USARIEM LETTER REPORT

RESEARCH RECOMMENDATIONS TO ADDRESS IMPACTS OF MILITARY OCCUPATIONAL CHEMICAL EXPOSURES: FOCUS ON DENSE URBAN ENVIRONMENTS IN MULTIDOMAIN OPERATIONS

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31 December 2020

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ACKNOWLEDGMENTS

The authors would like to thank Ms. Margaret Kelly for her assistance in the formatting and preparation of this report. We also would like to acknowledge LTC James McKnight and Dr. Roy Vigneulle for their continued support and promotion of military environmental hazards research activities.

EXECUTIVE SUMMARY

The goal of the project is to identify the most prevalent and high risk emerging chemical threats to Warfighter health, performance and lethality that may be present within dense urban (DUE) or subterranean environments (STE). This knowledge product is to be transitioned to Army Public Health Center (under Transition Agreement #T.MRIEM.2020.21) and Army leaders to support development of strategies to reduce risks to human performance and readiness related to chemical threats during multidomain operations (MDO).

Initial tasks of the project were aimed at establishing the current state of science identifying the common chemical exposure threats in deployment settings, including DUE and STE. Information regarding research findings, past or current assessment or surveillance efforts, and threats to Warfighter performance and readiness were collected directly from identified subject matter experts and select reports, as well as through a review of the research literature. Analysis of information obtained through these sources revealed an inconsistent and largely incomplete picture regarding current chemical threat assessment approaches and capabilities. These gaps in current knowledge and practice limit the ability to provide effective, targeted solutions to leaders and Warfighters to protect, sustain, or enhance performance and lethality, leaving **our objective of determining the most prevalent and high risk emerging chemical threats to Warfighter health, performance and lethality present within dense urban or subterranean environments not achieved.** In short, while there are select documents and surveillance reports that provide lists of the more common chemical exposure threats that have been detected in deployment settings, including DUE and STE, there remains limited documentation of objective exposure levels. In addition, minimal research or investigation has been described in the peer reviewed literature to direct the development of strategies to reduce chemical risks to Warfighter performance and readiness in MDO.

In light of this, we highlight two key gaps identified through this research and propose recommendations to address them. Specifically, these gaps include:

1) Inadequate objective evidence of actual chemical exposure threats in DUE and STE.

2) Lack of feasible exposure assessment tools and metrics with adequate sensitivity, specificity, and ecological validity to accurately detect and measure present chemical threats and relatedly, incomplete understanding of the relationships between exposure levels and degradation of operationally meaningful performance and lethality outcomes.

This report provides a summary of findings and identified knowledge gaps that were illuminated when working to complete the project. Several research recommendations are described to foster improved environmental exposure monitoring and assessment approaches to reduce risks to human performance and readiness related to chemical threats to the Warfighter in MDO.

INTRODUCTION

This project addressed the question, "What are the emerging chemical and material threats to human performance and readiness that are predicted or observed to be present in complex multi-exposure scenarios within military dense urban (DUE) or subterranean environments (STE)?"

Future military operations will increasingly be carried out within DUE and STE. These environments present a complex and often rapidly evolving landscape of chemical, material, and environmental hazards that will threaten Warfighter health and ability to maintain optimal performance and readiness. Degraded performance, including psychological, cognitive, and physical functional elements (e.g. appropriate decision-making, response times, physical job task performances) increases a Warfighter's risk of accidents, mistakes, and injuries and reduces the individual's and unit's ability to deliver lethal force when called upon to do so.

