# Chapter 5

# FUTURE IMPROVEMENTS TO INDIVIDUAL EXPOSURE CHARACTERIZATION FOR DEPLOYED MILITARY PERSONNEL

VERONIQUE HAUSCHILD, MPH*; AND JESSICA SHARKEY, MPH†



*Environmental Scientist, Injury Prevention Program, Epidemiology and Disease Surveillance Portfolio, Army Institute of Public Health, US Army Public Health Command, 5158 Blackhawk Road, Aberdeen Proving Ground, Maryland 21010-5403

†Epidemiologist, Environmental Medicine Program, Occupational and Environmental Medicine Portfolio, Army Institute of Public Health, US Army Public Health Command, 5158 Blackhawk Road, Aberdeen Proving Ground, Maryland 21010-5403

## INTRODUCTION

Despite the substantial environmental exposure data collection described in Chapter 2, the evidence of a relationship between specific chronic respiratory conditions and environmental exposure(s) experienced by service members while deployed to southwest Asia is still inconclusive. Both the National Research Council (NRC) and the Institute of Medicine (IOM) acknowledge the plausibility of a relationship.[1,2] However, lack of granularity of the exposure data, especially the inability to synthesize large-scale ambient air sampling data into individual exposure profiles, is consistently identified as a limitation in epidemiological studies investigating the possible environmental exposure–respiratory disease relationship.[1–3] In addition to the substantial political, financial, and emotional implications that are not being adequately addressed, clinical and preventive measures are hindered by the lack of knowledge regarding specific hazards and dose-response characteristics. For example, whereas clinicians have criteria to assess, diagnose, and treat individuals' respiratory diseases, more definitive knowledge of disease relationships to deployment exposures could expedite diagnosis and even prevent cases of misdiagnosis (see Chapters 1, 4, 7, and 9; also see the chapters in Section III on Follow-up Medical Care of Service Members and Veterans). Although the military is reducing reliance on burn pits, this is primarily because of political pressures, as more specific source risk reduction practices cannot be directed without a clear link to specific exposures (Chapter 2, Background of Deployment-Related Airborne Exposures of Interest and Use of Exposure Data in Environmental Epidemiology Studies).

Despite inconclusive evidence, the Department of Defense (DoD) and the Department of Veterans Affairs (VA) have acknowledged that some previously deployed persons may experience persistent symptoms or develop chronic respiratory conditions because of their combined deployment exposures, unique experiences, and/or individual susceptibilities (eg, smoking, existing health conditions, or genetics).[2,3] However, it remains unclear who these persons are and what specific individual characteristics, activities, or exposure experiences might translate into a higher risk of chronic respiratory health outcomes. Unfortunately, at the present time, there is inadequate data to define the specific subgroups of personnel who may be or have been at greater risk. This includes those who may have experienced more significant exposures while deployed, as well as personnel who may have additional nondeployment exposures or susceptibilities that put them at greater risk.

As discussed in Chapter 2, air, soil, and water sample data have been routinely collected to support deployment base camp exposure and health risk characterizations (eg, Periodic Occupational and Environmental Monitoring Summaries).[4–6] Yet established base camps can be like small cities, where exposures to hazards in the air can depend on the time spent at specific locations and facilities in or around the camp, job tasks, and personal activities. Therefore, even if deployed to the same base camp, *individual* exposures can be quite different. As a result, these general population-level exposure summaries are of limited clinical use and have not been used in epidemiological studies to date.[3–8] Instead, epidemiological studies of the relationships between deployment exposures and adverse health outcomes have primarily used generic deployment status information (eg, number of deployments, timeframes, and occasionally base camp location) as a surrogate for actual exposure data. In fact, most published epidemiological studies use "deployment to southwest Asia" as a proxy for "exposure."[3] A few studies have compared the health outcomes of personnel from different locations for which exposure conditions are considered uniquely different; however, actual exposure data were not used in these studies.[2,9] One case-crossover study used particulate matter data from different locations, but data were limited temporally and spatially and did not address other types of airborne hazards present.[10] As a result, these studies do not adequately represent the unique exposures experienced by various persons deployed to Iraq and Afghanistan.

The impact of the potentially substantial variations in individual exposures, as well as personal confounding risk factors or inherent disease susceptibilities, has been acknowledged. The need to systematically collect individualized service member exposure assessment data has been repeatedly advocated for several years. Yet, this critical gap continues to plague military and VA deployment health research, surveillance, and clinical applications. This section summarizes identified benefits/applications and key disadvantages/limitations of specific approaches and tools as they relate to the characterization of individual military deployment exposures and associated risk factors.

