Chapter 2

BACKGROUND OF DEPLOYMENT-RELATED AIRBORNE EXPOSURES OF INTEREST AND USE OF EXPOSURE DATA IN ENVIRONMENTAL EPIDEMIOLOGY STUDIES

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INTRODUCTION

Deployed US forces have faced several large- and small-scale airborne exposures from military operations since World War II. These forces have been deployed to worldwide locations that exhibit natural environmental conditions that create airborne exposures to particulate matter (PM) from sand and dust storms via the arid environment and active sand sheets. Examples of these locations include

- Northern Africa—World War II,
- Kuwait and Saudi Arabia—Operation Desert Storm,
- Afghanistan—Operation Enduring Freedom, and
- Iraq—Operation Iraqi Freedom and Operation New Dawn.

US forces have also been deployed to locations where operational aspects have inadvertently contributed to potential airborne exposures from chemical and combustion emissions. Examples of these include exposure to Agent Orange (Vietnam)[1]; low-level chemical agents (sarin/cyclosarin) in Khamisiyah, Iraq[2]; and airborne exposures to open-air burning and other local/regional pollution sources in Iraq and Afghanistan.[3]

The US Department of Defense (DoD) and the US Department of Veterans Affairs (DVA) remain diligent in protecting, maintaining, and improving the health of service members, veterans, and civilian employees. These departments strive to collaborate on understanding and sharing information and data on exposures that occur in deployed environments.

Over the past three decades, the DoD has worked to establish and focus proactive and retrospective efforts on deployment-related exposures. Past, current, and future populations of military personnel and veterans deserve the collaborative efforts of the DoD and DVA. Stakeholders need to understand and consider how airborne exposures can impact the health of these populations.

The DoD executed tactical-based operations in Vietnam, during which aerial spraying of tactical herbicide chemicals/Agent Orange—that contained 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD)—defoliated jungle canopies to decrease the enemy's advantage of camouflage. Through the Vietnam conflict and postdeployment years, the military and veterans communities gained knowledge from toxicological and medical studies that exposure to chemicals comprising TCDD could have health implications.[1]

Over the past two decades, the DoD has deployed US forces to contingency locations exhibiting arid environments with predominant sand/dust surfaces. In addition, some of these environments contain natural resources (eg, crude oil) of strategic interest. Anthropogenic (combustion-related), naturally occurring (sand/dust storms), and mechanical/fugitive (tracked vehicles) sources contributed to an increase in the PM loading in the lower atmosphere. The DoD has extensively sampled, analyzed, characterized, and assessed the PM at forward and rear troop locations since 1991.[4] The Kuwait oil well fires in 1991, along with regional sand/dust storms and localized fugitive emissions, significantly contributed to increased ambient PM levels in Kuwait and Saudi Arabia.[5]

In southern Iraq, Kuwait, and Saudi Arabia, the period from February through October 1991 displayed measured PM levels with concentrations from tens to thousands of micrograms per cubic meter of air. Analysis of 1991 ambient PM samples showed that the particles were mostly sand-based materials that relate to the observed high levels of PM typically found in southwest Asia.[6] In addition, associated heavy metals analyses displayed vanadium (a component of Kuwaiti crude oil) and lead (from combustion of leaded gasoline) were not associated with any long-term health risks. Electron microscopy of the ambient particles revealed that sand-based particles accounted for the majority of the particle mass on the samples.

During Operation Desert Storm, chemical agent exposure from demolition activities in and around Khamisiyah, Iraq, posed a potential airborne hazard. In early March 1991, US forces used explosives to destroy captured munitions from the Khamisiyah Storage Depot (bunkers and open pit). In 1996, the DoD and US Central Intelligence Agency (CIA) determined that those demolition activities potentially released low levels of the sarin/cyclosarin chemical agent from destroyed 122-mm rockets. Extensive retrospective assessments culminated in July 1997 with the DoD's and the CIA's announcement that no US troops were in the area that was predicted to have association with noticeable health effects during the March 10, 1991 demolition event. However, the modeling results did indicate that troops in Iraq and Saudi Arabia were possibly exposed to low levels of nerve agent over a 4-day period from March 10 to 13, 1991. Using data on then-available unit locations, the DoD identified 98,910 soldiers within the potential hazard area predicted by the models. From late July through September 1997, the DoD sent written notices to two categories of veterans: (1) those who had served in the potential chemical agent hazard area; and (2) those who had received a letter and survey from the Deputy Secretary of Defense, but who had not served in the potential chemical agent hazard area. On September 4, 1997, the DoD/CIA team published the details of this modeling effort in the document *Modeling the Chemical Warfare Agent Release at the Khamisiyah Pit.*[2]

