

# **A Review of the Potential Adverse Health Effects of Military Burn Pits**

By

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## ABSTRACT

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MAROKHOVSKY, SHELBY ANNE MILLER. A Review of the Potential Adverse Health Effects of Military Burn Pits. (Under the direction of Dr. Catherine LePrevost and Dr. Waverly Kallestad.)

Burn pits, areas of open burning utilized for waste disposal, have been operated by the United States military for several decades as a temporary means of eliminating solid waste generated at bases overseas until more permanent solutions are installed. The potential adverse environmental impacts of burn pits and the occupational health effects for military personnel living and working on bases that operate burn pits are not fully understood. The purpose of this literature review was to summarize the current knowledge of burn pit exposures and adverse health effects and identify relevant data gaps from existing studies. Limited studies have been conducted to assess the impacts of burn pits on soldiers, and these studies have not produced conclusive or reproducible results. The studies have also identified problems with data collection on military bases and generalizability of results such as the difficulty of managing environmental data collection during a military operation and the varying environmental conditions in different countries that have military bases. Unknowns, such as the specific composition of the materials within the burn pits and the byproducts from the combustion of a variety of different source materials, have also been identified as limitations of the studies. The potential resulting health impacts of burn pit exposure, therefore, remain unclear, and additional research is necessary to gain a more comprehensive understanding of the short-term and long-term health effects among soldiers, as well as ambient background environmental conditions and burn pit emissions.

## **DEDICATION**

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This research is dedicated to my late uncle, Sergeant Scott A. Miller, for his guidance in my childhood and teenage years. He was a strong, charismatic individual who taught me to be myself and to always follow my dreams. It was, in part, his love for his family and especially for his country that led me to work on this project. For him, I continue to Never Tire, Never Falter, and Never Fail.

## **BIOGRAPHY**

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Shelby Anne Miller Marokhovsky grew up in Massachusetts and earned a Bachelor of Science degree in Environmental Engineering from Worcester Polytechnic Institute in 2013. Immediately thereafter, Mrs. Marokhovsky began her professional career working for a private engineering consulting firm in the Oil and Hazardous Materials division, now the Remediation, Assessment, and Compliance Services Group. She currently lives in Rhode Island with her husband.

Throughout her career, Mrs. Marokhovsky has been responsible for a variety of environmental assessments, including ASTM Phase I & Phase II Environmental Site Assessments, Corridor Assessments, and state-specific investigations. Mrs. Marokhovsky has worked on a variety of projects including management of contaminated soil, groundwater monitoring, underground storage tank removal, and air quality monitoring. During her work on field sample collection, Mrs. Marokhovsky has written a variety of Health and Safety Plans which has led to her interest in toxicology and the protection of human health. Mrs. Marokhovsky plans to continue her education trending towards toxicology and occupational health and safety.

## ACKNOWLEDGEMENTS

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I would like to thank my advisors, Dr. Catherine LePrevost and Dr. Waverly Kallestad, for their incredible support and guidance throughout this research. Dr. LePrevost is a very thoughtful reviewer and extremely knowledgeable in the field of toxicology. Dr. Kallestad provided exceptional thoughts about structure, alternative options to evaluate, etc. This research would not have come together without their unique contributions.

I would also like to thank my husband, Jonathan, my mother, Diane, and my father, Mark, for their thoughts, opinions, continued support, and last second proofreading efforts. My mother's pursuit of a Master's Degree while raising my young brother and I was a true inspiration for me. You rock, Mom! Jon, thank you for keeping our house from falling apart and for keeping me fed and caffeinated throughout this degree process. Dad, thank you for always believing in me and encouraging me.

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## **Introduction**

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Open-air burn pits, which are not contained within a building or structure, are utilized at military bases as a way to dispose of wastes (Figure 1) (Institute of Medicine, 2011; American Public Health Association, 2015). The Department of Defense (DoD) defines a burn pit as an area that does not contain a commercially manufactured incinerator or specific equipment used to burn solid waste and, instead, disposes of solid waste by burning the waste in the open, outdoor air (Sharkey et al., 2014). More specifically, the DoD specifies that an open-air burn pit is at a location that contains more than 100 personnel and has been in operation for more than 90 days.

The United States Environmental Protection Agency (USEPA) defines solid waste as any garbage or refuse; sludge from a wastewater treatment plant, water supply treatment



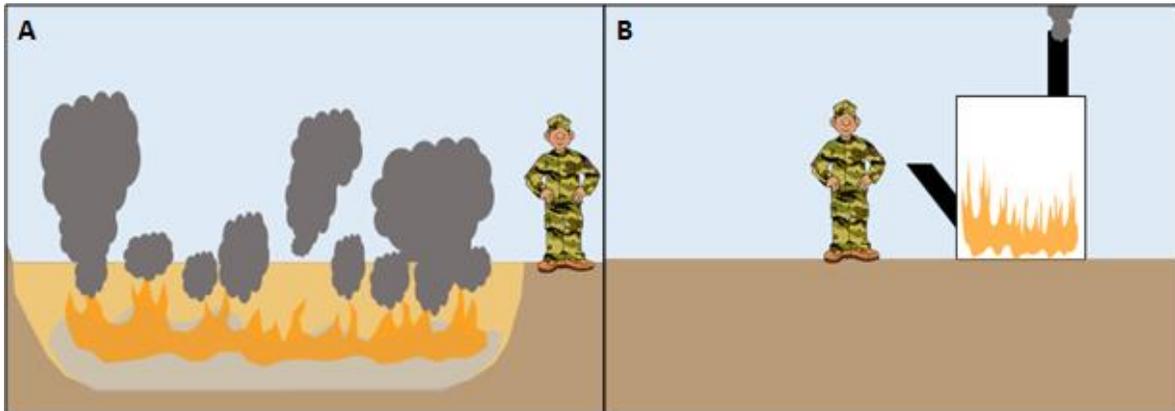
**Figure 1. A United States Department of Defense photograph of a front-end loader pushing trash into a burn pit at an undisclosed military base location.**

plant, or air pollution control facility; and other discarded material, resulting from industrial, commercial, mining, and agricultural operations, and from community activities (USEPA, 2017). Open-air military burn pits are substantially larger than a backyard fire pit and can cover several acres of land.

Open-air burn pits differ from incinerators, which are used to burn waste inside a contained system (Figure 2), by the temperature at which materials burn and the containment or capture of emissions (Hickman, 2016). Incinerators burn materials at a higher temperature than burn pits to convert raw, solid materials to gaseous emissions and residual ash (USEPA, 1997; Szema, 2009; US VA, 2010). The ash can then be removed from the incinerator and discarded.

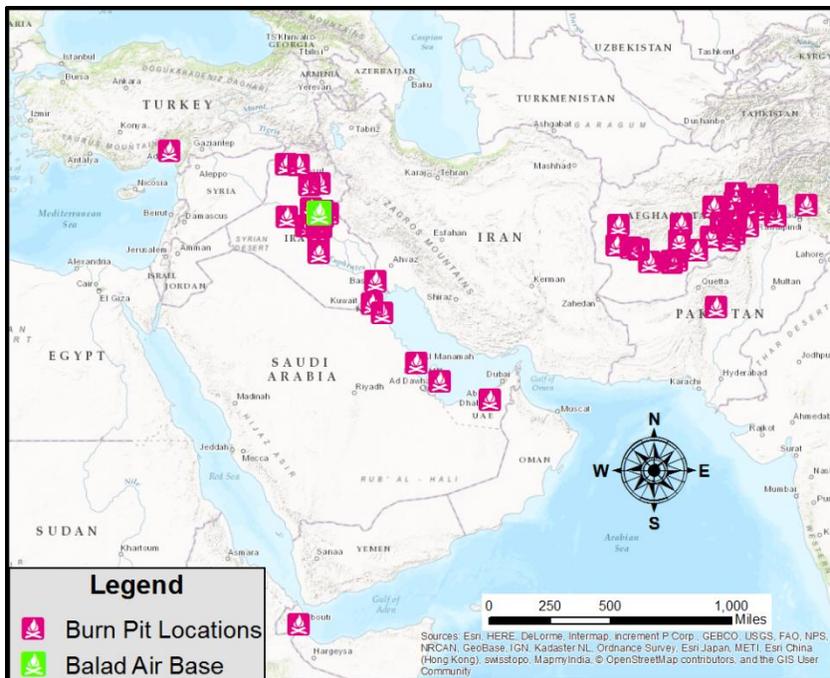
Generally lower, the temperatures at which burn pits operate may vary depending on the materials being burned and whether any accelerants have been added to aid in the burning process (Szema, 2009). Burning materials at lower temperatures may result in incomplete combustion, which can lead to a variety of emissions (USEPA, 1997). Additionally, incinerators have more control over the emissions that exit the system by the utilization of washing, filters, electrostatic precipitators, and scrubbers (National Research Council, 2000); these different techniques can be used to collect airborne particulate matter, heavy metal particles, and

several different gases. As burn pits are open to the environment, there are no techniques employed to curb or control different emissions.



