Oil Well Fires of Operation Desert Storm—Defining Troop Exposures and Determining Health Risks

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ABSTRACT During Operation Desert Storm, in February 1991, Iraqi troops began burning Kuwaiti oil wells. Almost immediately there was concern about possible adverse health effects in U.S. personnel exposed to crude oil combustion products. Combustion products were predicted from the known composition of Kuwaiti crude oil. Monitoring sites were established in Saudi Arabia and Kuwait; about 5,000 environmental samples were studied. Data collected were used to develop health risk assessments for the geographic areas sampled. This initial approach to assessing risk had to be greatly expanded when Congress passed Public Law 102-190, requiring development of means to calculate environmental exposures for individual U.S. service members. To estimate daily exposure levels for the entire area over 10 months for all U.S. troops, air dispersion modeling was used in conjunction with satellite imagery and geographic information system technology. This methodology made it possible to separate the risk caused by oil fire smoke from the total risk from all sources for each service member. The U.S. military responses to health concerns related to the oil well fires and to Public Law 102-190 were reviewed. Consideration was given to changes in technology, practices, and policies over the last two decades that might impact a similar contemporary response.

INTRODUCTION During Operation Desert Storm (ODS), in late February 1991, Iraqi troops began the demolition of oil wells in Kuwait. Out of a total of 854 well heads, 605 were ignited, 108 were damaged, 46 were gushing, and 95 were left intact. The individual plumes of burning oil wells merged to form a massive super plume of particulate and gaseous air pollutants. Although the plume touched ground on occasion, most of the time the base of the super plume was 10,000 to 12,000 ft above ground and the top of the plume reached as high as 30,000 ft. The super plume traveled hundreds of miles downwind as its components dispersed and settled out until the super plume literally disappeared. The super plume was easily observed from orbiting satellites. The general direction of the plume was from the northwest to the southeast, traveling down the Saudi Arabian Coast. Besides the particulate and gaseous pollutants from the combustion of the crude oil, oil that was not burnt settled on the desert sand, frequently generating large ponds that posed various hazards including the release of light volatile compounds. The total volume of crude oil that collected in ponds was estimated at 25 to 40 billion barrels. The combustion pollutants were estimated from the known composition of Kuwaiti crude oil. Virtually all of these pollutants, to include SO₂, NOₓ, H₂S, CO, suspended particulates, inorganic acids, metals, polycyclic aromatic hydrocarbons, and volatile organic compounds, carried short-term or long-term health risks, or both. In the vicinity of the oil well fires the degree of human risk depended on the pollutant concentrations in the breathing zones of exposed persons. Those concentrations could be determined through direct measurements. Consequently, groups from the United States, Saudi Arabia, Kuwait, Great Britain, France, Norway, and other countries launched a variety of air pollution monitoring efforts ranging from ground measurements of pollutants to measurements of pollutant concentrations directly within the super plume. These early efforts were focused on assessing potential acute health effects.

The initial environmental monitoring reports concluded that pollution coming from the oil wells was at levels that would not cause severe short-term (acute) health problems. However, the groups conducting the monitoring (U.S. Environmental Protection Agency [USEPA], French and Norwegian scientists, and the Kuwait Environmental Department) emphasized that long-term or chronic health effects in exposed individuals could not be evaluated because of insufficient data.

THE U.S. MILITARY MEDICAL RESPONSE Concern about a potential long-term impact on U.S. Department of Defense (DoD) military and civilian personnel prompted the DoD to initiate a study of long-term health effects. The Office of the Assistant Secretary of Defense (Health Affairs) [OASD (HA)], asked the U.S. Army Office of The Surgeon General to chair a Tri-Service medical working group to evaluate all potential health effects from the oil smoke on DoD personnel. The group consisted of medical personnel from each military service, in addition to representatives from the Department of Veterans Affairs, OASD (HA), and the Office of the Deputy Assistant Secretary of Defense for Environment. Additionally, the Deputy Assistant Secretary of Defense for Environment dispatched a team from the U.S. Army Environmental Hygiene Agency (AEHA), renamed the U.S. Army Center for Health Promotion and Preventive Medicine [CHPPM] on May 1, 1991, and currently part of the

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The views expressed are those of the author and do not necessarily reflect the official policies or positions of the Department of the Army, the Department of Defense or the U.S. Government.
U.S. Army Public Health Command) to collect environmental samples and monitor health effects in U.S. personnel in South West Asia, and prepare a health risk assessment (HRA). The HRA was to look at the theater-wide risks associated with oil fire smoke, industrial pollution (which was difficult to separate from oil smoke contaminants), and natural background pollution for specific troop units.