Concern regarding exposure to ambient PM for Operation Enduring Freedom and Operation Iraqi Freedom/Operation New Dawn continued in the mid-2000s. The DoD established a PM work group in 2005 to gather information and assess PM levels at 15 major base camps (troop locations) in the US Central Command area of responsibility.[7] Similar to those efforts conducted in 1991, extensive ambient air and surface soil sampling measures were completed. The samples characterized the mineralogy, particle size distribution, and geomorphological aspects of the ambient PM and surface soils at these locations. The primary conclusions from this study stated that,

> In general, we do not consider dust from the 2006–2007 studied areas in the Middle East to be out of the ordinary. Comparison of dust samples from the 15 Middle East sites to dust from the US, Sahara, and China shows similar chemical and mineralogical constituents in most cases. Mineralogical content, chemical composition, and to a lesser extent individual particle analysis of sieved and re-suspended dust as well as ambient samples from each site, bear the signature of that region's geology to some extent.[8(pii,7)]

Open-air burning of solid waste is a final example of an airborne hazard in a deployed environment. Open burning of solid waste materials and/or paper products has long been used by the DoD when other disposal options are not available.[3] During Operation Iraqi Freedom, open burning operations on various base camps increased in the mid-2000s because of the insurgency and the risks associated with offsite disposal. From 2007 to 2010, an ambient air sampling and surveillance effort was conducted at Joint Base Balad, Iraq, in response to concerns associated with solid waste burn pits. This proactive effort is an example of how sampling and information from occupational and environmental health site assessments were used to identify and assess inhalation hazards from a combination of the burn pits and other combustion sources, industrial activities, and natural PM. These air surveillance efforts provided enhanced data and information that helped to characterize the risk of possible acute and long-term health effects from degraded air quality and the effects of the measured pollutants.

In summary, the primary conclusions from these efforts showed that exposure levels of the receptors to carcinogenic chemicals of potential concern were within the exposure levels that the US Environmental Protection Agency (USEPA) generally considers acceptable excess lifetime cancer risk (1E-04 to 1E-06) and within which management of risk should be considered. The excess noncancer hazard indices exceed unity (ie, >1) primarily due to acrolein, indicating there may have been a concern for potential health effects. The associated health effects would primarily have been short-term, reversible, and possibly include irritation of the mucous membranes and dizziness or lightheadedness. Sensitive individuals, such as asthmatics, might have been more prone to develop worse, longer lasting symptoms (eg, wheezing and bronchitis), but these symptoms were expected to be reversible. Ambient particulate matter levels were typically elevated above respective military exposure guidelines. Because service members may be affected by longer term health effects—possibly from combined exposures (eg, sand, dust, industrial pollutants, tobacco, and other agents), as well as individual susceptibilities—studies continue.[4]

Since 1991, the DoD has extensively increased the amount of environmental sampling (ie, air, water, and soil) completed in deployed environments. It became apparent from evaluations of the Kuwait oil well fires and Operation Joint Endeavor (Bosnia) that the available environmental surveillance equipment for air, water, and soil sampling was complex, bulky, and expensive. In 1997, the US Army Center for Health Promotion and Preventive Medicine (now the US Army Public Health Command, Aberdeen Proving Ground, MD) initiated efforts to improve the environmental sampling equipment for military applications by obtaining available, commercial, and off-the-shelf sampling systems. Efforts were completed to make existing (garrison-based) equipment and sampling media lighter, smaller, simpler to operate, and more rugged. For ambient air sampling, efforts were completed to provide battery-operated, portable, commercial, off-the-shelf sampling equipment and media (along with needed training) to deploying and/or deployed personnel.[9]

The DoD has also enhanced exposure and health risk assessment processes so that predeployment or Phase I hazards assessment are completed for locations of interest.[4] This all-hazards analysis helps to identify the equipment, sampling media, and training required for "boots-on-the-ground" missions. When unique hazards or threats requiring special surveillance or sampling methods are identified, actions are taken to procure the special equipment and supplies needed by the deployed environmental health personnel to assess those hazards and threats. Sampling for dioxin levels near burn pit locations is an example. Risk is estimated using established health risk assessment methodologies from the USEPA and the DoD. The USEPA method summarizes exposure and toxicity data that are then integrated into expressions of risk. For potential noncarcinogenic effects, comparisons are made between projected intakes of substances and toxicity values. For potential carcinogenic effects, probabilities that an individual will develop cancer over a lifetime of exposure are estimated from projected intakes and chemical-specific, dose–response data. The DoD method uses health-based military exposure guidelines (ie, health-based chemical concentrations for various deployed military exposure scenarios representing levels at which no, some, or significant health effects could occur within the exposed, deployed population) for air, water, and soil to determine—via a military risk management framework—operational risk levels for deployed populations. In an iterative process, if results indicate that risk is high, the command is notified of mitigation options. Lower risks are prioritized and addressed with follow-on assessment and evaluation of mitigation methods. This ongoing effort has provided strong force health protection. This systematic and iterative assessment produces steady improvement in the understanding of risks.[4]