**Figure 2. Diagram A depicts a soldier standing next to an open-air burn pit that releases smoke and other emissions directly into the environment while Diagram B depicts a soldier standing next to an enclosed incinerator (cross-sectional view) that controls the release of smoke and emissions through a stack.**

Burn pits have been used at or near military bases in Iraq and Afghanistan as recently as 2010, but are not a new method of waste disposal and have a long history of military use (Institute of Medicine, 2011). Burn pits were originally developed as a temporary measure to easily and rapidly dispose of waste at military installations or camps, but due to their ease of operation and low cost to operate, they became regular fixtures in and around many military bases



**Figure 3. Locations of some of the reported military burn pits in the Middle East. Note that this figure may not be comprehensive in capturing all burn pit locations. (VetsHQ, 2017)**

note that Figure 3 may not be comprehensive in representing all burn pit locations, as there is

(Hickman, 2016). Due to the planned temporary nature of use and variations in record keeping, the total number of burn pits that have been operated is not known; however, some estimates indicate that there may have been more than 200 burn pits in operation at one time in the Middle East (Institute of Medicine, 2011; Dyhouse, 2016). Figure 3 shows the reported location of some burn pits by returning veterans. Please

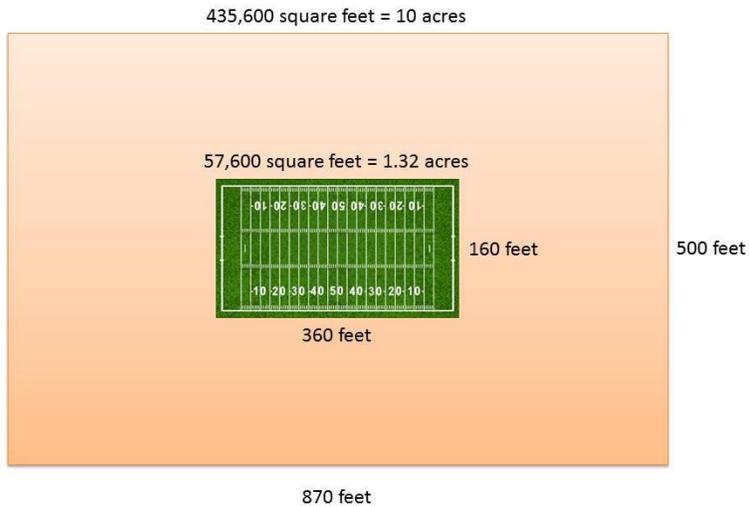
no publically available formal list of all burn pit sites and the location of many bases identified by veterans as having burn pits could not be located using public records.

The need to have fast and efficient methods of waste disposal on military bases is related to the large quantity of waste that is generated. For example, it is estimated that 10 pounds of solid waste is generated per soldier per day at military bases (Trimble, 2010). This would mean that Joint Base Balad, one of the largest bases in Iraq (shown in green on Figure 3), might have generated as much as 250,000 pounds of solid waste per day when the base was at its peak occupancy with an estimated 25,000 personnel (Weese, 2010; Falvo et al., 2015). Burn pits were used at Joint Base Balad as early as 2003 and usage continued through 2009 when several incinerators were installed at the base (Weese, 2010).

Disposal of waste, as opposed to storage, helps to minimize the potential for contamination of environmental media such as groundwater beneath the base (Weese, 2010). Disposal of waste also helps to reduce odors and materials that may attract animals or other vermin. The proper disposal of waste is also important to protect human health, by preventing the spread of wastes that may contain bacteria and other contaminants (War Related Illness & Injury Study Center, 2013).

Items that have been reported to be disposed of via burn pits range from typical “garbage” (e.g., paper and personal products) to food waste, tires, wood, plastics, batteries, appliances, medicine, and even amputated body parts (Institute of Medicine, 2011; Sopko, 2015; Kiriakou, 2016). Uniforms and apparel were commonly burned when they could no longer be serviced or used to avoid their potential misuse by enemy forces (Sagalyn, 2014). While some bases had policies about sorting waste and removing recyclables prior to placing waste in the pit, other simply disposed of everything in this way (Taylor, Rush, & Deck, 2008). In addition to all the materials that may have been present in a burn pit for disposal purposes, jet fuel was often added as an accelerant for setting the waste ablaze (Hickman, 2016). Due to the burn pit size and this means of ignition, control of the burn in regards to temperature, oxygen presence, and speed was difficult to manage (Weese, 2010).

Waste handling practices at military bases varied greatly depending on the size of the base, the age of the base (i.e., recently established versus well established), and the geographic location of the base (Weese, 2010). Burn pit sizes differed as a function of the size of the base they were serving and whether the base operated one or several burn pits. It is believed that the burn pit operated at Joint Base Balad was the largest military burn pit, swelling to a size of approximately 10 acres when the base was at peak occupancy. Figure 4 shows the relative size of this burn pit in relation to a standard American football field.



**Figure 4. Size comparison between Balad Air Base burn pit, estimated to be the largest known burn pit at 10 acres, and a standard American football field (Weese, 2010)**

Concerns about adverse human health effects related to burn pit exposure have been raised by soldiers returning home from deployment in Iraq and Afghanistan with reported changes in their health after being stationed at a base with an operating burn pit (Institute of Medicine, 2011). One of the proposed reasons that the burn pits in Iraq and Afghanistan may be associated with increased reported human health effects compared to burn pits in other countries during previous United States (US) military operations is related to the nature of base establishment in these countries and the location of some of the bases. Due to the rapid nature of setting up bases during the invasions of Iraq and Afghanistan, the US military often established their bases on abandoned Iraqi or Afghani bases (Hickman, 2016). Several of these bases are thought to have previously been chemical weapons manufacturing, testing, and/or warehouse facilities, including the bases in Mosul, Taji, Tikrit, Tallil, and Balad (Rostker, 1997; Federation of American Scientists, n.d.). It is possible that the soil at these bases had been previously contaminated due to past use. The chemicals present in the soil might then have been burned and released into the environment when the burn pits were utilized at the bases, which could further contribute to and complicate the mixture of chemicals emitted. The burn pits in Iraq and Afghanistan were operated by a military contractor, Kellogg Brown & Root (KBR), which was a subsidiary of Halliburton, and according to a former employee of KBR, the soil at proposed burn pit locations had not been tested prior to the establishment of the burn pits (Hickman, 2016). The process of testing for contaminated soil at military ranges was reviewed in 2007 and 2012, but focused on testing military ranges in the United States, not testing potential base locations overseas (Hewitt et al., 2007; Siebielec and Chaney, 2012). Establishing burn pits on contaminated sites may be one of the reasons that more soldiers have reported adverse health effects from deployment to the Iraq and Afghanistan military bases than from previous bases (Hickman, 2016).

Another factor that may have contributed to more soldiers reporting adverse health effects associated with burn pit exposures in Iraq and Afghanistan is increased use of disposable

materials on bases and in everyday life (Hickman, 2016). During previous wars, such as the Vietnam War, soldiers drank from metal canteens and ate on metal trays with real cutlery that would be washed and reused every day. In contrast, many of the bases in Iraq and Afghanistan utilized disposable plastic cups, plates, and utensils, producing larger amounts of waste and requiring larger or more constant use of burn pits. This practice is also associated with increased burning of plastic materials, further discussed below.

Burn pits were not included by Congress on its list of the Pentagon's peer-reviewed research programs for 2016. According to Mr. Ron Brown, president of the non-profit veterans' advocacy organization National Gulf War Research Center, it is not known why research into burn pits was discontinued at that time (Jordan, 2015). Most recently, bipartisan legislation was introduced on February 7, 2017, by U.S. Senators Amy Klobuchar, Democrat from Minnesota, and Thom Tillis, Republican from North Carolina, to create a center within the Department of Veterans Affairs to better understand the health effects associated with burn pits and treat veterans who have become sick after exposure (Klobuchar, 2017).

At present, the potential adverse health risks for military personnel exposed to burn pits are not fully characterized or understood. The purpose of this literature review is to summarize the current knowledge of burn pit exposures and adverse health effects and identify relevant data gaps from existing studies. The review includes the limited studies that have been conducted on the health impacts of burn pits on soldiers (Taylor, Rush, & Deck, 2008; The Armed Forces Health Surveillance Center et al., 2010; Conlin et al., 2012). Additionally, some information on chemical and particulate exposure as well as effects from smoke from studies on exposure to smoke inhalation by firefighters is included to address data gaps (Benowitz, 1999; Reinhardt, Ottmar, & Hanneman, 2000; Riberio et al., 2009).