## HISTORY

The inability to capture information about individual military exposures has been repeatedly recognized in numerous past reviews. In 2000, nine years after the end of Operation Desert Shield and Operation Desert Storm (the Persian Gulf War), the IOM identified the need for individual-level exposure data in its recommendations titled *Protecting Those Who Serve: Strategies to Protect the Health of Deployed U.S. Forces*.[11] Although data obtained during the Persian Gulf War were of substantial limitations, their collection served as a basis for lessons to enhance exposure assessment in Operation Iraqi Freedom/Operation Enduring Freedom.[12] However, in 2010, the NRC concluded that, it "is plausible that exposure to ambient pollution in the Middle East theater is associated with adverse health outcomes."[1(p8)] However, the NRC noted that, "available data are not sufficient to characterize adequately the likely exposures of people for whom health outcome data are collected," and that "epidemiologic study of associations between exposures of interest and outcomes of interest will not produce valid results."[1(p52)] That same year, the DoD convened the symposium and workshop on "Assessing Potentially Hazardous Environmental Exposures Among Military Populations" to review the status of military and VA efforts to identify, assess, address, and communicate deployment exposure information gaps.[13] Participants agreed at the time that, "we must continue to improve our ability to link defined exposures to military members who may have been exposed."[14(p7)] It was acknowledged that, "sample data are not representative of individual exposures" and that "collecting area samples [ambient environmental data] would not define the exposures for individual service members [that] was needed to make informed judgments about risks to individuals."[15(p11)] Many of the other symposium articles and panel discussions repeated these concerns.[7,8,16–21] Finally, and most recently, the IOM[2] has recognized that burn pits may not be the main cause of long-term health effects related to Iraq and Afghanistan deployment. The IOM states that, "service in Iraq or Afghanistan—that is, a broader consideration of air pollution than exposure only to burn pit emissions—might be associated with long-term health effects, particularly in highly exposed populations (eg, those who worked at the burn pit) or susceptible populations (eg, those who have asthma), mainly because of the high ambient concentrations of PM [particulate matter] from both natural and anthropogenic, including military, sources."[2(p7)]

Susceptible subpopulations are known to exist in the deployed military population. Yet, little has been done to identify and describe these subpopulations. Several unique susceptibility or risk factors in the development of chronic respiratory conditions have been identified in scientific literature. For example, the scientific literature identifies or suggests that smokers,[22,23] males,[24] asthmatics,[23,25,26] and persons with various genetic differences[27] (eg, the $\alpha_1$-antitrypsin deficiency that increases development of chronic obstructive pulmonary disease)[28] have higher risk for certain chronic respiratory conditions. Given repeated concerns regarding these unique subpopulations, identification of personnel who are "susceptible" (underlying disease or genetics) and/or who have "higher exposures" should be the focus of future enhancements to the military's exposure assessment process.

## RETHINKING EXPOSURE ASSESSMENT

Exposure assessment has been defined as "the process of estimating or measuring the magnitude, frequency, and duration of exposure to an agent in a specific exposed population."[1(p51)] It is part of the risk assessment process that is used to characterize risks of disease to specific populations that may be associated with the exposure. The resulting information is used to direct policies to prevent and mitigate exposures, focus future research needs, and in some cases direct medical interventions or surveillance.[29] Even in controlled US occupational or civilian settings, the use of current technologies, tools, and scientific models to conduct exposure assessments is not without notable limitations and uncertainties. These problems tend to be amplified by the austere *work environment* during deployment and numerous variables that reflect the exposures of deployed military personnel.[8,12–17,20,21] However, "in addressing the relationship between exposures of military personnel deployed in the Middle East theater … and the risk of adverse health effects, exposure assessment is a critical component."[1(p51)] For these reasons, the military has devoted substantial resources to the exposure assessment process over the past decade.[4,14–17,20,21]

The traditional exposure assessment process focuses on the exposure of a specific substance (eg, a chemical hazard) as experienced by an overall population. This construct ignores the numerous other external and internal factors that can impact the overall risk of a specific disease outcome that might be experienced by persons within a population (Figure 5-1). Current scientific models and data also do not tend to address the potential additive or synergistic impacts of these multiple hazards. Even when exposure assessment