In addition, the DoD has developed and operates corporate databases that store field (administrative) data, analytical data, and health risk assessment reports. These corporate solutions for environmental health information and data are known as the Defense Occupational and Environmental Health Readiness System (DOEHRS) and the Military Exposure Surveillance Library (MESL). The DOEHRS maintains more than 24,500 samples collected worldwide since 1996, and the MESL maintains more than 30,000 environmental health/preventive medicine data, reports, and assessments.[4]

To advance health service support to future joint force commanders, the DoD is working strategic-level efforts through the Joint Capabilities Integration and Development System process that is used by the Joint Requirements Oversight Council to fulfill advisory responsibilities in identifying, assessing, validating, and prioritizing joint military capabilities documents.[10] Unique outputs of this process are used to facilitate doctrine, organization, training, materiel, leadership, education, personnel, facilities, and policy changes to the defense acquisition system to inform the planning, programming, budgeting, and execution process in the acquisition and budgeting systems. A recent accomplishment resulting from this process is the 2010 DoD *Joint Force Health Protection Initial Capabilities Document* that identified capability gaps and shortfalls, and recommended solution approaches for providing Joint Force Health Protection during the 2015–2025 timeframe.[11] In particular, the Joint Health Surveillance, Intelligence, and Preventive Medicine functional area outlines three capabilities:

1. providing comprehensive health surveillance,
2. enhancing medical intelligence preparation of the operational environment, and
3. providing full-spectrum preventive medicine support.

These capabilities feed the three lines of action that address the identified shortfalls and support the development of enterprise-wide solution sets for joint operational capabilities and improved support to the warfighter. A working example of the joint operational capability is the use of the DOEHRS to operate and maintain an environmental health surveillance registries website that contains the Operation Tomodachi Registry for the 2011 Japan radiation incident from the earthquake and tsunami.[12] The DoD is collaborating with the DVA to establish an individual longitudinal exposure record (ILER) that will be part of the integrated electronic health record (IEHR) rollout to improve the exchange of health data between the two departments. This effort is scheduled to “go live” in 2017, and the IEHR will be an integral component that identifies a single common health record for service members and veterans that can be accessed at any DoD or DVA medical facility.[13]

POTENTIAL USES OF ENVIRONMENTAL SAMPLING DATA

As previously described, efforts to characterize and address risk from environmental exposures have strengthened over the past two decades. The ultimate goal of environmental sampling is the protection of health or, barring that, the assessment of the health impact to those exposed either at the individual or population level.[14] Exposure assessment at the individual level may serve clinical needs, epidemiological research needs, or support policy considerations.[15] Characterization of individual exposure supports epidemiological studies, ideally with quantitative dose information useful for dose–response trend analysis. It may also address potentially confounding variables. Exposure information may assist in the determination of eligibility for registries, if criteria exist, and may enable physicians to establish service connection for medical compensation purposes.[16] Individual exposure characterizations are also used to support commanders' decisions related to risk prevention and mitigation—eg, removal of personnel from a site, work/rest cycles, or personal protective equipment use—to accomplish the mission as effectively as possible with the fewest casualties.

Uses of sampling data for epidemiological purposes can be problematic. Following the first Gulf War, the Institute of Medicine (IOM) noted that because very little personalized exposure information was available, defining relevant exposed and control groups was difficult. This lack of exposure data limited even the most expert and well-funded investigations to identify health outcomes linked to specific exposures or risk factors.[17] Similarly, the US Government Accountability Office noted that, “without accurate exposure information, the investment of millions of dollars in further epidemiological research on risk factors or potential causes for Veterans' illnesses may result in little return.”[18] In the early 1990s, environmental sampling (apart from the testing of field drinking water) was not a traditional skill of environmental science officers. Appropriate equipment and methods included items that were not part of standard equipment sets, were complex to operate, had specific power requirements and were not field rugged, and often did not provide real-time results. In 2000, the IOM recommended a “systematic process to prospectively evaluate non-battle-related risks associated with the activities and settings of deployment.”[19] Similarly, in an article addressing the IOM report, Lioy notes that, “a key to success … is the rapidity with which individuals, including exposure scientists and occupational hygienists, can identify the source(s) and agent(s) of concern, characterize exposure pathways, and implement controls. Thus, training in exposure science is a needed specialization within the Armed Forces."[20]