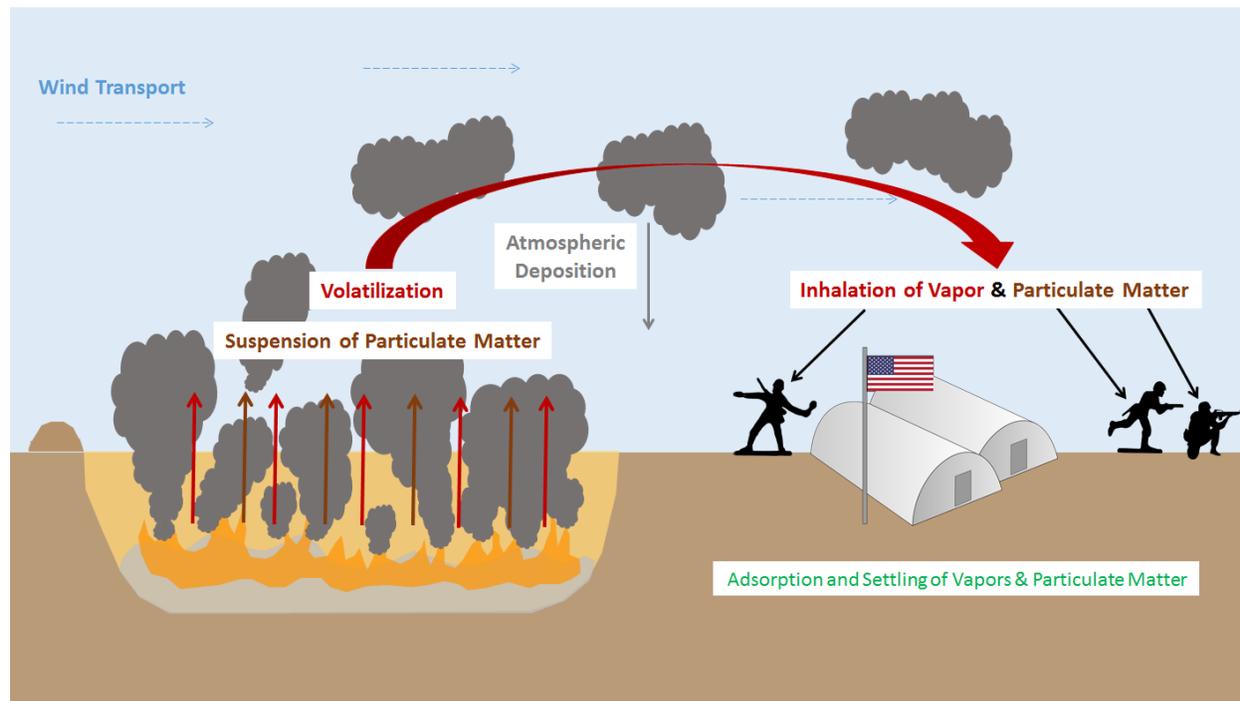
## **Potential Burn Pit Exposures**

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Military personnel who are stationed at bases that operate burn pits may be exposed to a variety of potential contaminants of concern through multiple exposure routes. The emissions from a burn pit may include the products of complete or incomplete combustion. A fate and transport diagram, Figure 5, shows the potential pathways of exposure from a burn pit.

Factors influencing burn pit exposure and resulting health effects are the proximity of the personnel to the burn pit and the duration of exposure. Some personnel, including soldiers and consultants, may be in charge of the operation and maintenance of burn pits. These personnel would be located in closest proximity to the burn pit and for extended periods of time. Other

personnel on base may also be exposed but to a lesser degree, given greater proximity from the source and less frequent time spent near the burn pits.

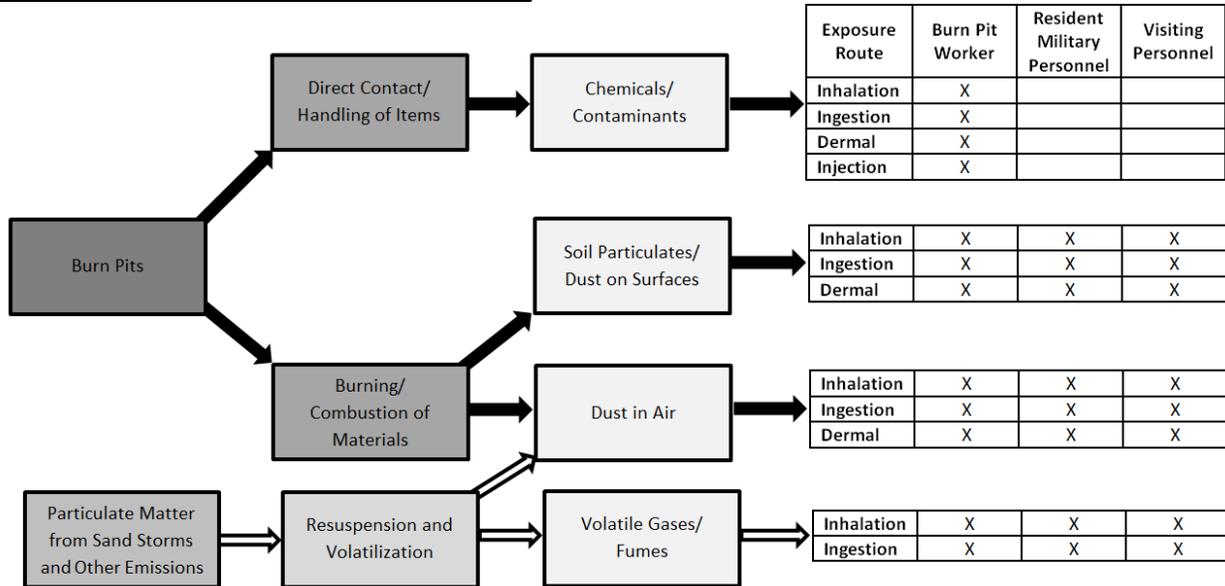


**Figure 5. Fate and transport diagram of a burn pit site showing emissions and the routes of transport throughout the environment and to the receptors.**

Specific contaminants may be more likely to enter the body via one route over another, depending on the physical and chemical properties of the contaminant. There are four main routes of exposure: inhalation, ingestion, skin (or eye) absorption (i.e., dermal), and injection. Inhalation is the main route of exposure for contaminants from burn pits, as airborne contaminants can reach a variety of receptors, including military personnel working and living near the burn pit and the general population who may live several miles from the burn pit. Ingestion, which occurs by consuming contaminated food products or from swallowing contaminant particles, is a less direct method of exposure than inhalation, but it may occur if soot or ash collects on surfaces that may come in contact with the mouth, such as hands. The third potential route of exposure, dermal absorption, occurs when skin, including the membrane of the eye, comes in contact with a contaminated media, such as smoke or particulate matter entering the eyes. The least likely method of exposure for burn pits is injection, which may occur when a contaminated item, such as needles or sharp objects, cuts or punctures the skin, injecting the contaminant directly into the bloodstream. A conceptual model of the exposure pathways for contaminants that may be found in burn pits includes all four major exposure routes and considers secondary exposure sources (i.e., air particulates) (Figure 6).

**LEGEND**

PRIMARY SOURCE(S)	PRIMARY RELEASE MECHANISM	EXPOSURE MEDIA	RECEPTOR
SECONDARY SOURCE(S)	SECONDARY RELEASE MECHANISM		



**Figure 6. Conceptual model of a burn pit site showing possible sources (dark gray) and release mechanisms (medium gray), exposure media (light gray), and routes of exposure and people who are likely to be affected (i.e., “receptors”) (white). Pathways for primary (filled arrows) and secondary (unfilled arrows) sources are shown.**

### Contaminants of Concern

Combustion can result in the breaking of chemical bonds for the compounds within burn pits, potentially leading to chemical reactions that generate a variety of byproducts. Chemicals and byproducts emitted from burn pits include dioxins, volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons (PAHs), and heavy metals (Institute of Medicine, 2011).

Dioxins are a group of persistent environmental pollutants that are found throughout the world. When ingested, dioxins are stored in the fatty tissue of the body. Due to incomplete combustion, burn pits are a major source of dioxin pollution into the environment (WHO, 2016). Dioxins are commonly created in the presence of chlorinated organic materials, such as the burning of polyvinyl chloride plastics (PVCs).

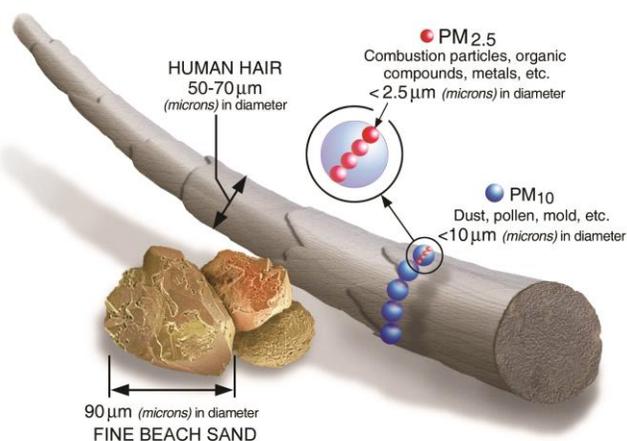
VOCs describe a family of organic chemicals that evaporate rapidly (volatilize) and are a byproduct of combustion, such as that occurring in burn pits. The most common route of exposure for VOCs, as they are typically present in gaseous form, is the inhalation route;

however, ingestion and skin and/or eye contact may also occur. Some examples of VOCs include benzene, ethylbenzene, trichloroethylene, and xylenes.