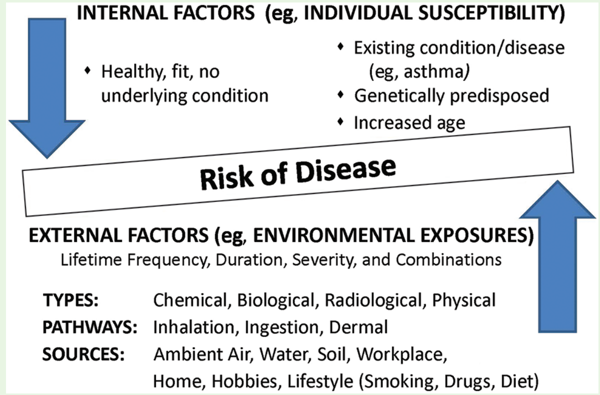


**Figure 5-1.** Factors that can impact an individual's risk of disease.

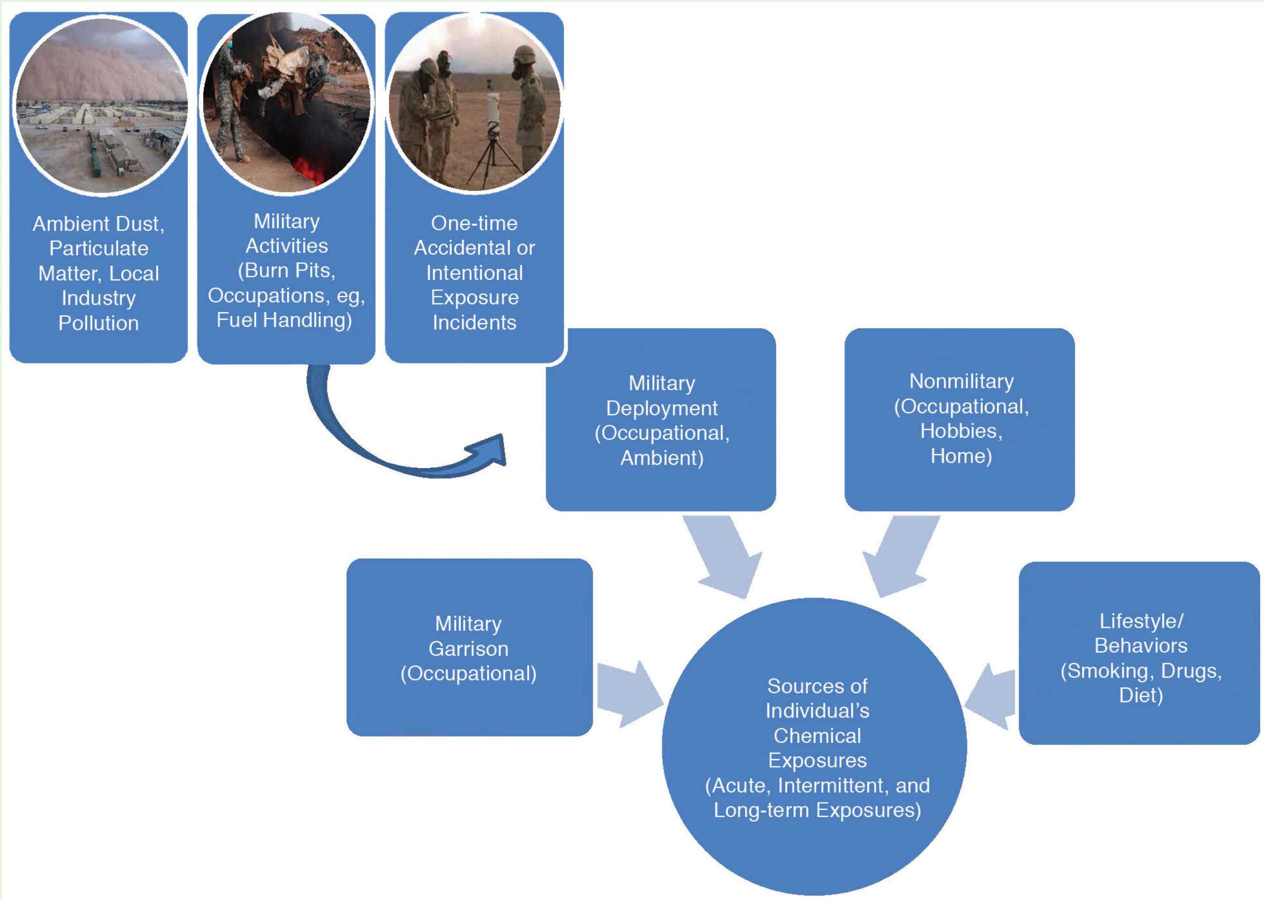


**Figure 5-2.** Deployment exposure contributes only a small part of an individual's lifelong chemical exposure profile.

attempts to address several hazards, there are numerous other types of prior, concurrent, and follow-on external stressors that may impact an individual's health condition. The environmental stressor may not reflect the combination of factors that results in an increased risk of disease. This need to consider tools that can provide information about the various contributing impacts to service members' health conditions has been previously identified[2,7,11,15,18] (Figure 5-2).

The traditional exposure assessment process itself cannot account for all factors that may influence individual health outcomes. However, the process should include identification of any subpopulations that are at higher risk of adverse health outcomes (eg, because of higher overall internal levels of the hazardous substance). Focus should shift from defining general population exposures to identifying the populations most likely to be at risk. This includes identifying and assessing the following subpopulations:

- Persons who experience hazardous exposures of greatest duration, frequency, and magnitude. Ideally, this would include consideration of key activities during *deployment* operations, as well as those experienced as part of military *garrison* occupational activities. These persons can be reflected by one or more similar exposure groups.
- Persons with lifestyle activities that may increase risk (eg, smoking history, physical fitness activities [such as poor aerobic conditioning, or alternately, frequent and high-intensity aerobic exercise that increases inhalation rate while deployed to areas with poor air quality], and/or exposures to chemicals from hobbies).
- Persons with unique susceptibilities to adverse health outcomes (eg, chronic pulmonary conditions).

The following section describes the benefits and disadvantages of different approaches for obtaining data to characterize individual exposures and relevant risk factors. Better individual data would help to identify subpopulations at greatest risk and possible prevention measures.

## DATA COLLECTION APPROACHES AND TOOLS: BENEFITS AND DISADVANTAGES

### Enhanced Environmental Monitoring

As described in Chapter 1, thousands of air, soil, and water samples have been collected during more than a decade of Operation Iraqi Freedom/Operation Enduring Freedom in southwest Asia. Data have been analyzed using peer-reviewed, state-of-the-art health risk assessment models[16,30,31] to provide summaries of typical ambient environmental exposures at deployment base camp locations.[5,6] Assessment of this environmental data has value as a screening tool to identify any substantial threats anticipated to have population-level impacts. The greatest limitation is that it cannot (or should not) be directly tied to individual service members.[1,2,4–6,14,15] Additionally, current military environmental data lack the scope and precision necessary to fully describe all the potential airborne chemical hazards and the associated temporal and spatial fluctuations. Because of the technology and resource limitations, environmental sampling also does not routinely include collection and analyses for volatile organic compounds or several irritating and acutely toxic industrial hazards, including those that represent primary US priority pollutants (eg, chlorine, ammonia, sulfur dioxide, and hydrogen sulfide). In addition, samples obtained from a larger area, such as a base camp, are generally limited in number and, therefore, cannot generally be used to describe temporal, spatial, geographic, or climate-related patterns.[2,5,14,15,20] Although improvements in this area could help to better identify major hazards or locations, these "area samples" will not provide information regarding individual exposure experiences. Furthermore, data associated with this approach would still be interpreted with a "single-hazard" assessment model.

