APPENDIX C

Strategies to Protect the Health of Deployed U.S. Forces: Detecting, Characterizing, and Documenting Exposures—Executive Summary

BACKGROUND

Since Operation Desert Shield/Desert Storm, Gulf War veterans have expressed concerns about the health effects associated with possible hazardous exposures during their service. In response, several expert bodies have conducted extensive studies and recommended improvements in U.S. Department of Defense (DoD) policies, procedures, and technologies for protecting military personnel during deployments. Recently, the National Academies was also asked to conduct an independent, external, unbiased evaluation of DoD's efforts to protect deployed forces and to provide advice on a long-term strategy for protecting the health of deployed U.S. military personnel.

The complete evaluation involves four areas: risk assessments; technologies for detecting and tracking exposures (the present study); physical protection and decontamination; and medical surveillance, record keeping, and risk reduction. These four preliminary studies will provide a basis for a synthesis report by a subsequent National Academies committee.

Task of This Study

The objectives of this study are listed below:

- Assess current and potential future approaches used by DoD for detecting and tracking exposures of military personnel to potentially harmful agents, including chemical and/or biological (CB)[1] warfare agents and other harmful agents.

- Evaluate the efficacy and implementation of current policies, doctrine, and training and identify opportunities for adjusting or augmenting strategies to provide better protection in future deployments.
- Review and evaluate tools and methods for tracking and characterizing inventories of CB agents in the deployed theater; for tracking and characterizing the locations and time-activity patterns of deployed military personnel; for detecting and monitoring concentrations of potentially harmful agents; for estimating exposure concentrations and patterns of exposure for individuals or groups; and for implementation (e.g., documenting exposures).[2]

Conduct of the Study

The principal investigator, an expert in exposure assessment, conducted the study with the help of National Research Council (NRC) staff, who collected data, and an advisory panel that reviewed the report while it was being developed and furnished additional information. Other sources of information included reports and databases of regulatory and research organizations, experts in relevant disciplines, meetings with DoD representatives, and reviews of relevant documents (e.g., field manuals) and literature.

Study Approach

This study focuses on technologies for detecting and monitoring concentrations of agents and for tracking exposures of troops to those agents. The study also includes a review of the overall framework in which these technologies could be used. No attempt was made to assess the budgetary impact on DoD of adopting some or all of the recommendations in this report. The study excludes the many computing, information processing, data storage, and communications technologies being developed, mostly in the private sector. DoD's use of these technologies has been investigated in many other reports; and 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, additional

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

[2]In this study, the terms detecting, monitoring, and tracking are differentiated as follows. Detecting is the process of determining the presence of agents. Monitoring is the process of collecting data to develop space and time profiles of agent concentrations. Tracking provides information on both the geographic locations of troops and on their activities at those locations (e.g., marching, operating inside a vehicle, sleeping in a tent, or eating).

data storage, and data distribution and analysis to achieve full, real-time, situational awareness on the battlefield and meaningful postdeployment assessments. If the recommendations in this study are implemented, they could add significantly to DoD's existing needs for improving computers, information processing and storage, and communications technologies.

This report is intended to assist DoD in coping with issues raised by exposures before, during, and after future deployments. Because data documenting past experiences are limited and variable, this report recommends a prospective strategy for handling exposure-related issues in future deployments.

Military Doctrine and Training

For many years the military has adhered to a doctrine of contamination avoidance, which involves four steps: (1) implementing passive defensive measures (e.g., camouflage, dispersion) to reduce the probability of exposures to CB agents; (2) warning and reporting attacks with CB agents to protect others who might be affected; (3) locating, identifying, tracking, and predicting CB hazards to enable commanders to decide whether to operate in spite of them or to avoid them; and (4) limiting exposures of personnel if operation in a contaminated area is deemed necessary. According to military guidance documents, avoiding CB hazards completely is the best course of action; but this is not always possible. Thus, military personnel are trained in the use of protective gear (e.g., masks and suits). Although operating effectively in a CB environment is extremely difficult, the military believes that well trained troops can survive and fight on a contaminated battlefield.