PAHs are a family of chemicals formed during the incomplete combustion of organic matter (Qi et al., 2017). PAHs are of particulate concern to human health as many have been classified by the USEPA as priority pollutants (USEPA, 2014). Some examples of PAHs include benzo(a)pyrene, chrysene, and naphthalene.

Metals, including heavy metals, are naturally occurring elements. Heavy metals are those metals with a high atomic weight and a density at least 5 times greater than that of water (Tchounwou et al., 2012). Heavy metals, such as lead and zinc, may be present in burn pit emissions as a result of the materials placed in the burn pit for combustion and from the ground surface of the burn pit. Heavy metals pose an environmental and human health concern because they are persistent; they do not degrade or naturally attenuate.

The burning of materials also generates smoke, which is a mixture of particles and chemicals produced by incomplete burning of carbon-containing materials (New York State Department of Health, 2016). While the smoke from any specific fire is unique to materials being burned and the temperature at which the fire burns, all smoke contains carbon monoxide, carbon dioxide, and particulate matter (New York State Department of Health, 2016). Smoke exposure can occur through inhalation and eye absorption and can result in acute, short-term symptoms such as reddened eyes, irritated respiratory passages, and cough (Betchley et al., 1997). Exposure to heavy smoke may also result in temporary changes in lung function (Kim et al., 2014).



**Figure 7. Relative size of particulate matter (PM10 and PM2.5) compared to a strand of human hair and grains of fine beach sand (USEPA, 2016)**

enter the deep tissues of the lungs. Figure 7 displays a visual from the EPA that shows the

Particulate matter, a physical substance present in smoke, consists of small particles, such as dust or droplets of liquid. When considering particulate matter, particles that are no larger than 10 microns (PM<sub>10</sub>) are the main focus of health studies because they are respirable in size and can thus enter the human body. Finer particulates are separately classified as being smaller than 2.5 microns (PM<sub>2.5</sub>) in diameter and can

relative size of PM<sub>10</sub> and PM<sub>2.5</sub> in comparison to a strand of hair and fine beach sand. The makeup of particulate matter may vary by location, such as geographic location, climate, industry, motor vehicle emissions, and construction operations (National Research Council, 2010). Long-term exposure to ambient air containing fine particles (PM<sub>2.5</sub>) has been associated with increases in cardiovascular disease and mortality (Morris, Zacher, & Jackson, 2011; New York State Department of Health, 2016). In addition to long-term health effects, short-term particulate matter exposure can lead to elevated blood pressure (Byrd et al., 2016).

## **Relevant Regulations**

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There are a variety of organizations that produce regulations or guidelines related to air quality and/or protection of human health. The USEPA has established National Ambient Air Quality Standards (NAAQS) for six criteria air pollutants considered harmful to public health and the environment. The NAAQS are further broken down into primary standards that provide public health protection, such as for sensitive human populations (e.g., children and the elderly), and secondary standards that provide public welfare protection, such as prevention of damage to vegetation. In addition to having primary and secondary standards, there are various exposure periods for which standards are provided, such as 24 hours or 1 year. The US Occupational Safety and Health Administration (OSHA) has established a series of permissible exposure limits (PELs) that are designed to protect workers from exposure during their work tasks. Globally, the World Health Organization (WHO) has developed air quality guidelines for several key pollutants that pose health risks to humans. The air quality guidelines provide one or more concentrations for the pollutants based on exposure periods, such as 1 hour or 24 hours.

Military personnel serving overseas are not protected by the same environmental regulations that are in effect in the US because they are not within the nation's borders. In order to protect service members, the military has developed its own policies and guidelines to handle solid waste management and exposure as it relates to military personnel serving overseas. For example, United States Army Public Health Command (USAPHC) has produced a technical guide with chemical exposure guidelines, known as Military Exposure Guidelines (MEGs), which are concentrations of chemicals in air, water, and soil that are designed for health risk assessment to evaluate chemical hazards during deployments (USAPHC Environmental Health Risk Assessment Program, 2013). According to the technical guide, MEG values are based on exposure guidelines and toxicological estimates published by reputable public health and scientific organizations. While each chemical is different, there may be several MEGs for an

individual contaminant based on hazard severity, such as catastrophic, critical, marginal, and negligible. A catastrophic MEG is anticipated to result in death or severe incapacitating effects. A critical MEG is a concentration at which the exposure could begin to result in serious health effects. A marginal MEG may result in decreased productivity following exposure. The negligible MEGs represent concentrations at which mild, non-disabling, and reversible effects may begin to take place.

United States Central Command (CENTCOM) developed guidance in September 2009 for solid waste management in areas of responsibility such as Iraq and Afghanistan (Trimble, 2010). The guidance provides a threshold for when a military base must develop a plan for installing alternative waste disposal technologies, such as incinerators, and phasing out open-air burn pits (Sopko, 2015). The guidance does not specify the use of incinerators, only that an alternative solid waste disposal method be employed. As previously mentioned, the threshold value in the guidance is when a military base exceeds 100 U.S. personnel for over 90 days. The CENTCOM guidance also prohibits the burning of certain items in open-air burn pits such as plastics, tires, and batteries (Trimble, 2010). In some cases, it is challenging to enforce the guidance; therefore, it is possible that plastics and other materials may have been burned in burn pits even after the guidance was established.

## **Review of Available Military Studies**

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Available military studies, including exposure studies, epidemiological studies, and burn pit-specific studies, were reviewed to determine what information is known. Specific information that was sought from the reviewed studies included findings about military exposure and effects, data gaps or limitations that were encountered, and areas in which research was inconclusive. The following section is divided into two subsections: the first evaluates studies of military exposures in the Middle East, including some studies that are specific to burn pits and others that are not, and the second evaluates studies that looked at specific chronic diseases or long-term health effects following burn pit exposure.

### **Studies Related to Military Exposures**

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Environmental sampling at or near military bases in the Middle East was initiated in the early 2000s due to an increased number of health complaints (i.e., eye and respiratory tract irritation, shortness of breath, cough, rashes, and fatigue) from soldiers returning from the Persian Gulf War (National Research Council, 2010). Sampling of air, water, and soil were initiated in Afghanistan in 2001 and Iraq in 2003 to gain an understanding of the potential

exposures that deployed military personnel may have been subjected to while stationed in the Middle East. While several studies have been conducted on military exposure in the Middle East, limited investigation into specific sampling activities directly related to burn pits is available (Brown et al., 2008; Taylor, Rush, & Deck, 2008; Engelbrecht et al., 2008).

*Characterization of Particulate Matter for Three Sites in Kuwait – Brown et al., 2008*

An 18-month study, begun in 2004, of airborne particulates in Kuwait found that pollutant sources ranged from arid desert soils to petroleum industrial operations and vehicle emissions. Samples were collected over 24-hour periods at three locations for various particle diameters and speciation (the presence of nitrate (NO<sub>3</sub><sup>-</sup>), sulfate (SO<sub>4</sub><sup>2-</sup>), and carbon) using a high-capacity Mini-Partisol Air Sampler and several different types of filters. A central sampling location was set up near the capital of Kuwait City. A northern location was selected in a rural area, downwind of an oil field, and a southern location was selected near both urban and industrialized areas, also downwind of an oil field.

The average sampling results for PM<sub>10</sub> at each of the three locations are shown in Figure 8. Despite the variation in results among the three locations for PM<sub>10</sub>, ranging from 65.8 micrograms per cubic meter (µg/m<sup>3</sup>) to 92.8 µg/m<sup>3</sup>, the average particulate matter concentration exceeded the WHO annual average guideline of 20 µg/m<sup>3</sup> and

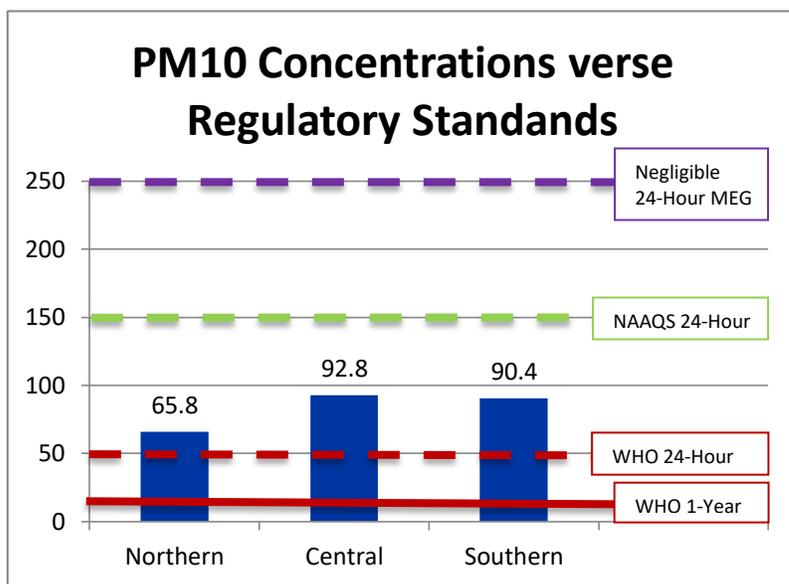


Figure 8. Average PM10 concentrations compared to various regulatory standards

the WHO 24-hour guideline of 50 µg/m<sup>3</sup> at each location. The average concentrations did not exceed the NAAQS 24-hour standard of 150 µg/m<sup>3</sup> or the negligible 24-hour MEG of 250 µg/m<sup>3</sup>. Based on the range of existing regulatory standards, it is not clear what the implications may be for military personnel and their health. Further, the study findings did not provide a direct linkage to the source of the particulate matter.