Although combatant commanders have recognized that a preventive medicine capability gap in the infectious disease realm can negatively impact current troop strength, most noninfectious environmental exposures pose a long-term risk of injury or illness, with the exception of acute, high-dose incidents (eg, chemical spills or releases). Despite the fact that DoD capabilities included environmental and occupational health specialists, many of these assets were not part of the typical deployment footprint, although this varies by service. Historically, forward-deployed preventive medicine assets focused on traditional public health activities, known as "field sanitation," which encompass food safety, vector control, water supply, and small scale waste management.[21] Traditional environmental exposure monitoring initiatives had been focused on chemical warfare agents, with a recent expansion into biological agent monitoring. This broadening followed key events, such as the anthrax exposures, as well as the increased availability of polymerase chain reaction technologies to identify agents. In light of the last decade's surge in global terrorist activities, commanders have expressed concern over the use of toxic industrial chemicals/toxic industrial materials (TICs/TIMs) as a cheap and effective way to induce casualties.[22]

Lioy[20] suggested that, for planning purposes, the military should consider the use of Acute Exposure Guideline Levels (AEGLs), established under the auspices of the USEPA, as short-term exposure guidelines when conducting health risk assessments in deployed settings. These AEGL values establish exposure levels for no-adverse effect, reversible effects, and as a lethal dose for specified time periods; this varies by chemical/material.[23] The military has used the AEGLs to serve as the starting point in the derivation of operationally specific Military Exposure Guidelines to address short-term exposures to highly toxic chemicals in deployed settings.[24] Long-term exposure levels have also been derived using other values, such as USEPA reference concentrations, as a starting point. Despite the available reference guidelines, there are technology gaps regarding the military's capability to monitor at those levels. The first AEGL chemical priority list included approximately 100 chemicals; the second list was several times as large. The development of field-rugged sensors for such an extensive list of hazards may be impractical. According to the National Research Council, improvements in military defense and preventive medicine material capabilities for chemical and biological exposures require a focused effort.[25] Although field gas chromatography/mass spectroscopy capability in deployed settings has become more widespread following post-9/11 concerns related to TIC/TIM releases, having the right equipment—at the right place and at the right time—remains a challenge.[14]

IMPLICATION OF DATA GAPS

Veterans who are injured as a result of their service, who become chronically ill while in service, or who (following their discharge) develop an illness whose origins are in their service have long been provided healthcare coverage and disability compensation. Any condition that develops while a service member is on military service is considered service-connected.[16] Whether his or her service caused or contributed to the condition or it occurred coincidentally while in service is not a factor if the service member did not have the condition upon entering the service, but does have it upon separation. The significance of the service connection is that it is necessary for awarding compensation to the service member. When a medical condition occurs after service, compensation may be provided if the condition is shown or "presumed" to be caused or aggravated by an exposure or event that occurred during military service. For example, asbestos-related disease in a service member with a known and documented past exposure to asbestos while in the military would be considered service-connected. Whereas it is recognized that service members may face a variety of exposures with the potential to affect their health, a presumption of service connection may be made when exposures are considered likely. Unfortunately, there is often limited documentation of exposure or uncertainty regarding who was exposed.[26] Presumption removes the need for the veteran to establish that the exposure occurred and that it contributed to a specific illness. The most well-known example of presumption addresses Agent Orange exposure during service in the Vietnam War.[16] Because of the uncertainty regarding the degree of exposure, the presumption is that all personnel with actual ground-based service in Vietnam were exposed.[27] Presumptions may result from limited records of the types and concentrations of environmental contaminants present in locations where service members served or difficulty in linking actual exposure data with individuals who spent time at those locations. However, potential exposure does not automatically equate to actual exposure or to a measurable risk of disease. During medieval times, physician and alchemist Paracelsus supposedly stated that, "Poison is in everything, and no thing is without poison. The dosage makes either a poison or a remedy."[28] This maxim recognizes that adverse health outcomes associated with exposure are dependent on the concentration (magnitude), frequency, and duration of exposure.