Permanent ambient air monitoring stations were established at four locations in Saudi Arabia and six locations in Kuwait, although two in Kuwait were quickly abandoned as a result of logistical difficulties (Fig. 1). The locations were selected because they were the major sites where DoD troops were to be stationed long term. Approximately 5,000 samples (air, 4000; surface soil, 200; industrial hygiene, 600; and radiological, 200) were collected at these locations. With 558 oil wells on fire, the environmental monitoring effort by the AEHA began on May 5, 1991 and continued until December 3, 1991. The fires were all extinguished by approximately November 6, 1991 but monitoring continued to obtain about 1 month of background data. The background data would assist AEHA scientists in differentiating contaminants that occurred naturally, those that came from the oil well fires and possible industrial contamination. The environmental exposure data were then used to support a typical USEPA “Superfund” HRA. The HRA characterized general cancer and noncancer risks for the 10 monitoring sites where samples were collected. There was no attempt to characterize risk on an individual basis because of a lack of knowledge about exact troop movements and locations relative to the monitoring sites, and when and for how long individuals were at each site. This situation changed with the passage of Public Law (PL) 102-190, Section 734, which required a means to calculate exposure to oil fire emissions for all DoD personnel located and exposed to oil fire emissions. Eight sites had sufficient data to do this. Determining individual service member exposures to oil fire emissions for all service members, as mandated by PL. 102-190, required much more innovative techniques. Nearly 700,000 mobile U.S. troops occupied a region of approximately 880,000 square miles within Kuwait, Saudi Arabia, and Iraq. Daily troop locations were not consistently documented and existing records were not readily available. Also, the environmental samples collected had limitations. First, AEHA scientists used only static sampling locations (10 stations), but troops moved throughout the region. Second, the sampling period had a 3-month gap. Samples were collected starting in May, yet the oil well fires began in February. Third, the 5,000 environmental and industrial hygiene samples did not distinguish between pollutants originating from oil fires and those originating from other sources, such as industrial sources and natural background material. Therefore, AEHA personnel enlisted the aid of the National Oceanic and Atmospheric Administration/Air Resources Laboratory (NOAA/ARL) and obtained geographic information system (GIS) software. The NOAA/ARL had been involved since 1991 with the Department of Commerce Arabian Gulf Program Office in an international effort to determine the atmospheric effects of the Kuwait oil well fires.

To determine daily exposure levels for the entire area over 10 months for all troops, air dispersion modeling was used in conjunction with satellite imagery. The combined set of modeled and sampled exposure data was then applied temporally and spatially to the approximately 700,000 deployed personnel. In augmenting the fixed location sampling data, the NOAA/ARL models predicted daily pollutant concentrations at geographic locations impacted by the oil well fires. The first NOAA/ARL model simulations of the Kuwait oil fires were run for the AEHA in 1993 and used data from the NOAA/National Center for Environmental Predictions Medium-Range Forecast global spectral model. These simulations included archived fields that defined meteorological transport winds and boundary layer turbulence parameters. The meteorological fields were then used in the NOAA/ARL Hybrid Single-Particle Lagrangian Integrated Trajectories (HYSPLIT) dispersion model to derive daily super plume boundaries from the Kuwait oil fires for February 2 to October 31, 1991. AEHA scientists consulted with NOAA/ARL scientists in 1996 to reproduce the daily, modeled derived...
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super plume boundaries for February 2 to May 15, 1991, using high-resolution reanalysis meteorological fields from the European Center for Medium-Range Weather Forecasting. AEHA personnel coordinated with NOAA/ARL scientists to provide 24-hour predicted unit emission concentration values on a 15 × 15-km grid encompassing the extensive ODS Theater of Operations.

To comply with the public law, additional data on the locations of the deployed personnel and their respective time in the Theater of Operations were needed. The U.S. Armed Services Center for Unit Records Research (CURR), Alexandria, Virginia, developed a database that contained daily troop unit geographic locations for the Theater of Operations. To construct the database, the CURR gathered all unit history data archives, such as log reports, after action reports, and other pertinent information. This amounted to over 5 million pieces of paper from which 800,000-unit grid coordinates were created. With the CURR troop unit movement database, AEHA scientists were able to locate daily company level unit identification code locations. The AEHA, now the USACHPPM, scientists also obtained a copy of the Defense Manpower Data Center Desert Shield/Desert Storm Personnel File. These data provided the USACHPPM personnel the dates when each deployed person entered and exited the theater of operations and their unit of assignment.