Although the military offers substantial guidance for protecting personnel against chemical attacks, it also acknowledges that its detection capabilities (especially for biological agents) are limited and is working to improve its equipment. As recently as 1996, troops were told to treat any future suspected biological attack like a chemical attack and to rely on protective masks, although then-current detector systems would not react to biological agents. Although contamination avoidance is still the guiding principle of CB doctrine, the military is also developing concepts for CB defense. The focus of CB defense will certainly change as technologies and threats evolve and as troops are deployed to areas where toxic industrial hazards are known to be present. Training goals for the future include virtual, live, and simulated training exercises, modeling and simulations (e.g., of agent dispersion), and specialized training in protecting troops against military and industrial toxic agents.

CHARACTERIZING EXPOSURES

Characterizing the effects of exposures to harmful agents is vital for defining the level of protection necessary for operations in contaminated areas and for providing postexposure medical treatment. Characterizing exposures requires detecting the presence of agents, assessing and monitoring agent concentrations, tracking time-specific locations of troops relative to these concentrations, and determining exposure pathways. Although all of these information sets are treated in this report, no single information set can provide sufficient information for characterizing exposures in real time or for completely characterizing potential or past exposures. As discussed below, information sets must be combined to be useful for decision makers.

Monitoring agent concentrations requires a system that can detect and record both concentrations and environmental factors, such as wind, that can affect the spread and concentration of agents. Perhaps the best way to monitor the movement of an agent is with a combination of a monitoring network and dispersion simulations. However, even detailed information on space and time distributions of concentrations is not sufficient to characterize troop exposures; the location of the troops in relation to the concentration, the rate and direction of their movements, and their degree of protection must also be known. Ideally, every individual should be tracked in real time, but this may not be practical in the near future. Modeling and war games can be used to help determine the feasibility of eventually tracking every individual. For now and in the near future, however, units could be tracked by tracking a representative sample of individuals in that unit.

DoD is aware that it must be able to anticipate significant exposures to CB agents and other harmful agents in future deployments. Therefore, DoD is currently devoting significant resources to improving its capabilities of anticipating health-threatening exposures. DoD is also aware of the need to collect and store information on low-level exposures to CB agents and other harmful substances. The low-level issue involves not only improved technology and equipment, but also interpreting trends from measurements collected near the detection limits of equipment and using exposure data for a representative fraction of the exposed population.[3]

Finding: To date, exposure assessments for both civilian and military populations have focused primarily on exposures to contaminants in a specific medium (e.g., air, water, soil, food) or on exposures to specific environmental pollutants. DoD's current plans for monitoring CB agents would also be limited to a specific medium and would not be time-space specific, would not include time-activity records, and would not account for both short-term and long-term expo-

[3] If tracking and exposure information on individuals could be temporarily stored and retrieved at a later date for historical purposes, this would alleviate the near-term problems of data overload and provide an option for determining later the effects on individuals of low-level exposures to CB agents. A high-capacity version of the Personal Information Carrier now under development by the Army might provide these capabilities.

sures. These factors would only be included in settings where deployed personnel were active (in garrisons or in the field).

Most of the sampling protocols included in CB agent reconnaissance operations are designed to provide comprehensive area coverage, rather than statistical sampling or stratification. DoD has not systematically evaluated how modeling, simulations, and decision analysis could be used in real time to anticipate acute exposures (especially imminent threats). DoD's current capabilities and strategies have not been structured for making optimum use of these tools.

Recommendation: The Department of Defense (DoD) should devote more resources to designing and employing both statistical sampling and sample stratification methods. Two useful examples of probability-based statistical sampling are the National Human Exposure Assessment Studies (NHEXAS) and Total Exposure Assessment Methodology (TEAM) studies. DoD should modify these sampling techniques to meet its needs and should evaluate how modeling, simulations, and decision analysis could be used in real time to anticipate acute exposures.

Finding: Personal passive monitoring of atomic radiation, in the form of dosimeters and radiation badges, has been successfully used for many decades. In some limited situations, small passive monitors have also been used to detect chemicals. However, current technology limits personal monitoring of many toxic gases and particulate matter to the use of active monitoring, which is a complex process.

