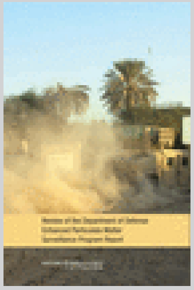

Review of the Department of Defense Enhanced Particulate Matter Surveillance Program Report

ISBN
978-0-309-15413-0

106 pages
6 x 9
PAPERBACK (2010)

Committee for Review of the DOD's Enhanced Particulate Matter Surveillance Program Report; National Research Council

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Board on Environmental Studies and Toxicology

Division on Earth and Life Studies

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This project was supported by Contract No. W81K04-06-D-0023 between the National Academy of Sciences and the U.S. Army. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the authors and do not necessarily reflect the view of the organizations or agencies that provided support for this project.

International Standard Book Number-13: 978-0-309-15413-0
International Standard Book Number-10: 0-309-15413-8

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Preface

Soldiers deployed during the 1991 Persian Gulf War returned from deployment with complaints of persistent respiratory symptoms. Several studies have shown an association between deployment to the gulf region during the war and various respiratory outcomes. In an effort to understand and characterize the environmental exposures of military personnel in the Middle East, the Department of Defense (DOD) initiated sampling of air, water, and soil at the beginning of military operations in Afghanistan in 2001 and Iraq in 2003. The most common ambient airborne pollutant measured was particulate matter, which has been shown to be associated with risks of premature mortality and morbidity.

To address concerns about the ambient environment in the Middle East, DOD designed and implemented the Enhanced Particulate Matter Surveillance Program to characterize and quantify the particulate matter at 15 sites in the Central Command Area of Operations in the Middle East. In 2009, the U.S. Army asked the National Research Council to review a report on the program titled *Final Report: Department of Defense Enhanced Particulate Matter Surveillance Program (EPMSP)*. The National Research Council's Board on Environmental Studies and Toxicology convened the Committee for Review of the DOD's Enhanced Particulate Matter Surveillance Program Report, which produced the present document. The committee members had expertise in exposure assessment, analytic methods, inhalation toxicology, epidemiology, and occupational health.

In its review of the DOD EPMSP report, the committee was specifically asked to address the approaches to sampling and analysis, site-specific differences in particulate-matter concentrations, and the potential acute and chronic health implications for deployed personnel based on the particle mass concentration and chemical composition data presented. The committee's review included consideration of epidemiologic investigations and health-surveillance information collected by the U.S. Army on deployed personnel presented to the committee during its first meeting. The committee was also asked to make recommendations for reducing or better characterizing health risks and for improving epidemiologic investigations.

The present report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise in accordance with procedures approved by the National Research Council's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards of objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report: Robert Burr, Wasatch Endocrinology and Diabetes Specialists; Judith C. Chow, Desert Research Institute; J. Timothy Dvonch, University of Michigan; John. M. Ondov, University of Maryland; Jonathan M. Samet, University of Southern California; Jeremy A. Sarnat, Emory University; Richard B. Schlesinger, Pace University; and Paul J. Villeneuve, Health Canada.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of the report was overseen by Samuel Kacew, University of Ottawa. Appointed by the National Research Council, he was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of the report rests entirely with the authoring committee and the institution.

The committee gratefully acknowledges the following for making presentations to the committee: Joseph Abraham, Coleen Baird, Ronald Ross, and James Sheehy, U.S. Army Center for Health Promotion and Preventive Medicine; William Darby, U.S. Army Medical Department Center and School; Alan Gertler, Desert Research Institute; Alan Peterson, University of Texas Health Science Center at San Antonio; and Michael G. Stockelman, Naval Health Research Center Environmental Health Effects Laboratory.

The committee is also grateful for the assistance of the National Research Council staff in preparing this report. Staff members who contributed to the effort are Heidi Murray-Smith, project director; Eileen Abt, senior program officer; James Reisa, director of the Board on Environmental Studies and Toxicology; Norman Grossblatt, senior editor; Mirsada Karalic-Loncarevic, manager, Technical Information Center; Radiah Rose, manager, editorial projects; and Panola Golson, program associate.

I would especially like to thank the members of the committee for their efforts throughout the development of this report.

Mark J. Utell, *Chair*
Committee for Review of the DOD's
Enhanced Particulate Matter Surveillance
Program Report

Abbreviations

AA	atomic absorption
AC	automated colorimetry
BALF	bronchoalveolar lavage fluid
CCSEM	computer-controlled scanning electron microscopy
DOD	Department of Defense
DRI	Desert Research Institute
EC	elemental carbon
EDXRF	energy dispersive x-ray fluorescence
EPA	U.S. Environmental Protection Agency
EPMSP	Enhanced Particulate Matter Surveillance Program
FEV_1	forced expiratory volume in the first second
FVC	forced-vital capacity
IC	ion chromatography
ICP-MS	inductively coupled plasma-mass spectrometry
ICP-OES	inductively coupled plasma-optical emission spectrometry
MEG	Military Exposure Guideline
NRC	National Research Council
OC	organic carbon
PM	particulate matter
QA	quality assurance
SEM	scanning electron microscopy
TOR	thermal optical reflectance
TOT	thermal optical transmission
TSP	total suspended particulates
USACHPPM	U.S. Army Center for Health Promotion and Preventive Medicine
XRD	x-ray diffraction
XRF	x-ray fluorescence

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Review of the Department of Defense Enhanced Particulate Matter Surveillance Program Report

Summary

Soldiers deployed during the 1991 Persian Gulf War were exposed to high concentrations of particulate matter (PM) and other airborne pollutants. Their exposures were largely the result of daily windblown dust, dust storms, and smoke from oil fires. On returning from deployment, many veterans complained of persistent respiratory symptoms. Studies of other populations have suggested that the increase in reported respiratory effects might be attributable, in part, to PM, among other exposures. With the renewed activity in the Middle East over the last few years, deployed military personnel are again exposed to dust storms and daily windblown dust in addition to other types of PM, such as diesel exhaust and particles from open-pit burning. At the beginning of military operations in Afghanistan in 2001 and in Iraq in 2003, the Department of Defense (DOD) initiated sampling of air, water, and soil to characterize the deployment environment where military personnel were stationed in the Middle East, including Egypt and central Asia. The most common airborne-pollutant measured was ambient PM. On the basis of the high concentrations observed and concerns about the potential health effects, DOD designed and implemented a study to characterize and quantify the PM in the ambient environment at 15 sites in the Middle East. The endeavor is known as the DOD Enhanced Particulate Matter Surveillance Program (EPMSP).

PARTICULATE-MATTER EXPOSURES IN THE MIDDLE EAST

Airborne PM concentrations are commonly measured as PM_{10} (particles less than 10 µm in diameter) and $PM_{2.5}$ (fine particles, less than 2.5 µm in diameter) and less frequently as total suspended particulates (TSP). In the United States, sources of coarse particles (2.5-10 µm in diameter) include resuspension of soil from roads and streets; disturbance of soil and dust by agricultural, mining, and construction operations; and ocean spray. Sources of fine particles include emissions generated by motor-vehicle combustion, smelters, and steel mills. In the Middle East, major sources of particles may differ from those in the United States and other industrialized regions, where fossil-fuel combustion and vehicle emissions are the primary sources of PM. Some studies conducted in the

Middle East indicate higher concentrations of both PM_{10} and $PM_{2.5}$ than in the United States and Europe. That may be partially explained by the resuspension of dust and soil from the desert floor, but there also may be substantial pollutant contributions from such combustion sources as traffic (for example, diesel emissions) and industry.

In humans, airborne PM in the ambient environment is deposited in the airways; PM_{10} reaches the upper airway and lung, and $PM_{2.5}$ penetrates deeper and reaches the alveolar region of the lung. A large body of epidemiologic research has shown associations between short-term and long-term exposures to PM and a broad array of respiratory and cardiovascular effects in the general population and in susceptible people. The risk of various adverse health outcomes increases with exposure concentration, and there is little evidence of a concentration below which no adverse health effects are observed. However, despite the quantity of evidence, the health effects of PM in the relatively healthy, active military personnel deployed in the Middle East have not been well characterized. That may be due in part to the difficulty of conducting an exposure-assessment and health-surveillance study in a military zone, where such efforts are not essential to the military mission; there are a limited number of personnel and resources available to conduct the studies, and extreme and variable temperatures and lack of electricity create challenges in collecting ambient samples. In addition, difficulties in characterizing the multiple sources (dust storms, vehicle emissions, and emissions from burn pits) to which troops are exposed and the frequent movement of troops create challenges for health surveillance. Finally, because of differences in the concentrations and composition of PM and differences in the population of deployed military personnel, extrapolating from population-based epidemiologic studies in the United States and Europe to military populations deployed to the Middle East may not be valid.

THE DEPARTMENT OF DEFENSE ENHANCED PARTICULATE MATTER SURVEILLANCE PROGRAM

In 2005, the assistant secretary of defense for health affairs chartered the Joint Particulate Matter Working Group to identify the potential health risks associated with exposure to PM. In September of that year, a symposium was held at the National Institute for Occupational Safety and Health to review sampling results, potential health effects, and knowledge gaps pertaining to PM exposures of military personnel in the Middle East. It was concluded that there was a dearth of data to answer fundamental questions, so several suggestions were made, including the conduct of enhanced particulate-matter surveillance, performance of routine predeployment and postdeployment health evaluations, improvement in the collection of disease and non-battle-injury data, conduct of an epidemiologic study of potential adverse health effects of exposures to PM in

Middle East areas of operation, and assessment of the effects of particulate matter to which deployed personnel are exposed.

In response to an identified data need, the EPMSP was designed and implemented by the U.S. Army Center for Health Promotion and Preventive Medicine (USACHPPM)[1]. Fifteen sites in the Middle East were selected for sampling because of potential exposures of military personnel. At each location, military preventive-medicine or public-health personnel stationed at the sites followed sampling protocols and collected PM (TSP, PM_{10}, and $PM_{2.5}$) and bulk soil samples. Data were collected for 12 months in 2006-2007.

The U.S. Army asked the National Research Council to review the EPMSP report (Appendix D is a copy of the EPMSP report). In its evaluation, the National Research Council was asked to consider the potential acute and chronic health implications on the basis of information presented in the report. It was also asked to consider epidemiologic and health-surveillance data collected by the USACHPPM, to assess potential health implications for deployed personnel, and to make recommendations for reducing or characterizing health risks. In response, the National Research Council convened the Committee for Review of the DOD's Enhanced Particulate Matter Surveillance Program Report, which prepared the present report.

SAMPLING DESIGN AND ANALYTIC METHODS

At each of the 15 sites[2] studied by the EPMSP, TSP, PM_{10}, and $PM_{2.5}$ samples were collected with MiniVol particle samplers. Three types of particle filters were used at each site (Teflon, quartz fiber, and Nuclepore[3]), and the three types were analyzed with different methods. Samples were collected on a 1-day-in-6 sampling schedule in which one sample set[4] was collected on a given sampling day. During a period of 1 month, there were two sampling days each for Teflon and quartz-fiber filters and one sampling day for Nuclepore filters.

Teflon and quartz-fiber filters were analyzed for mass concentration. Chemical analyses conducted on the filters included analyses for elements, soluble anions and cations, and carbon and carbonate. Individual particles were also characterized. At each of the 15 sites, one bulk sample was collected from the top layer of soil. Those samples were air-dried, and a subsample was taken for

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[1]At the time of this publication, USACHPPM was in the process of changing its name to U.S. Army Public Health Command (Provisional).

[2]The 15 sites were in the following countries: Djibouti (one), Afghanistan (two, in Bagram and Khowst), Qatar (one), United Arab Emirates (one), Iraq (six, in Balad, Baghdad, Tallil, Tikrit, Taji, and Al Asad), and Kuwait (four, in northern, central, coastal, and southern Kuwait).

[3]The three types of filters were used to conduct various PM and chemical analyses.

[4]A sample set consisted of TSP, PM_{10}, and $PM_{2.5}$ samples collected on one of the three types of filters.

soil chemistry, elemental composition, and mineral content. The analytic approaches used in the study were appropriate, standard methods that have been extensively used for analysis of ambient-aerosol samples.

The DOD EPMSP report presents the mass and chemical analytic data collected. The program found that PM concentrations exceeded the USACHPPM 1-year Military Exposure Guideline concentration of 15 $\mu g/m^3$ for $PM_{2.5}$. The chemical composition of the particles was related to the area's geology and generally showed high concentrations of crustal materials, such as calcium and silicon. Metals, such as lead and zinc, were also identified. The EPMSP report concluded that PM "dusts" were similar in composition to those from regions in the United States that are substantially impacted by geologic material and that the three likely primary sources of air pollution were geologic dust, burn pits, and sources of metals, such as lead-smelting and manufacturing sites, although the actual sources of air pollution and their relative contributions were not confirmed. Few specifics on the quality-control and quality-assurance procedures used in collecting and analyzing the data are presented in the EPMSP report.

DEPARTMENT OF DEFENSE HEALTH-EFFECTS STUDIES

In addition to the data collected in the EPMSP, the USACHPPM conducted two epidemiologic studies that examined acute and chronic outcomes and a medical-surveillance project to investigate the potential for adverse health effects of exposure to PM during military deployment in the Middle East. Toxicologic studies were conducted by the Navy to test specific hypotheses related to the exposures that may be encountered in the field.[5]

One of the epidemiologic studies described by USACHPPM used a case-crossover design to evaluate the association between daily average $PM_{2.5}$, PM_{10}, and TSP concentrations collected at the 15 sites in the EPMSP and cardiovascular and respiratory health outcomes on the basis of data collected from various military medical-record databases. No statistically significant associations were found between any of the PM metrics and the health outcomes. The study authors concluded that the results were difficult to interpret because the study suffered from a lack of statistical power owing to a paucity of health-outcome events and exposure data. The second epidemiologic study used a retrospective cohort design to examine the association between time-weighted average $PM_{2.5}$ and PM_{10} collected in the EPMSP and postdeployment cardiovascular or respiratory disease diagnoses in a cohort defined by deployment and location data. No

[5]The epidemiologic, health-surveillance, and toxicologic studies were presented to the committee at its first meeting: Abraham, J. 2009. Deployment-related Exposure to Particulate Matter and Medical Encounters for Respiratory and Circulatory Health Outcomes. Ross, R. 2009. Overview of Respiratory Function Assessment to Date in Deployed Units. Stockelman, M. 2009. Overview of Inhalational Toxicology Studies Using EPMS Particulate Matter.

statistically significant increases in diagnosis rates were found after adjustment for many confounding factors. The data were limited by potential exposure and outcome misclassification and by a relatively short followup period after deployment.

The USACHPPM's pilot medical-surveillance project was conducted at one military site and used spirometry to assess potential respiratory effects after exposures to PM. Mean postdeployment forced vital capacity and forced expiratory volume in 1 second were not significantly different from predeployment values. However, this study also suffered from inadequate statistical power and a lack of specific exposure data.

The Navy's toxicologic studies included an evaluation of the potential for desert sand to induce pulmonary and systemic injury after exposure; exposures were benchmarked against silica as a positive control and titanium dioxide as a negative control. The Navy also evaluated the potential for cigarette smoke to potentiate injury caused by desert sand. The data showed that high-dose exposures to desert sand caused modest injury that appeared transient, as much of the short-term injury resolved following long-term monitoring. The injury and inflammation from cigarette smoke were substantially greater than injury following exposure to desert sand.

CONCLUSIONS AND RECOMMENDATIONS

The DOD EPMSP was an ambitious effort, as it was one of the first studies to measure and characterize exposures to PM in an effort to assess the health effects on military personnel in the Middle East. The committee applauds the DOD's ability to carry out such a large-scale exposure-monitoring study in the midst of a military operation, despite the inherent challenges that result from a harsh climate and a lack of personnel and resources. The results of the EPMSP provide the basis for planning future exposure monitoring efforts that can be tied to health-effects studies, and it can and should serve as a precedent for future research and surveillance.

Although the ability to conduct such a study is a critical milestone, the design and conduct of the EPMSP and health-effects studies limit their usefulness.[6] The EPMSP achieved data recovery of 88%, which is impressive in light of the challenges of implementing protocols and operating samplers in a Middle East war zone. In addition, the sampling design and analysis captured many of the important physical and chemical properties of PM that have been shown in previous studies to affect health outcomes. The EPMSP, however, did not clearly articulate its objectives a priori, nor did it demonstrate how the sampling design and analyses would address these objectives. The MiniVol sampler, although

[6]The committee acknowledges that the monitoring study may not have been designed for the purpose of conducting health-effects studies, and it did not review the statement of work that DOD gave to the Desert Research Institute for conduct of the monitoring study.

evaluated in the United States, has not been validated at the high PM concentrations observed in this study, for example, through collection of replicate samples. The sampling strategy, which was designed to collect only one set of filters at a time, collected insufficient particle mass and species data on a consistent basis to be useful for quality assurance (QA) and for health-effects studies. Finally, the use of different filter media, which were analyzed with different techniques, introduces artifacts that make it difficult to compare results, so source-apportionment and mass-balance assessments are infeasible.

Although interpretation of the epidemiologic and health-surveillance studies was encumbered by uncertainties regarding the actual exposures, the small number of study subjects, and the limited amount of exposure data, the EPMSP results clearly document that military personnel deployed in the Middle East during the current Afghanistan and Iraq conflicts are exposed to high concentrations of PM and that the particle composition varies considerably over time and space.

The committee concludes that it is indeed plausible that exposure to ambient pollution in the Middle East theater is associated with adverse health outcomes. Some of the outcomes may present themselves as acute, affecting troop readiness during service, and some as chronic, occurring years after exposure. Therefore, to investigate further the health effects of exposure to a complex mixture of pollutants, the monitoring strategy needs to be tailored to the specific goals and hypotheses that future health-surveillance and research studies are designed to address. That includes matching the monitoring period with the deployment period of the military personnel being studied. In particular, different types of exposure monitoring may be required for the study of potential persistent effects, such as asthma and chronic obstructive pulmonary disease, compared to the study of acute effects, such as day-to-day variability in respiratory or cardiac responses.

