 187 of 232 units reviewed, unit commanders generally were not fully integrating chemical and biological defense into unit mission training. As a result, commanders could not adequately assess unit readiness to successfully complete wartime missions under chemical and biological conditions (DoD, 1998b, p. i).

The Annual Report to Congress included an extensive discussion of training for CB operations by all of the military services, as well as an

assessment of training and readiness (DoD, 1999a). The assessment identified the following three unresolved issues (solutions suggested by DoD are summarized in parentheses):

- "DoD lacks a mechanism to provide adequate information on the current status of training, equipment, and readiness" (p. 5-34). (Solution: assign higher priority to defense against NBC attacks; provide adequate resources to joint service organizations.)
- "There are limited chemical and biological features in wargames and planning models" (p. 5-34). (Solution: add CB warfare defense to joint simulations in funding for fiscal year 1999 and beyond.)
- "Joint NBC defense doctrine needs to be continually developed to include joint service tactics, techniques, and procedures" (p. 5-34). (Solution: continue interaction and cooperation by military services to produce next-generation doctrine.)

The Army is exploring concepts for CB defense for its army of the next decade, known as Force XXI (U.S. Army, 1998). The Army argues that Force XXI must have the capability (1) to sense the battle space (i.e., identify hazards in air, water, or land to personnel, equipment, or facility by means of surveillance, detection, identification, monitoring, and reconnaissance); (2) to shape the battle space (i.e., provide visualization so the commander can clearly understand the current and predicted situation); (3) to shield the force (i.e., prevent casualties by reducing the threat, contamination avoidance, protection); and (4) to sustain the force (i.e., medical intervention and decontamination).

Although contamination avoidance remains the guiding principle, the Army states that chemical doctrine will change "to include considerations of evolving technology, chemical force structure, and threats . . . in support of other services . . . for operational concerns across the spectrum of conflict." The Army concept also delineates the following training goals for the future: (1) virtual, live, and synthetic theater of war training exercises; (2) modeling and simulations; and (3) specialized training in toxic and industrial hazards (U.S. Army, 1998, p. 16).

OVERVIEW OF THE REPORT

The purpose of this report is to evaluate DoD's ability to cope with the range of exposures faced during a deployment, including exposures to CB agents, to other harmful agents, to vaccines, and to drug interactions. The recommendations are made with the knowledge that data on past deployments are limited and variable and that DoD will have to

develop a prospective strategy for handling exposure issues in future deployments.

This report lays out a sequence for planning and information-gathering activities that could be followed in exposure characterizations. Chapter 2 describes approaches for estimating exposure concentrations and patterns of exposure for individuals or groups by a combination of computational methods and biological markers. The chapter also describes tactical and administrative procedures for detecting, monitoring, and documenting exposures. A technical annex discusses exposure assessment.

In Chapter 3, detecting and monitoring a range of agents, as well as characterizing exposures, are discussed. Once detection and monitoring properties of agents have been identified, their exposure pathways must be determined. Chapter 4 addresses the processes that transport and transform agents along possible pathways from their sources to points of contact with deployed troops. An understanding of these processes will be essential for tracking and characterizing inventories of agents that exist in or are released or dispersed into the deployment theater.

Characterizing potential exposures requires information on how agent concentrations vary, both geographically and in time. Chapter 5 addresses techniques for detecting and monitoring concentrations of potentially harmful agents by both fixed-site and mobile methods. Because characterizing exposures requires an understanding of how and where troops might come into contact with agents, their geographic locations—using technologies such as GPS—and their specific activities at those locations must be identified. Chapter 6 addresses the challenge of tracking and characterizing locations and time-activity patterns of deployed military personnel. The chapter also includes a discussion of subpopulations that might be at higher risk, such as individuals or units that have been subjected to previous exposures. In closing, chapter 7 recommends strategies to meet the challenges of detecting and tracking exposures of deployed military personnel to potentially harmful agents.