Recommendation: The Department of Defense should explore and evaluate the use of personal monitors for detecting chemical and biological agents, toxic industrial chemicals, and other harmful agents at low levels. If all personnel were equipped with monitors, probabilistic sampling could be used to select a subset of data for short-term, immediate use (e.g., to define the contaminated parts of the deployment area). The full data set could be used for long-term purposes (e.g., recording an individual's exposure to low-level toxic agents). Stratification of the subsets should be decided on the basis of exposure attributes, such as location, unit assignment, and work assignment. If the logistics problems can be solved, every deployed person could ultimately wear a personal monitor.

Finding: DoD is currently devoting significant resources to improving its capabilities of monitoring life-threatening exposures but not of significant exposures to other harmful agents. At this time, DoD also recognizes the value of, but has taken little action, to collect and store information on low-level exposures to CB agents, toxic industrial chemicals (TICs), environmental and occupational contaminants, and endemic biological organisms. Different capabilities will be required for detecting life-threatening exposures, monitoring low-level exposures to CB and industrial agents, monitoring potential exposures to harmful microorganisms, and maintaining complete exposure records for all military personnel.

Recommendation: The Department of Defense (DOD) should rank the threat levels of all known harmful agents and exposure pathways based on the dimensions of harm (e.g., health consequences, the number of personnel affected, the time to consequences). When assessing the need for and applications of new equipment, increased surveillance, and improved documentation, DoD should include these data, and, if applicable, use decision analysis methods, such as probabilistic decision trees, to make decisions and prepare operations orders.

THRESHOLDS OF HEALTH EFFECTS

Measures of safe and unsafe doses have been established for high-level exposures to both CB agents and TICs. Information on dose responses for low dose rates and long-term exposures to chemical agents is still sparse. In addition, exposures to biological agents have been much more difficult to detect and measure than exposures to chemical agents. For chemical agents, a low-level exposure is one that does not result in acute effects. However, over the long term, low-level exposure may increase the likelihood of chronic illness. In contrast to high-level exposures, for which clear evidence of health effects exists, as low-level chemical exposures increase, it is postulated that the probability of disease increases. Risks from chemical agents have been assessed, but risks from biological agents have not. Therefore, it is difficult to define a low-level exposure to biological agents. Although an acute threshold concentration for chemical agents can be characterized and a safety factor establishing a low-level exposure can be applied, this information is rarely available for biological agents.

Finding: Because little information is currently available to relate long-term health effects to low-dose or low-dose-rate exposures to chemical agents, it is extremely difficult to set performance criteria for detecting and monitoring concentrations of these agents to assess long-term health effects. As a starting point for a working definition of low-level concentration, DoD could use the low-dose data currently available and the capability of available detection equipment.

Recommendation: The Department of Defense (DoD) should increase its efforts to collect and evaluate individual and group dose-response data for a broad set of chemical warfare agents. Studies could include standard animal toxicity testing protocols for long-term effects, as well as retrospective epidemiological studies on individuals exposed to these substances in their occupations. DoD should use the detection capability of available equipment as its working definition of low-level concentration.

Finding: In addition to chemical warfare agents, thousands of TICs are in or are brought into the theater of deployment. These chemicals include pesticides, fuels, paints, and lubricants. Under combat conditions, existing controls and safety precautions may not be practical. Storage tanks, production facilities, pipelines, and other equipment may be damaged, for example, and the TICs dispersed. Exposure under these conditions may be uncontrolled, unreported, unrecorded, and extremely dangerous. Exposures could have long-term health effects that cannot be easily distinguished from the long-term health effects of low-level exposures to chemical warfare agents.

Detecting and monitoring exposures continually to the full set of toxic chemicals, would be extremely difficult, if not impossible. Toxicity data for a number of TICs being developed by some government agencies, such as the Environmental Protection Agency (EPA) and the Occupational Safety and Health Administration (OSHA), are being reviewed by independent groups, such as the NRC Committee on Toxicology. The data thus far show large variations in toxicity.