Preventing performance degradation requires calculated risk management and adequate preparation, both of which rely heavily upon an accurate understanding of the hazards that may be present in the operational environment and the risks to health and performance posed by these threats. Hazards have been characterized, in most circumstances, for common chemicals and materials by the National Institute for Occupational Safety and Health (NIOSH), Centers for Disease Control and Prevention (CDC), Army Public Health Center (APHC), and other organizations within and outside Department of Defense (DoD). However, technological innovations in both science and industry have resulted in the emergence of new chemicals and materials with toxicological profiles that have yet to be evaluated. Moreover, the presence of multiple chemical and material hazards within operational environments creates complex exposure scenarios that may evolve with changes in environmental conditions (e.g., heat, humidity, cold, altitude) as well as microclimate situations (e.g. distinct urban building landscapes). The effects of multi-exposure scenarios on human health and performance are only beginning to be addressed. Predictive health risk models and mitigation strategies to preserve life and maintain Warfighter functionality (i.e., readiness and lethality) depend upon establishing an accurate understanding of exposure dynamics, received dose, and human response. Developing exposure-dose-response profiles of multi-exposure scenarios requires considerable research effort using animal models, humans, or both, but must first begin with the identification of potential chemical and material hazards that may reasonably be present in the operational settings of interest.

HISTORICAL BACKGROUND

While the threat of chemical and materiel hazards within military operational settings has long been acknowledged and risk management strategies are in place [1], research examining the potential impacts of these exposures on Warfighter health and readiness has lagged. For example, in the mid-1990's, the DoD requested that the

Institute of Medicine conduct an independent investigation into exposures encountered by Service Members (SMs) during the 1991 Gulf War. The resulting series of reports, ‘Strategies to Protect the Health of Deployed US Forces,’ [2,3] and other reports [4,5] detailed lessons learned from surveillance conducted in theater, reports from personnel deployed to the region, and post-war research examining the health of SMs, and proposed strategies to better protect the health of troops in future deployments. In addition, the Research Advisory Committee on Gulf War Veterans’ Illnesses was established by Congress in 1998 by Section 104 of Public Law 105-368 to provide advice to the Secretary of Veterans’ Affairs (VA) on research studies, plans, and strategies related to the health of SMs’ who served in the Southwest Asia theater of operations during the 1990-1991 Gulf War. Some key conclusions drawn by this committee, which continues to serve at present, included:

- There is little available systematic data that provides an assessment of the SM’s health and level of function prior to deployment.
- There are limited objective measurements of the multitude of purported exposures or events present during deployment.
- Post-deployment assessment strategies for health and performance outcomes historically have not been standardized and, for the most part, have relied heavily on symptom questionnaire instruments administered several-to-many years following deployment.

Over the past 30 years numerous high-level DoD and VA research workshops, General Accounting Office examinations, Federally Sponsored Gulf War Veterans’ Illnesses Research conferences, Presidential Advisory Committees, and Institute of Medicine/National Academy of Sciences Working Groups have convened to examine the knowledge and infrastructure gaps related to chemical exposures in military operational settings during the Gulf War to the present, and to provide solutions to address the potential effects of these exposures on the health, readiness and performance of SMs.

While progress has been made in some areas, such as expanded pre-deployment health assessments to include neurocognitive assessment [6], these recognized gaps and ‘lessons learned’, in particular following the 1991 Gulf War, continue to drive the military operational medicine and research agenda. For example, in 1998, the Presidential Review Directive 5 (www.fas.org/irp/offdocs/prd-5-report.htm) stated that DoD (with VA and Department of Health and Human Services (DHHS)) establish programs that ‘collect and maintain military personnel data, including demographic and occupational data, and longitudinal records of SMs military experiences, including pertinent data on occupational and environmental exposures and events and ensure that military medical manpower requirements include scientists trained in the medical specialties essential for force protection research and program execution’. The former effort was further spelled out in Public Law 105-85, which directed the DoD to create an individual hazard record for each Warfighter, an effort that reached fruition in 2020 with the establishment of the Individual Lifetime Exposure Record (ILER). Other directives and drivers of research in this area include the DoD’s

Directive on Force Health Protection (DoD Directive number 6200.04), and the Initial Capabilities Document for Military Operational Medicine[7], and more recent efforts to establish a comprehensive exposure monitoring (CEM) strategy capabilities-based assessment and concept of operations [8].