Future monitoring studies need to include other ambient pollutants that military personnel may be exposed to in the field and that may be relevant to human health, such as ozone, air toxics, and other gaseous materials. In addition, more repeated sampling with the same filter type (for example, Teflon) would provide a greater library of gravimetric and chemical-specific data and thus increase statistical power. Finally, increasing the sampling frequency will make it possible to estimate more accurate annual-average concentrations of particle mass and chemical components.

OVERARCHING RECOMMENDATIONS

The committee developed several overarching recommendations that cut across the entire EPMSP, including sampling, analytic approaches, and health effects. The incorporation of these recommendations would strengthen the exposure-surveillance study design and the robustness of the health-outcome analyses.

• *In the development of future studies by the DOD, it is important that study objectives be clearly defined to ensure that the environmental-sampling strategy meets the desired study objectives.* That is, the questions that are being asked should be clearly specified a priori. Therefore, it is critical that future epidemiologic studies be undertaken in conjunction with appropriate monitoring studies so that exposure and health outcomes can be examined simultaneously.

• *The committee recognizes the difficulty of performing sampling and health studies in an active theater. However, it also recognizes that exposure sources in this environment are more complex and potentially more toxic than in the United States and Europe, where health studies are traditionally conducted. A more complete inventory of all major sources of ambient pollutants and potential emissions in the theater should be constructed before assessment of health effects to ensure that all relevant pollutants are monitored.* Such an exercise could be based mainly on an inventory of processes, substances, and materials disposed of in burn pits. Pollutants may include the criteria pollutants (fine and coarse particle mass, carbon monoxide, lead, nitrogen dioxide, ozone, and sulfur dioxide) and other hazardous air pollutants (for example, metals, selected volatile organic compounds, and PM-associated organic compounds, such as polycyclic aromatic hydrocarbons).

• *After conducting an inventory of toxicants of concern and potential sources of those toxicants, health surveillance and epidemiologic studies that investigate the consequences of those exposures could benefit greatly from coordination with other large-scale efforts that are underway.* An example is the Millennium Cohort Study, which has explored the impact of deployment on respiratory health.

• *Given the complexities of pollutant exposures and the potential acute and chronic health effects associated with these exposures, the military should consider establishing an independent multidisciplinary advisory group composed of internal and external members to provide guidance in the development and conduct of future exposure-assessment and epidemiologic studies of military personnel in combat.* The advisory group—comprising experts in statistics, analytic chemistry, exposure assessment, epidemiology, toxicology, and occupational and environmental medicine—would provide guidance on and review of study objectives, study design, protocols, and results. For example, the Ranch Hand Advisory Committee was established in 1981 by the secretary of the Department of Health and Human Services to provide oversight of the Ranch Hand Study and the Vietnam Veterans Health Study.

• *To conduct a well-designed epidemiologic study of the potential adverse health effects of exposure to PM in deployed military personnel in the current Middle East conflict, a major effort of many units and possibly multiple military branches will be required.* Such a study will be organizationally and logistically challenging, given the temporally and spatially comprehensive monitoring of PM and other pollutants and the large number of samples that would be needed.

TECHNICAL RECOMMENDATIONS

- *In designing a comprehensive monitoring scheme, a set of study objectives should be developed that provides the rationale and selection of the samplers, filter media, sampling frequency, and data-quality standards to be used.*
  - Future studies should use particle samplers that operate reliably on the basis of field testing in environmental conditions that are similar to the conditions in which they are likely to be used. For the EPMSP, such field testing was not conducted, and high PM concentrations may have led to overloading of the samplers, judging by prior results from Kuwait.
  - The frequency of sampling and the types of analyses applied to the samples should be tailored to the study objectives. Such an approach maximizes the benefits of the resources expended on the study.
  - In future monitoring studies, it is critical that QA and control procedures be implemented and specified in writing to ensure the integrity of the samples collected and analyzed.
    - Replicate samples should be collected at selected sites during future monitoring efforts, where feasible, to assess sampler performance.
    - Measurement uncertainties should be reported for all PM components. That will make it possible to interpret, with caution, the concentration data on PM components whose concentrations are mostly below the detection limit of the analytic method, as in the case of the x-ray fluorescence data.
    - Mass closure (that is, comparison of particle mass with the sum of the individual-particle components) should be performed as part of the overall QA process.
- *Because this is likely to be a continuing effort, the military might consider developing real-time continuous particulate-matter monitoring equipment whose use is recommended in the EPMSP report.* Such equipment could be based on commercially available models but adapted to withstand the theater environment, including extreme temperatures, moisture, and particle concentrations; rough handling; and minimal maintenance. The monitors should be battery-powered and should report particle-size mass concentrations.

CONCLUDING REMARKS

The committee recognizes the importance of this initial effort to characterize the composition of PM and to understand the potential for health effects of exposures in the active theater. The feasibility of conducting future exposure assessment and health surveillance has been demonstrated. The committee strongly endorses DOD's effort and encourages it to continue and to expand its surveillance and research protocols to characterize health outcomes related to air-pollution exposures during military service. DOD should consider expanding medical surveillance, especially for deployed personnel, to include additional data (for example, results of pulmonary-function tests) that could be used to assess health outcomes. The information currently collected by the military in medical databases is not designed for use in research studies to assess associations with air-pollution exposures. However, collection and use of that medical information, with an eye to developing a more robust surveillance system, could strengthen the ability to study environmental-health issues of concern.

The committee also considers that, whenever feasible, efforts should be made to minimize exposures of the troops. There are a number of ways to accomplish that; for example, if there is a prevailing wind direction, emission sources (such as burn pits and incinerators) could be located downwind of bases. For periodic emissions, such as from waste-burning, burns should take place when the prevailing meteorologic conditions favor dispersion of the emissions. That would be a general approach for reducing exposures and improving health.

1

Introduction

BACKGROUND

Epidemiologic studies have consistently found associations between short-term and long-term exposure to particulate matter (PM) and risks of morbidity and premature mortality (Dockery et al. 1993; Pope et al. 1995; Levy et al. 2000; Samet et al. 2000; Pope et al. 2002; Dominici et al. 2003; Katsouyanni et al. 2003; Pope and Dockery 2006). The range of adverse health effects associated with exposure to air pollution is broad, affecting the respiratory and cardiovascular systems (see Table 1-1 for an illustration of effects related to short-term and long-term exposure) (Alfaro-Moreno et al. 2007; Brook 2008; Craig et al. 2008).

Exposure to PM affects the health of children, the elderly, and those who have such conditions as cardiopulmonary disease. The risk of various adverse health outcomes increases with exposure concentration, and there is little evidence of a threshold below which no adverse health effects are expected (WHO 2005). Other variables that influence the nature and probability of health outcomes are the size fraction, the chemical composition, and the duration of exposure.

PM concentrations in epidemiologic studies are typically measured as PM_{10} or $PM_{2.5}$, referring to particles that have an aerodynamic diameter of less than 10 µm or less than 2.5 µm. A metric less commonly used is total suspended particulates (TSP), a measure of all PM in the atmosphere that does not discriminate by size. PM_{10} may deposit in the upper airways and lung, whereas fine particles ($PM_{2.5}$) can penetrate more deeply into the lung and may reach the alveolar region. In the atmosphere, fine particles remain suspended for days to weeks and can travel hundreds to thousands of kilometers, whereas coarse particles (2.5-10 µm in aerodynamic diameter) deposit rapidly on ground surfaces with lifetimes on the order of minutes to hours (Wilson and Spengler 1996).

TABLE 1-1 Examples of Health Outcomes[a] Measured in Air-Pollution Exposure Studies

Effects related to short-term exposure
Inflammatory reactions in the lung
Respiratory symptoms
Adverse effects on cardiovascular system
Increase in use of medication (such as asthma medication)
Increase in hospital admissions
Increase in mortality
Effects related to long-term exposure
Increase in lower-respiratory symptoms
Reduction in lung function in children and adults
Exacerbation of chronic obstructive pulmonary disease
Reduction in life expectancy owing mainly to cardiovascular disease and lung cancer

[a]These effects may not pertain to the military population.
Source: Adapted from WHO 2006.

PM originates from natural and human-made sources, and the composition and size of the particles depend on the source. Sources of coarse particles include resuspension of soil from roads and streets; disturbance of soil and dusts by agricultural, mining, and construction operations; and ocean spray (Wilson and Spengler 1996). Sources of fine particles include emissions from combustion of motor-vehicle fuel (EPA 2002, Pakbin et al. 2009, and Zhang et al. 2009); high-temperature operations such as smelters and steel mills; combustion of coal, oil, and wood; and atmospheric transformation products of nitrogen oxides, sulfur dioxide, and organics (Wilson and Spengler 1996).

AIR-POLLUTION SOURCES AND EXPOSURES RELEVANT TO THE MIDDLE EAST

There have been efforts to examine PM exposures in the Middle East, particularly with regard to how the composition and concentration of PM differ from those in the United States and other industrialized regions where fossil-fuel combustion and vehicle emissions are the primary sources of PM. In the Middle East, where climatic conditions may be more arid, PM sources may include dust storms, dust from motor-vehicle disturbance of the desert floor, agricultural activities, emissions from burn pits where trash is burned, lead-zinc smelters, battery-processing facilities, refineries, power stations, fertilizer plants, and emissions from vehicles that use leaded gasoline (UNEP 2007; Engelbrecht et al. 2009). Dust storms may carry pollutants great distances and in large amounts;

for example, it has been estimated that the average dust fallout along the coastal area of Kuwait may travel up to 1,000 tons/km^2 annually (UNEP 2002, 2007). Richards et al. (1993), who examined respiratory disease in military personnel in Saudi Arabia in the early 1990s, described the sandy conditions: "the sand in Saudi Arabia was a major problem for equipment maintenance personnel and a leading concern for the medical staff. The sand was often powdery in consistency, and entered, in varying degrees, all living and working areas" (p. 3).

A recent paper by Brown et al. (2008) characterized PM concentrations at three sites in Kuwait from 2004 to 2005 and found that the arithmetic mean PM_{10} concentrations ranged from 66 to 93 μg/m^3 and the annual average PM_{10} concentrations at all three sites exceeded the World Health Organization air-quality guideline of 20 μg/m^3. The arithmetic mean $PM_{2.5}$ concentration at the three sites ranged from 31 to 38 μg/m^3, and all the sites had mean $PM_{2.5}$ concentrations more than double the annual U.S. National Ambient Air Quality Standard for $PM_{2.5}$ of 15 μg/m^3. $PM_{2.5}$ made up 47% of PM_{10} at two of the sites and 41% of PM_{10} at the other site; in contrast, studies in the United States and Europe have shown fine particles to make up 60-75% of PM_{10}.

Brown et al. (2008) concluded that the overall higher concentrations of PM_{10} and $PM_{2.5}$ compared with studies in the United States and Europe are partially explained by the resuspension of dust and soil from the desert crust. However, the high concentrations of such particulates as nitrate, sulfate, elemental carbon, organic carbon, and elements (for example, lead and sulfur) indicated substantial contributions from combustion sources, such as traffic and industry. The authors concluded that the PM concentrations are high enough to cause health effects on the Kuwaiti population. As illustrated by Brown et al. (2008), two significant sources of PM in the Middle East include combustion-related processes and dust storms. Because of the paucity of PM exposure assessment studies conducted in the Middle East, data collected in other regions (including the Middle East) are discussed below.

Combustion-Related Sources

In studies conducted in the U.S. and in Cairo, Egypt, combustion-related sources of PM included emissions from vehicles, cooking, wood and natural-gas combustion, and open trash-burning (Gertler et al. 2000; EPA 2004; Abu-Allaban et al. 2007; Schauer et al. 2007; Zheng et al. 2007). Abu-Allaban et al. (2007) conducted a monitoring study in Cairo, Egypt, and used a chemical mass-balance model to estimate source contributions. Based on the model results, the authors found that $PM_{2.5}$ tended to be dominated by mobile-source emissions, open burning, and secondary species. In a review of 22 chemical-mass balance $PM_{2.5}$ and PM_{10} source-apportionment studies in several countries (including the U.S., Canada, China, and South Africa), the largest contribution to fossil-fuel emissions in a majority of the studies was attributed to gasoline and diesel-vehicle exhaust rather than industrial sources with modernized controls for pollution (Chow and Watson 2002). Lewtas (2007) observed that combustion emissions account for over half of ambient $PM_{2.5}$ and noted that the combustion of plastics, chemicals, and other wastes can lead to the formation of potentially hazardous pollutants. Studies conducted in U.S. cities have found similar results (Watson and Chow 2001; Maykut et al. 2003; de Kok et al. 2006; Schauer et al. 2007; Zheng et al. 2007). Many other pollutants in addition to PM are generated during combustion, including sulfur dioxide, nitrogen oxides, ozone, and volatile organic compounds.

A large body of research has shown a link between exposures to specific sources of air pollution and health effects. H. Chen et al. (2008) conducted a systematic review of the literature on associations between long-term exposure to air pollution and risks of nonaccidental mortality and the incidence and mortality from cancer and cardiovascular and respiratory disease. In addition to finding associations between exposure to $PM_{2.5}$ and increased risks from nonaccidental mortality and mortality from lung cancer and cardiovascular disease, the authors concluded that living close to busy traffic appeared to be associated with increased risks of the three outcomes. Short-term and long-term exposure to traffic-related pollution has been associated with increased morbidity and mortality (for example, Kunzli et al. 2000; Beelen et al. 2008a; Beelen et al. 2008b; Zhang et al. 2009). A health assessment by the U.S. Environmental Protection Agency (EPA 2002) suggested that acute exposure to diesel-engine exhaust causes transient irritation and inflammation, particularly in people who have allergies and asthma symptoms. That conclusion is supported by a recent study by Zhang et al. (2009) in London that showed significant decreases in forced expiratory volume in the first second (FEV_1) (3-4.1%) and forced vital capacity (FVC) (3.1-3.7%) and an increase in markers of airway inflammation in asthmatic people after short-term exposures to urban air pollution, including diesel exhaust on a busy urban street, compared to a control site without traffic.

Dust Storms

Middleton et al. (2008) examined the effects of changes in daily concentrations of PM_{10} and ozone on hospital admissions for respiratory and cardiovascular causes in Nicosia, Cyprus, from 1995 to 2004. They found that for every 10-$\mu g/m^3$ increase in daily average PM_{10} concentration, there was a 0.9% increase in all-cause admissions and a 1.2% increase in cardiovascular admissions. They also observed an increase in hospitalizations, particularly for cardiovascular causes, on dust-storm days. However, the authors cautioned that the possible health effects of dust storms have not been extensively studied.

Perez et al. (2008) found that during Saharan dust outbreaks, a daily increase of 10 $\mu g/m^3$ in $PM_{10\text{-}2.5}$ increased daily mortality by 8.4% compared with 1.4% during non-Saharan dust outbreaks. In contrast, other studies have not found an association between high PM_{10} concentrations and morbidity or mortality. A study in Spokane, Washington, found no association between days with high PM_{10} concentrations from windblown dust and mortality (Schwartz et al. 1999). In a study in the Greater Vancouver area, clouds of dust transported from the Gobi Desert to Canada showed no effect on hospital admission rates (Bennett et al. 2006); in the Coachella Valley of California, there was a slight reduction in the effect of PM on mortality on windy days (Ostro et al. 2000).

Several studies have investigated the health effects of Asian dust storms in Taipei, Taiwan. They examined the association between PM_{10} and hospital admissions of residents of Taipei from 1996 to 2001, comparing hospital admissions during dust-storm episodes (index days) with admissions on days without dust storms (comparison days) (Chen and Yang 2005; Yang et al. 2005; Yang 2006; Cheng et al. 2008; Chiu et al. 2008; Yang et al. 2009). Average PM_{10} concentrations on index days were 111.68 $\mu g/m^3$, or 56.25 $\mu g/m^3$ higher than on comparison days. Analyses indicated that Asian dust-storm events may result in an increase in daily hospital admissions for chronic obstructive pulmonary disease (Chiu et al. 2008), cardiovascular disease (Chen and Yang 2005), congestive heart failure (Yang et al. 2009), asthma (Yang et al. 2005), allergic rhinitis (Chang et al. 2006), conjunctivitis (Yang 2006), and pneumonia (Cheng et al. 2008), although none of the associations were statistically significant. The study authors noted that the lack of statistical significance may be the result of a lack of power due to an inadequate sample size for hospital admissions during dust-storm events.

Bell et al. (2008) conducted time-series analyses in Taipei, Taiwan, examining the association between various indicators of sandstorms and the pollutants nitrogen dioxide, carbon monoxide, ozone, sulfur dioxide, PM_{10}, and $PM_{2.5}$ and the number of hospital admissions for asthma, pneumonia, ischemic heart disease, and cerebrovascular disease from 1995 to 2002. Admissions for ischemic heart disease were associated with several sandstorm metrics, including indicators of high PM_{10}, high $PM_{10\text{-}2.5}$, and a high ratio of PM_{10} to $PM_{2.5}$, although the lag structure of effect was not consistent among sandstorm indicators. Hospital admissions for ischemic heart disease were 16-21% higher on sandstorm days than on other days.

EXPOSURES OF AND HEALTH EFFECTS ON MILITARY PERSONNEL

Despite the large body of evidence on the general population and on susceptible individuals, the health effects of PM in relatively healthy, active military personnel deployed in the Middle East are not well characterized. Part of the reason may be the challenges in conducting an exposure-monitoring and health-surveillance study in a military zone. Because of the differences in exposure concentrations and PM chemical composition, and because of the differences in deployed military personnel compared to the general population, extrapolating results directly from population-based epidemiology studies conducted in the United States and Europe to populations in the Middle East may not provide appropriate estimates of health effects. In addition, because each military deployment is unique, the environmental exposures and health risks may vary (IOM 2006, 2008), and this could hinder the comparison of exposures and health effects in deployed personnel among different studies, especially if they are under stress.

Deployment of forces in hostile or unfamiliar environments is inherently risky because of conditions imposed by the military mission. Each deployment involves an array of military and nonmilitary threats, known and unknown, and mission objectives dictate that the threats be dealt with as they arise. Many activities carried out in such an environment are not routine; tasks must be accomplished with the means at hand despite potential dangers and in a setting where time and attention are at a premium (NRC 2000).