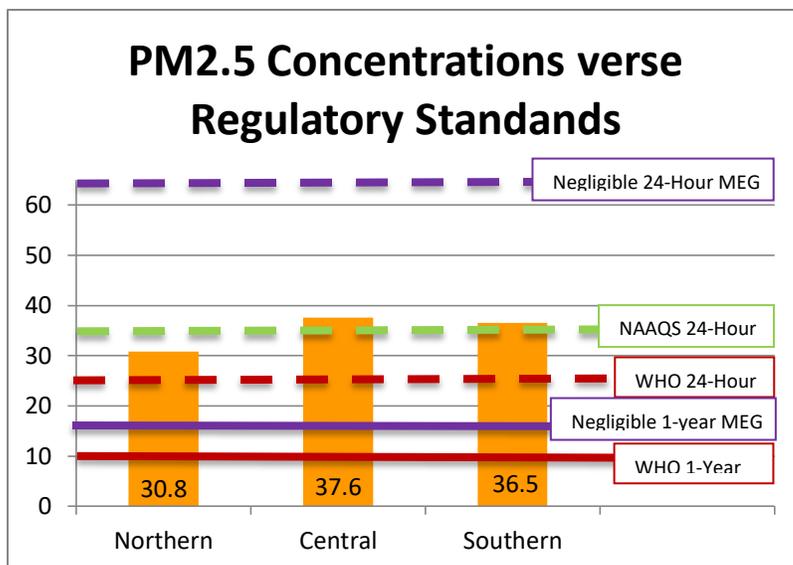


Figure 9. Average PM<sub>2.5</sub> concentrations compared to various regulatory standards

The average sampling results for PM<sub>2.5</sub> at each of the three locations are shown on Figure 9. The average PM<sub>2.5</sub> concentrations at the three sampling locations, ranging from 30.8 µg/m<sup>3</sup> to 37.6 µg/m<sup>3</sup>, exceeded the WHO annual average (10 µg/m<sup>3</sup>), the WHO 24-hour average (25 µg/m<sup>3</sup>), and the 1-year negligible MEG (15 µg/m<sup>3</sup>). The

NAAQS 24-hour standard of 35 µg/m<sup>3</sup> falls between the average concentrations at the three sampling sites; the northern location measurement average was below standard and the averages for the other two locations were above the standard. The average concentration at the three sampling locations did not exceed the 24-hour negligible MEG (65 µg/m<sup>3</sup>). Again, due to the range of regulatory standards, it is difficult to interpret these findings.

Brown et al. (2008) postulated that the higher levels of particulate matter, compared with previous studies conducted in the United States and Europe, were partially the result of Kuwait’s geographic location consisting primarily of desert, an environment which commonly features the resuspension of dust and soil. This finding may be relevant to exposures of military personnel stationed at bases in Iraq and Afghanistan, as the geographic location is similar. The ambient elevated levels of particulate matter should be considered as an existing exposure when evaluating particulate matter during burn pit studies.

*Screening Health Risk Assessment, Burn Pit Exposure, Balad Air Base, Iraq – Taylor, Rush, & Deck, 2008*

Between January and April 2007, public health personnel were stationed at Joint Base Balad to collect air quality samples in order to evaluate the emissions of classes of pollutants expected to be released by the burn pit at the base. These samples were collected at five different locations at the base over varying 24-hour periods to account

for the differences in burn pit emissions based on the operations of the burn pit. The burn pit was located at the northeast corner of the base and the five sampling locations were placed to the south and west of the burn pit. Based on meteorological data collected during the study, wind at the base was predominantly from the west and northwest, which means that the sampling locations may not have been downwind from the burn pit during predominant wind conditions and as such, the empirical air data may not reflect the highest concentrations present during operations.

Overall, 60 samples were collected using an Airmetrics Minivol sampler to evaluate PM<sub>10</sub> and metals, 41 samples were collected using 6-liter stainless steel summa canisters for VOC analysis, and 30 dioxin and furan samples and 41 PAH samples were collected using a Hi-Volume PS-1 unit. According to the study results, 1-year MEGs were exceeded in 52 of the 163 samples (approximately 32%), with 50 of those exceedances being for PM<sub>10</sub> and two for VOCs. The PM<sub>10</sub> concentrations that exceeded the 1-year MEG ranged from 53.1 µg/m<sup>3</sup> to 299 µg/m<sup>3</sup>. At the time of the study, the 1-year MEG for PM<sub>10</sub> was 50 µg/m<sup>3</sup>. The MEGs were revised in 2013 and the latest edition does not include a 1-year MEG for PM<sub>10</sub>. With the revised MEGs, only two samples exceed the negligible 24-hour MEG for PM<sub>10</sub> of 250 µg/m<sup>3</sup>. The concentrations of the two VOCs detected, acrolein and hexachlorobutadiene, were 2.6 µg/m<sup>3</sup> and 27.8 µg/m<sup>3</sup>, respectively. At the time of the study, the 1-year MEG for acrolein was 0.014 µg/m<sup>3</sup> and the MEG for hexachlorobutadiene was 5.2 µg/m<sup>3</sup>. The revised MEG for hexachlorobutadiene is 73 µg/m<sup>3</sup>, which indicates that the concentration no longer exceeds the applicable MEGs. The revised MEG for acrolein is unchanged. It is important to note that while VOC and PM<sub>10</sub> exceedances were observed, the samples were taken over 24-hour periods, not 1-year periods, which are the standards to which the results were compared. One individual 24-hour exceedance does not necessarily indicate that there would be an exceedance over a 1-year period. The study reported that there were no exceedances of the 1-year MEGs for dioxins, furans, or PAHs.

Taylor, Rush, & Deck (2008) concluded that there are no types of illness that would be expected as a result of exposure to emissions from the burn pit with the exception of acute respiratory irritation. It is important to note that the levels of particulate matter detected near the burn pits (i.e., related to burn pit operations) were similar to levels detected at background locations selected away from burn pit areas. Although the results are not suggestive of negative health effects due to burn pit operations, the authors suggest several engineering controls to minimize exposure, such as a reduction

in use of plastic products, sorting of the used plastic products to minimize what may be discarded in the burn pit, installation of an incinerator, and proper information for burn pit location selection (i.e. downwind of receptors).

*Final Report – Department of Defense Enhanced Particulate Matter Surveillance Program – Engelbrecht et al., 2008*

In 2005, the Joint Particulate Matter Working Group (JPMWG), which consisted of individuals from each of the three armed services and government organizations, was chartered by the DoD to investigate potential health issues related to particulate matter exposure. The JPMWG identified a need for particulate matter data, which led to the creation of the Enhanced Particulate Matter Surveillance Program (EPMSP). The program designated fifteen sampling locations in the Middle East, selected according to the potential for military personnel to be exposed at the sites, though not specifically based on the location of burn pit operations. The monitoring locations were spread throughout several countries in the Middle East, including Djibouti, Afghanistan, Qatar, the United Arab Emirates, Iraq, and Kuwait (Figure 10).

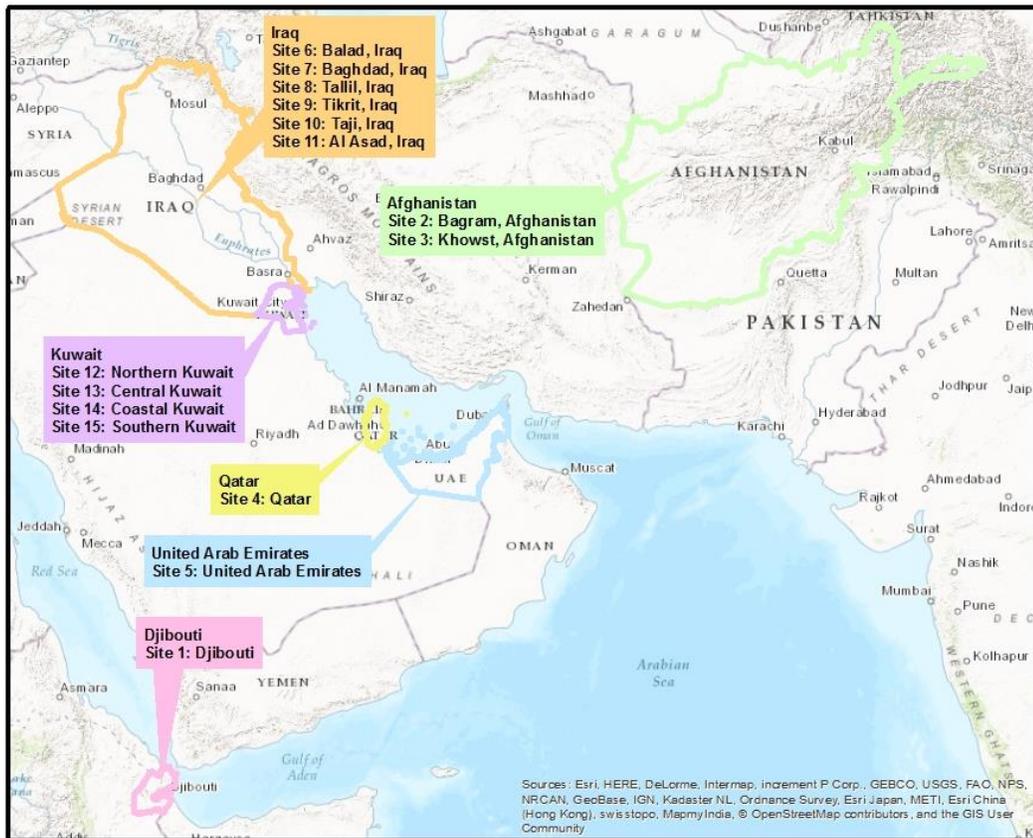


Figure 10. Locations of the 15 sampling sites from the Enhanced Particulate Matter Surveillance Program (Engelbrecht et al., 2008)