SMs continue to conduct their work and training in diverse environments that present risk of exposure to a wide range of occupational and environmental hazards. Exposures to toxicants in these settings can lead to numerous acute conditions requiring immediate first aid, hospitalization, and/or medical evacuation from theater (see [9]) and can adversely impact individual and unit medical readiness. In addition, such exposures can contribute to longer-term morbidity and mortality [10-12]. Significant attention has been paid to the potential health impacts of exposures to toxic chemicals during military occupational and operational activities, including exposures to Agent Orange/herbicides [13], smoke from burn pits [14,15], pesticides [16,17], fuels [18,19], and organophosphate nerve agents [20-22]. Although representing diverse environments and ecosystems across decades of combat and non-combat operations, these reports, in general, do not address exposures that occur within highly dense population centers or sub-surface spaces.

Looking toward the future operational environment, the DoD has recognized DUEs or “megacities” and STEs as probable areas of operation [23-25]. DUE can be defined as densely populated and industrialized urban areas with more than 10 million inhabitants [26,27]. The sprawling nature of DUE, and the potential for ungoverned areas within these spaces, provide likely opportunities for enemy combatants to operate undetected [28]. Similarly, STE have been recognized as strategically valuable assets in military operations for centuries [25,29]. However, military leaders and others have noted that U.S. Forces are ill prepared at present to engage in large scale military maneuvers within DUE and STE, and are largely unfamiliar with the known and probable hazards to human health associated with operations in these environments [25,26,30,31].

METHODS

The project goal, to identify the most prevalent and high risk emerging chemical threats to Warfighter health, performance and lethality that may be present within dense urban or subterranean environments, was addressed in two steps. These included i) communications with subject matter experts within Army and DoD public health, environmental health and industrial hygiene groups with direct experience with research, surveillance, and/or evaluation of chemical and material hazards and/or their health impacts within operational settings (i.e., Medical Research and Development Command (MRDC) and APHC) to determine what resources or reports were available specifically pertaining to DUE or STE, and 2) conducting a review of the recent peer-reviewed research literature.

Identification of high-risk and emerging chemical hazards in these environments, which is a primary focus of this report, is a critical first step towards reducing the threat of exposure and preventing or mitigating associated decrements in Warfighter performance and readiness. In addition, linkages must be made between exposure levels and associated human dose levels (exposure-dose assessment). This requires expanding current understanding of the degree of threat posed by these operational chemical exposures on SMs health and readiness, and ensuring the availability of validated, objective methods for measuring exposure levels and accurate and appropriate dosimetric information. Moreover, in order to establish human health outcomes associated with operational chemical exposures, biomarkers of effect must be identified and validated. These steps, achieved through rigorous exposure-dose assessment methods and health outcomes research, and supported by validated sensor technologies, enable the capability to accurately and expeditiously alert SMs of chemical threats, and human health hazard levels, within their immediate environment. And finally, longitudinal tracking of SMs' health and continued medical follow-up are essential to identifying and understanding the longer-term health outcomes associated with these exposures. It is important to note that several Federal Government-level (largely DoD and VA) program efforts related to addressing chemical threats in operational environments were identified, such as Comprehensive Exposure Monitoring Strategy; ILER; Joint Health Risk Management (JHRM); Military Operational Medicine Research Program (MOMRP) Wearables Strategy, and Health Readiness and Performance System (HRAPS). Although some of these activities, highlighted in a recent joint VA-DOD Seminar [32] (Occupational and Environmental Exposures: Assessing, Protecting, Preventing, and Recording, 15 Oct 2020) are important for addressing the need to improve human risk assessment in operational settings, they are not specifically focused on our primary research objective to identify high risk chemical threats in DUE and STE, and are thus not detailed in this report.

RESULTS

During our review of existing reports and outreach to subject matter experts, several lists of identified chemical exposures were identified. But, in only a few instances were these chemicals described in ways specific to DUE/STE or able to provide details relating exposures to specific Warfighter performance outcomes in order to address relative exposure risks to readiness. Of those lists identified that were related to the topic of interest, none completely addressed the specific project question.