Conducting exposure-assessment research and health-surveillance studies presents additional obstacles, given that they are not essential to the military mission. Obstacles include limitations on the personnel available to conduct and maintain exposure assessment and surveillance, inasmuch as a brigade has only two persons responsible for the health of about 2,000 soldiers (Sheehy 2009); frequent movement of troops, which makes health-surveillance followup challenging; difficulty in acquiring Institutional Review Board approval from the military to conduct health surveillance in the field (Baird 2009); and exposure of troops to multiple sources (dust storms, vehicle emissions, and emissions from burn pits) and to confounding factors (such as smoking) that may not be well characterized. Other challenges that make exposure assessment difficult include the extreme and variable temperatures that may cause malfunctions of electronic sampling equipment; lack of access to electricity to operate PM samplers, which makes it necessary to use batteries; the increased PM concentrations that can overload the samplers and necessitate special sampler preparation (for example, Demokritou et al. 2004); and less than optimal settings for locating the samplers.

Military personnel—especially those deployed to war zones—are considered “healthy adults” because of their age and the military’s physical and health requirements. However, a small percentage of deployed people will have conditions that put them at greater risk for health effects from exposure to PM. For example, despite a screening program and regulations that prohibit enrollment of asthmatics, it is estimated that—because of waivers, late onset of asthma, and misdiagnosis—3-5% of military personnel have asthma (DeKoning 2006; Smith et al. 2009) compared with about 7% of the general population who have asthma and about 13% who have ever been diagnosed with asthma (CDC 2008). Moreover, some people may have underlying conditions that are not diagnosed (for example, respiratory and cardiovascular disease).

Military personnel may also have risk factors that can exacerbate the effects of PM exposure (for example, smoking and stress), but no studies have evaluated the joint influence of these risk factors and exposure to air pollution on health effects in the military. A number of studies in children have examined the association. Understanding the influence of these risk factors in children might help to elucidate factors that affect the health of military personnel. For example, Shankardass et al. (2009) found that children living in stressful households were more susceptible to the effects of traffic-related air-pollutant emissions and in utero tobacco-smoke exposure than those in less stressful ones. Clougherty et al. (2007) found that a 4.3-ppb increase in nitrogen dioxide exposure increased the risk of asthma (odds ratio, 1.63; 95% confidence interval, 1.14-2.33) solely in children who had above-median exposure to violence. Other researchers have reported similar findings in children (Lee et al. 2006; E. Chen et al. 2008).

There are few studies of the association between concentrations of PM and health effects in deployed personnel in the Middle East. Petruccelli et al. (1999) studied health-related complaints of soldiers who lived and worked in Kuwait during the oil-well fires in 1991. They used self-administered questionnaires after the soldiers' return and found that deployment to Kuwait was associated with an increased incidence of eye and upper respiratory tract irritation, shortness of breath, cough, rashes, and fatigue. Those symptoms were reported more often by soldiers who perceived oil-fire smoke, pollution, heat exhaustion, flying insects, and sunburn as posing substantial problems. Lange et al. (2002) examined the relationships between respiratory symptoms in military personnel 5 years after deployment to the Persian Gulf War and self-reported and modeled exposures to smoke from oil fires. Self-reported symptoms of asthma and bronchitis increased with the number of days exposed to the oil fires, but there was no correlation of reported symptoms with modeled exposures. Cowan et al. (2002) conducted a case-control study of asthma in Army Gulf War veterans and modeled exposure to oil-well fire smoke. Two modeled exposure estimates were used: cumulative smoke exposure and the number of days subjects were exposed at 65 $\mu g/m^3$ or greater. They found a significant association between asthma and both estimates of exposure, and a dose-response relationship was observed for both measures.

Other studies have investigated respiratory symptoms in general in military personnel deployed to the Middle East. Sanders et al. (2005) conducted a survey to assess the prevalence of common ailments in U.S. military personnel deployed to Iraq and Afghanistan during 2003-2004, and the impact of those ailments on the military missions. Mission impact was determined by a questionnaire in which a person reported missing a patrol or being grounded from flying. They found that 69.1% of those surveyed reported respiratory illnesses; in 17% of these cases, medical care was sought. Another example is the Millennium Cohort Study, which is a 21-year longitudinal study by the U.S. Department of Defense (DOD) to evaluate risk factors related to military service that may be associated with long-term health outcomes. Participants were U.S. military personnel who were serving on active duty or in the reserves or National Guard in October 2000 (Smith et al. 2007). A recent study of this cohort investigated newly reported respiratory symptoms and conditions among military personnel deployed to Iraq and Afghanistan (Smith et al. 2009). Data from baseline and followup questionnaires found that new-onset respiratory symptoms were reported by 14% of deployed soldiers compared to 10% of nondeployed soldiers, while rates of chronic bronchitis or emphysema and asthma were similar between the deployed and nondeployed groups. In addition, increased risk of symptoms was associated with deployments on land compared to sea-based deployments. The Millennium Cohort Study is examining PM exposures of military personnel, but the data have not yet been published.

HISTORY OF PARTICULATE-MATTER SAMPLING BY DEPARTMENT OF DEFENSE

At the beginning of Operation Enduring Freedom (Afghanistan, 2001) and Operation Iraqi Freedom (2003), DOD initiated sampling of air, water, and soil in the Central Command Area of Operations (that is, the Middle East region, including Egypt and Central Asia) to characterize the deployment environment. The most common type of ambient air sample collected was PM.

In 2005, the assistant secretary of defense for health affairs chartered the Joint Particulate Matter Working Group (DOD-NIOSH 2005) to identify health issues that were potentially associated with exposure to PM. A workshop was held at the National Institute for Occupational Safety and Health to review sampling results, potential health effects, and knowledge gaps pertaining to PM exposure of military personnel in the Middle East. Data-related needs identified in the symposium included enhanced PM surveillance, routine predeployment and postdeployment health evaluations, improved disease and nonbattle-injury data, epidemiologic study of potential adverse effects of exposures to PM in the Middle East areas of operation, and assessment of the toxicity of the PM to which deployed personnel are exposed.

In response to an identified data need, the Enhanced Particulate Matter Surveillance Program (EPMSP) was implemented by the U.S. Army Center for Health Promotion and Preventive Medicine and a report was prepared by Engelbrecht et al. (2008) that included the design, analysis, and results of the EPMSP (see Appendix D). The report presents data on PM concentrations (that is, $PM_{2.5}$, PM_{10}, and TSP), chemical composition, and bulk soil samples at 15 locations in the Middle East. The results of the EPMSP are "available to the [U.S.] Department of Defense's occupational and health physicians, as well as environmental health professionals, to assist them in assessing potential human health risks from exposure to ambient particulate matter at their Middle East military base. In addition, information on dust allows for an assessment of its potential harmful effects on military equipment" (Engelbrecht et al. 2009).

STRUCTURE OF THIS REPORT

This report constitutes an independent assessment of the DOD EPMSP report (Engelbrecht et al. 2008). The U.S. Army asked the National Research Council to review sampling and analytic approaches and potential acute and chronic health implications on the basis of information presented by Engelbrecht et al. The National Research Council was also asked to consider the epidemiologic, health-surveillance, and toxicologic data collected by DOD (Abraham 2009; Ross 2009; Stockelman 2009), assess the potential health implications for deployed personnel, and make recommendations for reducing or better characterizing health risks, including improving epidemiologic investigations. In response, the National Research Council convened the committee for Review of the DOD's Enhanced Particulate Matter Surveillance Program Report, which prepared the present report.

The committee conducted its evaluation of the EPMSP report by reviewing the sampling methodology (Chapter 2) and the analytic approaches and data presented (Chapter 3) by Engelbrecht et al. Chapter 4 moves beyond the results presented by Engelbrecht et al. to evaluate health and toxicology data presented at the committee's first meeting (see Appendix C).[1] In this chapter, the committee addresses information needed to characterize health risks to deployed personnel. Chapter 5 presents the committee's conclusions and recommendations and looks toward designing studies to improve understanding of the health implications of PM for personnel deployed to the Middle East.

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2

Sampling Methodology Used in the Department of Defense Enhanced Particulate Matter Surveillance Program

METHODS OF SAMPLE COLLECTION

For the Department of Defense Enhanced Particulate Matter Surveillance Program (EPMSP), sampling sites were selected to represent areas of potential exposure of military personnel in the Middle East. At each location, military preventive-medicine or public-health personnel were stationed for the duration of the sampling and were responsible for collecting the samples. Fifteen sites were selected: one in Djibouti, two in Afghanistan (in Bagram and Khowst), one in Qatar, one in the United Arab Emirates, six in Iraq (in Balad, Baghdad, Tallil, Tikrit, Taji, and Al Asad), and four in Kuwait (in northern, central, coastal, and southern Kuwait). For reasons of confidentiality related to military security, the specific bases where the sampling was conducted were not named. In addition, specific information on the location of the sampler at each of the 15 sampling sites, including the geography of the immediate surrounding area, was not provided to the committee. At each site, samples were collected during a period of 12 months from about 2006 to 2007. Table 2-1 shows the sampling locations and sampling periods.

Total suspended particulates, PM_{10}, and $PM_{2.5}$ samples were collected at each of the 15 sites with a low-volume (5-L/min) Airmetrics MiniVol particle sampler. Three types of 47-mm-diameter particle filters were used: Teflon, quartz fiber, and Nuclepore. Each filter type was used for a different analytic method. The U.S. Army Center for Health Promotion and Preventive Medicine collected the samples in theater and sent them to RTI International for unloading and analysis. RTI International was responsible for x-ray fluorescence (XRF), ion chromatography (IC), inductively coupled plasma-optical emission spectroscopy (ICP-OES), inductively coupled plasma-mass spectrometry (ICP-MS), and carbon analyses. The Desert Research Institute conducted x-ray diffraction (XRD), XRF, carbon, and ion analyses on 15 resuspended samples. R.J. Lee Group was responsible for individual particle analysis using computer-controlled scanning electron microscopy (CCSEM) and the secondary electron imaging by high magnification scanning electron microscopy (SEM).

A sampling schedule of 1 day in 6 was followed. Because of the limited availability of samplers and personnel to conduct the sampling, only one sample set (with Teflon filters, "Sample Set T"; with quartz-fiber filters, "Sample Set Q"; or with Nuclepore filters, Sample Set "N") was collected on a given sampling day. During a period of 1 month, there were two sampling days each for Teflon and quartz-fiber filters, and one sampling day for Nuclepore filters. During the field campaign period, 40% of the samples were collected on Teflon filters, 40% on quartz-fiber filters, and 20% on Nuclepore filters. Thus, during the period of the sampling year, Teflon and quartz-fiber filters each were collected for a maximum of 7% of the days. The sampling time for Teflon and quartz-fiber filters was 24 hours. For the Nuclepore filters, the sampling period was only 2 hours because CCSEM analysis requires that filter samples be only lightly loaded.

TABLE 2-1 Sampling Sites and Sampling Periods

	Sampling Period	
Sampling Location	Beginning	End
Djibouti	12-05-2005	06-09-2007
Bagram, Afghanistan	12-07-2005	05-21-2007
Khowst, Afghanistan	04-28-2006	06-22-2007
Qatar	02-16-2006	02-06-2007
United Arab Emirates	02-18-2006	02-07-2007
Balad, Iraq	01-15-2006	03-24-2007
Baghdad, Iraq	01-08-2006	01-11-2007
Tallil, Iraq	01-15-2006	02-15-2007
Tikrit, Iraq	01-12-2006	03-12-2007
Taji, Iraq	02-05-2006	02-11-2007
Al Asad, Iraq	01-08-2006	12-26-2007
Northern Kuwait	01-28-2006	02-04-2007
Central Kuwait	03-14-2006	03-19-2007
Coastal Kuwait	01-20-2006	03-20-2007
Southern Kuwait	01-21-2006	01-15-2007

Source: Adapted from Engelbrecht et al. 2008.

For each of the 15 sites, bulk soil samples were collected from the top 10 mm of soil near the particle-sampling sites. The samples were air-dried, and subsamples were taken for soil analysis. Later, a portion of each soil sample was sieved to remove particles larger than 38 μm. The soil particles were aerosolized and then collected onto filters for chemical and mineralogic analyses. Specifically, the samples were analyzed for: soil chemistry (carbonate content and electric conductivity), elemental composition by XRF, and mineral content (including quartz, feldspars, calcite, dolomite, clay, and iron oxides in fine dust) by XRD.

Table 2-2 shows the number of samples collected for each filter type and the analytic methods used.

TABLE 2-2 Filter Media and Corresponding Analytic Methods

Type of Samples	Number of Samples	Analytic Method
AMBIENT FILTER SAMPLES		
Teflon filters		
Mass	1,224	Gravimetric
Elemental analysis	1,224	XRF
Trace metal analysis	1,224	ICP-MS
Quartz-fiber filters		
Mass	1,223	Gravimetric
Soluble anions and ammonium	1,223	IC
Soluble cations	1,223	ICP-OES
Carbon and carbonate	1,223	TOT
Nuclepore filters		
Individual particle analysis 0.5-15 μm	243	CCSEM
Images and spectra	84	SEM
Ultrafines <0.5 μm	15	CCSEM
RESUSPENDED DUST SAMPLES		
Teflon filters		
Mass	30	Gravimetric
Elemental analysis	30	XRF
Trace metal analysis	30	ICP-MS
Quartz-fiber filters		
Mass	30	Gravimetric
Soluble anions	30	IC
Soluble cations	30	AA
Carbon and carbonate	30	TOR
Ammonium	30	AC
Nuclepore filters		
Individual particle analysis	15	CCSEM

(Continued)

TABLE 2-2 Continued

Type of Samples	Number of Samples	Analytic Method
BULK DUST SAMPLES		
Soil chemistry		
Hydrogen-ion activity	15	pH
Carbonate content	15	Acid Digestion
Electrical conductivity	15	EC
Elemental and minerals analysis		
Elemental analysis	15	XRF
Minerals analysis	15	XRD
Particle-size analysis		
Particle-size distribution (sand, silt, clay)	15	Laser Diffraction

Abbreviations: AA, atomic absorption; AC, automated colorimetry; CCSEM, computer-controlled scanning electron microscopy; EC, electrical conductivity; IC, ion chromatography; ICP-MS, inductively coupled plasma-mass spectrometry; ICP-OES, inductively coupled plasma-optical emission spectrometry; SEM, scanning electron microscopy; TOR, thermal optical reflectance; TOT, thermal optical transmission; XRD, x-ray diffraction; XRF, x-ray fluorescence.
Source: Adapted from Engelbrecht et al. 2008.

STRENGTHS AND LIMITATIONS OF SAMPLING

Strengths

The EPMSP is one of the first large-scale attempts to characterize exposure of military personnel to air pollution in a combat setting in the Middle East. The program demonstrated the feasibility of conducting exposure monitoring in a war zone and, despite the challenging environment, achieved a data recovery of 88%. Strengths of the sampling approach include the use of multiple locations, with collection from 15 sites, over a 1-year period. The sampling sites were chosen to represent areas where military personnel would be exposed. The sampling design recognized the need to do field and shipping blanks for quality control. A blank is treated in the same manner as a standard sampling filter. The program also recognized the importance of distinguishing among particle sources, chemical compositions, and size distributions inasmuch as there is strong evidence that these characteristics affect particle toxicity (Laden et al. 2000; Lippmann et al. 2006; Bell et al. 2009; Peng et al. 2009). The sampling design called for use of continuous samplers, specifically the DustTrak, although the extreme temperatures and high dust concentrations prevented them from operating in the field (Sheehy 2009). The collection of soil samples from areas close to the particle-sampling sites will be helpful in investigating whether observed high soil particle concentrations originated from local activities, such as the movement of trucks over unpaved surfaces, or from other military activities.

Limitations

In designing an exposure monitoring study, it is important to develop well-defined study objectives before the start of the study. It is also important to tailor the sampling methods to the objectives and, if appropriate, to consider how the study design could complement a health-effects study. With those considerations in mind, the committee noted several limitations in the study design, particularly an absence of a rationale for the design and for the methods used. For example, why was the MiniVol sampler used, and why was a schedule of 1 day in 6 for collecting samples used? In the following paragraphs, the committee addresses several concerns about the study design, including the type of particle sampler and the precision and representativeness of the samples. In addition, although field blanks were collected, the blanks for organic and elemental carbon may not have provided an adequate basis for determining the blank given the results of Watson et al. (2009) and Chow et al. (2009).

Particle Sampler

The particle sampling device, MiniVol, may not be suitable for collecting particles when concentrations are excessively high, for example, during a dust storm. It uses an inertial impactor to remove particles above 2.5 or 10 μm in aerodynamic diameter ($PM_{2.5}$ or PM_{10}). Inertial impactors have been used extensively for particle collection and size classification (Marple et al. 1987, 1991; Hinds 1999).

A conventional impactor consists of a nozzle for the acceleration of particle-laden gas and a flat, rigid impaction surface (substrate). The basic mechanism for inertial deposition of particles is based on the momentum of the accelerated aerosol particles and thus their ability to cross the streamlines above the impaction zone. Particles that have aerodynamic diameters larger than the impactor's size cutpoint have enough momentum to cross the streamlines and deposit onto the substrate, but smaller particles, which have insufficient momentum to cross the streamlines, remain suspended in the sample air and are not collected. Figure 2-1 shows the components of a MiniVol sampler, and Figure 2-2 shows an assembled MiniVol sampler.

To minimize particle bounce-off and re-entrainment, impaction substrates are usually coated with adhesives, such as mineral oil or grease. However, those substances have a limited loading capacity (Sehmel 1980; Wall et al. 1990; John et al. 1991; Demokritou et al. 2001). (Box 2-1 describes how impactors may become overloaded and sampling artifacts can be introduced.) Some researchers have used a cyclone as the particle-separation device to increase loading capacity to as much as 6 mg (Kenny et al. 2000). The Well Impactor Ninety-Six Impactor, which is used as a U.S. Environmental Protection Agency Federal Reference Method sampler to collect PM2.5 particles, was found to have a loading capacity of only about 1.5 mg (Kenny et al. 2000). Demokritou et al. (2004) has developed and used high-loading samplers for $PM_{2.5}$ and PM_{10}. These samplers use a polyurethane foam substrate to improve the performance of the inertial impactor by minimizing bounce-off and re-entrainment losses. The foam substrate also allows for a large collection of particles per unit surface area (Kavouras et al. 2000; Demokritou et al. 2002).[1] Brown et al. (2008) used the high-loading samplers to collect high concentrations of crustal particles in Kuwait. Data from this study indicated excellent agreement between replicate measurements of $PM_{2.5}$ and PM_{10} mass concentrations.