### Personal and Occupational Monitoring

Personal monitoring—including the use of passive chemical dosimeters, personal air sampling pumps, and portable real-time detection devices—has been repeatedly discussed as a means to obtain more specific exposure data from individuals and units during deployments.[1,2,8,15–17] However, limitations of current technologies, especially in the austere military operational environments, are a recognized problem with this approach.[2,8,16,17] Technologies today are only developed for a subset of the numerous hazards present in a military setting, have high detection level and/or low confidence in results, and have numerous logistical resource needs for accurate employment. Aside from limited use of chemical agent detectors,[32] portable field devices for chemical hazards have been extremely limited and the source of substantial evaluation over the years.[16,19,33]

For the last few years, however, the US Army has attempted to conduct occupational assessments of specific personnel in deployed settings and make use of available technologies. One example involved assessment of a security unit conducting missions near a brick factory.[34] Sampling was conducted by deployed military personnel who had received equipment and guidance from subject matter experts in the United States. Interpretations of results were hindered by problems with equipment and sample collection. A more recent, and still ongoing, industrial hygiene survey is assessing occupational exposures to members of a similar exposure group at Al Shuaiba Port of Debarkation/Embarkation, Kuwait. The initial survey was conducted by a specific team of experts with dedicated equipment from the US Army Public Health Command. According to one of the team's industrial hygienists (J. Cambre, oral communication, December 2012), personal air samples were collected using passive chemical dosimeters and a multigas analyzer to investigate chemicals that had been identified as potential exposure concerns during site industrial source assessments and prior environmental data collection. The chemicals included the following:

- ammonia,
- carbon monoxide,
- chlorine,
- hydrogen sulfide,
- nitrogen dioxide, and
- sulfur dioxide.

The potential exposure sources included the surrounding Kuwaiti industries and US Army vehicle and generator exhaust. The first phase is helping to highlight critical data gaps and equipment limitations, as well as to prioritize future efforts to enhance data confidence and detail through further sampling. Although efforts of this magnitude may not be feasible at other deployment locations, lessons learned may provide insights into activity-based exposures.

Finally, although not directly related to the feasibility of implementing field technologies to obtain individual-level, deployment-related exposure data, there is the question of how to factor in occupational exposures in garrison into the overall exposure assessment process. The long-term implications of daily occupational exposures experienced by Army personnel in nondeployed settings may be as important as those experienced during deployment. Military occupational tasks and associated exposures should be considered when identifying more highly exposed subpopulations. Occupational exposure data, such as that reported in the Defense Occupational and Environmental Health Readiness–Industrial Hygiene system, may be used to help identify priority hazards, personnel, and tasks/operations.

## Biomonitoring

Biomarkers are broadly defined as measurements in biological systems or samples that are indicators of an event within the organism or compartment of the organism. There are three types of biomarkers: (1) exposure, (2) effect, and (3) susceptibility.[35] These are summarized in Table 5-1. Biomarkers are a tool to complement an overall exposure assessment process, especially where specific high-risk hazards, exposure sources, and populations have been identified. Whereas the Centers for Disease Control and Prevention reports results for more than 200 chemical biomarkers as part of its National Health and Nutrition Examination Survey, these data are for comparison reference purposes.[36] These data do not provide substantial information as to sources of exposure, the clinical significance of biomarker measurements, or actions to be taken. Because of these limitations, few public health and occupational applications require specific use of chemical biomarker data.

In military settings, biomonitoring procedures for certain exposures to lead and depleted uranium are required by policy.[37] In these cases, specific effects and medical actions are correlated to defined biomarker levels. Broader use of biomarkers by the military has been suggested.[5,14,38] The current DoD policy describes specific criteria to determine biomarkers that would be useful for military applications. Although no other biomarkers have met the criteria for assessment of deployment exposures, biomarkers that define deployment-related exposures have been attempted in several cases. Examples include the

- evaluation of Vietnam exposures to Agent Orange,[39,40]
- Gulf War assessment of depleted uranium and polycyclic aromatic hydrocarbon exposures,[16,41]
- Joint Base Balad dioxin assessment,[2,41] and
- medical assessment for chromium exposure during the Qarmat Ali chromium incident.[42]

In these cases, which all used biomarkers of exposure, the value of the results was questionable, especially given the many interpretive limitations[14,15,39,40,41] (see Table 5-1). Biomarkers of effect could facilitate medical intervention and/or provide a means for more concrete case definition. An example of a potential marker for disease that has been the subject of ongoing evaluation is the use of spirometry for lung function testing (Chapter 9, Discussion Summary: Recommendation for Surveillance Spirometry in Military Personnel). Of more recent scientific interest to the exposure science community has been the field of metabolomics and use of exposomic research to identify early indication of effect, disease, or susceptibility.[43,44]

The use of biomarkers of susceptibility has been a key area of pharmacological and medical research,[45–48] but has received lesser consideration by the military or VA.[15] Use of susceptibility biomarkers may have some relevance to better determine personnel at risk for chronic respiratory disease. Four broad types of susceptibility mechanisms particularly relevant to pulmonary health outcomes have been suggested:

1. toxicokinetic factors that affect the delivery and/or persistence of the chemical or particle in the lung,
2. regulation and resolution of inflammation and fibrogenesis,
3. immunological sensitization, and
4. biochemical (enzymatic and nonenzymatic) defense mechanisms to protect cells and tissues from oxidative stress.[27]

For example, the deficiency in the $\alpha_1$-antitrypsin enzyme is a documented susceptibility factor in the development of chronic obstructive pulmonary disease in young adult nonsmokers.[28] Ideally, biomarkers of relevance to the military would be relatively low in cost, involve minimally complex procedures, be noninvasive, and ultimately provide discrete useable data that would support prevention and/or medical treatment and surveillance objectives.