Within MRDC, there were a number of initiatives in collaboration with several partner organizations that are relevant to this project. One activity spearheaded by the U.S. Army Center for Environmental Hazard Research (USACEHR) focused on identifying optimal biomarkers of effect that could be used to screen Warfighters for resultant medical and health impacts. As part of this effort, a series of reports were generated and presented [33-36]. Of interest to this project was the Naval Research Laboratory (NRL) effort to identify prevalent megacity chemical hazards [33]. For further detail, see Table 1 and discussion below.

APHC is responsible for maintaining chemical and environmental surveillance in areas where Warfighters are deployed. As such, for this project, a report from the Occupational and Environmental Health Site Assessment (OEHSA) group was requested and received that summarized the top chemicals present during sampling activities within Central Command theaters of operations during 2018. Out of 28 different chemicals monitored, those detected as present in greater than 50 samples during this period and at levels higher than Military Exposure Limit were **cadmium, cobalt, vanadium, aluminum, acrolein, benzoic acid,1,3,5 trimethylbenzoic acid, benzene, chlorine, lead, manganese**, and **butadiene**. The following subset was present in greater than 100 samples during this period and at levels higher than Military Exposure Limit: **cadmium, cobalt, vanadium, aluminum, acrolein, benzoic acid,** and **1,3,5 trimethylbenzoic acid**. In addition, an anecdotal report from a 2003 Operation Iraqi Freedom (OIF) deployment observed the presence of other chemicals (i.e., **dioxin, sodium cyanide, methyl ethyl ketone**), that were not identified on this APHC list. To our knowledge, APHC has not, and currently is not, conducting specific surveillance in DUE and STEs, per se.

Communications with the Materials of Emerging Regulatory Interest Team (MERIT), established, led and supported by the Emerging Contaminants Directorate, Office of the Under Secretary of Defense for Installations & Environment (DUSD(IE), indicated the following compounds on their current emerging contaminants list: **phthalate esters, beryllium, hexavalent chromium, sulfur hexafluoride, hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX),** and **lead** [37]. However, as this group focuses on installation and environmental clean-up activities, these chemicals do not necessarily relate to DUE and/or STE.

Table 1 provides a crosswalk depicting the identified chemical hazards described above from the various sources examined (NRL, OEHSA, MERIT).

Table 1. Crosswalk of Military Relevant Chemical Hazards

	High Priority Military Relevant, Industrial Chemical Hazards (Megacities)[a]	Most prevalent exposures found CENCOM surveillance, 2018[b]	Merit[c]
Chlorine	X	X	
Ammonia	X		
Hydrogen chloride	X		
Sulfuric Acid	X		~
Hydrogen fluoride	X		
Formaldehyde	X		
Mercury	X		
Nitric acid	X		
Sulfur dioxide	X		~
Phosgene	X		
Hydrogen bromide	X		
Nitric oxide	X		
Octamethyl pyrophosphoramine	X		
Boron trilfuoride	X		
Methyl bromide	X		
Phosphoryl trichloride	X		
Chlorine dioxide	X		
Bromine	X		
Nitrogen dioxide	X		
Phosphorus trichloride	X		
Fluorotrichloromethane	X		
Hydrogen sulfide	X		~
Molybophosphoric acid	X		
Toluene 2,4- diisosynate	X		
Fluorine	X		
Malathion	X		
Parathion	X		
Acetylene tetrabromide	X		
o-Anisidine	X		
Phosphine	X		
Cadmium		X	
Cobalt		X	
Vanadium		X	
Aluminum		X	
Acrolein		X	
Benzoic acid		X	
1,3,5 trimethyl benzene		X	
Benzene		X	
Lead		X	X
Manganese		X	
Butadiene		X	
Phthalate esters			X
Sulfur			X
Beryllium			X
Hexavalent chromium			X
Hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX)			X

Note: [a] Data from Sutto TE. *NRL Industrial Chemical Assessment for Hazard, Probability, and Biomarker Prioritization.* Naval Research Laboratory, Washington DC, United States. 2016, NRL/MR/6364--

16-9618 (reference #33). [b] Data requested for this project from Army Public Health Center (APHC), Occupational and Environmental Health Site Assessment (OEHSA) reports; [c] Data from the Materials of Emerging Regulatory Interest Team (MERIT) website, accessed at https://www.denix.osd.mil/cmrmp/index.html (reference #37).