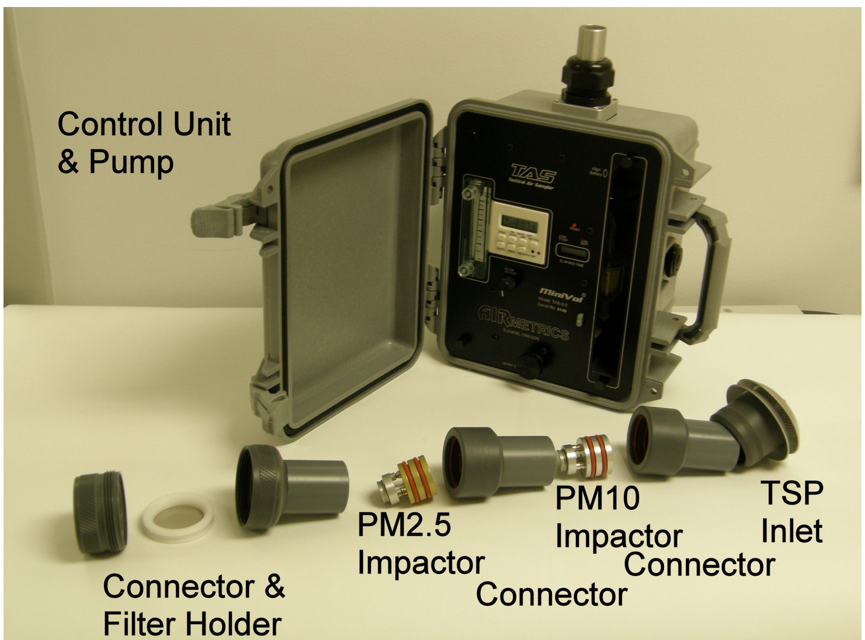


FIGURE 2-1 Disassembled MiniVol sampler. Photo courtesy of Philip Hopke, 2009.

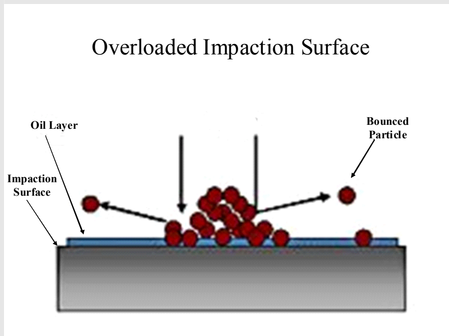
[1]The polyurethane foam functions by allowing penetration of particles into its open pores. Passage into the pores reduces the air velocity, allowing the particles to be deposited more gently on the pore surfaces with insignificant re-entrainment or bounce-off. The combination of reduced velocity and the relatively large internal pore surface area allows considerably greater amounts of particles to be collected than could be collected on rigid, flat substrates. The samplers were evaluated by using artificially generated polydisperse aerosols and demonstrated mass loadings of at least 35 mg; this is equivalent to a concentration of 1,456 μg/m^3 in a 24-hour sampling period.

FIGURE 2-2 Assembled MiniVol sampler. Photo courtesy of Philip Hopke, 2009.

There is confidence in the precision and functionality of the MiniVol sampler under U.S. climatic conditions (Baldauf et al. 2001); however, such factors as the harsh environment of the Middle East may affect sampler results. Data from Baldauf et al. (2001), in addition to a study performed in Kuwait (Brown et al. 2008), found lower concentrations of PM than those reported by Engelbrecht et al. (2008). Although these two studies (Baldauf et al. 2001; Brown et al. 2008) do not provide a direct comparison to the sampling devices used in the EPMSP, the resulting data provide some evidence that the MiniVol sampler could overestimate concentrations in locations impacted by dust storms (see Box 2-1).

An indirect way to detect bounce-off problems is to examine the sampler precision at high concentrations. However, because no replicate samples were collected, it was not possible to examine the influence of sampling artifacts with these measurements. A reasonable agreement between replicates, especially when concentrations are high, would provide reassurance that sampling artifacts are low. However, as mentioned, the reported PM_{10} and $PM_{2.5}$ concentrations in Engelbrecht et al. (2008) are considerably higher than those reported by other investigators who have used sampling devices that have greater capacity.

BOX 2-1 Overloading of Impactors and Introduction of Sampling Artifacts



At the beginning of sampling, particles adhere to the coated impaction surface. Oil wicks out of the substrate (oiled porous metal or grease) through the first layer of particles, and this enables additional particles to adhere to previously collected ones. Therefore, many layers of impacted particles are deposited onto the impaction surface during sampling. As a result, a small "mountain" is formed on the impaction surface. When impactors are exposed to excessive concentrations, such as those encountered during dust storms, the finite capacity of the impaction substrate is exceeded. That can happen for two reasons. First, because of the large amount of particles deposited per unit time, there is not enough time for particles to be coated by the oil, which wicks upward from the impaction substrate to the different layers of the collected particles. Particles therefore are loosely attached to each other and can be reentrained and enter into the air sample. The detached particle agglomerates can deposit onto the sampler walls. However, some of them can land on the filter sample and result in a positive sampling artifact (for both mass and composition measurements). Second, when a small "mountain" of collected particles is formed (reducing the distance between the substrate and the acceleration jet), it can affect the streamlines of the accelerated air flow and thus change the particle size cutpoint of the impactor. More important, large pieces of the already collected particles can detach from the "mountain," some can reach the filter collection surface and lead to a positive sampling artifact. The extent of the sampling artifacts depends on the particle loading on the impactor surface and the sampler characteristics and is difficult to estimate. The magnitude of the artifacts is not reproducible. If two identical samplers were exposed to the same high particle concentrations, the positive artifacts would not be the same.

Sampling Precision

A major shortcoming of the EPMSP is the lack of replicate samples (that is, use of side-by-side samples) to assess precision in the environment where the sampling was conducted. The committee understands that that is due to the paucity of human resources and the difficult circumstances under which sampling was conducted. However, it is an important limitation of this program that replicate measurements were not conducted at noncombat sites. Because of the lack of replicate samples, it is not possible to evaluate the performance of the MiniVol samplers, which operated at high temperatures and often collected large amounts of particles. It is also not possible to examine whether other factors—such as technician performance, transportation, and storage—had an effect on the quality of the data. The committee presumes that there should be less concern about sample analysis because specimens were analyzed by well-equipped and experienced laboratories; however, such quality-control information is not presented in the report.

Sample Representativeness

For a given pollutant, a small number of samples were collected per year. For example, only two $PM_{2.5}$ Teflon filters were collected per month—corresponding to 24 samples for a year. Considering the high variability of concentrations, especially during dust storms, the calculated annual-average concentrations are unlikely to be adequately representative of actual exposures, and this would hinder health studies that rely on accurate assessments of chronic exposure. In addition, low sampling frequency may limit the utility of the data for health surveillance because of inadequate sample size. Less frequent measurements may lead to significant bias in reported exposures, especially in areas that are affected by transient spikes in atmospheric pollutants due to wind or other events.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

- *The investigators conducted an ambitious and challenging sampling campaign that produced an important dataset.* In spite of the difficulties in implementing study protocols and operating samplers in a challenging environment with limited human resources, sample completeness was high at 88%. The committee applauds the effort to use a continuous monitor for mass measurement (DustTrak). Although it was not possible to use that monitor at high temperatures and with excessive particle loadings, other continuous samplers may be available for future studies.
- *The particle sampler was not adequately validated for its intended use.* The MiniVol has not been evaluated in environments in which concentrations are excessively high, so there is a potential for sampling artifacts. The lack of replicate samples makes it difficult to assess the extent to which the measured particle concentrations accurately reflect the true concentrations at these sites.
- *The sampling approach yielded a small number of measurements for assessing particle mass and distinguishing chemical species.* Sampling was conducted on a schedule of 1 day in 6, and one sample set (that is, TSP, PM_{10}, and

$PM_{2.5}$ samples collected on either Teflon, quartz fiber, or Nuclepore filters) was collected on a given day during a 30-day period. As a result, in a 30-day period, Teflon and quartz filters were each sampled twice, and Nuclepore filters once. During the sampling year, Teflon and quartz-fiber filters each were collected for a maximum of 7% of the days. The sampling frequency for Nuclepore filters was half that for Teflon and quartz-fiber filters. Because of the paucity of data, it is not possible to determine accurate annual-mean concentrations.

- The s*amples collected with the three different filter media are not necessarily comparable since they introduce different artifacts and are used for different chemical analyses.* Particle mass concentrations obtained with Teflon and quartz-fiber filters might not be comparable.[2] In addition, particle mass and composition were not measured at the same time, so mass closure cannot be performed (that is, comparison of particle mass with the sum of the individual particle components).

Recommendations

- *A well-defined set of study objectives should be developed.* In designing a comprehensive monitoring scheme, a set of study objectives that provides the rationale for the selection of samplers, filter media, sampling location, sampling frequency, and data-quality standards should be developed.
  - Sampling should be tailored to the questions being asked; for example, the sampling frequency would be different if one were interested in acute exposures instead of chronic exposures.
  - The number of Teflon filters should be increased. A move toward that goal could be accomplished by eliminating Nuclepore filter collection, which is feasible because the SEM studies do not need to be repeated.
- *Future studies should use particle samplers that can collect particles during sand storms, when concentrations exceed 200-400 μg/m^3.* The committee has suggested and described a new method that has been tested at three Kuwait sites (Demokritou et al. 2004; Brown et al. 2008). However, it is possible that other technologies are adequate and should be considered. A pilot study should be conducted at one of the sites—preferably a noncombat site—to validate the MiniVol and one or more alternative methods. That would make it possible to assess the quality of the previously collected data and to select an alternative sampling method if necessary. Finally, replicate samples should be collected to assess sampling performance during future sampling campaigns.
- *The report needs more details on the quality-assurance and data-validation procedures that were used to assess the adequacy of the data.* Proce-

[2]The quartz filter is quite friable, and without extremely careful handling, small portions can flake off (Chow 1995), which negatively biases the filter weight. The tendency for the quartz filter to adsorb organic vapors positively biases the filter weight.

dures for quality assurance and quality control are important for both the sampling and handling of the filters and for the gravimetric and chemical analyses. That is mentioned in Chapter 3 in connection with the analytic procedures, but it is also relevant to sampling and handling. Discussions with the investigators indicated that there were quality-assurance procedures, but the committee is concerned that the procedures focused primarily on the analytic techniques and not the sampling procedures. In this type of study, a lack of quality-assurance procedures at the sampling stage might introduce more errors than problems with quality-assurance procedures during the analytic stage. In addition to validating the sampling devices for their intended use, robust quality-assurance procedures should be implemented to ensure the integrity of the collected samples.

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3

Evaluation of Analytic Results

The Department of Defense (DOD) Enhanced Particulate Matter Surveillance Program (EPMSP) analyzed samples of particulate matter (PM) that were collected with the methods described in Chapter 2. This chapter will review the analytic methods used and the evaluation of the resulting data on chemical composition. The objective of the EPMSP was to identify the general chemical characteristics of PM at 15 sites in the Middle East with methods that were similar to those used for ambient-air monitoring networks in the United States, including the Environmental Protection Agency's Chemical Speciation Network and the Interagency Monitoring of Protected Visual Environments network. The analytic approaches used in the EPMSP are standard methods that have been widely used for the characterization of ambient aerosol samples.

The Teflon filter samples were analyzed for mass with gravimetry and for elemental composition with energy dispersive x-ray fluorescence (EDXRF) and inductively coupled plasma-mass spectrometry (ICP-MS). Anions on quartz filters were determined by using ion chromatography (IC) and cations with inductively coupled plasma-optical emission spectroscopy (ICP-OES). Carbon on quartz filters was measured as organic carbon (OC) and elemental carbon (EC) with a thermo-optical method. X-ray diffraction was used to determine the mineralogy of the samples by determining the spacing of layers in crystalline materials. In addition, samples were collected for examination with scanning electron microscopy (SEM) to characterize individual particles and provide information on particle structure and composition. Those are standard analytic methods that are applied to samples in the United States. In this chapter, the committee examines the validity of those approaches as applied to samples collected in the DOD EPMSP and reviews the comparability of the resulting data with those collected in the networks in the United States.

METHODS

Engelbrecht et al. (2008) selected the appropriate particle-collection media and analytic methods. The selected protocols have been extensively tested and used by a wide array of organizations, including universities and research centers, government (for example, the Chemical Speciation Network), and industry. All methods used are state-of-the-art methods and have adequate sensitivity for the types of samples collected.

Gravimetry

The mass on the filters was measured with gravimetry. Using standard methods (40 CFR 50 [2010]), the blank filters were equilibrated at 23°C and 35% relative humidity for 24 hours and then weighed before they were sent to the field. After sample collection, the filters were sent back to the laboratory for a second equilibration and reweighing. Airborne-mass concentration was calculated as the difference between filter weights divided by the volume of air sampled.

Although there were limitations in the sampling methods, as described in Chapter 2, there are no questions about these laboratory measurements because the weighing can be highly precise and accurate. However, there is concern about the potential loss of PM from the filters during shipping. The measurements showed PM concentrations high enough to suggest sampler overload, as discussed in Chapter 2.

X-Ray Fluorescence

EDXRF was used to measure 40 chemical elements nominally: sodium, magnesium, aluminum, silicon, phosphorus, sulfur, chlorine, potassium, calcium, titanium, vanadium, chromium, manganese, iron, cobalt, nickel, copper, zinc, gallium, arsenic, selenium, bromine, rubidium, strontium, yttrium, zirconium, molybdenum, palladium, silver, cadmium, indium, tin, antimony, barium, gold, mercury, thallium, lead, lanthanum, and uranium. For samples of airborne particles, x-ray fluorescence (XRF) was operated by using the thin-sample approach in which the sample is assumed to be thin relative to the range of the excitation or emission x rays in matter. For low-atomic-number elements or heavy elements in which outer-shell x rays are used for analysis, there can be attenuation of the emitted x rays, and particle-size-correction factors are often applied to compensate for absorption of the x rays in the sample. In the analysis of the EPMSP samples, however, no particle-size corrections were applied, and low-atomic-number elements are probably substantially underestimated.

The mass concentrations observed in the EPMSP are much higher than those currently measured in the United States. However, they are comparable with values observed 30-40 years ago when studies of airborne-particle composition began to use XRF as an analytic tool (Jaklevic et al. 1981). The MiniVol sampler uses a 47-mm filter that permits a reasonable mass loading while providing a uniform, thin film sample that is suitable for analysis. However, when the total mass loading exceeds around 1,000 µg, there are increased problems of self-absorption that require the application of appropriate corrections.

There is little description of the procedures used in the XRF analyses, particularly for PM_{10} and total suspended particulate samples, which have higher mass loadings and larger individual particles. Thus, there could be additional errors in the estimation of the composition of the particle samples if the mass-loading and particle-size corrections were inappropriate. In addition, it is unlikely that all the elements in the XRF protocol can be measured adequately. For example, the primary uranium M x rays have energies of 3.171 and 3.337 eV. The potassium x-ray energy for its Kα line is 3.312 eV and for its Kβ line is 3.589 eV (Lide 1991). Given the resolution of the detectors in commercial XRF systems and the concentrations of uranium in samples, the uranium lines will be lost in statistical fluctuations in the potassium x-ray emissions. Thus, there needs to be a more careful review of the elements that can be reported using XRF analyses.

Inductively Coupled Plasma-Mass Spectrometry

ICP-MS is a destructive method that requires dissolution of a sample, so an entire sample is used. Although problems with sample collection outlined in the previous chapter may be applicable to the XRF analyses, there would not be a problem in analyzing heavily loaded samples with methods in which samples are leached or solubilized, such as ICP-MS. In those cases, a combination of nitric acid and hydrochloric acid was used to solubilize selected elements, including antimony, arsenic, beryllium, cadmium, chromium, lead, manganese, nickel, vanadium, zinc, mercury, and strontium. If uranium was an element of interest, it would have been possible to measure it with this procedure. It would also have been easy to identify other elements that could be used to compare with the XRF results and to provide support for additional quality-assurance (QA) comparisons.

Inductively Coupled Plasma-Optical Emission Spectrometry

Aliquots of the water-soluble species that were obtained by leaching the quartz-fiber filters were analyzed with ICP-OES. In ICP-OES, the heat of the plasma causes the elements of interest to emit light of specific wavelengths that can be separated and used for quantititative analysis. There are unlikely to be substantial problems with this assay because the approach used was standard and straightforward.

Ion Chromatography

Another aliquot of quartz-fiber leachate was analyzed with IC for the water-soluble anions sulfate (SO_4^{2-}), nitrate (NO_3^-), chloride (Cl^-), and phosphate

(PO_4^{3-}) and the ammonium (NH_4^+) cation. There are unlikely to be substantial problems with this assay because the approach used was standard and straight-forward.

Organic Carbon and Elemental Carbon

In the OC-EC analysis, the National Institute for Occupational Safety and Health method was used (NIOSH 2003). A small punch of quartz filter was heated in helium gas to evolve the organic compounds associated with the PM. The evolved compounds were oxidized to carbon dioxide, the carbon dioxide was converted to methane, and the methane was quantitatively measured with a flame ionization detector. After the organic compounds were evolved at the highest temperature, the gas was changed to a mixture of a few percent oxygen in helium, and the refractory carbon, EC, was oxidized. The resulting carbon dioxide was again converted to methane and measured.

There are several protocols for the sequence of temperatures and times of exposure at each temperature. As the organic compounds are evolved, the filter darkens because of pyrolysis, and corrections are made for the carbon that was pyrolyzed and not evolved. These protocols produce somewhat different results (Chow et al. 2004), particularly in the amount of EC.