## Modeling

Modeling refers to computational air dispersion simulation tools that can be used to predictively or retrospectively estimate the direction and magnitude/extent of airborne hazards over time. Of critical importance, however, is that the air modeling tools can only be used to estimate specific substance(s) released from a known source. Current tools can incorporate satellite imagery, a variety of climate and geographic variables, and field sample results for validation or correction.[49] Tools can display results visually, for example, as plumes or wind rose plots. Air dispersion and/or plume estimation techniques and tools were used to estimate the 1991 Gulf War oil well fire plumes[16,17,50] and the 1991 Khamisayah exposures to agent sarin potentially released during munitions disposal operations.[16,51] The size of the plume exposure area investigated as part of the 2003 Al-Mishraq sulfur fire incident was determined by simplistic estimation drawn from satellite images of the smoke.[9] The use of wind rose plots to identify and prioritize sampling efforts of burn pit smoke at Joint Base Balad was evaluated by IOM.[2] The IOM discussed potential improvements to modeling of burn pits so that average concentrations could be estimated over time to describe possible exposure gradients. However, the quality of this information would depend on better knowledge of the types and quantities of materials burned, as well as more detailed individual activities and locations. Perhaps of greater consideration is that modeling of a burn pit would not address other possible sources of concurrent exposure. Furthermore, as concluded by the IOM, burn pits may not be the main cause of long-term health effects related to Iraq and

**TABLE 5-1**

**SUMMARY OF BENEFITS AND ADVANTAGES**

| Approach/Tool | Applications/Possible Benefits to Improve Individual Assessments | Possible Disadvantages and/or Limitations |
|---|---|---|
| **Environmental monitoring** | Cost-effective approach to broadly assess population exposures to certain widespread hazards, such as particulate matter<br><br>Use of continuous air monitoring systems at deployment locations has been employed at one location (SPOD/E, Kuwait) | Does not provide individual data<br><br>Technology and resource limitations include gaps in hazards of concern (eg, VOCs, irritating and acutely toxic industrial hazards, priority pollutants [chlorine, ammonia, sulfur dioxide, and hydrogen sulfide]), and gaps in quantifying exposure variations (eg, temporal, spatial, geographic, or climate-related differences) |
| **Occupational and personal monitoring** | Can provide individual exposure data<br><br>Recent/ongoing attempts pave the way for prioritizing follow-on assessment of personal occupational activities and/or hazards<br><br>Helps focus priority needs for future military capabilities and technology improvements<br><br>Garrison-based industrial hygiene surveys and exposure assessments may be used to help identify at-risk groups | Technology and resource limitations:<br>• not available for many chemicals<br>• detection levels not always quantifiable<br>• low confidence in results (false-negatives and false-positives)<br>• lack of criteria for interpretation of health impact<br>• substantial cost and logistics to use in field |
| **Biomarkers of exposure** | Individual data (direct internal measurement of the chemical hazard or its metabolite[s], or indirect measurement of an interaction between the chemical and some target molecule[s] or cell[s])<br><br>Possibly could be used to identify subpopulations at higher risk for disease outcome and/or to categorize degree of exposure relative to US population norms or to other deployed personnel results<br><br>Current military applications include lead and DU biomonitoring | Lack of inferable significance of measurement (generally cannot define exposure source OR indicate adverse effect or susceptibility)<br><br>Measurements specific for a single chemical hazard<br><br>Depending on the properties of the substance (eg, biological half-life) and environmental conditions, all or some of the substance and its metabolites may leave the body prior to sample collection<br><br>Burden of a substance may be the result of exposures from more than one source<br><br>External as well as internal (eg, essential mineral nutrients) |

(**Table 5-1** *continues*)

**Table 5-1** *continued*

| | | |
|---|---|---|
| **Biomarkers of effect**<br>Measurements of biochemical, physiological, or other alteration within an organism that, depending on magnitude, can be recognized as an established or potential health impairment or disease | Individual data can possibly be used to identify subpopulations at higher risk for disease outcome<br><br>Utility of lung function testing (spirometry) is an example being evaluated<br><br>Can be used to support standard case definitions and diagnosis<br><br>Can be used to identify effect that might be caused or influenced by multiple separate exposure types<br><br>Would not need to be implemented in the field; greater time and logistics flexibility | Does not generally indicate specific exposures/not often substance-specific<br><br>May not be directly adverse, but can indicate potential health impairment (eg, DNA adducts) |
| **Biomarkers of susceptibility**<br>Indicators of an inherent or acquired limitation of an organism's ability to respond to the challenge of exposure to a specific substance | Individual data; can also be used to help identify subpopulations at higher risk for disease outcome<br><br>Avoids need to infer impacts from single exposure pathway<br><br>Would not need to be implemented in the field; greater time and logistical flexibility | Does not address specific exposures<br><br>Knowledge of susceptibilities may be associated with legal or ethical concerns |
| **Modeling** | Can be used to estimate gradients of average levels resulting from a known source at various locations<br><br>Can be enhanced by sample data | Not intended to define individual exposures, with the limited possible exception of case-specific use to rule out or verify the plausibility of substantial exposures to a specific source if adequate source and personal location data were available<br><br>Hazard source-specific<br><br>Requires accurate information regarding types and quantities of hazards (eg, materials in a burn pit) and release processes (eg, temperatures of fires)<br><br>Many models exist and can produce different results |
| **Self-reported data**<br>(questionnaires, surveys) | Mechanism design to capture individual data<br><br>Can address many data gaps<br><br>Flexibility for different applications<br><br>Relatively inexpensive | Potential recall bias<br><br>Data are subjective surrogate for objective measure of exposure<br><br>Time and logistical constraints; ideally electronic system is needed<br><br>Personal and privacy issues regarding collection, storage, and use of data |