REVIEW OF LITERATURE

To supplement knowledge gained from subject matter expert reports describing occupational and environmental health monitoring activities in deployed settings and related programmatic efforts, a review of the literature was conducted emphasizing research related to human environmental hazard scenarios within DUEs and STEs. Search engines used in this review included Google Scholar, Pub Med and Defense Technical Information Center (DTIC). Search terms, used in combination and with word variants, included the following: dense, urban, subterranean, environment, megacity, chemical, hazard, pollutant, exposure, air, soil, quality, monitoring, sampling, military, deployment, and health. Search criteria included peer-reviewed manuscripts, technical reports, and news articles published prior to December 2020.

The initial review produced hundreds of articles meeting broad search criteria. A second-level inspection of these articles was conducted to identify those studies most relevant to the aims of the present report. Specifically, we focused on those studies that examined the effects of exposure to chemical hazards, via inhalation, ingestion, or absorption through skin and assessed, on health outcomes in either humans (primary focus) or animal models, using a range of collection methods. In all, nearly 100 articles met these more restricted search criteria. It is important to note that this review of the literature was not intended to be an exhaustive search. Rather, our intent was to capture a broad and representative survey of significant and probable chemical hazards present in DUE and STE that could be used to inform exposure risk assessment for future operating environments.

Overall, analysis of the published literature revealed a diverse array of chemical hazards detected in both DUE and STE. However, the chemical hazards reported in the NRL, OEHSA and MERIT reports showed only modest overlap with those cited in the literature. In general, a majority of studies explored the effects of human and industrial activities within densely populated regions on air or water quality and subsequent human health outcomes, typically with emphasis on a particular class or subset of toxic hazards, such as fine particulate matter or heavy metals. Another large subset of studies examined the effects of both manmade and naturally occurring toxic substances on workers' health in both DUE and, to a lesser extent, STE. In these studies, the emphasis again was on either specific chemical hazards or classes of hazards, such as pesticides, fuels, or particulate matter. Importantly, no studies were found that reported comprehensive objective monitoring or assessment of toxic hazards within a defined DUE or STE.

As previously mentioned, an important aim of this literature review was to identify significant and likely chemical hazards within DUE and STE of relevance to the health of military SMs who may be required to operate within such environments. Among the chemical hazards most frequently detected in DUE settings across studies were: **fine particulate matter** from a variety of sources, primarily combustion (PM_1, $PM_{2.5}$, PM_{10}; [38-52], **nitrogen oxides** [39,41,45,49,52-55], **ozone** [41,42,52], **sulfur dioxide**[49,52], **carbon monoxide**[52, 56], **heavy metals**[40,52,57], **benzene**[52,58,59], **polycyclic aromatic hydrocarbons** (PAH;[52,59], including **naphthalene**[60]). Within STEs, the most commonly reported hazards included: **heavy metals** such as mercury, lead, cadmium, and uranium [61-66], **carbon**[61,63,67], **radon**[61,68], **silicon**[65-67], **organic pollutants**[69], **Nitrogen oxides**[63,67,70-73], **carbon dioxide**[67,73-75], and **carbon monoxide**[67,72,73,76,77].