A major problem in OC measurements was noted by Engelbrecht et al. (2008). They were high, and the authors hypothesized that organic material evolved from the plastic containers in which the quartz filters were stored because of the very high temperatures at which they were exposed. Thus, no OC data were reported. However, the increased organic material would also contribute to additional pyrolytic carbon, which is difficult to separate from EC. Thus, there is considerable uncertainty as to whether the EC data in the EPMSP study were adequately characterized.

Individual-Particle Analysis

Computer-Controlled Scanning Electron Microscopy

Nuclepore filters were used for computer-controlled scanning electron microscopy (CCSEM) to characterize individual particles. Nuclepore filters were also used for SEM analysis to analyze individual particles for shape, surface coatings, and chemical composition. CCSEM is a combination of backscattered electron imagery and energy-dispersive spectroscopy that automatically analyzes a large number (1,000-1,500) of individual particles for size and chemical composition. The particles are grouped in “bins” by chemical composition and particle size. The x-ray data are qualitative but can provide a basis for classifying particles into classes of similar composition (Kim et al. 1987; Xie et al. 1994). In the EPMSP, the classes were determined by expert judgment rather than through the application of specific data-analysis methods. These methods are adequate for the purposes of the EPMSP, although more information could be gleaned from their results if more thorough data analysis was applied.

Scanning Electron Microscopy

There was an interest in identifying particle types that would probably induce silicosis, with an emphasis on crystalline silica. High-resolution SEM was applied to the samples to provide the needed information. It was likely that a sufficient sample size was analyzed. However, no statistical analysis was provided to suggest that the observed subsample adequately reflected the larger population of samples.

QUALITY CONTROL

The EPMSP report does not adequately address QA. A strong QA assessment includes details of the results of replicate analyses and other measures (for example, calibration procedures) to assess analytic precision, accuracy, and sensitivity. Furthermore, a strong QA analysis reports information on field or laboratory control samples (blanks) that could affect the reported values. Such data do not necessarily need to be included in the body of the report, but the details need at least to be included in an appendix. In addition, the lack of uncertainty estimates associated with the numbers reported prevents the reader from determining the degree of confidence in the data. For example, many of the reported elements (the committee estimated up to 40%)—especially uranium, gallium, rubidium, strontium, yttrium, zirconium, molybdenum, palladium, silver, cadmium, indium, tin, antimony, gold, and mercury—are reported at concentrations that may be below the concentrations at which they can be measured accurately. The reporting of those elements may lead to misinterpretation of the composition of the samples.

A commonly used QA approach for PM composition data is to perform a mass-closure analysis (Malm et al. 1994). In this approach, the measured chemical species are summed, and the concentration is compared with the gravimetric mass concentration as a benchmark. Some elements are not measured but can be estimated. For example, silicon would typically be found in airborne particles as SiO_2, and the mass of SiO_2 can be estimated from the silicon concentration and the appropriate gravimetric factor (molecular weight of SiO_2 divided by the molecular weight of silicon). Analogous factors are applied to aluminum, calcium, titanium, and iron. The organic mass is estimated from the measured OC by multiplying by a factor that estimates the amount of hydrogen, nitrogen, and oxygen associated with the carbonaceous material. The factors range from 1.4 (Malm et al. 1994) to possibly 2.1 (Lim and Turpin 2002). In the major U.S. monitoring networks, there is generally good mass closure, and this analysis serves as an important QA check of the data.

In the design of the EPMSP, however, only one type of filter was collected at each site during each sampling period. Therefore, Engelbrecht et al. (2008) could not conduct an analysis for all species at any site in the network, making it impossible to attempt a mass-closure assessment. Furthermore, the study design does not permit an understanding of the complete composition of the PM and its variance in time and space on the basis of the data presented.

As discussed in Chapter 2, the particle-sampling schedule influences the estimation of mean particle compositions measured in a network of sites and the chemical composition of the particulate mass. Because concentrations and compositions are not uniformly distributed in time, a given sampling frequency may not provide a truly representative set of samples for characterizing the PM in an area. Thus, care needs to be exercised in interpreting the results as accurate estimates of potential exposure.

SITE-SPECIFIC DIFFERENCES IN PARTICULATE-MATTER CONCENTRATIONS BETWEEN THE MIDDLE EAST AND THE UNITED STATES

The EPMSP attempted to compare data gathered from 15 Middle Eastern sites with data gathered in the United States. The committee surmised that the comparison was probably performed to demonstrate that there are no substantial differences in PM composition between the Middle East and the United States despite higher mass concentrations in the Middle East. As indicated above and in Chapter 2, the sampling protocol limits the ability to obtain a complete measurement of the PM composition of the samples. However, the data allow an initial assessment of the concentrations and a qualitative assessment of the major components found in PM in the region.

As expected, the major portion of PM in all size fractions was of geologic origin. The investigators were able to show linkages of PM composition to the regional composition of the soils in the area. The soils would have a different composition from soils in the United States and may have different types and amounts of flora and microorganisms although the species were not directly measured as part of this effort. The fine PM fraction of the Middle Eastern samples may have been affected by regional transport of PM from other areas, depending on wind patterns. The PM also included carbon, both OC (not measured but presumed) and EC. The OC was presumed because it could not be measured directly. However, without detailed understanding of OC composition, it is difficult to define its origin accurately.

The region has a large particle contribution from combustion sources, including both stationary and mobile sources. For example, high concentrations of lead were observed relative to that in the United States, with the lead being attributed primarily to poorly controlled smelter operations and the use of leaded gasoline. Anecdotal evidence suggests that a major portion of combustion emissions from the military bases is due to poorly run vehicles with minimal emission controls. Another potential contribution is from open burn pits. Without more detailed composition data, it is difficult to identify the air toxicants that originate in the pits. It will be important to consider burn pits for future work because there is ample evidence that uncontrolled burning produces air toxicants.

Comparison of Particulate-Matter Data with Air Quality and Health Standards

The MiniVol sampler is not a Federal Reference Method sampler, nor has it been designated as a Federal Equivalent Method. Thus, the results of these measurements are not fully comparable with the results of samples collected in the regulatory monitoring network for determining attainment of the $PM_{2.5}$ or PM_{10} National Ambient Air Quality Standards. There is a reasonable correspondence between the performance of the MiniVol and Federal Reference Method samples under United States air-quality conditions (Baldauf et al. 2001), but evidence based on sampling performed in Kuwait (Brown et al. 2008) suggests that the MiniVol may overestimate concentrations. (See discussion in Chapter 2.)

Consideration of Particulate-Matter Sources and Additional Analyses Needed

The data obtained in the EPMSP are not useful for source identification and apportionment, because the design does not permit complete characterization of the particle mass for any given set of samples. It is always possible to provide some apportionment on the basis of the composition data that are available, but the analysis would be incomplete.

The critical issue is that there needs to be more clearly defined objectives of the sampling and analysis scheme at the outset of the program. If source apportionment is a desired outcome, it is important that likely source types be identified and, from that information, that chemical constituents be determined so that an appropriate chemical-analysis scheme can be used. Planning for all the desired outcomes is essential in the design of an ambient-aerosol sampling and analysis program.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

- *The surveillance efforts undertaken by the EPMSP are commendable and, with some changes in approach, the data could be better suited for defining regional composition and could contribute to the design of health studies to address the potential role of air quality in health.* The study design, in which different types of sampling media are not collected simultaneously, did not permit a quantitative understanding of PM composition. In addition, as indicated below, some analytic concerns may need to be better addressed to adequately characterize exposure for health studies. However, the ambitious survey of composition in the region provided a qualitative understanding of the composition of major components, and the observations will help to define questions and analytic issues for future surveillance efforts.

- *Some of the samples that have already been collected may be analyzed further to improve understanding of additional chemical components in the region.* There is an opportunity to identify selected particle-bound toxic species (for example, endotoxins and other biologic materials, polycyclic aromatic hydrocarbons, dioxins, and dibenzofurans) by analyzing composites of the quartz-filter samples. The additional measurements would lead to improved understanding of the chemicals in the region that may be appreciably toxic and could form a basis for improving the prioritization of objectives for future surveillance efforts.
- *XRF, which was used to measure a major fraction of the reported data, may have some technical barriers that were not accounted for in the EPMSP report.* The technical issues may affect the quality of the reported data. They include the need to correct for the size of particles and the potential for heavily loaded samples to interfere with the analysis of some elements. Only elements that are accurately determined by the method should be reported.
- *The QA of the exposure-surveillance effort needs to be better defined, and the analytic certainty of the data should be reported to reflect the confidence in the measurements.* A number of elements, particularly uranium, are reported at concentrations that are known to be poorly measured by XRF. Future efforts should analyze uranium with ICP-MS, and the reported data should include the analytic uncertainty.
- *The suite of chemicals investigated in routine U.S. monitoring studies might not be appropriate for understanding exposures in the military environment of the Middle East.* There may be a number of sources that contribute to PM in the ambient environment that were not considered (for example, burn pits and demolition debris).
- *To the extent that it is possible to compare compositions measured by the EPMSP with those observed in the U.S., there appear to be no significant differences from U.S. regions that are substantially affected by geologic material.* There were higher proportions of lead than are currently seen in the United States, presumably from smelters and the use of leaded gasoline. Further comparisons would require more detailed assessment of the carbonaceous component, including the volatile fraction generated from open-pit burning.

Recommendations

- *As discussed in Chapter 2, the committee recommends the development* *of a well-defined set of study objectives.* It is important to define project objectives a priori so the exposure monitoring is designed to meet project objectives.

- *If understanding PM chemical composition is a project objective, surveillance should be designed with an array of sampling media that are collected simultaneously.* That will ensure that the sampling and analytic methods permit mass-closure testing as part of the overall QA process. Future efforts may omit total suspended particulates if the goal is to understand potential health effects from exposures.
- *The comparisons of PM composition in the EPMSP report should be interpreted with caution because they may not fully represent the true underlying distribution of PM concentrations.* Therefore, the variability in the PM composition may contribute substantial error and make it difficult to conduct accurate and complete apportionment studies. It is important not to overinterpret concentrations of potentially toxic elements. Uranium, for example, was found in measurable amounts, but the lack of confidence in the measurements renders the data unusable for assessing the risk of exposure to that material in theater.

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4

Health Research and Surveillance Needs

Despite the large body of evidence of adverse effects of particulate matter (PM) in susceptible subgroups in the general population, the effects of PM on military personnel deployed in the Middle East are not well characterized. Extrapolation from general population-based epidemiologic studies may not provide appropriate estimates of the effects on health, because the chemical composition of PM, the magnitudes of exposure, and the characteristics of deployed military personnel are different from those in the general population. The deployed personnel may be considered relatively healthy compared to the general population with regard to past medical history and physical fitness; however, deployed personnel are exposed to dangerous, stressful conditions and adverse environmental exposures that may affect their overall health adversely. Thus, epidemiologic research to address the question of whether exposure to PM in the Middle East is associated with increased risk of illness in military personnel is needed.

This chapter will discuss the rationale for conducting research on the health effects of exposure to PM in U.S. military personnel in the Middle East theater and the study design features, exposure-assessment needs, and health-outcome data requirements for such research to be successful. It will also review the epidemiologic and toxicologic work presented by staff of the U.S. Army Center for Health Promotion and Preventive Medicine (USACHPPM) and the Naval Health Research Center at the July 2009 committee meeting (see Appendix C).

It is important to note the differences between health surveillance and research. Health surveillance is the continuous, routine collection of data related to health or exposures of populations over the long term and the associated analysis, interpretation, and dissemination of the results. In an occupational setting, surveillance involves the systematic assessment of the health of employees, in this case military personnel, who are exposed to occupational hazards. The fundamental purpose of surveillance is to detect and eliminate the exposures to hazards to prevent adverse health effects. Research is the search for knowledge through systematic investigation. Health-effects research typically uses the scientific method, which involves the formulation and testing of hypotheses and the collection of data through observation and experimentation. Results of research can lead to the initiation of surveillance and vice versa, but the two activities are not synonymous.

THE NEED FOR HEALTH SURVEILLANCE OF MILITARY PERSONNEL DEPLOYED IN THE MIDDLE EAST

After the first Persian Gulf War in 1991, many veterans who had been deployed to that military theater complained of persistent respiratory symptoms. Multiple reports in the published literature have shown associations between deployment to the gulf region during the war and increases in various respiratory outcomes (Richards et al. 1993; Iowa Persian Gulf Study Group 1997; Proctor et al. 1998; Gray et al. 1999; Petruccelli et al. 1999; Gray et al. 2000; Lange et al. 2002; Kelsall et al. 2004). Because the ambient environment during and immediately after the 1991 Gulf War was characterized by high concentrations of particulate matter and other pollutants due to windblown dust and smoke from oil fires, exposure to PM has been suggested to be responsible for the reported increase in respiratory symptoms among veterans (Richards et al. 1993; Petruccelli et al. 1999; Cowan et al. 2002; Kelsall et al. 2004). The health risks of PM generated in the Gulf War may not be confined to veterans of the conflict. A risk assessment of civilian mortality in Saudi Arabia estimated that over 1,000 excess deaths during 1991-1992 could be attributed to increases in PM due to the war (White et al. 2008).

With the renewed U.S. military activity in the Middle East (Afghanistan and Iraq) over the last 9 years, deployed military personnel are again experiencing exposure to high concentrations of wind-blown dust. They are also exposed to other types of PM, including diesel-exhaust particles and smoke from open-pit burning that has been used at military bases to dispose of various waste materials. A cross-sectional survey of personnel deployed in the Middle East during 2003 and 2004 found that respiratory illness was the second-most common condition to result in short-term disability and hospitalization of deployed troops (Sanders et al. 2005).

MORBIDITY AND MORTALITY IN POPULATIONS EXPOSED TO COARSE PARTICLES

Air pollution in the Middle East is characterized by episodes of resuspended windblown dust from desert regions, which increase particle concentrations to levels above the Military Exposure Guidelines (MEGs) many times each year. As noted above, high concentrations of both coarse particles ($PM_{10-2.5}$) and fine particles ($PM_{2.5}$) have been measured by the military during both the Afghanistan and Iraq conflicts. A recent study of PM in Kuwait also documented relatively high concentrations of PM_{10}, probably because of the resuspension of dust from the desert crust (Brown et al. 2008). There is abundant evidence that exposure to fine PM in urban centers—arising mainly from combustion of oil, gasoline, and natural gas—increases the risks of acute cardiac events (such as myocardial infarction, arrhythmia, and exacerbation of congestive heart failure), acute respiratory events (such as pneumonia and exacerbation of asthma), and cardiopulmonary mortality (Pope and Dockery 2006). In addition, controlled human-exposure studies have shown that exposure to particles can affect sub-clinical cardiovascular responses (Brook 2008). It is not clear, however, whether high concentrations of PM from crustal sources pose the same risks to cardio-vascular and respiratory health as PM from anthropogenic combustion. In fact, there is a body of evidence that demonstrates that the chemical composition of PM and its size fraction affect the relationship between PM exposure and human health (Laden et al. 2000; Lippmann et al. 2006; Bell et al. 2009; Peng et al. 2009).

Several studies have shown links between coarse particles and human health (Ostro et al. 1999; Ostro et al. 2000; Middleton et al. 2008; Peng et al. 2008; Perez et al. 2008; Malig and Ostro 2009). Specifically, studies have shown associations between windblown dust from the Mongolian desert and increased cardiac and respiratory morbidity in Taiwan and Korea (Kwon et al. 2002; Chen and Yang 2005; Yang et al. 2005; Bell et al. 2008; Cheng et al. 2008; Chiu et al. 2008; Yang et al. 2009). In Taiwan, analyses indicate that Asian dust storms may result in increases in daily hospital admissions for chronic obstructive pulmonary disease (Chiu et al. 2008), cardiovascular disease (Chen and Yang 2005), congestive heart failure (Yang et al. 2009), asthma (Yang et al. 2005), allergic rhinitis (Chang et al. 2006), conjunctivitis (Yang 2006), and pneumonia (Cheng et al. 2008), although none of the associations were statistically significant. In contrast, some studies in North America have not found an association between coarse PM and adverse health effects. In a time-series study conducted over a 6-year period in Spokane, Washington, there were multiple episodes when coarse PM concentrations were high in the absence of increased fine-particle concentrations, and results of the study showed that high-dust days did not have an effect on mortality (Schwartz et al. 1999). Another study of hospital admissions in the greater Vancouver area (Bennett et al. 2006) showed no effect of clouds of dust that were transported from the Gobi Desert to Canada. In a study of the effect of PM on mortality in Salt Lake City, Utah, the PM-mortality association was strengthened when days with high concentrations of windblown dust were excluded (Pope et al. 1999). In another study in the Coachella Valley of California, there was less effect of PM on mortality on windy days (Ostro et al. 2000).

Given the paucity of studies and the relative uncertainty about the toxicity of coarse PM in the epidemiologic literature, a well-designed investigation of the effects of windblown dust on the health of military personnel in the Middle East could contribute considerably to scientific understanding of the potential risks associated with exposure to coarse PM. In addition, military personnel constitute a unique population (for example, they are typically healthier and more physically fit than the general public; they have different age and sex distributions, different activity patterns, and different rates of smoking; and they are potentially under greater stress), and this is another reason that studies of military personnel are important for understanding the effects of coarse PM. An important issue is that in most of the epidemiologic studies, adverse effects have been observed in elderly persons who had pre-existing cardiopulmonary disease, a group that is quite different from the healthy military population.

EXPOSURE ASSESSMENT

Exposure assessment is the process of estimating or measuring the magnitude, frequency, and duration of exposure to an agent in a specific exposed population. Ideally, it describes the sources and routes of exposure, the dose delivered to target tissues, and relevant uncertainties. Proper assessment of exposure is essential for the validity of any environmental epidemiologic study.