DNA: deoxyribonucleic acid; DU: depleted uranium; SPOD/E: Shuaiba Port of Debarkation/Embarkation; VOCs: volatile organic compounds

Afghanistan deployment, but the IOM states that, "service in Iraq or Afghanistan—that is, a broader consideration of air pollution than exposure only to burn pit emissions—might be associated with long-term health effects."[2(p7)]

## Self-Reporting Tools

Self-reporting tools include questionnaires and surveys that are either provided to service members to complete or used by providers or researchers to ask patients/study participants about their past exposures. Benefits and key limitations, such as recall bias for use in military exposure assessments, have been assessed.[7,12] However, as described in Appendix A (A Self-Reporting Tool to Collect Individual Data for Respiratory Health Effects and Military Airborne Exposures) of this book, the use of self-reported exposure data in public health research and occupational applications has been long utilized by various national and international research and occupational entities. The military has also continuously relied on such tools; numerous questionnaires have been developed and used to collect exposure-related data with various cohorts of Gulf War veterans.[7,12,18,52–55] Current DoD policy requires use of Post-Deployment Health Assessment forms and Post-Deployment Health Reassessment forms that include questions about exposures experienced while deployed.[52] These forms, however, are for screening purposes and do not provide detailed information regarding magnitude, duration, and frequency of chemical exposures experienced or other relevant activities. Several studies of service members and veterans of the more recent and current operations have been conducted as part of the Millennium Cohort Study,[7] which utilizes self-reported occupational exposures as a source of *exposure assessment* information. Study investigators have noted the critical need for obtaining quantified measures of individual exposure and also that, "retrospective self-reported assessment of exposure is a viable option if designed in such a way that exposures and health outcomes are not collected simultaneously."[7(p60)] These Millennium Cohort Study investigators, as well as others,[2,56] have specifically recommended efforts to establish a standardized self-reported exposure assessment tool to be used across services and by the VA. Such a tool could improve case identification in clinical applications, as well as provide additional delineation of potentially higher risk factors and associated subgroup populations among deployed personnel. Appendix A provides a specific example of a library of questions that could be used to serve as a basis for future applications.

## SUMMARY

The relationship between exposures experienced while deployed in southwest Asia and chronic respiratory effects is considered plausible, yet remains unproven. However, experts seem to agree that some persons may be at greater risk to develop these health outcomes because of their unique susceptibilities and exposures. Use of periodic, large-scale ambient environmental sampling will not help us identify these persons or their risk factors.

To better address the medical and deployment health issues faced by the DoD and the VA, the traditional concept of exposure assessment should be evaluated more broadly. Specifically, the collection of data that would help distinguish higher risk activities and/or susceptibilities to identified adverse health outcomes of interest should become a greater priority. No single approach or tool can address all the gaps in our understanding of an individual's unique exposure history. However, certain tools alone or in combination could be used to increase our understanding of individual military exposures, as well as key confounding factors and susceptibilities that may result in a higher risk of chronic respiratory conditions.

The approaches that would most effectively differentiate individual exposure variation and higher risk subpopulations should be priorities for future research, field work, and medical evaluation protocols. Areas of promise include the following:

- personal monitoring and occupational activity exposure assessment,
- biomarkers (especially of effect and susceptibility), and
- establishment and implementation of standardized self-reporting tools.

Ongoing field industrial hygiene efforts could be evaluated as a means to identify technological enhancements needed for personal monitoring and/or to help identify priority hazards or higher risk (exposure) military occupational activities. However, individual sample results for a single hazard from a single activity period will not adequately address the complex interaction of lifetime external stressors, and exposures and individual susceptibilities. Biomarker research has come a long way. Instead of biomarkers of exposure, research should perhaps focus more on applications and technologies for biomarkers of effect and susceptibility. Finally, use of a consistent set of standardized questions related to exposure and health history (such as those provided in Appendix E, Frequently Asked Questions About Military Exposure Guidelines) should be considered across services and agencies for future public health research, as well as clinical applications.

## REFERENCES


1. National Research Council. *Review of the Department of Defense Enhanced Particulate Matter Surveillance Program Report.* Washington, DC: The National Academies Press; 2010.

2. Institute of Medicine. *Long-Term Health Consequences of Exposure to Burn Pits in Iraq and Afghanistan.* Washington, DC: The National Academies Press; 2011.

3. US Department of the Army. *Summary of Evidence Statement: Chronic Respiratory Conditions and Military Deployment*. Aberdeen Proving Ground, MD: US Army Public Health Command; 2011. Factsheet 64-018-1111.