Using the specific diseases that are presumed to be related to Agent Orange exposure as an example, presumptions are based on the IOM's reviews of the scientific evidence and the DVA's assessment of those reviews. Since 1921, Congress and the Secretary of the DVA have made nearly 150 presumptions.[16] The DVA "now provides disability compensation to approximately 3,000,000 veterans and 342,000 beneficiaries (survivors of those who died as a result of their conditions), expending approximately $41 billion annually for this purpose."[16]

When an exposure is considered for presumption, the IOM conducts a systematic review of the available evidence regarding the exposure and assesses the weight of evidence and the strength of any associations. Under the Agent Orange model, four levels of evidence are identified:

1. Sufficient evidence of an association.
2. Limited/suggestive evidence of an association.
3. Inadequate/insufficient evidence to determine whether an association exists.
4. Limited/suggestive evidence of no association.

More recently, the IOM has added the category "sufficient evidence of a *causal* relationship."[3] Sufficient evidence of an association requires positive health outcomes in human studies in which bias and confounding have been ruled out with reasonable confidence. Sufficient evidence of *causality* requires the evidence to meet several of the Hill[29]criteria for causation:

- strength of an association,
- temporal association,
- dose–response relationship, and
- plausibility and specificity.

Following such a review, the DVA receives the report and determines whether particular health outcomes will be considered service-connected on a presumptive basis. Congress and the DVA generally "act to provide compensation so as to not exclude veterans deserving of compensation ('false negatives') while recognizing that some veterans with illnesses not caused by military service will be compensated as a result ('false positives')."[16] Therefore, evidence of a causal relationship is not necessary; indeed, consistent evidence of an association is not necessary because limited/suggestive evidence of an association has been found to be sufficient for presumption in some cases. This could be because of a statistically significant finding in one high-quality study. In the report on potential improvements to the presumptive disability decision-making process, the IOM recommended the preferred role of causation over association in evidence-based decisions.[16] It also recommended stakeholder input/nomination of illnesses and exposures for consideration (a transparent process), flexibility, and the consideration of the extent of a disease attributable to an exposure relative to other potential causes or contributors (eg, smoking).[26] The committee recognized that evidence might accumulate over time to alter the balance. To reduce uncertainty in assessing the relationship between health conditions and military service, the committee logically recommended better exposure information, but also recognized the complexity of exposures received during deployment and the complications from combat conditions. Exposures were broadly considered as complex physical, chemical, biological, and psychological stressors. It was recognized that feasibility and cost of data collection may be an issue, but these costs may be far less than those of presumptions made because of lack of data.

USE OF SAMPLING DATA FOR EPIDEMIOLOGY

Given the importance of human studies in the evidence base considered for presumptions, the use of available exposure information to conduct epidemiological studies is expected. Following the first Gulf War, modeled oil well fire smoke exposures were used to assess associations with hospitalizations, particularly for respiratory conditions.[30] The findings in these efforts were clouded by factors such as modeling based on limited sampling data points, limited access to unit location records, and the fact that hospitalization is an insensitive health outcome measure. In recent conflicts (Operation Enduring Freedom/Operation Iraqi Freedom/Operation New Dawn), likewise, available data have been leveraged in an attempt to assess exposure/outcome relationships. In the recent review of the long-term health consequences of exposure to burn pits, the IOM had five epidemiological studies of military personnel available for review.[3] These studies were conducted by the Armed Forces Health Surveillance Center, the Naval Health Research Center, and the US Army Public Health Command. All of them were contained in a report released by the Armed Forces Health Surveillance Center in 2010.[31] In these studies, exposure was defined as deployment to a site with an active burn pit because individual exposure data were not available. The report included one study of the respiratory health outcomes of individuals deployed to locations with and without burn pits, discussed elsewhere in this book. The four additional studies utilized a similar methodology and examined the rates of a variety of other outcomes. One study compared birth outcomes in infants of military personnel who were within certain distances from a burn pit or at a location without a burn pit before or during pregnancy. The other three studies utilized participants in the Millennium Cohort Study, comparing those who had deployed to locations with burn pits to those deployed to sites without burn pits. The outcomes examined included respiratory symptoms and conditions, birth outcomes, chronic multisystem illness, and physician-diagnosed lupus or rheumatoid arthritis. Although a discussion of the individual study findings and their strengths and limitations is beyond the scope of this chapter, taken as a whole, there were no consistent findings associated with past deployment to a site with an open burn pit. The IOM review noted that exposure misclassification was possible, and the IOM committee considered the studies important, but "supporting" versus "key" for the following reasons:

- because the follow-up period (36 months) was considered too short for some long-term outcomes to manifest, and
- because the studies lacked information on other hazardous environmental exposures common in the context of desert and war (eg, smoking, diesel exhaust, kerosene heaters, PM, and local and regional pollution).