In addressing the relationship between exposure of military personnel deployed in the Middle East theater to airborne PM and the risk of adverse health effects, exposure assessment is a critical component. There are many levels on which exposure can be assessed, including a broad geographic level and a personal level. Ideally, the dose to target organs is the gold standard, but it is not practical to measure the concentration of inhaled particles in the airways and lungs of exposed military personnel. Personal measurements of exposures in breathing zones are possible, but these could be conducted in a war zone only with great difficulty.[1] When measurements for each individual are impractical, a surrogate can be constructed by using the route of exposure (for example, inhalation), the magnitude or intensity of exposure (for example, particle concentration in micrograms per cubic meter of air), the duration of exposure (for example, minutes, hours, or days), and the frequency of exposure (for example, daily, weekly, or monthly). Those characteristics of exposure and the physical, chemical, and biologic properties of the complex mixture of particles can be used to determine indirectly the amount of particles to which a person is exposed, the amount deposited in the airways, and ultimately the dose that specific organs may receive. There are no data that specifically address whether PM fixed-site monitoring stations in the Middle East theater correlate with personal PM exposures among military personal. However, there is evidence that measurements of daily fluctuations in urban populations, specifically $PM_{2.5}$, correlate well with most daily measurements of personal exposures (Oglesby et al. 2000; Liu et al. 2003; Brunekreef et al. 2005; Sarnat et al. 2009). It is important to note that daily fluctuations in $PM_{2.5}$ concentrations are different from long-term average $PM_{2.5}$ exposures, and the contribution of long-term ambient $PM_{2.5}$ concentrations

[1]Because military personnel have to wear considerable gear for warfare, additional personal monitoring equipment would likely be considered too burdensome, as it is not essential to the mission (Sheehy 2009).

to personal $PM_{2.5}$ concentrations and how this relationship varies with averaging time is not well understood.

If the available exposure data are not sufficient to characterize adequately the likely exposures of people for whom health-outcome data are collected, then an epidemiologic study of associations between the exposure of interest and the outcomes of interest will not provide valid results. The committee concluded that the exposure data contained in the Department of Defense (DOD) Enhanced Particulate Matter Surveillance Program (EPMSP) report, although informative, were insufficient to characterize the exposure of most deployed personnel during the period of monitoring for the purpose of linking exposure to health. Therefore, any linkage of the exposure data with health-outcome data should be viewed with caution.

HEALTH FOLLOWUP BY THE U.S. ARMY CENTER FOR HEALTH PROMOTION AND PREVENTIVE MEDICINE

Several presentations were made by members of the Environmental Medicine Program of the USACHPPM to the committee (see Appendix C for the meeting agendas). Preliminary results of two epidemiologic studies that used EPMSP data collected from deployed personnel were presented (Abraham 2009).

The first study evaluated the association between acute (short-term) exposures to PM and the risk of an adverse health response in an effort to answer the question, "If exposure to particles on a specific day increases, does the risk of adverse health outcomes increase on that day or subsequent days?" The study used a case-crossover design to evaluate the association of daily average concentrations of $PM_{2.5}$, PM_{10}, and total suspended particulates with reported in-theater visits to health-care facilities for cardiovascular and respiratory outcomes. There was no mention of lags or moving averages in the presentation given to the committee. For the sampling period (late 2005 to early 2007) at the 15 EPMSP sites, health-outcome data were obtained from electronic medical records (gathered with JMeWS, a web-based medical surveillance tool), an evacuation database (TRANSCOM Regulating and Command & Control Evacuation System), and in-garrison inpatient and outpatient medical records (gathered with the Defense Medical Surveillance System Standard Inpatient Data Record and Standard Ambulatory Data Record). The cardiovascular and respiratory outcomes identified in the health databases were myocardial infarction, other ischemic heart disease, other forms of heart disease, acute respiratory infections, pneumonia and influenza, and chronic obstructive pulmonary disease and related conditions. Demographic data from the Defense Manpower Data Center, personnel-location data (gathered with Defense Theater Accountability Software), and meteorologic data from the Air Force Combat Climatology Center were also used in the analyses. An initial base-camp-specific analysis was followed by a pooled analysis over base camps; only 10 of 15 base camps had data sufficiently complete for inclusion in the analysis. No associations were found between any of the PM metrics and cardiovascular or respiratory health outcomes. Although this was the first study of its kind in a deployment setting and may inform the design of future studies, the results are difficult to interpret because the study suffered from limited statistical power owing to the short period of study, few health-outcome events, incomplete health-outcome data, and misclassified and relatively sparse exposure data as a result of the 1-day-in-6 EPMSP sampling protocol (see Chapters 2 and 3). Thus, the null findings do not necessarily indicate that there is no association.

In the second study, a retrospective cohort design was used to assess persistent health effects of exposure to PM. The study was used to examine long-term rather than short-term effects on health. Personnel deployment and location data were used to define the cohort, EPMSP data were used to assess exposures (quartiles of time-weighted-average $PM_{2.5}$ or PM_{10}; see Chapters 2 and 3), post-deployment cardiovascular or respiratory disease diagnoses were the outcomes evaluated[2], and the Cox Proportional Hazards model was used to estimate exposure-disease associations. No rates of diagnoses were found to be associated with exposure to particles in analyses that accounted for potential confounding factors—sex, age, marital status, service branch, rank, deployment, and pre-existing conditions. Limitations of the study include potential misclassification of exposure and outcomes, a relatively short followup after deployment, and a lack of smoking data. As was the case with the first study, care should be taken not to overinterpret the results or to conclude that there is no association.

In recognition of occupational exposure of deployed military personnel to potentially hazardous PM, some USACHPPM teams endeavored to conduct medical surveillance of exposed soldiers. A pilot surveillance project conducted at one military base (Joint Base Balad) used spirometry to assess respiratory effects of exposure to PM (Ross 2009). Over 670 soldiers deployed at the base underwent spirometry from September to October 2005. Followup spirometry of 103 of the soldiers after deployment was completed. Mean postdeployment forced vital capacity (FVC) and forced expiratory volume at 1 second (FEV_1) were not different from values obtained during deployment. A small number of soldiers tested did have a greater than 15% decline in FVC, FEV_1, or both; this indicated the possibility of a more susceptible subgroup. Two other medical-surveillance projects conducted during 2007-2009 deployments (n = 29 and n = 39) also showed predeployment-to-postdeployment FVC and FEV_1 changes

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[2]Health databases were searched for specific diagnosis codes pertaining to the circulatory system (cardiovascular system, ischemic heart disease, acute myocardial infarction, other forms of heart disease, and cardiac dysrhythmias), respiratory system (acute respiratory infections, other diseases of the upper respiratory tract, chronic obstructive pulmonary disease and allied conditions, asthma, and other diseases of the respiratory system), and signs, symptoms, and ill-defined conditions (symptoms involving the cardiovascular system, symptoms involving the respiratory system and other chest symptoms, dyspnea and respiratory abnormalities, and chest pain).

consistent with that possibility. None of these medical-surveillance activities were designed as research studies, and they all suffer from inadequate statistical power, lack of specific exposure data, probable selection bias, and possible inadequate data-quality assurance. Those initial Army surveillance efforts are commendable, but implementation of a medical-surveillance program that includes the continued systematic collection of health data over a long term is required to provide information that can lead to effective interventions to reduce exposures to hazardous agents.

TOXICOLOGIC STUDIES OF PARTICULATE MATTER COLLECTED BY THE ENHANCED PARTICULATE MATTER SURVEILLANCE PROGRAM

Toxicologic studies of samples collected through the EPMSP can test hypotheses about the potential of components of PM to cause adverse health effects. Such studies may provide insight into potential mechanisms, dose-response relationships, relative toxicity among different sources, and interactions with coexposures, such as smoking, that may enhance responses. The committee heard an overview presentation by a member of the Naval Health Research Center Environmental Health Effects Laboratory (see Appendix C) on inhalation-toxicology studies that used EPMSP samples (Stockelman 2009). Soil samples were selected from Middle East military-theater sites and were studied in vitro and in vivo for PM toxicity. Three rodent studies were conducted: 1) particle exposure by single intratracheal instillation of PM (identified as desert-sand PM_{10}) with up to a 6-month postinstillation evaluation, 2) oral gavage of Iraqi PM from Camp Victory for 28 days, and 3) sand and smoke exposure that used cigarette smoke and aerosolized sand over a total period of 6 weeks.

In the first study, sand (defined as PM_{10} desert sand), titanium dioxide, or silica was administered to rats via a single intratracheal instillation of 1, 5, or 15 mg suspended in 400 µl of sterile saline. Sacrifice times were 1, 3, 7, and 35 days and 6 months after instillation. The end points measured were inflammation and injury to the lungs, lung endotoxin, histopathologic findings in major organs, and the presence of heavy metals in major organs. Clear effects were seen 1, 3, and 7 days after a dose of 5 or 15 mg of Iraqi PM_{10} sand. The effects included dose-related alveolitis, perivascular eosinophilic infiltrates, and limited nephropathy and hepatic inflammation. Resolution of those effects was almost complete by 35 days after instillation, and no further effects were noted 6 months after instillation.

The second study exposed rats to suspended Iraqi PM from Camp Victory via oral gavage for 28 days. The doses administered were 0-20 mg/kg per day diluted in 200 µl of sterile saline. The study end points were gross and microscopic pathologic and immunotoxicologic conditions. The interim conclusions from the study were that concentrations of B cells were increased and that the immune response to staphylococcal enterotoxin B (which activates T and B cells) was depressed in the PM groups.

The third study was performed to examine the toxic effects of desert sand (Iraqi PM) alone and in combination with inhaled cigarette smoke. Pure silica sand from a site in the United States was used as a control. The experiments evaluated the tissue burdens of PM constituents after inhalation and the biologic activity of soluble PM constituents. The study began with a nose-only pre-exposure period of 4 weeks, during which time rats were exposed to air or cigarette smoke. The main-exposure period lasted for 2 weeks and used nose-only exposure to cigarette smoke or air and whole-body exposure to Iraqi PM, purified silica sand, or air. Respirable particles were generated from both the Iraqi soil samples collected from the field and purified silica. The mass median aerodynamic diameter, exposure times, and inhaled mass were well controlled.

Following the 2-week main-exposure period, pulmonary and systemic effects were measured in blood and plasma and in bronchoalveolar lavage fluid (BALF) with cytokine assays, enzymes, and cytology. Lung histopathology, protein analysis, and proteomics were also used. After exposure to dusts and/or cigarette smoke, BALF failed to demonstrate changes in numbers of cells recovered or a shift in cell types. Protein and lactate dehydrogenase measurements were also unchanged by dust and/or cigarette-smoke exposure. Lung histopathology demonstrated a mild to moderate hyperplasia of the tracheal epithelium after the 2-week exposures. However, exposure to cigarette smoke created far greater lung changes that were not exacerbated by inhalation exposure to sand. Protein analysis of BALF suggested that exposure to cigarette smoke caused a greater effect on chitinase, kininogen, and the pi form of glutathione-*S*-transferase than exposure to sand. An interesting finding was that cigarette smoke appeared to suppress the responses associated with Iraqi PM and purified silica.

Chemical analysis of PM soil specimens from different Middle East military sites demonstrated similarities in composition for a wide variety of elements. In vitro studies of soluble extracts of soil from military sites used cell lines and demonstrated cell death and selective cytotoxicity that varied with time and the region from which the soil sample was collected.

In summary, the Navy evaluated the potential for desert sand to induce pulmonary and systemic injury; exposures were benchmarked against silica as a positive control and titanium dioxide as a negative control. It also evaluated the potential for cigarette smoke to potentiate injury that was due to desert sand. The studies showed that high-dose exposures to desert sand caused modest injury that could be characterized as transient. When monitored over long periods, much of the pulmonary injury resolved. The data suggested that the inhaled silica was of an amorphous form that does not have the toxicity of crystalline silica. That was confirmed by scanning electron microscopy analysis of the particles. The observation that injury and inflammation from cigarette smoke were substantially higher than those caused by desert sand was interesting. The toxicologic studies conducted by Navy investigators provide initial insight into the potential pulmonary hazard posed by desert sand. Although healthy animals may not represent susceptible populations, such as the elderly and people who have pre-existing conditions, the preliminary data suggest that healthy subjects may not be at markedly increased risk for acute responses to desert sand. However, the studies are limited in that the exposures did not include the full array of constituents that military personnel are exposed to, they did not investigate chronic effects, and humans may respond differently from rodents. Future studies may also consider other biologic responses of interest, such as cardiovascular responses, and may look at the effects of direct or interactive exposures to other sources of interest, such as burn pits. It should be noted that the Navy considered burn pits as an important item for future study.

THE VALUE OF THE DEPARTMENT OF DEFENSE ENHANCED PARTICULATE MATTER SURVEILLANCE PROGRAM

The EPMSP was impressive in many ways, especially given that it was one of the first efforts to characterize environmental exposures of deployed military personnel that could potentially affect human health. The project faced many challenges in assessing exposures to PM in a military operation, doing it with limited resources, and doing it in conditions in which the primary job functions of many of the personnel conducting the monitoring were unrelated to the investigations. Challenges included the need for easy-to-use equipment so that monitors could be operated by personnel without previous experience and the presence of extreme temperature and magnitudes of pollution that were often outside the design specifications of the instrumentation. The usefulness of the monitoring campaign's results to studies of the health of deployed troops has been limited largely by the combination of uncertainties regarding the actual exposures, the small number of study subjects, and the limited amount of exposure data. The 1-day-in-6 sampling schedule provided relatively sparse exposure data, and this hinders the study of both acute and chronic exposures.

Regardless, the results of the EPSMP clearly show that military personnel deployed to the Middle East during the current Afghanistan and Iraq conflicts are often exposed to high concentrations of PM and that the composition of PM varies considerably over both time and space. Those characteristics of exposure could be exploited to address some of the current gaps in data on the toxicity of windblown PM and could potentially be used to understand the toxicity of open-pit burning of waste materials. That is, the results of the EPMSP can be viewed as a pilot exposure-assessment study that could form the basis of the design of specific objectives for a followup research project that would carefully link exposure measurements to health data. The results of the EPMSP can also be viewed as providing sufficient evidence of occupational exposure to a potential hazard, ambient PM, that would justify the implementation of a comprehensive medical-surveillance program to assess PM-related health effects in military personnel deployed to the Middle East theater. Moreover, the committee can envision a health-surveillance program that could be linked to research studies.

SURVEILLANCE: CONTINUING ASSESSMENT OF THE HEALTH OF ARMED FORCES PERSONNEL

The health status of personnel can be determined with medical surveillance, which can include periodic administration of symptom questionnaires and tests for specific respiratory and cardiovascular adverse effects (for example, pulmonary-function testing) and the collection, storage, and analysis of regularly collected data (for example, data in medical records or in clinical information systems). The weight of evidence of an association between data on exposure to a specific hazard, such as ambient PM, and various types of health-status data is generally based on evidence in the epidemiology and toxicology literature. If "sufficient evidence" of a hazard is available in the literature, it is advisable to link the exposure and medical-surveillance data in an effort to reduce exposures and prevent adverse effects (see Box 4-1, which describes such surveillance). If the evidence of hazard is deemed insufficient, the design and conduct of a new epidemiologic study to address the data gap may be appropriate.

CONSIDERATIONS FOR INVESTIGATING THE HEALTH EFFECTS OF EXPOSURE OF MILITARY PERSONNEL TO POLLUTANTS

It is plausible that exposure to ambient pollution in the Middle East theater is associated with a number of adverse health outcomes. Some may present themselves as acute effects that are manifested during service in the theater and some as chronic effects that occur many years later. Further investigation is warranted to understand the health burden that results from exposure to potentially toxic mixtures of pollutants that vary in time and concentration. Important sources of exposure include open-pit burning upwind of personnel operations, diesel fumes, and resuspended dust from deserts and sandstorms.

It is suggested that future investigations consider characteristics of the military target population—activity patterns, baseline health status, occupations, and other characteristics—that differ from those of the general population. For example, in most occupational settings, exposures to hazards occur only during work hours, but military personnel deployed at some bases in the Middle East may be exposed to ambient PM 24 hours a day, 7 days a week. (The military has established 1-year MEGs[3] for $PM_{2.5}$ of 15 $\mu g/m^3$. See Box 4-2 for a discussion of

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[3]MEGs are defined as a chemical concentration which represents an estimate of the level above which certain types of health effects may begin to occur in individuals within

BOX 4-1 General Approach to Medical Surveillance

An important complement to environmental monitoring is medical surveillance, which is recommended by the National Institute for Occupational Safety and Health when workers are exposed to hazardous materials. The recommendation is clearly applicable to exposure of military personnel deployed in the Middle East to ambient PM. *Surveillance* describes any use of health or exposure data to identify cases or monitor trends; direct medical evaluations of people at risk for the development of particular disorders (screening for cases) is one source of health data (Murthy and Halperin 1995).

In this brief review, *medical surveillance* refers to the continuing application of medical tests and procedures to workers who may be at risk for morbidity because of exposure to hazardous material. The elements of a medical-surveillance program generally include the following:

- An initial medical examination and collection of medical and occupational history.
- Periodic medical examinations at regularly scheduled intervals, including specific medical screening tests when warranted. Screening tests have operational characteristics that should be considered in designing and evaluating medical-surveillance programs, such as sensitivity, specificity, predictive value, and reliability and reproducibility.
- More frequent and detailed medical examinations as indicated on the basis of findings from examinations.
- Postincident examination and medical screening after uncontrolled, or nonroutine, increases in exposure.
- Training of exposed or potentially exposed groups to recognize symptoms of exposure to a given hazard.
- A written report of medical findings.
- Action by authorities (employers and supervisors) in response to identification of potential hazards.

The importance of a well-functioning surveillance system is discussed in great detail in IOM (2008). The report describes this type of system as follows, “A fully functioning surveillance system would track military exposures and health outcomes, during military service and after discharge, and maintain a repository of data and biological specimens so that emerging and unanticipated questions could be retrospectively addressed” (IOM 2008, p. 21).

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the exposed population after a continuous, single exposure of a specified duration (USACHPPM 2003).