Sampling took place over a 1-year period beginning in 2006 and ending in 2007, and resulted in 3,136 24-hour filter samples at each of the fifteen designated locations. Three different low-volume Airmetrics MiniVol particulate samplers with size-specific filters were used to differentiate between total particulates, PM<sub>10</sub>, and PM<sub>2.5</sub>. The filters were analyzed for quantity of particulate matter and were also evaluated for organic chemicals and metals. The chemical analysis included targeted contaminants, such as heavy metals, to determine the potential exposure for military personnel through inhalation or accidental ingestion of particulate matter. In addition to the various air filter samples collected, one bulk soil sample was collected from an undisturbed area within 10 millimeters of the ground surface at each of the 15 monitoring sites.

Trace metals, including lead, arsenic, cadmium, antimony, and zinc, were detected and appeared to be largely concentrated within the smaller PM<sub>2.5</sub> particulates. According to the report, all of the sites exceeded the 1-year MEGs for both PM<sub>10</sub> and PM<sub>2.5</sub>, with the highest concentrations detected at locations in Iraq. Because the revised 2013 MEGs (released after the study was published) did not include a 1-year concentration for PM<sub>10</sub>, the average concentration at each location was compared to the negligible 24-hour MEGs. This comparison indicated that four of the sampling locations (three in Iraq and one in Kuwait) exceeded the PM<sub>10</sub> MEG and eight of the sampling locations (four in Iraq, two in Kuwait, one in Afghanistan, and one in Qatar) exceeded the PM<sub>2.5</sub> MEG. While the MEGs are the most relevant standard for gauging health risks for deployed personnel, the results were also compared to several other standards, including the NAAQS and the WHO guidelines for particulate matter. Average concentrations at each sampling location exceeded the WHO 24-hour standard for PM<sub>10</sub> (50 µg/m<sup>3</sup>) and 24-hour standard for PM<sub>2.5</sub> (25 µg/m<sup>3</sup>). Additionally, ten of the locations exceeded the NAAQS 24-hour standard for PM<sub>10</sub> (150 µg/m<sup>3</sup>), and fourteen of the locations exceeded the NAAQS 24-hour standard for PM<sub>2.5</sub> (35 µg/m<sup>3</sup>).

Engelbrecht et al. (2008) suggested that smoke events from burn pits may have impacted some of the monitoring stations in Iraq, resulting in elevated trace heavy metal concentrations. Also identified as potential sources of heavy metals were meteorological events (e.g., wind, dust, and sand storms), lead smelting, and battery manufacturing facilities. Additional research is necessary to identify the source of heavy metals. It may also be informative to compare particulate matter concentrations to short-term exposure guidelines, such as those put forth by OSHA, to account for high concentrations that may be experienced during certain events like dust storms.

The Enhanced Particulate Matter Surveillance Program is considered to be significant because many of the other studies in the Middle East focused on one base or several bases in a cluster, while the Surveillance Program evaluated a broad range of locations in a number of different countries (Morris, Zacher, & Jackson, 2011). Limitations of the program, however, include the difficulty of extrapolating the findings to other bases due to the variety of potential sources (both natural and anthropogenic) of contaminants, the rotating nature of personnel at military bases, the geographic variation of different bases, and the variation in population at each base (National Research Council, 2010).

## Studies on Chronic Effects

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### *Constrictive Bronchiolitis in Soldiers Returning from Iraq and Afghanistan – King et al., 2011*

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One of the suspected long-term health effects of burn pit exposure is constrictive bronchiolitis, a small airway fibrotic respiratory disease (Epler, 2010). Constrictive bronchiolitis results from the deposit of fibrotic tissue in the bronchiolar airways that overtime restricts airflow (Lewis-Smith et al., 2015). This particular respiratory disease was considered quite rare until an increase in prevalence among soldiers returning from the Middle East (King, et al., 2011).

An early study (conducted 2004-2009) of the respiratory health of soldiers deployed in the Middle East evaluated 80 soldiers who had respiratory symptoms that restricted their exercise abilities. Thirty-eight of the soldiers were found to have constrictive bronchiolitis based on the results of lung biopsies. King et al. (2011) suggested that the development of constrictive bronchiolitis was related to deployment during the 2003 sulfur mine fire in northern Iraq, as 74% of the diagnosed participants had reported exposure to the fire. Ten soldiers from the study diagnosed with constrictive bronchiolitis did not report exposure to the sulfur mine fire, but their results were thought to be an outlier or based on other factors, such as pre-existing conditions. Beyond the sulfur mine fire, suggested contributors to constrictive bronchiolitis development included exposure to incinerated solid waste (63% of the 38 soldiers), incinerated human waste (47% of the 38 soldiers), and dust storms (83% of the 38 soldiers).

King et al. (2011) concluded that the potential major sources of exposure leading to constrictive bronchiolitis included sulfur mine fire, burn pits, and dust storms. The authors recommended that additional studies be conducted to evaluate particulate

matter exposure and the potential association with constrictive bronchiolitis diagnosis. One limitation of the King et al. (2011) study was the lack of pre-deployment health data on individuals; prior to enlisting, soldier candidates must pass a physical examination and a set of physical tests, but more specific tests, such as blood tests or lung function tests, are not a requirement. Additionally, this study did not have a control group and focused investigation narrowly on the group of referred soldiers with exercise restrictions.

*Birth Outcomes among Military Personnel after Exposure to Documented Open-Air Burn Pits Before and During Pregnancy – Conlin et al., 2012*

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In the general population, studies of birth outcomes have shown that an increased risk of birth defects, low birth weight, and preterm delivery are associated with maternal exposure to particulate matter and air pollution during pregnancy (Glinianaia et al., 2004; Sram et al., 2005). Additional research has evaluated the reproductive health of men exposed to environmental pollutants and reported a reduction in sperm quality (Rubes et al., 2005; Cordier, 2008).

Conlin et al. (2012) examined potential impacts on birth outcomes as a result of burn pit exposures, utilizing the DoD-developed Birth and Infant Health Registry. The researchers specifically investigated birth defects and preterm deliveries among children born to personnel who are DoD beneficiaries, including 1,171 children born to active-duty military women and 6,703 children born to spouses of military men. The study included live births between 2004 and 2007; miscarriages and children who were still-born were not evaluated. For the purposes of the study, Conlin et al. (2012) defined parental exposure to a burn pit as being deployed to a region within a 3-mile radius of a documented burn pit.

Conlin et al. (2012) found that active duty women who were exposed to a burn pit before or during pregnancy did not show a significant increase in preterm births or recorded birth defects. Closer evaluation of the data showed a slight increase in the odds of birth defects for children born to women who were exposed during pregnancy over women who were exposed prior to pregnancy; however, this slight increase was not found to be significant. In addition, recorded birth defects among children of exposed military women were more prevalent than recorded birth defects in the military registry overall, including among non-exposed military women. The study found that children born to spouses of active duty men who were exposed to a burn pit prior to conception also did not show a significant increase in preterm births or recorded

birth defects. A slight increase in birth defects was noted in children whose fathers were exposed to burn pits more than 280 days before the estimated date of conception; however, this result was not statistically significant.

A limitation of the Conlin et al. (2012) study was the small sample size of exposed active duty military women, as DoD policy prohibits deployment during pregnancy and the study was therefore limited to women who were deployed in the early stages of pregnancy (before the pregnancy had been confirmed). Further, based on the late determination of pregnancy, these women may have been exposed to other sources of contaminants, including smoking and drinking. Additional limitations of this study, as well as other studies of burn pit exposures, included difficulty collecting and correlating health data to burn pit exposure, due to lack of data on smoke direction and materials being burned in the pit at any given time.