The committee identified a variety of factors—such as job duties, specific locations, smoking status, activities, etc—that would enhance exposure characterization.[3] Acknowledging the limitations of the military studies, the IOM chose the approach of evaluating human health effects from exposure to combustion products.[3] These studies were evaluated for their quality and for their relevance to the situation and used in a weight-of-evidence approach. Studies on firefighters (those exposed to chemical and wildfires) and incinerator workers were most frequently relied upon, although studies of communities around incinerators were also reviewed. Outcomes in multiple organ systems, as well as cancer, were evaluated. On the basis of these reviews, the committee was "unable to say whether long-term health effects are likely to result from exposure to emissions." However, based on their review of the epidemiological literature, the committee concluded that there was limited/suggestive evidence of an association between exposure to combustion products and reduced pulmonary function in the populations studied. They also concluded that, "there is inadequate/insufficient evidence of an exposure to combustion products and cancer, respiratory disease, circulatory disease, neurologic disease, and adverse reproductive and developmental outcomes in the populations studied."

Regarding the military studies, while limitations due to length of follow-up are correctable as more time has elapsed, there is little accessible and available information to further evaluate other potential exposures. When base camp rosters are used to assess computerized coded health outcomes in large groups of interest and control groups, information on smoking status is not easily available, although it is certainly recorded somewhere within the actual medical record. Although the other hazards were known in some detail (PM levels and ranges at the base level), the magnitude of exposure to the other noted "hazards" would vary according to duties and location, and was not available for these cohorts.[8] Despite specific occupations, duties may change during deployments. For example, guard duty may be performed by a variety of individuals who have other typical duties, and these individuals likely had the highest exposure to burning trash. Information on local microclimates or specific areas on the camps is lacking.

It is interesting, however, to note that the committee stated that exposure misclassification was also a significant uncertainty/limitation in the key studies evaluated in addition to the military studies. "None of the studies … have actual measures of inhalation to combustion products. Without measured individual exposure information, an individual might be assigned to the wrong level of exposure, thus masking the association between exposure and effect."[3] They also noted that most of these studies classified exposure qualitatively by employment status (yes/no), although a few attempted to quantify cumulative dose (duration of employment or number of fires fought) and distance from an incinerator for those studies of communities living around incinerators. In many of the epidemiological studies of respiratory effects potentially associated with deployment, exposure is defined as deployment, with nondeployed personnel serving as a comparison group.[32–37] Although some exposure data may be available, it is generally limited in scope, time, or space, and is rarely tied to an individual. It is difficult to assess dose–response trends without information on the frequency, magnitude, and duration of an exposure, ideally at the individual level. Data used comes from sampling that is conducted for hazard screening, not individual exposure assessment.

Despite these limitations, several additional attempts have been made to utilize the available data to perform epidemiological studies. Just as the committee relied on studies of populations exposed to combustion products lacking exposure measurements or data on other potential exposures, the study of deployment-related health conditions may never have the luxury of complete exposure information. Even so, if plausible health effects are demonstrated consistently in those deployed in excess of those who have not with no other explanation, this provides some evidence of association to airborne hazards, particularly for respiratory conditions. As the committee noted, these effects, if they occur, may be related to combustion products, PM exposure, air pollution, or other hazards alone or in combination. Conditions that occur more frequently in the broadly "exposed" that are plausibly associated with the potential exposures—after a time sufficient to cause disease, in the presence of clinical or laboratory findings compatible with that disease, and in the absence of other explanations for that disease—may be considered deployment-associated without complete information on exposure. Various studies have attempted to evaluate potential associations using available information, as discussed below.

Thus, in what ways are the IOM conclusions valid for a cause-and-effect relationship for burn pit exposure and lung disease? Consider, perhaps (among other notions), that the symptoms that developed in the exposed were the same. Then, those with greater exposures (nearer the burn pit or more time working at the burn pit) had more illnesses and recognition of the clearly toxic materials in the pits could explain the findings. We make this conclusion/diagnosis all the time—witness coal workers' pneumoconiosis and silicosis diagnoses. All that is made without personal sampling.

If we needed personal sampling to diagnose occupational/environmental illnesses, we would not diagnose many. To bring all this into the deployed environment is a grand expectation. Perhaps we should use a clinical definition for respiratory illness attributed to burn pit exposure to make the diagnosis (as we do for pneumoconiosis):

- exposure to the material in question for a time sufficient to cause disease;
- clinical features (including imaging if relevant) consistent with that disease; and
- the absence of other exposures that could be responsible for the illness.