Overall, considerable variability was observed in the chemical hazards reported across studies. This is not surprising given differences in study design and sampling approaches implemented, as well as unique study objectives and targeted outcomes of interest. Although many have noted the need for more comprehensive and pervasive strategies for monitoring chemical hazards within DUE (e.g., [78]), the costs of implementing such strategies would likely be prohibitive if not undertaken and overseen by a larger governmental or health organization. Moreover, as many authors have noted, no two megacities or sub-surface areas are alike, creating infinite combinations of topographical, atmospheric, and structural features that can directly impact exposure risk and severity. Such features can include variations in sources of pollutants (e.g., type and density of industrial activity, local agriculture and mining, transportation dynamics, construction materials, population density, sources of energy), atmospheric conditions and weather patterns, placement and density of manmade structures within settings, and topographic and geologic features (e.g., elevation, terrestrial and subterranean features, green spaces, native soil composition [53]). In addition, conditions and features within discrete geographic areas are rarely static. Although certain features within environments may exhibit predictable (e.g., seasonal) patterns over time, factors such as weather and the nature of human activities undertaken within these settings contribute to continuously evolving patterns and concentrations of chemical hazards over time. Moreover, the complexity of features within DUE and STE result in environmental zones that can vary considerably from one zone to the next, even one block to the next [49]. Such factors complicate efforts to effectively, and reliably model moment to moment shifts in chemical hazard profiles in any given setting. Kinnee and colleagues [79] noted that across a number of studies utilizing various geocoding methods, over and under estimations of chemical exposures can occur.

In addition to variability in the types and concentrations of chemical hazards in diverse DUE and STE settings, there was also an observed lack of uniformity in the methods by which exposure data were collected across studies. Although recommendations for standardizing assessment procedures were reported by a number of authors, no one approach has emerged as a generally agreed upon standard of practice (e.g.,[44,49,51]). Similarly, the literature continues to reflect a general lack of consensus regarding the most appropriate methods for modeling exposures and related health outcomes[48,71].

Overall, the review of the literature produced a list of potential multi-exposure environmental risks but limited knowledge with respect to exposure levels and the relationships between these exposures and both acute and longer-term human health and performance impacts, particularly in the context of military operational settings.

KEY KNOWLEDGE GAPS AND RESEARCH RECOMMENDATIONS

We highlight two interrelated gaps identified through this research project to identify the most prevalent and high risk emerging chemical threats to Warfighter health, performance and lethality that may be present within DUE and STE and propose recommendations to address them. Specifically, these gaps include:

1) Inadequate objective evidence of actual chemical exposure scenario threats in DUE or STEs.

2) Lack of feasible exposure assessment tools and metrics with adequate sensitivity, specificity, and ecological validity to accurately detect and measure present (singly and concurrent multiple) chemical threats in DUE or STEs to determine the relationships between exposure levels, human dose, and degradation of operationally meaningful Warfighter performance and lethality outcomes in order to determine threat risk levels.

With respect to the first gap, based on our review of the literature and DoD and VA-related efforts and documentation, we find that there is ongoing monitoring of chemical exposures for a common set of chemicals in military operational settings, which in some cases may represent megacity or DUEs. But, in review of the chemicals listed from the APHC OEHSA and MERIT emerging chemical risks and those provided in the NRL report, the only chemicals appearing on more than one list were chlorine, lead, and sulfur compounds (Table 1). It is conceivable that pockets of information are being, or have been, collected over time for specific chemicals in specific DUE and/or STE settings [such as from the Defense Occupational and Environmental Health Readiness System – Industrial Hygiene (DOEHRS-IH) and Periodic Occupational and Environmental Monitoring Summary (POEMS)]. However, it appears that such information is being collected through surveillance methods primarily designed to monitor a standard set of chemical risks or through research efforts conducted in laboratories and/or simulated environments rather than through real world field assessments.