*Newly Reported Lupus and Rheumatoid Arthritis in Relation to Deployment within Proximity to a Documented Open-Air Burn Pit in Iraq – Jones et al., 2012*

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An increase in reported cases of rare autoimmune diseases, including lupus and rheumatoid arthritis, among service members led to an assessment with the Millennium Cohort participants (Jones et al., 2012). The Millennium Cohort is a DOD research program based out of San Diego, California that consists of 200,000 people participating in a prospective health study. Jones et al. (2012) evaluated the relationship between diagnosis with lupus or rheumatoid arthritis and exposure to a burn pit during deployment (again using a 3-mile radius to define exposure). The study evaluated soldiers who were stationed at three bases that had documented burn pits: Balad Air Base, Camp Taji, and Camp Speicher.

Overall, 3,201 personnel were evaluated for lupus and 3,104 personnel were evaluated for rheumatoid arthritis. Six participants exposed to burn pits were newly diagnosed with lupus, which is approximately 0.2%, compared to the 0.1% of personnel newly diagnosed with lupus who were not exposed to a burn pit during deployment. Forty-one participants exposed to burn pits were newly diagnosed with rheumatoid arthritis, which is approximately 1.3%, compared to the 1.2% of personnel newly diagnosed with rheumatoid arthritis who were not exposed to a burn pit during deployment. Jones et al. (2012) determined that exposure to a burn pit was not significantly associated with increases in newly reported lupus or rheumatoid arthritis.

One of the limitations of this study is that the follow-up was conducted over a relatively short period, and autoimmune diseases may be a long-term consequence of exposure. Long-term studies may produce different results. Other limitations of this study include its reliance on self-reported data and the fact that only three burn pits were evaluated, which may not be representative of the reported 200 burn pits that were operated in Iraq and Afghanistan. Finally, meteorological data and burn pit content composition were not considered.

## **Studies of Related Occupations**

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Due to the limited number of published studies on military personnel's exposure to burn pits and the noted limitations of these studies, an evaluation of the literature for research involving related professions was conducted in an effort to garner additional information about the potential exposures and health outcomes. Specifically, studies of firefighters were examined because their exposures to smoke, particulate matter, and emissions from combustion of a variety of materials would be similar to the exposures of military personnel working at or near an active burn pit. Additionally, incinerator worker studies were reviewed as individuals in this occupation perform work tasks, such as waste handling, ash handling, and maintaining burning waste, similar to those of military personnel maintaining a burn pit.

### Studies of Health Effects of Firefighters

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Firefighting is a hazardous occupation that can lead to exposures to a range of toxicants via inhalation and skin absorption. To categorize the carcinogenic hazards associated with firefighting, the International Agency for Research on Cancer (IARC) assigned a hazard classification to the occupation of Group 2B, indicating it is possibly carcinogenic to humans (Graveling & Crawford, 2010). As with burn pit analysis and studies of exposure, one of the complications in understanding health risks to firefighters is the variable composition of the materials being combusted and the produced smoke. Fires may include building materials such as wood, metal, fiberglass, and paint, as well as materials found within burning buildings such as plastics, cleaning products, and other chemicals. Smoke composition of exterior forest fires can also vary depending on the types of vegetation present and whether the area has been treated with pesticides (Bush, Neary, & McMahon, 2000).

A cross-shift study of 76 forest firefighters working in Oregon and Washington examined changes in respiratory health from before to after a work shift during the 1992 firefighting season by collecting spirometric measurements and a self-administered questionnaire

(Betchley et al, 1997). Respiratory symptoms, such as cough, sore throat, and wheezing, were increased from pre-shift to mid-shift (when documented) to post-shift. Additionally, there was a significant decrease in forced vital capacity, forced expiratory volume in one second, and the amount of air expelled from the lungs during the middle half of the spirometry test.

In São Paulo, Brazil, a comparison study was conducted with municipal firefighters and police officers, using a survey to evaluate the presence of asthma-related respiratory symptoms (Ribeiro et al., 2009). The survey included questions about habits (such as smoking), habitat, and work-related exposures, as well as information about the types of symptoms experienced and the duration of the experienced symptoms. In total, 2,200 firefighters and 3,000 police officers were surveyed. The results of this comparison study indicated that wheezing was strongly associated with work as a firefighter (Ribeiro et al., 2009). It should be noted that the results were based on self-report, which may have yielded biased results.

The U.S. Forest Service measured smoke exposure among 200 firefighters in the Pacific Northwest at prescribed burns between 1991 and 1994 to determine the firefighters' average exposure to smoke during burns and over entire work shifts (Reinhardt, Ottmar, & Hanneman, 2000). The overall findings indicated that some of the measured exposures to respirable particles, acrolein, and carbon monoxide exceeded the OSHA PEL.

Although each fire is unique in composition, similar to burn pits, several findings appear to be consistent across the reviewed studies. Short-term exposure to fire emissions is associated with an increase in airway sensitivity and respiratory symptoms, such as wheezing. Also, lung function is decreased following a firefighting shift (Betchley et al., 1997).

## Studies of Health Effects of Incinerator Workers

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Incinerator workers have been studied to evaluate their exposure to various materials, such as metals, fly ash, and dioxins (Lee et al., 2011; Yamamoto et al., 2015; Zhou et al., 2015). A majority of these studies have focused on the incineration of municipal waste, rather than the incineration of medical or hazardous waste.

A study conducted in Japan between 2000 and 2007 examined the health of 678 male private and public municipal incinerator workers (Yamamoto et al., 2015). Rather than collecting environmental air samples as in the previously discussed DOD studies, Yamamoto et al. (2015) collected blood samples that were analyzed for concentrations of dioxins. The

study participants also completed surveys to answer questions about lifestyle habits and pre-existing conditions. Study participants were evaluated for dioxin levels in the blood, and the presence of one or more of these conditions: diabetes, hypertension, hyperlipidemia, and liver dysfunction. The authors reported increased blood concentrations of polychlorinated dibenzofurans among incinerator workers as compared to the general population. However, for overall dioxin levels, there was no significant difference in the blood levels of the incinerator workers and the levels of the general population. It should be noted that Japan has in place a variety of countermeasures to reduce exposure to dioxin and other pollutants among incinerator workers, such as requirements for wearing personal protective equipment like respirators, goggles, gloves, and other protective clothing.

Municipal solid waste incinerator fly ash is considered to be a hazardous waste based on its components, including heavy metals and dioxin compounds (Zhou et al., 2015). The contents of fly ash are an exposure concern because fly ash is the main material that is handled by incinerator workers when they are cleaning out the incinerator unit. Zhou et al. (2015) evaluated the presence and concentrations of heavy metals and other chemicals (zinc, lead, copper, cadmium, chromium, silicon, and chloride) in fly ash. A low-volume sampler was utilized to collect fly ash samples, and quartz-fiber filters were utilized to differentiate the collected sample by particulate matter size. The fly ash had a wide range in particle size, between 0.3 and 70 microns; however, about 36% of the sample was less than 10 microns. Several heavy metals were individually analyzed. The largest concentration was of zinc, which had concentrations ranging from 1,267 – 4,587 mg/kg. The authors concluded that there are elevated health risks associated with exposure to heavy metals in fly ash, which are the result of enrichment from iron oxide.

## **Studies of Waste Combustion Emissions**

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As previously noted, health effects related to exposure to a burn pit likely vary based on the specific materials being combusted and the associated emissions. A couple of studies have been conducted to characterize the emissions of waste combustion.

A 1997 study was conducted by the USEPA to characterize emissions from the combustion of household waste (USEPA, 1997); air samples and ash residue samples were analyzed for a variety of chemical compounds, including semi-volatile organic compounds, PAHs, polychlorinated biphenyls, chlorobenzenes, polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans, aldehydes and ketones, hydrogen chloride, hydrogen cyanide, and metals (USEPA, 1997). Similar to military burn pits, combustion of household waste in burn

pits or barrels is generally uncontrolled and open to the environment. However, household and military waste combustion differ in scale, with household waste combustion being much smaller, and waste stream composition, as the military may be burning materials such as tires, uniforms, and medical waste. The study found that benzene emissions were approximately 1 gram per kilogram of waste burned (USEPA, 1997). The OSHA PEL for benzene is 1 ppm, which is equivalent to 0.001 gram per kilogram. The results indicate that the levels of benzene emitted from waste burning may be hazardous to human health.

A controlled study was conducted to simulate burn pit emissions at forward operating bases (i.e. a secured military position used to support tactical operations) (Aurell, Gullett, & Yamamoto, 2012). Six emissions tests were conducted using two types of waste at a testing range in Utah. Two different waste types were utilized due to the known variation in military waste. The first type was designed to represent waste generated at an active military base and included food waste and packing materials, while the second type was designed to be similar to municipal waste. To mimic the process of burn pit ignition, diesel was sprayed on the waste pile to initiate combustion. The findings of the controlled study found that burn pile emission factors, mass of pollutant per unit mass of burn waste, increased with burn time. Lead, iron, and copper were also detected in all of the samples that were collected. Lead had the highest emission factors collected via PM<sub>2.5</sub> filters, ranging from 0.38 µg/g of Carbon<sub>burned</sub> to 59 µg/g of Carbon<sub>burned</sub>.