Recommendation: The Department of Defense should review its current efforts to catalog and prioritize toxic industrial chemicals. This information should be used to anticipate the types of chemicals that may be encountered during a deployment and to prioritize them.

Finding: Very little information is currently available to relate long-term health effects to low-level exposures to biological agents. Almost no information is available on how combined or sequential exposures to low levels of CB agents can affect the short-term or long-term health of troops. Until DoD can accumulate and analyze information on low-level exposure or dose response, as well as on long-term chronic effects, it will be very difficult to set performance criteria for detecting and monitoring concentrations of CB agents for assessments of long-term health effects. Potential interactions among agents add to the difficulty. Interactions can be cumulative, synergistic, or antagonistic. For example, chemical interactions may, in fact, abate, or even destroy, a biological agent. In fact, at one time, DoD research focused on using a chemical agent to counter a biological agent cloud.

Recommendation: The Department of Defense should increase its efforts to collect and evaluate low-level dose-response data for a broad set of biological agents. The data should include information on the infectivity of a range of both warfare and endemic biological agents. At the same time, studies should be undertaken to determine whether and which combined chemical and/or biological agent exposures should be investigated. This information should be used for defining a strategy for monitoring exposures to multiple agents.

Finding: Current criteria for detecting CB agent concentrations are designed to prevent exposures to lethal and incapacitating levels. Often the only way to determine if individuals have been affected by exposures to harmful agents is if they have immediate symptoms. Thus, data are not provided in a form that can be used to establish or verify retrospectively the health effects of CB agents over the long term.

Recommendation: The Department of Defense should establish a plan to collect data for all types of potential agent exposures to identify potential or emerging medical problems quickly. If possible, these medical problems should then be evaluated in terms of any prior exposures to chemical and/or biological warfare agents that have been associated with that health outcome. This plan should include guidelines for who should get the information and when they should receive it.

ENVIRONMENTAL AND EXPOSURE PATHWAYS

Potential environmental exposure pathways are important considerations of a strategy to protect the health of deployed forces. In an overt attack with CB agents, the inhalation path, and to a lesser extent, the dermal path, are obvious exposure pathways. However, when assessing low-level, long-term, or episodic exposures to either CB agents or TICs, persistent and indirect pathways must also be investigated. Total exposure assessments must take into account ambient concentrations of harmful agents in multiple environmental media (e.g., air, water, solid surfaces), as well as the time and activity patterns and microenvironments of individuals. Exposure can only be quantified when pathways and routes that account for a substantial fraction of the intake have been identified.

Unfortunately, much of the current data on environmental contaminants cannot be synthesized into an understandable form because no comprehensive framework has been developed for evaluating chemical transport, transformation, and interactions in multiple media. Another important aspect of a credible exposure assessment is the possibility of concurrent or sequential exposures. Tracking these exposures can be a complex undertaking, especially if the agents interact synergistically or antagonistically.

Finding: During deployment, troops may be exposed to multiple harmful agents from multiple sources at various concentrations. Therefore, measurements and models must be designed to evaluate the factors that affect the multipathway intake of pollutants released from single or multiple sources. In preparing a detection and monitoring strategy for the large number of potentially harmful agents and the variety of pathways by which a person can come in contact with agents, priorities must be set on combinations of agents and pathways. Past experience can provide valuable information for ranking threats, but the list should also include plausible threats that have not been encountered in past deployments.

Recommendation: The Department of Defense should develop a portfolio of exposure threats that can be used to set priorities (based on the dimensions of harm), to distinguish between short-term and long-term hazards, and to establish plausibility. Developing this portfolio is likely to require the cooperation of other federal agencies, such as the Food and Drug Administration, the Environmental Protection Agency, the National Oceanographic and Atmospheric Administration, and the Centers for Disease Control and Prevention. The decision-making strategy should include probabilistic techniques to ensure that it is applicable to situations with many uncertainties and rapid changes.