Regarding the second gap, a number of recent efforts have highlighted these concerns and taken steps to try and address them through focused efforts to develop real-time sensor technologies for specific chemical threats. However, there is little scientific effort being dedicated to establishing clear linkages between exposure levels, particularly involving multi-exposure scenarios measured in actual DUE or STE settings, and human health and performance outcomes. Addressing this research gap is complex and requires multi-tiered approaches. For example, efforts would likely require a re-examination of the Federal Government's paradigm for identifying and establishing exposure standards [80], which has relied on hazard assessment and toxicological research conducted using exposure measured via time weighted average methods. With sensor technologies now able that measure exposure in real or near-real time, exposure level data are available in continuous streams [81]. However, the relationship between continuously sampled chemical exposure levels, dose rates and related health risk are unclear, and their comparability to health risk assessments based on time weighted averaging (TWA) have not yet been established. Also, understanding the complex associations between exposure dose, biomarkers of exposure, biomarkers of effect and Warfighter performance and readiness - both with respect to acute DUE or STE exposure scenarios and long-term impacts on future deployability - has largely not been addressed. Research examining these issues is critical for determining high risk emerging chemical threats to Warfighter health, performance and lethality that may be present within DUE or STEs.

RECOMMENDATIONS

Recommendations for future research:

1. Conduct direct field research within military relevant DUE or STE to identify the prevalent and high risk, emerging chemical threat scenarios to Warfighter health, performance and lethality.

2. Create a research program roadmap that establishes clear milestones for delivery of validated metrics for actual multi-exposure scenarios present within DUE or STEs and associated human performance and readiness risks, to support and provide guidance to the planned programmatic and interlinked efforts of the ILER, OEHSA, JHRMS, and HRAPS recording, surveillance and monitoring capabilities.

CONCLUSIONS

Review of the information obtained from the literature, government reports, and subject matter experts revealed an inconsistent and largely incomplete picture regarding current chemical threat risks present within DUE or STEs. While there are select documents and surveillance reports that provide lists of the more common chemical exposure threats that have been detected in deployment settings, including DUE and STE, there remains limited documentation of objective exposure levels. Moreover, there has been insufficient empirical research investigation to direct the development of strategies to reduce chemical risks to Warfighter performance and readiness in DUE and STE. These gaps prevent us from achieving our objective of determining the most prevalent and high risk emerging chemical threats to Warfighter health, performance and readiness present within DUE or STEs. In order to provide effective, targeted solutions to leaders and Warfighters to protect, sustain, or enhance performance and lethality in DUE and STE, we recommend coordinated, targeted research efforts to characterize dynamic chemical exposure scenarios in DUE and STE environments, develop and validate appropriate exposure metrics, and clarify linkages between these complex exposures and human health risk.

ACRONYMS

APHC	Army Public Health Center
CDC	Centers for Disease Control and Prevention
CEM	Comprehensive Exposure Monitoring
DHHS	Department of Health and Human Services
DoD	Department of Defense
DOEHRS-IH	Defense Occupational and Environmental Health Readiness System – Industrial Hygiene
DTIC	Defense Technical Information Center
DUSD(IE))	Directorate, Office of the Under Secretary of Defense for Installations & Environment
DUE	Dense Urban Environment
HRAPS	Health Readiness and Performance System
ICD	Initial Capabilities Document
ILER	Individual Longitudinal Exposure Record
JHRMS	Joint Health Risk Management
MDO	Multidomain Operations
MERIT	Materials of Emerging Regulatory Interest Team
MIT	Massachusetts Institute of Technology
MOMRP	Military Operational Medicine Research Program
MRDC	Medical Research and Development Command
NIOSH	National Institute for Occupational Safety and Health
NRL	Naval Research Laboratory
OEHSA	Occupational and Environmental Health Site Assessment
OIF	Operation Iraqi Freedom
PAH	Polycyclic Aromatic Hydrocarbons
PM	Particulate Matter
POEMS	Periodic Occupational and Environmental Monitoring Summary
RDX	Hexahydro-1,3,5-trinitro-1,3,5-triazine
SMs	Service Members
STE	Subterranean Environments
TWA	Time Weighted Average
USACEHR	U.S. Army Center for Environmental Hazard Research
USARIEM	United States Army Research Institute of Environmental Medicine
VA	Department of Veterans' Affairs

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