AMBIENT PARTICULATE MATTER

During Operation Enduring Freedom/Operation Iraqi Freedom, ambient air sampling identified PM levels that were elevated, compared with US levels.[38] Data from epidemiological studies based in the United States had identified a number of acute and chronic health concerns, but these effects were identified in study populations to include children, adults over age 65, and those who had chronic conditions and, as such, were a somewhat different population than deployed forces.[39] Additionally, it was recognized that PM in southwest Asia was likely different in composition than the PM in the United States.[38] As a result, a more extensive, every-sixth-day sampling effort for PM was initiated and supported by forward-deployed preventive medicine assets. The samples were analyzed for PM concentration, as well as numerous other parameters (eg, heavy metals). Following this effort, two epidemiological studies were conducted to evaluate potential associations with measured PM levels and health outcomes.[40,41] One study attempted to correlate acute, in-theater health events with days during which PM levels were high. Individuals served as their own control by looking at acute visits for respiratory and cardiovascular events the day of and the day following high PM levels compared with other days. However, given the every-sixth-day sampling schedule, events that occurred on days when no samples were taken could not be evaluated. Because of this and the fact that the overall number of events was low, this effort suffered from low power to detect an association.[40] The other study identified populations at the base camp locations where sampling was conducted, and it compared postdeployment health outcomes by exposure levels. To do so, a variable associated with the PM exposure had to be created, and a decision was made to construct a time-weighted average based on the every-sixth-day sampling.[41] PM levels were divided into quartiles, and association between increasing quartiles of exposure and increased number of health events was assessed. Although this study also failed to identify a dose–response increase in health effects, it was noted that the every-sixth-day sampling may have been insufficient to characterize the exposure, and the constructed exposure variable may not have been sensitive for the outcome of interest. The PM sampling plan was primarily focused on characterization of the airborne PM because of concerns about its potential to cause a hazard; it had not been designed specifically to support epidemiological studies. However, when the studies attempted to utilize the data, it was recognized that there were data limitations. Health concerns in populations for which there is some exposure data often generate interest in utilizing the exposure data to assess health outcomes. Historically, in the field of occupational medicine, this approach was used to assess potential human health effects associated with occupational cohorts for whom limited sampling existed.[42] Then, as now, the generalizability of intermittent sampling—whether it represented peak or average exposures—remains an issue. Many of these occupational studies suffered from potential misclassification, were too small to have sufficient statistical power to detect elevated rates of significance, and lacked information on confounding variables (eg, smoking).[42] These limitations were evident in the studies utilizing deployment sampling data, as well. Regarding the use of the enhanced PM surveillance (EPMS) data for epidemiology, the Committee on Toxicology of the National Academy of Sciences reviewed the studies and noted that, "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 epidemiological study of associations between the exposure of interest and the outcome of interest will not provide valid results."[41] The committee concluded that the exposure data in the EPMS 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.

THE 2003 SULFUR MINE FIRE

Another effort to use limited environmental data for epidemiological purposes followed a 2003 sulfur mine fire. On June 24, 2003, US military field reports indicated a large fire had started at the state-run Al-Mishraq Sulfur Plant near Mosul, Iraq.[43] The fire burned continuously for almost a month—until approximately July 21, 2003—emitting dense clouds of sulfur dioxide (SO_2), a byproduct of the combustion of elemental sulfur piles.

The overall amount of SO_2 released into the atmosphere during the fire was later estimated at approximately 600 kilotons (Kt), with a daily average of approximately 21 Kt per day. In comparison with highly polluting plants in the United States that produce 20 Kt per year, the Mishraq sulfur fire was considered an exceptionally strong point source of SO_2.[44] At the time of the incident, thousands of US military personnel were deployed to the area in support of Operation Iraqi Freedom. Some of the troops in the area were called on to assist local Iraqis with fighting the sulfur fire. Others assisted with evacuating civilians from local towns nearby or continued various military missions and transport operations in the area. Military reports noted that odors characteristic of sulfur were reported at a base camp referred to as Q-West, which was 25 km southwest of Al-Mishraq, and also as far away as the Mosul International Airport area, approximately 50 km to the north. Medical personnel at Q-West reported that medical visits potentially associated with the fire, mostly associated with respiratory irritation, increased by approximately 20% during the period of the fire. Available direct-reading monitoring equipment was used to obtain a limited number of grab samples for SO_2 and hydrogen sulfide (H_2S); these samples demonstrated extremely variable concentrations over a broad area and time. Some of the grab sample concentrations were high enough to be consistent with significant acute effects, such as eye and respiratory tract irritation, and were compatible with some of the physical complaints reported by field personnel. Over long periods, these levels are potentially associated with chronic respiratory conditions. Because of the limited availability of equipment and personnel for this extensive area, these real-time samples were taken at only a few locations and only on a few days. Therefore, these sample results did not provide an adequate basis to characterize the exposure received by any particular person or group. Both SO_2 and H_2S can be acutely fatal at high levels of exposure, but no deaths were documented secondary to the fire.[43] High, but nonfatal, exposures can result in notable acute respiratory effects, as well as ocular and skin irritations. Neither SO_2 nor H_2S is a known carcinogen.[45–47]