4. Baird CP. The basis for and uses of environmental sampling to assess health risk in deployed settings. *Mil Med*. 2011;176(suppl 7):84–90.

5. US Department of the Army. *The Periodic Occupational and Environmental Monitoring Summary (POEMS)—History, Intent, and Relationship to Individual Exposures and Health Outcomes*. Aberdeen Proving Ground, MD: US Army Public Health Command; 2010. Technical Information Paper 64-002-1110.

6. US Department of the Army. *Documentation of Deployment Exposures and the Periodic Occupational Environmental Monitoring Summary (POEMS) Information for Preventive Medicine Personnel*. Aberdeen Proving Ground, MD: US Army Public Health Command (Provisional); 2010. Factsheet 64-010-0410.

7. Smith TC, Millennium Cohort Study Team. Linking exposures and health outcomes to a large population-based longitudinal study: the Millennium Cohort Study. *Mil Med*. 2011;176(suppl 7):56–63.

8. Riddle M, Lyles M. Panel 4: linking service members and exposure data to support determination of risk-proceedings of an educational symposium on assessing potentially hazardous environmental exposures among military populations. *Mil Med*. 2011;176(suppl 7):105–109.

9. Baird CP, DeBakey S, Reid L, et al. Respiratory health status of US Army personnel potentially exposed to smoke from 2003 Al-Mishraq Sulfur Plant fire. *J Occup Environ Med.* 2012;54:717–723.

10. Abraham JH, Debakey SF, Reid L, et al. Does deployment to Iraq or Afghanistan affect respiratory health of US military personnel? *J Occup Environ Med.* 2012;54:740–745.

11. Committee on Strategies to Protect the Health of Deployed U.S. Forces. *Protecting Those Who Serve: Strategies to Protect the Health of Deployed U.S. Forces*. Washington, DC: The National Academies Press; 2000.

12. Glass DC, Sim MR. The challenges of exposure assessment in health studies of Gulf War veterans. *Phil Trans R Soc Lond B Biol Sci.* 2006;361(1468):627–637.

13. US Department of Defense. Proceedings of the 2010 symposium "Assessing Potentially Hazardous Environmental Exposures Among Military Populations," May 19–21, 2010, Bethesda, Maryland. *Mil Med*. 2011;176(suppl 7):1–112.

14. Gaydos JC. Military occupational and environmental health: challenges for the 21st century. *Mil Med*. 2011;176(suppl 7):5–8.

15. Mallon TM. Progress in implementing recommendations in the National Academy of Sciences reports: "Protecting Those Who Serve: Strategies to Protect the Health of Deployed U.S. Forces." *Mil Med*. 2011;176(suppl 7):9–16.

16. Richards EE. Responses to occupational and environmental exposures in the U.S. military—World War II to the present. *Mil Med*. 2011;176(suppl 7):22–28.

17. DeFraites RF, Richards EE. Assessing potentially hazardous environmental exposures among military populations: 2010 symposium and workshop summary and conclusions. *Mil Med*. 2011;176(suppl 7):17–21.

18. Brix K, O'Donnell FL. Panel 1: medical surveillance prior to, during, and following potential environmental exposures. *Mil Med*. 2011;176(suppl 7):91–96.

19. Lioy PJ. Exposure science for terrorist attacks and theaters of military conflict: minimizing contact with toxicants. *Mil Med*. 2011;176(suppl 7):71–76.

20. Martin NJ, Richards EE, Kirkpatrick JS. Exposure science in U.S. military operations: a review. *Mil Med*. 2011;176(suppl 7):77–83.

21. Batts R, Parzik D. Panel 3: conducting environmental surveillance sampling to identify exposures. *Mil Med*. 2011;176(suppl 7):101–104.

22. Smith B, Ryan MA, Wingard DL, et al. Cigarette smoking and military deployment: a prospective evaluation. *Am J Prev Med*. 2008;35:539–546.

23. Global Initiative for Chronic Obstructive Lung Disease (GOLD). *Global Strategy for the Diagnosis, Management and Prevention of COPD.* Bethesda, MD: National Heart, Lung and Blood Institute; February 2013.

24. Yancey AL, Watson HL, Cartner SC, Simecka JW. Gender is a major factor in determining the severity of mycoplasma respiratory disease in mice. *Infect Immun*. 2001;69:2865–2871.

25. London SJ. Gene–air pollution interactions in asthma. *Proc Am Thorac Soc*. 2007;4:217–220.

26. Silva GE, Sherrill DL, Guerra S, Barbee RA. Asthma as a risk factor for COPD in a longitudinal study. *Chest*. 2004;126:59–65.

27. Nemery B, Bast A, Behr J, et al. Interstitial lung disease induced by exogenous agents: factors governing susceptibility. *Eur Respir J Suppl*. 2001;18:30s–42s.

28. Sandford AJ, Silverman EK. Chronic obstructive pulmonary disease. 1. Susceptibility factors for COPD the genotype–environment interaction. *Thorax*. 2002;57:736–741.

29. Abt E, Rodricks JV, Levy JI, et al. Science and decisions: advancing risk assessment. *Risk Anal*. 2010;30:1028–1036.

30. National Research Council. *Review of the Army's Technical Guides on Assessing and Managing Chemical Hazards to Deployed Personnel*. Washington, DC: National Academies Press; 2004.

31. US Department of the Army. *Environmental Health Risk Assessment and Chemical Exposure Guidelines for Deployed Military Personnel*. Aberdeen Proving Ground, MD: US Army Public Health Command (Provisional); 2010. Technical Guide 230.