Six primary data sets were gathered and loaded for use in the GIS. The data sets were spatially and temporally associated to derive daily exposure estimates of the troop units in theater. The first set of data was the sampled concentration data gathered from the 10 sites in Kuwait and Saudi Arabia. These sites sampled ambient air and soil media during May 5 to December 3, 1991 and represented primary troop staging locations. The second data set was the model simulations of the fire emissions generated by NOAA/ARL scientists. The model output was used to determine the location, extent, and concentration of the oil fire smoke. The output also supplemented the sampling data, as the sampling effort missed the first 3 months of the fires. The third set of data contained the satellite images of the oil fires combined smoke plumes (i.e., super plumes), obtained from the National Center for Atmospheric Research. The images were captured using the NOAA Advanced Very High Resolution Radiometer and were used to supplement and validate the spatial aspect of the NOAA/ARL model results. The fourth set of data was the troop unit locations provided by the CURR. These data provided the daily locations of company-sized units (about 75–150 people) in theater. The fifth set of data was the personnel data from the Defense Manpower Data Center, which provided service members’ units during their time in theater and the dates they entered and exited the theater. The final data set was obtained from standard USEPA data sources and included the toxicity values used to determine health effects possibly associated with oil well fire exposures.

For each day the fires were burning, daily grid locations (over 40,000) of the smoke were created with the GIS software. Each daily grid set was then used to digitize the outer most boundary of the smoke for that day (Fig. 2). Each modeled grid point contained data regarding the composition of the oil fire smoke. HYSPLIT predicted the concentrations and composition of each grid point by factoring in the oil fire’s extinguishment rate, emission rates, plume transects, and ground data. Similarly, the satellite images of the oil well fires “super plume” were georeferenced to the Theater of Operations and the outermost boundary of the satellite super plume boundary was also manually digitized (Fig. 3). Then, the GIS software merged the modeled and satellite boundaries together creating the outermost union of the two boundaries. The software then added a 15 km buffer around the merged boundary to help compensate for any user digitizing errors.
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and to have a more conservative estimate of the super plume on each day (Fig. 4).

Once a daily boundary was created, troop unit locations provided by CURR were placed at their geolocations within the theater to determine if they were within the super plume boundary (Fig. 5). Units within a daily super plume boundary were run through a custom program generating exposure levels. A unit’s associated exposure level was determined from the closest modeled grid point on that day. Each grid point contained the concentrations of the smoke compounds at the breathing zone (2-m height). The identified compounds and concentrations were used to derive associated health risk factors. This routine continued for the unit’s entire duration in the theater. The program was complete when every unit in theater had been evaluated to see if it was within the super plume boundary and those that were, had a daily health risk factor assigned. Another program assigned risk levels to individual personnel. That program assigned risk to a service member based upon the risk identified for their unit identification code. The program also factored in the service member’s theater entrance and exit dates so their risk was generated only for their time in the theater.

The oil well fire exposure and risk generating methodology made it possible to separate the risk caused by oil well smoke from the risk from all sources, as required by PL 102-190. Table I shows an example of the exposure to particulate matter caused by oil well fire smoke (modeled) vs. all source particulate exposure (measured from oil well smoke, sand, and industrial pollution).

CRITIQUE AND SUMMARY

Planning started in December 1990 when intelligence reports suggested Iraqi forces might ignite Kuwaiti oil wells as a means of unconventional warfare. As a result of this early threat recognition, there was sufficient time to plan this project, train the people who deployed to carry out the mission, and obtain the sampling equipment. Due to the large scale of the project, much of the air sampling equipment had to be borrowed from the USEPA.

The methods used for sampling and analysis were the USEPA “gold standard” methods for the time. There were no methods developed specifically for use in deployment. The risk assessment method selected to analyze the sample data and present the risk was conservative to be protective of our forces, and again USEPA “gold standard” methods at the time were used.

Over 5000 environmental samples were collected and analyzed from 10 sites dispersed around the theater. Samples were analyzed for over 50 different pollutants, including particulates, metals, inorganics, acid gases, criteria pollutants, volatile organic compounds, and polycyclic aromatic

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<th>Day (1991)</th>
<th>Oil Fire Contribution (Model Results, µg/m³)</th>
<th>Total Level (Sample Results, µg/m³)</th>
<th>Sand/Industrial Contribution (Total Minus Model, µg/m³)</th>
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hydrocarbons. The contaminants sampled and analyzed comprised a very long list selected from the known constituents of the Kuwaiti crude oil, and data collected from earlier international sampling efforts, including sampling in the smoke plume. Sampling went on for 9 months to insure a representative data set was collected as the fires were extinguished. Despite these extensive efforts, many scientists would have preferred having more acid gas and criteria pollutant samples.

Before and during the study other U.S. agencies were contacted for help, advice, equipment, and guidance. USEPA provided significant equipment and advice on risk assessment and analytical methodologies. NOAA/ARL provided significant help with atmospheric dispersion modeling and satellite imagery.