Finding: Combined exposures to drugs, vaccines, chemical substances, and biological substances have been suggested as causal factors for the symptoms among Gulf War veterans. Gulf War veterans had ample opportunities to be exposed to these substances in many different combinations, and interactions can be cumulative, synergistic, or antagonistic.

The risk assessment community has done very little research to provide exposure assessments of the combined health impacts of even two interacting agents.

Recommendation: The Department of Defense (DoD) should begin scientific studies to measure interactions among chemical and/or biological agents and industrial chemicals. DoD's analysis of the effects of mixed-agent exposures should include toxicological studies on mixtures and epidemiological evidence of mixed-agent effects.

DETECTING AND MONITORING HARMFUL AGENT CONCENTRATIONS

CB agents can be detected and monitored in several ways: (1) point and area sampling; (2) local, stand-off, and remote detection; and (3) real-time and delayed analysis. In assessing technologies and detection and monitoring equipment, it is important to consider whether they can provide information on both long-term and short-term (e.g., acute effects that could immediately affect a unit's ability to fight) health effects. Until recently, the focus has been only on short-term affects.

Technologies and equipment are evaluated for accuracy, reliability, sensitivity, selectivity, speed, portability, and cost. Two very different kinds of information are essential during a deployment: (1) real-time detection of harmful agents; and (2) monitoring and archiving of low levels of agent concentrations for postdeployment assessments.

Many harmful agents are dispersed as aerosols or attached to aerosols. Detecting them requires either collecting and analyzing the aerosol particles or using particle spectrometry. Currently, mass spectrometry is used to characterize atmospheric aerosols in an attempt to provide on-line, real-time analysis of individual aerosol particles. However, results of current systems are questionable. Current detection methods involve isolating particles on filters and subsequent analysis performed in the laboratory. The isolation processes often disturb the aerosol, which renders the data questionable because the chemicals on particles can evaporate or react before analysis. To overcome these difficulties, technologies such as aerosol time-of-flight mass spectrometry (ATOFMS) have been developed to eliminate the need for filters and chemical collection.

Current mass spectrometers weigh a few hundred pounds and are, therefore, not easily portable. Ion-mobility spectrometers (now under development) may weigh only 10 pounds. Other developments could also improve spectrometers. In addition to basic mass spectrometry, DoD is investigating surface acoustic wave (SAW) and light detection and ranging (lidar) technologies to detect CB agent aerosols. The information provided by this equipment will require data evaluation systems to sort and assess the large amount of information.

Current and planned detection equipment is primarily designed to detect nerve and blister chemical agents. TICs have not been given as high a priority. Most technologies that can detect chemical agents in air, water, and food, however, can be adapted to detect TICs and other harmful chemicals likely to be found in the deployment environment. The SAW detector, for example, would have a limited capability of detecting TICs and other harmful chemicals.

Although the current capability to detect biological agents is limited, developing that capability has recently been given a high priority. Emerging technologies for detecting and identifying microorganisms include polymerase chain-reaction amplification, microchips, molecular beacons, electrochemiluminescence, biosensors, mass spectrometry, and flow cytometry.

Finding: Overall, the technologies and equipment either in use or under development are severely limited in their ability to measure concentrations associated with long-term health risks. A significant reason for this problem is that no formal requirements have been established for detecting and monitoring low-level, long-term exposures. Until acceptable low-dose exposures are specified, performance goals for low-dose detection technology cannot be established. Specifications would provide designers, developers, and operators of detection and monitoring equipment with goals for their research.

Recommendation: The Department of Defense should establish criteria for detecting and monitoring low-level exposures to chemical and biological warfare agents and toxic industrial chemicals. These criteria should specify three detection levels: (1) immediate, dangerous, and life-threatening hazards; (2) short-term hazards; and (3) long-term health risks.

Finding: Because different technologies have different strengths and weaknesses, no single technology should be relied on for detection. By using complementary and redundant technologies and sensor fusion techniques, which are commonly used in other areas of the military (e.g., air defense and antisubmarine warfare), the risk of false alarms could be reduced, and agents could be detected at lower limits.

Recommendation: At least two different but complementary technologies should be used, along with sensor fusion techniques, for the detection of a given type of agent. This combination could significantly reduce the number of false positives and false negatives.