32. Sferopoulos R. *A Review of Chemical Warfare Agent (CWA) Detector Technologies and Commercial-Off-The-Shelf Items*. Victoria, Australia: Human Protection and Performance Division, Defence Science and Technology Organisation; March 2009. Report DSTO-GD-0570.

33. US Department of the Army. *Health-Based Chemical Vapor Concentrations Levels for Future Systems Acquisition and Development*. Aberdeen Proving Ground, MD: US Army Center for Health Promotion and Preventive Medicine (now the US Army Public Health Command); February 2008. Technical Report 64-FF-07Z2-07.

34. US Department of the Army. *Medical Assessment of Air Quality at Narhwan Brick Factory and FOB Hammer in Iraq (2008-9)*. Aberdeen Proving Ground, MD: US Army Public Health Command; 2012. Factsheet 64-023-0412.

35. National Research Council. *Biological Markers in Pulmonary Toxicology*. Subcommittee on Reproductive and Neurodevelopmental Toxicology, Committee on Biologic Markers. Washington, DC: National Academies Press; 1989.

36. US Department of Health and Human Services. *Fourth National Report on Human Exposure to Environmental Chemicals, Updated Tables, March, 2013*. National Biomonitoring Program. Atlanta, GA: Centers for Disease Control and Prevention; 2013.

37. US Department of Defense. *Department of Defense Deployment Biomonitoring Policy and Approved Bioassays for Depleted Uranium and Lead*. Washington, DC: Under Secretary of Defense (Personnel and Readiness); February 2004. DOD Memorandum (HA Policy: 04-004).

38. May LM, Weese C, Ashley DL, et al. The recommended role of exposure biomarkers for the surveillance of environmental and occupational chemical exposures in military deployments: policy considerations. *Mil Med*. 2004;169:761–767.

39. Young AL, Cecil PF Sr. Agent Orange exposure and attributed health effects in Vietnam veterans. *Mil Med*. 2011;176(suppl 7):29–34.

40. Brown MA. Science versus policy in establishing equitable Agent Orange disability compensation policy. *Mil Med*. 2011;176(suppl 7):35–40.

41. Deeter DP. The Kuwait Oil Fire Risk Assessment Biological Surveillance Initiative. *Mil Med*. 2011;176(suppl 7):52–55.

42. US Department of the Army. *Health Assessment of 2003 Qarmat Ali Water Treatment Plant Sodium Dichromate Incident Status Update: May 2010*. Aberdeen Proving Ground, MD: US Army Public Health Command (Provisional); 2010. Factsheet 64-012-0510.

43. Rappaport SM. Implications of the exposome for exposure science. *J Expo Sci Environ Epidemiol*. 2011;21:5–9.

44. Lioy PJ, Rappaport SM. Exposure science and the exposome: an opportunity for coherence in the environmental health sciences. *Environ Health Perspect*. 2011;119:A466–A467.

45. Mayr M. Metabolomics: ready for the prime time? *Circ Cardiovasc Genet*. 2008;1:58–65.

46. Jian ZH, Rommereim DN, Minard KR, et al. Metabolomics in lung inflammation: a high-resolution $^{1}$H NMR study of mice exposed to silica dust. *Toxicol Mech Methods*. 2008;18:385–398.

47. Aich P, Potter AA, Griebel PJ. Modern approaches to understanding stress and disease susceptibility: a review with special emphasis on respiratory disease. *Int J Gen Med*. 2009;2:19–32.

48. Lash LH, Hines RN, Gonzalez FJ, et al. Genetics and susceptibility to toxic chemicals: do you (or should you) know your genetic profile? *J Pharmacol Exp Ther*. 2003;305:403–409.

49. US Environmental Protection Agency. *Evaluation of Chemical Dispersion Models Using Atmospheric Plume Measurements from Field Experiments*. Research Triangle Park, NC: USEPA; September 2012. Final Report. EPA Contract EP-D-07-102.

50. Heller JM. Oil well fires of Operation Desert Storm—defining troop exposures and determining health risks. *Mil Med*. 2011;176(suppl 7):46–51.

51. US Department of Defense. *Case Narrative: US Demolition Operations at Khamisiyah*. Washington, DC: Assistant Secretary of Defense (Health Affairs) and Special Assistant to the Under Secretary of Defense (Personnel and Readiness) for Gulf War Illnesses, Medical Readiness, and Military Deployments; April 2002. Final Report.

52. US Department of Defense. *Post Deployment Health Assessment*. Washington, DC: Assistant Secretary for Defense (Health Affairs); March 2005. DOD Memorandum.

53. Helmer DA, Rossignol M, Blatt M, et al. Health and exposure concerns of veterans deployed to Iraq and Afghanistan. *J Occup Environ Med*. 2007;49:475–480.

54. Quigley KS, McAndrew LM, Almeida L, et al. Prevalence of environmental and other military exposure concerns in Operation Enduring Freedom and Operation Iraqi Freedom veterans. *J Occup Environ Med*. 2012;54:659–664.

55. Proctor SP. *Development of a Structured Neurotoxicant Assessment Checklist (SNAC) for Clinical Use in Veteran Populations*. Boston, MA: Department of Veterans Affairs, VA Boston Healthcare System; 2006.

56. Rose C, Abraham J, Harkins D, et al. Overview and recommendations for medical screening and diagnostic evaluation for postdeployment lung disease in returning US Warfighters. *J Occup Environ Med*. 2012;54:746–751.