## **Discussion**

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Exposures are unique to each burn pit due a variety of factors, such as the size of the burn pit, the makeup of the materials being burned, the frequency of burning (continuous, once a day, once a week), the temperature of the burn, the geographic location of the base and the burn pit on the base, and meteorological conditions. For these reasons, as evidenced by the reviewed research, it is challenging to quantify emissions and human exposures and to characterize health effects associated with burn pits.

Particulate matter is a prevalent air contaminant, especially in the Middle East because of its geographic location and arid climate. Long-term exposure to elevated levels of particulate matter has been associated with adverse respiratory outcomes. The reviewed studies indicated that identifying the source of elevated levels of particulate matter on bases is difficult due to the variety of potential sources, including burn pits, dust storms, industrial emissions, and vehicle emissions. To evaluate health impacts and to mitigate exposure, it is important to identify specific sources of particulate matter. Future study design for particulate matter

sample collection should include identification of the source of the measured contaminants to allow for more concrete recommendations for human health protection and exposure mitigation efforts.

Future research should also evaluate ambient levels of particulate matter on bases when considering the health of military personnel. The dry and arid desert conditions in the Middle East correspond to large amounts of sand and dust, which can be picked up by the wind and transported great distances. Some of the regions in the Middle East are also prone to dust storms, contributing to the suspension of “ambient” particulate matter in the area that can then be inhaled or accidentally ingested by military personnel. Meteorological data may be helpful in considering sources of particulate matter by indicating when a dust storm has occurred during a sampling time frame. This type of data can also provide information about wind speed and direction. When this information is correlated with spikes or time periods of elevated concentrations, sources can be sought in the upwind direction, while downwind sources can be eliminated.

To isolate the impacts of burn pit emissions from ambient air pollution, it is recommended that air quality data at a base or proposed base location be collected prior to the operation of a burn pit to establish background information about the particulate levels present and the presence of any chemicals in the air (or soil) from local industry or prior land use. A major challenge to this approach is an emphasis on national security during war-time operations. Allowing environmental personnel onto a base for an assessment would require a substantial amount of background research, which costs time and money that could be spent on other base security and setup. Additionally, environmental and human health issues may be overlooked due to more immediate threats and the fast pace at which military bases are established. Planning for base locations according to measured contaminants and the availability of baseline data will be a lower priority than base selection related to the goals of the mission. If pre-characterization and/or background data cannot be collected prior to establishment of a burn pit, a sampling location should be selected upwind and as far away from the burn pit as possible to collect ambient samples with a low chance of burn pit contamination (i.e., a contemporaneous control/reference location). Ambient levels of particulate matter may be higher than in the US and higher than domestic regulations deem to be safe, and this information will be helpful in determining whether a burn pit is contributing to elevated concentrations. In the absence of baseline data, burn pits should be installed in locations on bases where they will be frequently downwind of receptors, such as residential quarters.

The studies of military personnel included in this review are few, and existing studies have a number of limitations, indicating that additional studies are necessary to fully understand the health impacts of burn pit exposure. A lack of publically available information (e.g., verified burn pit locations, sizes, hours of operation, and procedures) hinders the understanding of burn pit emissions on human health. Researchers need access to this information to have a more comprehensive understanding of each individual burn pit and to determine the potential health risks that may be associated with exposure. Information that would be helpful to researchers in assessing exposure include the size of the burn pit (to indicate a general volume (or mass) of material that is undergoing combustion and the size of the emission area), the hours of operation of the burn pit (to determine whether exposure is constant for personnel at the base or if it occurs over short time periods), the contents of the burn pit (to allow for a more in-depth analysis of the materials undergoing combustion and a more concrete idea of the potential byproducts), and the procedures of burn pit maintenance and operation (information about sorting out recyclables and hazardous waste and how, if at all, the burn pits are cleared of residual ash and uncombusted materials). Procedures that limit the materials that are combusted in burn pits or that implement more stringent control measures may reduce the types of emissions generated from partial or incomplete combustion. Emission-reduction measures may include implementation of recycling practices to keep materials (e.g., plastics), out of the burn pits and the use of reusable materials (e.g., metal utensils) at the base, and the reduced usage of disposable paper and plastic materials. With more detailed information about burn pit contents, including types, quantities, and frequencies of the materials that are being placed into the burn pit, controlled burn pit barrel studies could provide information on the potential hazards based on the emissions produced.

Although the available studies do not show a significant increase in adverse human health outcomes following exposure to burn pits, the paucity of studies, limitations discussed above, and evidence of health effects among workers with similar occupational exposures (firefighters and municipal incinerator workers) suggests that more research into burn pits is necessary before a definitive conclusion about human health impacts can be reached. Research has shown that firefighters experience symptoms of respiratory distress following even short-term exposure to smoke and that there is a documented decrease in respiratory function following a shift fighting fires. Incinerator workers have documented exposure to heavy metals and dioxins as a result of their work activities. Military personnel exposed to burn pits might be at risk for similar exposures and health effects.

A noteworthy observation from the evaluation of existing studies, including those of firefighters and incinerator workers, is the heavy focus on the inhalation route of exposure. While this is the most obvious route of exposure, other possible routes, such as ingestion and dermal contact, have not been thoroughly studied. Future research should evaluate all three routes of exposure to expand the knowledge of health effects from burn pit exposure.

Reporting of acute symptoms among veterans prompted the initial examination of burn pit exposure and health effects. Several exposure reduction measures are recommended to address the concern of military personnel in the short-term while additional research is being conducted.

The use of personal protective equipment while maintaining burn pits can reduce the exposure that personnel experience (Yamamoto et al., 2015). Safety glasses afford military personnel working at or near a burn pit protection of the membrane of the eyes from coming into contact with particulate matter that might serve as an eye irritant or be absorbed into the body. Personnel who are not working near a burn pit but who experience symptoms of itchy or watery eyes may also choose to wear safety glasses. Half-face respirators provide personnel with protection from exposure via the inhalation route. A review of online photographs suggests that soldiers working near burn pits may wear surgical or dust masks. While this type of mask provides a basic level of protection, it does not create a tight seal on the face and is primarily protective against the inhalation of large particles, not specific contaminants or very small particulate matter. Half-face respirators are specific for particular contaminants and more protective. Wearing this type of respirator can be cumbersome, so while it will provide extra protection, it is best suited for personnel who are directly working with burn pit operations and are within close proximity to the pit. A half-face respirator may be over-protective and unnecessary for visiting personnel or personnel who live at the base but are not located near the burn pit. Thick gloves provide military personnel who directly handle burn pit material protection from exposure via the dermal or injection route. The gloves should be cut and/or puncture resistant to mitigate the chances of exposure via the injection route.

A second mechanism for exposure reduction is personal hygiene. Washing hands prior to eating, drinking, and smoking removes particulate matter that may have collected on the hands and reduces exposure via ingestion. Similarly, military personnel should eat, drink, and/or smoke away from the burn pit to reduce both ingestion and inhalation of contaminants. Storing materials and supplies that are used for eating, drinking, and personal care away from a burn pit, such as inside a cabinet or container within a building, limits the extent to which these items become coated in particulate matter and a means of exposure. To reduce the likelihood

that particulate matter or other contaminants will be introduced into the living space where they could be inhaled, ingested, or come in contact with the skin or eyes, personnel should remove their outer layer of clothing, including jackets, boots, and helmets prior to entering living spaces. Finally, military personnel can reduce exposure by avoiding entering the burn pit location unless specifically required to do so to perform their job tasks.

## **Conclusions**

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For this review of the literature, it is clear that insufficient research has been conducted/ published on the health effects associated with burn pit exposure and that additional studies are warranted given the adverse health outcomes observed in other occupations with similar exposures. Until more is known about the health effects of burn pit exposure, military personnel should utilize protective equipment and hygiene practices to mitigate their exposures.

While some regulations are in place to manage or mitigate the potential human health risks of exposure to military burn pits, stronger regulations could further reduce exposure. For protection of human health, the focus of additional regulation should be governing where and when burn pits can be operated (for example, such as in specific locations and only during temporary or short-term timeframes) and how they are operated (for example, what may be burned; what accelerants, if any, can be used; and when the burn pit can function during the day). Additionally, enforcement of existing regulations is needed. A reporting system might facilitate tracking of where burn pits are located, when they were started, their size, and how long they have been in operation in order to ensure that a burn pit is not being utilized beyond the 90-day limit that is currently in place. Burn pit phase out may be supported through assistance (e.g., in the form of additional personnel) to establish more permanent forms of waste disposal, such as incinerators, and transitioning from burn pit operation to the new form of disposal.

Finally, there is a need for the military and Office of Veterans Affairs to provide education to military personnel prior to deployment to inform them of exposure prevention measures, including use of personal protective equipment and hygiene best practices, and the health risks that they may face while they are deployed. Education that is broad in focus, to include occupational and environmental exposures beyond burn pits, should be provided to all. Veterans and their families need information on possible symptoms that may result from deployment-related exposures, recommendations for maintaining health, and resources in case of adverse health effects. Additionally, military personnel should be encouraged to participate

in the Airborne Hazards and Burn Pit Registry created in 2013 to aid in the collection of data that may be used by both the DoD and outside organizations to continue research on burn pit exposure and related health effects.

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