BOX 4-2 Interpretation of Military Exposure Guidelines for Particulate Matter

The EPMSP study found PM concentrations to exceed the USACHPPM 1-Year Military Exposure Guideline (MEG) of 15 μg/m^3 for $PM_{2.5}$ (Engelbrecht et al. 2008). The chemical composition of the particles was related to the area's geology, and indicated elevated concentrations of crustal materials, such as calcium and silicon. Such metals as lead and zinc were also identified. $PM_{0.5}$ was found to have a different chemical structure, with more combustion-related products. The authors of the study concluded that PM "dusts" were similar in composition to those in other regions and that the three primary origins of air pollution were geologic dust, burn pits, and sources of metals, such as lead smelting and manufacturing sites. Those conclusions are plausible, but the true sources of the pollution and relative contributions are not well characterized.

Challenges arise in extrapolating results of studies of associations of PM with adverse human health outcomes to other regions, populations, or periods. As noted, military personnel deployed in the Middle East differ greatly from the U.S. general population. In addition, the chemical composition of PM is hypothesized to affect its toxicity. Studies have shown that for a given size distribution of particles, relative rates of health outcomes differ by region, season, and source (for example, Laden et al. 2000, Peng et al. 2005, Dominici et al. 2006, Andersen et al. 2007, Bell et al. 2009, Peng et al. 2009, Qu et al. in press). Similarly, the chemical composition of PM follows regional and seasonal patterns (Bell et al. 2007).

Therefore, the health effects of exposure to the PM measured in the EPMSP are likely to differ from those of exposure to other types of PM. Typical PM in an urban environment in the United States would have lower concentrations of crustal components than PM in the EPMSP. Comparing measured concentrations of PM with regulations or guidelines poses similar limitations. The MEGs were designed to help characterize health risks associated with environmental exposures during deployment, with recognition that assessing data in the context of the MEGs should incorporate professional judgment (USACHPPM 2003). It is important to emphasize that there is no guarantee that health effects will not occur below the MEGs. Comparison of observed PM concentrations with the MEGs or U.S. Environmental Protection Agency regulatory guidelines (the National Ambient Air Quality Standards) should be interpreted in relation to the uncertainties in the current scientific literature regarding how the chemical composition of particles influence their effects on human health.

the challenges of interpreting the MEGs for PM.) Despite the potential for continuously high exposures during deployment, the types of associations with ambient PM that are found in the general population—such as increases in daily emergency-department visits, in hospitalizations, and in mortality—may not be observed in this relatively young, healthy, and physically fit population. However, there may be exceptions in personnel who have particular chronic diseases, such as asthma, that may be exacerbated by exposure to short-term increases in ambient PM. The incidence of most chronic diseases increases with age; given that some personnel are middle-aged and older, there may be relatively large groups that are more susceptible. Other acute or chronic detrimental health outcomes may also result, given the high exposures and the unique sources encountered. Acute exposures to toxicants from burn pits and other sources could lead to immediate and possibly severe reactions.

Detection of short-term effects of exposure to ambient PM in deployed military personnel may be difficult because the effects can be relatively small and sample sizes can be small, so complex panel studies with measurements of both selected physiologic parameters and personal exposures may be required. Moreover, some of the acute effects observed may lead to chronic health conditions. For example, evidence is emerging from controlled human exposure studies of young healthy persons that exposure to particles and secondhand tobacco smoke can induce acute changes in vascular function and increases in blood pressure (Heiss et al. 2008; Brook et al. 2009). In addition, epidemiologic studies have demonstrated associations between exposure to PM and increased systemic inflammation (Liu et al. 2009) and literature reviews have discussed pulmonary and cardiovascular effects related to PM exposure (Alfaro-Moreno et al. 2007; Brook 2008). The current medical data collected routinely by the Army in its health-informatics systems may offer an opportunity to assess potential long-term health outcomes that may be associated with air pollution (such as hypertension and diabetes).

The composition of air pollutants in the Middle East theater is clearly distinct from that in urban centers in industrialized countries, and it probably varies from site to site within the theater. The effects of weather may also be important. The design of an exposure monitoring strategy of deployed personnel must be tailored to the specific health effect questions to be assessed either with continuing surveillance or with directed research. In particular, the exposure assessment required for the study of potential persistent effects, such as the development of asthma or chronic obstructive pulmonary disease, may be different from that for the study of acute effects, such as respiratory symptoms that vary day to day or heart-rate variability.

There is a notable dearth of exposure data from previous wars, particularly the Vietnam War and the first Gulf War. That has led to barriers to the understanding of chronic health effects and to the provision of appropriate compensation for war-related diseases. The recent large-scale efforts to conduct exposure assessment indicate that the military takes the issue of PM exposure seriously, and the committee commends the work reported by Engelbrecht et al. (2008), Abraham (2009), Ross (2009), and Stockelman (2009) that was presented to it (see Appendix C).

However, to gain a better understanding of the exposures experienced by deployed military personnel and their potential health effects, an essential first step should be to conduct an inventory of potentially toxic compounds (Froines at al. 1989). That would entail generating a list of possible sources, emissions, and exposure pathways, and it would include the processes and substances used on site and those anticipated to result from items being placed in the burn pits. Such a list could be reviewed with regard to known and suspected human-health outcomes of exposure to these compounds, and this information could help to guide the design of exposure studies and health-surveillance and research studies. One potential advantage of epidemiologic studies of military populations is that they can be followed relatively easily over time, in this case, before, during, and after deployment to the Middle East theater. However, a problem with many previous studies of deployed military personnel is the lack of data on relevant exposures. If the decision is made to conduct a long-term follow-up study of deployed personnel in Iraq or Afghanistan, the collection of adequate exposure data to appropriately classify study participants will be of paramount importance.

Utilizing the Millennium Cohort Study

One possibility for conducting an epidemiologic study of the effects of PM on deployed military personnel in the Middle East is for the USACHPPM to work collaboratively with the Millennium Cohort Study (Gray et al. 2002). That study was launched in October 2000 in response to a DOD recommendation for a coordinated effort to study the potential health effects of deployment-related exposures (Secretary of Defense 1998) and the Institute of Medicine recommendation for a systematic, longitudinal, population-based assessment of service members' health (IOM 1999). Enrollment for the 21-year longitudinal study began in July 2001 and was completed in June 2003. The millennium cohort consists of 77,047 consenting military service members who were enrolled through both Web and U.S. Postal-Service-based submission options (36% response rate of those invited to participate) (Ryan et al. 2007). The invited personnel were sampled through electronic personnel records representing about 11.3% of the 2.2 million men and women who were in service as of October 1, 2000. U.S. military personnel serving in the Army, Navy, Coast Guard, Air Force, and Marine Corps were recruited. The Millennium Cohort Study participants have already been used to investigate the incidence of self-reported respiratory symptoms (persistent or recurring cough or shortness of breath), asthma, and chronic bronchitis or emphysema among the 46,077 participants who completed baseline and followup (June 2004-February 2006) questionnaires (Smith et al. 2009). Similar rates of asthma, chronic bronchitis, and emphysema were observed in deployed and nondeployed personnel. Deployment was, however, associated with increased respiratory symptoms in Army and Marine Corps personnel but not in Navy or Air Force personnel. That result was independent of smoking status; duration of deployment was linearly associated with increased reporting of symptoms by Army personnel. In deployed personnel, increased risk of symptoms was associated with land-based as opposed to sea-based deployments. The investigators commented that their results suggest that environmental exposures may be responsible for the increased respiratory symptoms reported by land-based combat troops. They specifically cited the EPMSP results reported in *Inhalation Toxicology* (Engelbrecht et al. 2009a,b) as support for the need to conduct further research to address this issue.

The USACHPPM team could collaborate with the Millennium Cohort Study investigators to devise an environmental monitoring strategy to assess PM exposures of deployed members of the millennium cohort before the next round of questionnaire completion. The millennium cohort is large enough to avoid the sample-size issues that beset the initial efforts by USACHPPM to conduct epidemiologic studies of cardiopulmonary outcomes. In addition, the cohort has many nondeployed participants who could serve as nonexposed controls.

GUIDING PRINCIPLES FOR ASSESSING THE HEALTH OF SOLDIERS IN THE MIDDLE EAST CONFLICTS

Predicting likely acute and chronic health effects is complex and difficult. For example, in the case of Agent Orange, although there was a priori concern over its potential carcinogenicity, the findings of excess risk of diabetes came as a surprise to many (Henriksen et al. 1997). That is not atypical; prediction of health effects is highly constrained by current knowledge. Nevertheless, some guiding principles could be stated to help to define the objectives of surveillance and research programs:

- It is possible that the health responses for the military population will differ from those of the general population, given differences in factors such as baseline health, age, and smoking status. Some acute responses may be identified only through subtle physiologic changes, such as vascular responses and increased concentrations of markers of inflammation. The very high concentrations of particles may lead to an overload of the pulmonary clearance system (Ballew et al. 1995; Oberdörster 2002) and could conceivably be manifested in respiratory and cardiovascular outcomes. Coupled with that could be effects arising from other routes of exposure to pollutants (for example, dermal exposure and ingestion). A carefully designed surveillance program is essential and should include inventories of pollutants from the enhanced monitoring program and a detailed review of human and toxicologic studies. As in any epidemiologic investigation of acute or chronic effects, consideration of concomitant illnesses (for example, infectious diseases), stress, and other environmental factors is required. Studies of subacute effects could conceivably be carried out in personnel not involved directly in the conflict, such as clerical and administrative personnel; this would lessen any burden on military operations, but the issue that exposures of these personnel differ from exposures of other military personnel would need to be addressed.

- The investigation of chronic effects should have high priority in any health-surveillance programs that the Army implements. A cohort of exposed people should be developed and followed to assess associations with indicators of their health and exposures in the theater. That type of surveillance, although complex, is not unique in a military setting; for example, there are standard methods for the U.S. Air Force Ranch Hand Study that examined health effects of Agent Orange. The committee concluded that the Army is in an excellent position to develop cohorts for study, but detailed assessment of baseline exposure in the theater would be required. Questionnaires and specific medical assessments can be administered through time. The clinical-informatics systems of the Army and of the Department of Veterans Affairs, in addition to the usual methods of followup (such as the National Death Index and state cancer registries), can be used to identify the incidence and prevalence of health conditions.
- Development of testable research questions and specific objectives to address the questions are required for the conduct of any epidemiologic research study. The objectives should be used to motivate essential study-design features. Examples of those features are subject to eligibility criteria, size and demographic characteristics of the cohort (particularly for statistical-power purposes), length of followup required, health outcomes and the frequency required to assess them, critical periods of exposure, and potential confounding and modifying factors that would need to be measured. Careful consideration should be given to the design of the exposure assessment for the cohort, including accounting for duration of exposure, activity patterns, and changes in deployment locations, so that potential associations with health outcomes can be appropriately evaluated.
- An independent oversight committee composed of internal and external members who have expertise in air pollution, analytic chemistry, exposure assessment, epidemiology, toxicology, biostatistics, and occupational and environmental medicine should be established to provide guidance and to review specific objectives, study designs, protocols, and results of the various exposure and health-surveillance or research programs that are developed. Such a committee could provide an essential peer-review function, as well as an oversight function, lending scientific credibility to the investigations. An example is the advisory committee that was established to oversee the conduct of the Air Force Ranch Hand Study (FDA 2009).
- The location of monitoring sites needs to account for where the largest numbers of military personnel are stationed and where they are working in the ambient environment to maximize study power and minimize exposure misclassification. Daily sampling frequency, for at least PM mass, would greatly increase the amount of exposure data available for an analysis of acute effects on health. Measurement of other relevant pollutants will greatly aid any efforts.

Conducting a well-designed epidemiologic study of the potential adverse health effects of exposure to PM in deployed military personnel in the current Middle East conflicts will require a major effort in many units and possibly multiple military branches. Such a study will be organizationally and logistically challenging, given the temporally and spatially comprehensive monitoring of PM and other pollutants and the large sample sizes needed.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

- The data presented by Engelbrecht et al. (2008) constitute compelling evidence that a large-scale assessment of the air-pollution exposures of military personnel and associated health risks is feasible and needed. The data that were collected are not adequate for performing a useful health-effects research study, but they afford a preliminary understanding of the composition of particles in the setting in question, which can help to guide the design of future surveillance and research programs. To assess health responses, it will be necessary to collect more data to increase statistical power, to account for effects of other exposures, and to improve data quality.
- Efforts to conduct surveillance and research programs to assess effects of exposure to PM in military personnel deployed to the Middle East theater should follow the guiding principles outlined in this chapter.

Recommendations

- *The DO D should take an inventory of potentially toxic compounds to which deployed personnel may be exposed.* That would entail generating a list of possible sources, emissions, and exposure pathways. Such a list could be reviewed with regard to known and suspected human-health effects of exposure to the compounds, and this information could help to guide the design of exposure and health-surveillance and research studies.
- *Surveillance efforts for potentially harmful exposures, such as exposure to ambient PM, and epidemiologic investigations could benefit greatly from coordination with other large-scale efforts that are under way.* An example is the Millennium Cohort Study, which has explored the effect of deployment on respiratory health.
- *Although the EPMSP was intended to characterize exposure to particles, a full understanding of the air-pollution exposures of deployed personnel should include other key pollutants that may be relevant to human health*. Examples are other criteria pollutants (such as ozone), metals, hazardous air pollutants (air toxics), and diesel exhaust.

- *Medical information collected routinely by the DOD should be analyzed in such a way that health outcomes that may be associated with air pollution can be identified with a view to developing a more robust surveillance system and to understanding the health effects of exposures.* Care should be given to consideration of the original design and purposes of the medical databases, which were not intended for research purposes. The DOD should consider expanding medical surveillance, especially for deployed personnel, to include additional data that could be used to assess health effects. In light of the known respiratory effects of inhaled pollutants, consideration should be given to performing spirometry before, during, and after deployment to the Middle East theater.
- *In selected cases, complementary toxicologic studies of PM to the theater might yield insights.* Emphasis should be placed on source characterization of collected particles from the Middle East theater to define more fully the relative toxicity of these particles compared with other reference materials.
- *An independent oversight committee should be formed.* Such a committee—composed of internal and external members who have expertise in air pollution, analytic chemistry, exposure assessment, epidemiology, toxicology, biostatistics, and occupational and environmental medicine—would provide guidance and review specific objectives, study designs, protocols, and results of the various exposure and health-surveillance or research programs that are developed.
- *When possible, exposures should be minimized.* There are a number of ways to accomplish that. For example, if there is a prevailing wind direction, emission sources (such as local generator farms, burn pits, and incinerators) should be located downwind of the bases. For periodic emissions, such as waste burning, burns could be conducted when meteorologic conditions favor dispersion of the emissions.

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5

Conclusions and Recommendations

OVERARCHING CONCLUSIONS

The Department of Defense (DOD) Enhanced Particulate Matter Surveillance Program (EPMSP) was an ambitious effort, as it was one of the first studies to measure and characterize exposures to particulate matter (PM) in an effort to assess the health effects on military personnel in the Middle East. The committee applauds the DOD's ability to carry out such a large-scale exposure-monitoring study in the midst of a military operation, despite the inherent challenges that result from a harsh climate and a lack of personnel and resources. The results of the EPMSP provide the basis for planning future exposure monitoring efforts that can be tied to health-effects studies, and it can and should serve as a precedent for future research and surveillance.

Although the ability to conduct such a study is a critical milestone, the design and conduct of the EPMSP and health-effects studies limit their usefulness.[1] The EPMSP achieved data recovery of 88%, which is impressive in light of the challenges of implementing protocols and operating samplers in a Middle East war zone. In addition, the sampling design and analysis captured many of the important physical and chemical properties of PM that have been shown in previous studies to affect health outcomes. The EPMSP, however, did not clearly articulate its objectives a priori, nor did it demonstrate how the sampling design and analyses would address these objectives. The MiniVol sampler, although evaluated in the United States, has not been validated at the high PM concentrations observed in this study, for example, through collection of replicate samples. The sampling strategy, which was designed to collect only one set of filters at a time, collected insufficient particle mass and species data on a consistent basis to be useful for quality assurance (QA) and for health-effects studies. Fi-

[1]The committee acknowledges that the monitoring study may not have been designed for the purpose of conducting health-effects studies, and it did not review the statement of work that DOD gave to the Desert Research Institute for conduct of the monitoring study.

nally, the use of different filter media, which were analyzed with different techniques, introduces artifacts that make it difficult to compare results, so source-apportionment and mass-balance assessments are infeasible.

Although interpretation of the epidemiologic and health-surveillance studies was encumbered by uncertainties regarding the actual exposures, the small number of study subjects, and the limited amount of exposure data, the EPMSP results clearly document that military personnel deployed in the Middle East during the current Afghanistan and Iraq conflicts are exposed to high concentrations of PM and that the particle composition varies considerably over time and space.

The committee concludes that it is indeed plausible that exposure to ambient pollution in the Middle East theater is associated with adverse health outcomes. Some of the outcomes may present themselves as acute, affecting troop readiness during service, and some as chronic, occurring years after exposure. Therefore, to investigate further the health effects of exposure to a complex mixture of pollutants, the monitoring strategy needs to be tailored to the specific goals and hypotheses that future health-surveillance and research studies are designed to address. That includes matching the monitoring period with the deployment period of the military personnel being studied. In particular, different types of exposure monitoring may be required for the study of potential persistent effects, such as asthma and chronic obstructive pulmonary disease, compared to the study of acute effects, such as day-to-day variability in respiratory or cardiac responses.

Future monitoring studies need to include other ambient pollutants that military personnel may be exposed to in the field and that may be relevant to human health, such as ozone, air toxics, and other gaseous materials. In addition, more repeated sampling with the same filter type (for example, Teflon) would provide a greater library of gravimetric and chemical-specific data and thus increase statistical power. Finally, increasing the sampling frequency will make it possible to estimate more accurate annual-average concentrations of particle mass and chemical components.

OVERARCHING RECOMMENDATIONS

The committee developed several overarching recommendations that cut across the entire EPMSP, including sampling, analytic approaches, and health effects. The incorporation of these recommendations would strengthen the exposure-surveillance study design and the robustness of the health-outcome analyses.

- *In the development of future studies by the DOD, it is important that study objectives be clearly defined to ensure that the environmental-sampling strategy meets the desired study objectives.* That is, the questions that are being asked should be clearly specified a priori. Therefore, it is critical that future epidemiologic studies be undertaken in conjunction with appropriate monitoring studies so that exposure and health outcomes can be examined simultaneously.