The process for review and approval of reports was very extensive and involved numerous Federal agencies. The following reviewed the study: USEPA, U.S. Department of Health and Human Services, NOAA/ARL, National Institute of Environmental Health and Science, Agency for Toxic Substances and Disease Registry, National Science Foundation, Department of Veterans Affairs, Centers for Disease Control and Prevention, National Institute of Standards and Technology, National Research Council, and DoD. The following organizations reviewed and concurred with the oil fire HRA: National Academy of Science—Institute of Medicine, Presidential Advisory Committee on Gulf War Veterans’ Illnesses, DoD Science Board Investigating Persian Gulf Mystery Illnesses, NIH Technology Assessment Workshop on the Persian Gulf Experience and Health, Government Accounting Office, and Office of Technology Assessment. The data, information and reports generated by this study were provided to many national and international scientific groups. Over the 20 years since the study was initiated, the results and data contained within the reports have been shared with many researchers and used in numerous publications. 12–14

ODS veterans have developed many health problems over the last 2 decades and many attribute these to ODS exposures. The exposures include: oil well fire smoke or petrochemicals, chemical or biological warfare agents, pesticides, vaccines, depleted uranium, nerve agent pre-exposure treatment, particulate matter, insect repellants, and emissions from tent heaters. Unlike many of the other exposures of concern, oil well fire exposures and associated risks were characterized using a considerable amount of collected field data. The soil and air samples collected as part of the oil well fires study were used to assist with assessment of depleted uranium and pesticide exposures.

Reviews of the oil well fire exposure studies have identified some areas where the study could have been improved: deploying earlier, right after the ground war ended in late February; identifying areas of interest where U.S. forces had been located before sampling was initiated and testing these sites even though U.S. forces were no longer there; and collecting more acid gas and criteria pollutant samples.

Changes in Deployment Environmental Surveillance Since 1991

There have been numerous changes in the tools used for deployment environmental surveillance and the policies and practices that support environmental surveillance since the 1991 oil well fires study. These include improvements in: equipment, sampling and analytical methods, training, specialized military units, risk assessment methods, troop tracking systems, routine health surveillance, data archiving, and military policy and doctrine. Equipment has become smaller, lighter, battery powered, and more rugged. DoD personnel have worked with commercial vendors to modify commercial equipment to suit DoD needs. Getting new equipment through the military bureaucracy to be available in timely fashion is an ongoing challenge, but military staff members are constantly working to place the best available tools in the military sets that accompany deployed units. Sampling methods have been modified to require less sample volume for easier transport. Environmental surveillance training is being conducted in military schools and equipped, trained personnel have been and are being assigned to specialized units in all the services to carry out deployment surveillance. The Army has had Area Medical Laboratories; the Navy has used field Forward Deployed Preventive Medicine Units; and the Air Force has deployed Preventive Medicine Teams-Air Force.

Risk assessment methods have undergone refinement and are now supported by Military Exposure Guidelines that have been developed for air, water, and soil, different exposure time frames, and thousands of chemicals. The Military Exposure Guidelines were developed by DoD with other Federal agencies using standard toxicological data and military specific exposure factors. They have been peer reviewed by the National Academies of Science. 15

Troop tracking systems to monitor individual troop locations on a daily basis continue to improve and undergo refinement. Currently, a useful system for medical investigations is the Defense Theater Accountability Software, which is available in the Central Command Area of Responsibility. Social security number and location (latitude and longitude) are entered every day for each individual. The system contains basic demographic data and military specific information, including occupational specialty. A limitation on use is the security classification of the system.

Routine environmental surveillance is now carried out at most deployment sites, to include the Central Command Area of Responsibility. Requirements and guidance for conducting the surveillance are in DoD directives and instructions, Joint Chiefs of Staff memoranda and service specific documents. The data collected are archived in a document called the Periodic Occupational and Environmental Monitoring Summary, the standard DoD document for archiving...
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environmental exposures. Additionally, most environmental exposure data and preventive medicine documents, surveys, and information relating to deployments are also archived in a system called the Defense Occupation Environmental Health Readiness System. The Defense Occupation Environmental Health Readiness System can be accessed over the internet.

CONCLUSION

Since the 1991 Kuwait Oil Fire HRA was developed, the DoD has made great strides in the area of deployment surveillance. There are trained and equipped units in all the services and trained individuals imbedded with deployed combat units. This infrastructure is intended to respond to an environmental catastrophe like the oil well fires or to smaller episodes like a fire or accident at an industrial facility, and to conduct routine surveillance. The DoD response to the 1991 Oil Well Fires required considerable resources, a great deal of time, and considerable consultation and collaboration with many U.S. Government agencies. The intent of the improvements within the DoD described above was to prevent or limit the consequences of environmental catastrophes and smaller accidents through preventive assessments and rapid, capable responses and to provide rapid, reliable, and actionable HRAs. The oil well fire exposure and risk generating methodology made it possible to separate the risk caused by oil fire smoke from the risk from all sources, as required by PL 102-190. The table shows an example of the exposure to particulate matter caused by oil well fire smoke (modeled) vs. all source particulate exposure (measured from oil fire smoke, sand, and industrial pollution).

REFERENCES