Finding: Most of the equipment currently available, as well as most of the equipment under development, for sensing CB agents is designed for detection and warning only. Detection devices typically give off audible or visible signals when the concentration is above the sensitivity level of the device or above a preset value. These devices are valuable for protecting troops from immediate harm but do not provide the kind of monitoring needed to assess less-than-debilitating exposures or to assess exposures that might lead to delayed health impacts.

Not enough attention has been given to archiving the measurements from different detectors. In some cases, archiving is not possible because of the nature of the device. Devices operated for “warning-only” cannot be used in combination with systems like the multipurpose integrated chemical alarm and Joint Warning and Reporting Network (JWARN) to determine the spatial and temporal trends in agent concentrations—essential information for determining the evolution of a threat or for confirming the absence of an agent.

Recommendation: The Department of Defense should develop a comprehensive plan for collecting and archiving data and samples based on a matrix of short-term threats and long-term health risks for situations before, during, and after deployment. This matrix could be used to prioritize types of information.

TRACKING DEPLOYED MILITARY PERSONNEL

A full characterization of an individual’s exposure requires knowing where that person is and what (s)he is doing. General-population, time-activity data cannot be used for estimating exposures of deployed troops; only data specific to deployed personnel can yield accurate estimates of exposures. These data can be provided by the global positioning system (GPS), the total isolated microenvironment exposure (TIME) monitor, and various motion sensors and data loggers, which have been recently introduced.

The GPS will help greatly with the location of units and even of individual soldiers. Miniaturized instruments would have to be developed for use in the field. A wristwatch style GPS, for example, combined with a miniaturized data logger, would provide activity and location information that could be used to prevent acute exposures, as well as to estimate long-term exposure. The most promising automated approach for obtaining data for estimating long-term exposures appears to be a modified TIME device or similar data logger combined with GPS.

Finding: GPS is a critical component of an effective system for predicting and preventing exposures to CB agents, including accidental agent releases. Currently, only one individual per unit or squad carries a GPS receiver. Once GPS devices have been miniaturized and militarized, each individual could carry one. The location of each individual and the individual's proximity to identified or suspected releases of CB agents could then be identified, and orders for preventive actions could be directed to the individuals at greatest risk.

Recommendation: The Department of Defense should continue to support the development of miniature (e.g., wristwatch style) military GPS receivers. Given current technology, receivers could be fielded within five years. The actual decision to equip every deployed unit or individual with a GPS-based receiver should be based on the results of trade-off analyses.

Finding: A miniaturized, multifunctional device that can detect CB agents and TICs, determine location and time, and record the data would be extremely valuable both for protecting deployed troops and for analyzing past exposures. These devices could detect threats from harmful substances, locate the wearer in time and space, and store the data until it could be downloaded. There are, of course, many technical challenges (e.g., size, weight, power requirements) to achieving this capability. Very small devices already exist, however, that could partly meet these goals. The Army's Man-in-Simulant Test (MIST) Program, for example, uses a passive sampler no thicker than a common adhesive bandage and less than one inch square. Establishment of a goal to develop these devices would offer, at a minimum, a valuable target for researchers and developers.

Recommendation: The Department of Defense should support the goal of developing a miniaturized, multifunctional device for detecting agents, determining location, and storing data.

Finding: Individuals may have performed jobs prior to or during their deployment that involved higher-than-average or longer-than-average exposures to toxic pollutants. Predeployment information could be used to identify individuals whose prior exposures put them at higher risk from additional exposures during deployment, as well as to identify possible prior exposures to harmful agents that otherwise might be believed to have occurred during deployment. The postdeployment information would provide a concise record of major duties performed and the use of, or proximity to, possible or confirmed sources of pollutants.

Recommendation: The Department of Defense should implement measures to identify individuals whose predeployment exposures might put them at higher risk of harm from additional exposures during deployment. The information should include major duties performed and the use of, or proximity to, possible or confirmed sources of pollutants during deployment.