- *The committee recognizes the difficulty of performing sampling and health studies in an active theater. However, it also recognizes that exposure sources in this environment are more complex and potentially more toxic than in the United States and Europe, where health studies are traditionally conducted. A more complete inventory of all major sources of ambient pollutants and potential emissions in the theater should be constructed before assessment of health effects to ensure that all relevant pollutants are monitored.* Such an exercise could be based mainly on an inventory of processes, substances, and materials disposed of in burn pits. Pollutants may include the criteria pollutants (fine and coarse particle mass, carbon monoxide, lead, nitrogen dioxide, ozone, and sulfur dioxide) and other hazardous air pollutants (for example, metals, selected volatile organic compounds, and PM-associated organic compounds, such as polycyclic aromatic hydrocarbons).
- *After conducting an inventory of toxicants of concern and potential sources of those toxicants, health surveillance and epidemiologic studies that investigate the consequences of those exposures could benefit greatly from coordination with other large-scale efforts that are underway.* An example is the Millennium Cohort Study, which has explored the impact of deployment on respiratory health.
- Given the complexities of pollutant exposures and the potential acute and chronic health effects associated with these exposures, the military should consider establishing an independent multidisciplinary advisory group composed of internal and external members to provide guidance in the development and conduct of future exposure-assessment and epidemiologic studies of military personnel in combat. The advisory group—comprising experts in statistics, analytic chemistry, exposure assessment, epidemiology, toxicology, and occupational and environmental medicine—would provide guidance on and review of study objectives, study design, protocols, and results. For example, the Ranch Hand Advisory Committee was established in 1981 by the secretary of the Department of Health and Human Services to provide oversight of the Ranch Hand Study and the Vietnam Veterans Health Study.
- To conduct a well-designed epidemiologic study of the potential adverse health effects of exposure to PM in deployed military personnel in the current Middle East conflict, a major effort of many units and possibly multiple military branches will be required. Such a study will be organizationally and logistically challenging, given the temporally and spatially comprehensive monitoring of PM and other pollutants and the large number of samples that would be needed.

TECHNICAL RECOMMENDATIONS

- *In designing a comprehensive monitoring scheme, a set of study objec-*

tives should be developed that provides the rationale and selection of the samplers, filter media, sampling frequency, and data-quality standards to be used.

- Future studies should use particle samplers that operate reliably on the basis of field testing in environmental conditions that are similar to the conditions in which they are likely to be used. For the EPMSP, such field testing was not conducted, and high PM concentrations may have led to overloading of the samplers, judging by prior results from Kuwait.
- The frequency of sampling and the types of analyses applied to the samples should be tailored to the study objectives. Such an approach maximizes the benefits of the resources expended on the study.
- In future monitoring studies, it is critical that QA and control procedures be implemented and specified in writing to ensure the integrity of the samples collected and analyzed.
    - Replicate samples should be collected at selected sites during future monitoring efforts, where feasible, to assess sampler performance.
    - Measurement uncertainties should be reported for all PM components. That will make it possible to interpret, with caution, the concentration data on PM components whose concentrations are mostly below the detection limit of the analytic method, as in the case of the x-ray fluorescence data.
    - Mass closure (that is, comparison of particle mass with the sum of the individual-particle components) should be performed as part of the overall QA process.

- *Because this is likely to be a continuing effort, the military might consider developing real-time continuous particulate-matter monitoring equipment whose use is recommended in the EPMSP report.* Such equipment could be based on commercially available models but adapted to withstand the theater environment, including extreme temperatures, moisture, and particle concentrations; rough handling; and minimal maintenance. The monitors should be battery-powered and should report particle-size mass concentrations.

CONCLUDING REMARKS

The committee recognizes the importance of this initial effort to characterize the composition of PM and to understand the potential for health effects of exposures in the active theater. The feasibility of conducting future exposure assessment and health surveillance has been demonstrated. The committee strongly endorses DOD's effort and encourages it to continue and to expand its surveillance and research protocols to characterize health outcomes related to air-pollution exposures during military service. DOD should consider expanding medical surveillance, especially for deployed personnel, to include additional data (for example, results of pulmonary-function tests) that could be used to assess health outcomes. The information currently collected by the military in medical databases is not designed for use in research studies to assess associations with air-pollution exposures. However, collection and use of that medical information, with an eye to developing a more robust surveillance system, could strengthen the ability to study environmental-health issues of concern.

The committee also considers that, whenever feasible, efforts should be made to minimize exposures of the troops. There are a number of ways to accomplish that; for example, if there is a prevailing wind direction, emission sources (such as burn pits and incinerators) could be located downwind of bases. For periodic emissions, such as from waste-burning, burns should take place when the prevailing meteorologic conditions favor dispersion of the emissions. That would be a general approach for reducing exposures and improving health.

Appendix A

Biographic Information on the Committee for Review of the Department of Defense's Enhanced Particulate Matter Surveillance Program Report

Mark J. Utell is a professor of medicine and environmental medicine, director of occupational and environmental medicine, and former director of pulmonary and critical-care medicine at the University of Rochester Medical Center. He serves as associate chairman of the Department of Environmental Medicine. His research interests have centered on the effects of environmental toxicants on the human respiratory tract. Dr. Utell has published extensively on the health effects of inhaled gases, particles, and fibers in the workplace and indoor and outdoor environments. He is co-principal investigator of an Environmental Protection Agency (EPA) Particulate Matter Center and chair of the Health Effects Institute's Research Committee. He has served as chair of EPA's Environmental Health Committee and on the Executive Committee of the EPA Science Advisory Board. He is a former recipient of the National Institute of Environmental Health Sciences Academic Award in Environmental and Occupational Medicine. Dr. Utell is currently a member of the National Research Council Board on Environmental Studies and Toxicology. He previously served on the National Research Council Committee on Research Priorities for Airborne Particulate Matter, the Institute of Medicine (IOM) Committee to Review the Health Consequences of Service during the Persian Gulf War, and the IOM Committee on Biodefense Analysis and Countermeasures. He received his MD from Tufts University School of Medicine.

John R. Balmes is a professor of medicine at the University of California, San Francisco and chief of the Division of Occupational and Environmental Medicine at San Francisco General Hospital. He is also a professor of environmental health sciences at the University of California, Berkeley and director of the Northern California Center for Occupational and Environmental Health. Dr.

Balmes has been studying the respiratory health effects of various air pollutants for the last 22 years. He has a particular interest in occupational respiratory disease. He has investigated the acute effects of inhalation exposures to ambient-air pollutants in his human-exposure laboratory at San Francisco General Hospital and the chronic effects of such exposures in epidemiologic studies with collaborators at the University of California, San Francisco and the University of California, Berkeley. Dr. Balmes also is investigating genetic determinants of responses to air pollutants. He has led research, funded by the U.S. Centers for Disease Control and Prevention, to assist in the development of a national program to link environmental hazards with health-outcome data to improve the tracking of diseases potentially related to environmental exposures. He has served as a member of the National Research Council Committee to Review the NIOSH Respiratory Disease Program and is a member of the Institute of Medicine Committee for the Review of the NIOSH Research Roadmap on Asbestos and Other Mineral Fibers. Dr. Balmes earned an MD from Mount Sinai School of Medicine.

Michelle L. Bell is an associate professor of environmental health at the Yale University School of Forestry and Environmental Studies with joint appointments in the Yale School of Public Health and the Yale Environmental Engineering Program. Her research addresses air pollution and human health through the integration of several disciplines, including epidemiology, engineering, and biostatistics. Her primary research focus is impact of air pollution and weather on adverse human health end points. She is also interested in the potential health impacts of climate change. She is the recipient of the National Institutes of Health Outstanding New Environmental Scientist (ONES) award and the Health Effects Institute Rosenblith Young Investigator Award. Dr. Bell earned a PhD in environmental engineering from Johns Hopkins University.

Mark S. Goldberg is a professor in the Department of Medicine at McGill University, Montreal. He is also an associate member of the Department of Epidemiology and Biostatistics, the Department of Occupational Health, and the Department of Oncology and a medical scientist at the Royal Victoria Hospital at the McGill University Health Centre. Dr. Goldberg is an occupational and environmental epidemiologist. His current research interests include the investigation of occupational and environmental risk factors for breast cancer and the health effects associated with exposures to ambient-air pollution. He was a member of the Institute of Medicine Committee to Review the Health Effects in Vietnam Veterans of Exposure to Herbicides, and he served on the National Research Council Committee on Health Risks of Trichloroethylene and other committees. He is co-editor-in-chief of the journal *Environmental Research*. Dr. Goldberg earned his PhD in epidemiology and biostatistics in 1990 from McGill University.

Philip K. Hopke is the Bayard D. Clarkson Distinguished Professor in the Department of Chemical and Biomolecular Engineering and the Department of Chemistry at Clarkson University. He is also director of the university's Center for Air Resources Engineering and Sciences. His research interests are primarily related to particles in the air, including particle formation, sampling and analysis, composition, and origin. His current projects are related to receptor modeling, ambient monitoring, and nucleation. Dr. Hopke has been elected to membership in the International Statistics Institute, and he is a fellow of the American Association for the Advancement of Science. He is also a fellow of the American Association for Aerosol Research, in which he has served in various roles, including as president, vice president, member of the board of directors, and editor-in-chief of its journal, *Aerosol Science and Technology*. Dr. Hopke is a member of the American Institute of Chemical Engineers, the International Society of Exposure Science, and the International Society of Indoor Air Quality and Climate. He has served as a member and chair of the U.S. Environmental Protection Agency Clean Air Scientific Advisory Committee and as a member of several National Research Council committees, most recently the Committee on Energy Futures and Air Pollution in Urban China and the United States, the Committee on Research Priorities for Airborne Particulate Matter, and the Committee on Air Quality Management in the United States. Dr. Hopke received his PhD in chemistry from Princeton University.

Petros Koutrakis is a professor of environmental sciences and director of the Exposure, Epidemiology, and Risk Program at Harvard University. He is also the director of the U.S. Environmental Protection Agency-Harvard University Ambient Particle Center. Dr. Koutrakis's research interests include human exposure assessment, ambient and indoor air pollution, environmental analytical chemistry, and environmental management. He has more than 180 peer-reviewed publications and nine patents, and he has conducted a number of comprehensive air-pollution studies in the United States, Canada, Spain, Kuwait, Chile, and Greece. Dr. Koutrakis is the past technical editor-in-chief of the *Journal of the Air & Waste Management Association*. He is a member of several national and international committees, and he has served as a member of the National Research Council Committee on Research Priorities for Airborne Particulate Matter. Dr. Koutrakis received his PhD in environmental chemistry from the University of Paris.

Jacob D. McDonald is a scientist and director of the Chemistry and Inhalation Exposure Program at Lovelace Respiratory Research Institute. He conducts research that bridges his education and experience in analytical chemistry, aerosol science, and toxicology. Dr. McDonald has experience in the aerosolization and vaporization of gases and particles for a wide array of applications. He has an interest in developing laboratory exposures that represent "real-world" conditions and conducting characterizations of these exposures that allow toxicity results to be placed in the context of human exposures to environmental pollutants or drug products. His work spans the study of complex mixtures, respiratory drug delivery, animal-model development, and metabolism in mammals. He is a member of the American Association for Aerosol Research, the Society of Toxicology, and the American Chemical Society. Dr. McDonald earned a PhD in environmental chemistry and toxicology from the University of Nevada.

Kent E. Pinkerton is a professor of pediatric medicine and anatomy, physiology, and cell biology at the University of California, Davis. He also serves as director of the university's Center for Health and the Environment. His research interests focus on the health effects of environmental air pollutants on lung structure and function, the interaction of gases and airborne particles in specific sites and cell populations of the lungs in acute and chronic lung injury, and the effects of environmental tobacco smoke on lung growth and development. Dr. Pinkerton is a member of the American Thoracic Society and the Society of Toxicology. He has served as a member of the Chemical Safety Advisory Committee; the Long-Range Planning Committee for the American Thoracic Society; and the National Research Council Committee on Estimating Mortality Risk Reduction Benefits from Decreasing Tropospheric Ozone Exposure. Dr. Pinkerton received a PhD in pathology from Duke University.

Bailus Walker is a professor of environmental and occupational medicine and toxicology at Howard University College of Medicine. His research interests include lead toxicity and environmental carcinogenesis. Dr. Walker has served as commissioner of public health for the Commonwealth of Massachusetts, chairman of the Massachusetts Public Health Council, and state director of public health for Michigan. He is past president of the American Public Health Association and a distinguished fellow of the Royal Society of Health and the American College of Epidemiology. Dr. Walker is a senior science adviser for environmental health to the National Library of Medicine and a member of the Institute of Medicine. He has also served on several National Research Council committees, most recently the Committee on Improving Risk Analysis Approaches Used by the U.S. EPA, the Committee on Mine Placement of Coal Combustion Wastes, and the Committee on Toxicology. Dr. Walker received a PhD in occupational and environmental medicine from the University of Minnesota.

Anthony S. Wexler is a professor in the Department of Mechanical and Aeronautical Engineering, the Department of Civil and Environmental Engineering, and the Department of Land, Air and Water Resources at the University of California, Davis. He is also director of the university's Air Quality Research Center. Dr. Wexler's research focuses on understanding the atmospheric processes that transport and transform particulate pollutants from emission to reception. He is also interested in the deposition of aerosol particles in human airways and the dynamic response of muscles to stimulation. Dr. Wexler has served on the Editorial Boards of *Aerosol Science and Technology* and *Atmospheric Environment*. He has also been the recipient of numerous honors, including the Dean's

Special Merit Award (1991-1998) and the Provost's Special Merit Award (1993, 1996, and 1999) at the University of Delaware. Dr. Wexler received a PhD in mechanical engineering from the California Institute of Technology.

Appendix B

Statement of Task of the Committee for Review of the Department of Defense's Enhanced Particulate Matter Surveillance Program Report

An ad hoc study committee under the oversight of the Standing Committee on Toxicology will review the DOD's Enhanced Particulate Matter Surveillance Program Report, which is a public report issued in February 2008 that includes an analysis of the concentration and composition of particulate matter at fifteen sites in the Central Command Area of Operations. The study committee's assessment will include a review of the report's approaches for sampling and analysis, site-specific differences in particulate matter concentrations, and the potential acute and chronic health implications for deployed personnel on the basis of the report's information on particle sizes, mass, and chemical composition. The review will also include consideration of epidemiologic investigations and health surveillance information collected by the Army on deployed personnel. On the basis of its review, the study committee will assess the potential health implications for personnel deployed in the Central Command Area and make recommendations for reducing or better characterizing health risk. Recommendations will also be made for improving ongoing epidemiological investigations or new ones that are possible within the limitations/constraints of the available outcome data and the restrictions imposed by deployment conditions.

Appendix C

Public Agendas

Committee for Review of the DOD's Enhanced Particulate Matter Surveillance Program Report

First Meeting: Thursday, July 9, 2009
Room 208, Keck Center of the National Academies
500 5th Street, NW, Washington, DC

Public Agenda

1:45 p.m.	Welcome and Introductory Remarks *Mark Utell, Chair* *NRC Committee for Review of the Army's Enhanced Particulate Matter Surveillance Project Report*
2:00 p.m.	Overview of Force Health Protection Issues Related to Particulate Matter *Dr. Coleen Baird, Program Manager, Environmental Medicine* *U.S. Army Center for Health Promotion and Preventive Medicine*
2:30 p.m.	Enhanced Particulate Matter Surveillance (EPMS) *Mr. James Sheehy, Project Environmental Engineer, CENTCOM Project Officer* *Deployment Environmental Surveillance Program* *U.S. Army Center for Health Promotion and Preventive Medicine*

3:30 p.m.	Overview of Health Outcome Studies Using EPMS Data *Dr. Joseph Abraham, Epidemiologist, Environmental Medicine Program* *U.S. Army Center for Health Promotion and Preventive Medicine*
4:30 p.m.	Overview of Respiratory Function Assessment to Date in Deployed Units *LTC Ronald Ross, M.D., Environmental Medicine Program* *U.S. Army Center for Health Promotion and Preventive Medicine*
5:00 p.m.	Overview of Inhalational Toxicology Studies Using EPMS Particulate Matter *LCDR Michael G. Stockelman, Scientific Director, Naval Health Research* *Center Environmental Health Effects Laboratory* *Wright Patterson Air Force Base*
5:30 p.m.	Public Comments
5:45 p.m.	Adjourn Public Session

Second Meeting: Thursday, September 24, 2009
Room 110, Keck Center of the National Academies
500 5th Street, NW, Washington, DC

Public Agenda

1:00 p.m.	Welcome and Introductory Remarks *Mark Utell, Chair, NRC Committee for Review of the Army's Enhanced Particulate Matter Surveillance Project Report*
1:05 p.m.	Overview of Sampling Design and Methodology for the Enhanced Particulate Matter Surveillance Program *Dr. Alan Gertler – Research Professor, Division of Atmospheric Sciences, Desert Research Institute*
1:40 p.m.	Panel Discussion with Committee Members: Experiences with conducting exposure assessment and health surveillance in military personnel in the Middle East

Dr. Alan Peterson – Professor, Deputy Chair for Military Collaboration; Director, STRONG STAR Multidisciplinary PTSD Research Consortium; Deputy Chair for Military Collaboration - University of Texas Health Science Center at San Antonio

LTC William Darby – Combat Developer, U.S. Army Medical Department Center and School

2:30 p.m. Public comments

2:40 p.m. Adjourn Public Session

Appendix D

Final Report: Department of Defense Enhanced Particulate Matter Surveillance Program (EPMSP)[1]

The *Final Report on the Department of Defense Enhanced Particulate Matter Surveillance Program* is available on CD-ROM on the inside of the back cover of this report.

[1]Engelbrecht, J.P., E.V. McDonald, J.A. Gillies, and A.W. Gertler. 2008. Department of Defense Enhanced Particulate Matter Surveillance Program (EPMSP). Final report. Desert Research Institute, Reno, NV. February 2008 [online]. Available: http://chppm-www.apgea.army.mil/foia/DOCS/Final%20EPMSP%20Report%20without%20appx%20Feb08.pdf [accessed Feb. 1, 2010].