A roster of individuals onsite to extinguish the fire was identified; a larger group was known to be within a 50-km radius of the site. These two groups were considered “exposed” and were followed to assess the impact of exposure to the smoke plume on the health of US Army personnel deployed to the area.[43] Self-reported, postdeployment health status and the occurrence of postdeployment medical encounters for respiratory health outcomes for these two groups were compared with corresponding data from two unexposed comparison groups. Postdeployment, self-reported health concerns were common in the population of interest, as were complaints of symptoms of difficulty breathing and shortness of breath. Medical encounter rates for chronic respiratory conditions increased not only in the two potentially exposed groups (firefighters, as well as personnel in the 50-km area), but also in both comparison groups when pre- to postdeployment time periods were compared.

The occurrence of postdeployment medical encounters for chronic respiratory conditions among the exposed group did not differ significantly from that expected, based on the unexposed comparison groups. In this study, postdeployment medical encounters for respiratory conditions were not associated with exposure to the sulfur fire. Troops deployed to the sulfur fire site well after the fire had been extinguished were more likely to have an initial, postdeployment respiratory disease medical encounter than did personnel exposed to the sulfur fire. All groups showed an increase in respiratory visits postdeployment compared with predeployment, although this increase was statistically significant in only one of the unexposed comparison groups. At least some of the increase in healthcare encounters after redeployment is expected because of referrals generated from self-reported symptoms and exposure concerns identified in the postdeployment health assessments. The limitations of this study were similar to those studies previously discussed, including a lack of individual exposure data and information on confounding variables. Unit location data might have placed some personnel at Q-West, for example, when they actually spent most of their time traveling the supply route to the north. Even when information regarding the base camp for a unit is available, the individual activity of the unit and its location patterns differ.

SUMMARY

Efforts to characterize the deployed environment have markedly increased in the last 15 years, and location data have improved as well. Although data identifying the exact location and activities of an individual are still lacking, the base camp locations of units are known. Much ambient sampling data are available; the lack of available individual data remains a concern. As previously described, the DoD has funded an electronic ILER for every service member to improve the availability of exposure information on individuals.[13] Conceptually, ILERs will be produced using a person-centric business intelligence strategy that connects person, time, place, event, and all available occupational and ambient environmental monitoring data with medical encounter information (diagnosis, treatment, and laboratory information, including biomonitoring where available). Information currently available to populate ILERs includes deployment dates and locations to the level of base camp, exposure concerns self-reported on the Post-Deployment Health Assessment, general location and time-specific ambient sampling data, and sampling information on specific exposure incidents that may have occurred (with rosters of those potentially exposed, where available). Utilizing individual identifiers, it is possible to tie base camp locations and sampling information to medical visit information codes (ICD [*International Classification of Diseases*] 9/10 revisions) either through direct connection of the systems or through data-use agreements between systems.[31] Because the current data are population-level data, all individuals at a location are considered equally exposed, which certainly has limitations. However, for PM at least, the exposure profiles, PM characteristics, and composition differ by base camp and might be used as a variable.

The ILER will facilitate the creation of exposure registries that can be assembled based on a multitude of parameters, including dates, locations, and types of exposure where such information exists. The Operation Tomodachi Registry, which includes more than 60,000 individuals who were in Japan at the time of the Fukushima nuclear reactor accident and their radiation doses, is such an example.[12] The value of the ILER will be enhanced with the fielding of technologies, including passive individual exposure dosimeters, occupational monitoring and the creation of similarly exposed groups in deployed settings, and validated biomarkers that may improve individual exposure assessment or serve as early indicators of effect. This knowledge can be used to enhance both the DoD's and DVA's medical care, medical surveillance, and disability evaluation and benefits determination processes. Characterizing deployed environments poses considerable challenges, but improvements in technological and information management systems will allow such characterizations to become more widely available. The challenge remains to improve them by means of selecting valid, reliable, and efficient exposure assessment tools for the most relevant exposures.

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