STRATEGY

DoD should modify its overall strategy in two ways: (1) by increasing the emphasis on detecting and monitoring concentrations of biological agents during troop deployments; and (2) by addressing the detection and monitoring of a broader range of CB and TIC concentrations and tracking low-level exposures to them in an integrated, systematic way. These two changes will require that DoD take the following steps:

- Develop and procure the technical means of assessing potential and actual exposures (e.g., real-time, field-usable devices for detecting biological agents and improved devices for detecting chemical agents).
- Develop doctrine and training protocols based on improved knowledge of CB exposures for conducting military operations.
- Collect information on the postdeployment health of troops, whether or not they remain in the military.

Defining Needs

Recommendation: The Department of Defense should formulate an integrated approach to assessing the threats of chemical and/or biological agents. The approach should include: (1) a near-term and long-term perspective; (2) data collection; (3) estimates of the relative importance of various threats (e.g., biological threats, chemical threats, and chemical toxins derived from organisms) in a variety of overseas theaters; and (4) data on the effects of low-level doses of a broad range of agents.

Determining Exposure

Recommendation: The Department of Defense (DoD) should proceed with a robust program to develop chemical detectors and biological detectors that can detect and measure low-level as well as high-level concentrations. The first priority should be the development of improved passive sampling devices based on existing technologies that could be fielded quickly. The DoD should also develop a support structure for using the devices and for archiving the data.

Recommendation: The Department of Defense should expeditiously develop the capability of identifying and archiving continuous data on the operational location of each small unit—and, if practical, each individual—as well as the unit or individual's proximity to actual or suspected releases of potentially harmful agents. Technical assessments and cost-benefit analyses should be used to determine the best ways to accomplish these functions in the near term (e.g., the best way of supplementing the miniature global positioning system receiver to achieve the desired result).

Recommendation: The Department of Defense should establish a long-term goal to develop very small devices that could be deployed with each individual to measure and record automatically exposures to one or more of the most threatening agents, the location of the individual, the activity of the individual, the microenvironment, and the time.

Recommendation: The Department of Defense should develop and field improved meteorological measuring and archiving systems to provide finer data grids of wind, temperature, and atmospheric stability in the theater of operations. These data will be necessary for improved transport modeling and for after-action analyses of data on the movements of chemical and biological "clouds."

Recommendation: The Department of Defense should support research to clarify how chemical and biological processes affect the rate of transformation of agents in different environmental media under a variety of conditions.

Handling Data

Recommendation: The Department of Defense should develop a representative activity-location database for different types of units, major military duty categories, and high-risk subpopulations of personnel likely to be deployed. This database, along with models and simulations, should be used to provide insights about potential exposures associated with specific deployments.

Recommendation: The Department of Defense should develop its data-handling capability to track the locations of all individuals (or, at least, the smallest units) during future deployments and compare them to the locations of actual or potential agent concentrations at the same point in time. The data-storage capacity should be increased simultaneously so that these locations can be recalled and analyzed after each deployment (e.g., data could be recalled from a high-capacity personal information carrier).

Recommendation: In the future, the Department of Defense should characterize the variations in exposures of members of groups believed to have been exposed during their deployment. To help accomplish this, location data and agent-concentration data that pertain to individuals or small units should be analyzed thoroughly, using statistical methods where applicable.

Recommendation: The Department of Defense should study the ramifications of establishing a national chemical and biological hazardous agent data center.

Doctrine, Training, and Administration

Recommendation: Doctrine and training for taking protective action should be reviewed to ensure a proper balance between military necessities and the risks of harmful exposures. The Department of Defense should reevaluate its doctrine and training for handling and reporting alarm activations and false alarms and revise them, if necessary.

Recommendation: Doctrine and training should take account of predeployment exposures that might put some individuals at greater risk during deployment. This information, along with data gathered on actual or suspected exposures or on the locations of individuals or units and the locations of concentrations of agents, should be used to assess the risk to individuals.

Recommendation: The Department of Defense should review its doctrine and training protocols governing the interactions of offensive operations and protective measures. If an offensive operation may cause exposure to troops nearby, this information should be factored into the decision.