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Are Gulf War Veterans Experiencing Illness due to Exposure to Smoke from Kuwaiti Oil Well Fires? Examination of Department of Defense Hospitalization Data

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There has been much concern among the public and veterans that specific environmental exposures incurred during the Gulf War were the cause of subsequent illness among Gulf War veterans. In this historical cohort study, the authors compared the postwar morbidity of US military personnel exposed to smoke from the 1991 Kuwaiti oil well fires with that of unexposed personnel. Complete exposure and demographic data were available for 405,142 active-duty Gulf War veterans who did not remain in the region after the war. The authors used data from all Department of Defense hospitals for the period August 1, 1991–July 31, 1999 to estimate rates of hospitalization due to any cause, hospitalization due to a diagnosis in one of 15 major categories, and hospitalization due to one of nine diagnoses likely to be manifestations of smoke exposure. Exposures to particulate matter from oil-well-fire smoke were based on the integration of meteorologic data, diffusion modeling, and troop location data. The authors constructed seven exposure groups combining duration and amount of exposure. In Cox modeling, three of the 25 models showed an increased adjusted risk of hospitalization. However, there was no evidence of a dose-response relation. Despite some limitations, these data do not support the hypothesis that Gulf War veterans have an increased risk of postwar morbidity from exposure to Kuwaiti oil-well-fire smoke. *Am J Epidemiol* 2002;155:908–17.

environmental exposure; hospitalization; inhalation exposure; morbidity; Persian Gulf syndrome; petroleum; smoke; veterans

Since returning from the Gulf War in August 1991, some of the nearly 700,000 US military personnel who served in the Gulf have reported a wide range of symptoms that have been difficult to classify. Recent studies have demonstrated that Gulf War veterans are much more likely to report these symptoms than are their military peers (1–7), yet numerous research teams and expert panels have been unsuccessful in clearly implicating any specific Gulf War exposure as a cause of postwar symptoms. While the cause of these postwar symptoms remains elusive, researchers have not found evidence to suggest excess morbidity among Gulf War veterans, as measured by hospitalizations (8–10), mortality (11, 12), or birth defects (13). Recent efforts to group symptoms reported by Gulf War veterans into a unique syndrome or symptom complex have also been unsuccessful, because the same statistically associated symptom groupings occur among both Gulf War veterans and nondeployed veterans (2, 14–16).

Medical experts have suggested that increased symptoms may be the result of battle stresses associated with serving in a war zone (17) and that Gulf War veterans' symptoms are consistent with those reported after previous wars (18). Other studies have suggested that life in the military may be more stressful than civilian life for multiple reasons, including sudden and prolonged deployments, separation from family and friends, the threat of exposure to known and unknown chemical or biological weapons, the demanding operational tempo involving strenuous physical and mental exertion, and the pressure to become proficient at operating technologically unique weaponry under less-than-ideal weather conditions and other adverse environmental conditions (19–22).

Although specific Gulf War exposures have been difficult to assess, several researchers have speculated that there are exposures unique to the Gulf War that may be associated with the increased symptom reporting (3, 6, 23–25). However, objective quantitative estimates of Gulf War exposures have been sparse. Recently, retrospective gaseous plume modeling permitted estimation of potential exposure to nerve agents following the destruction of a large weapons bunker in Iraq in

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Abbreviations: CI, confidence interval; HYSPLIT, Hybrid Single-Particle Lagrangian Integrated Trajectories; ICD-9-CM, *International Classification of Diseases, Ninth Revision, Clinical Modification*; RR, risk ratio.

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March 1991 (26). A study of Gulf War veterans' hospitalization experience following possible ultra-low-level or subclinical exposures to nerve agents demonstrated no evidence of excess postwar morbidity among those possibly exposed (27). Just as there was concern about the potential health effects of possible exposure to nerve agent plumes, there is also concern that exposure to smoke plumes from oil well fires may be related to postwar morbidity or to increased reporting of symptoms (28–34). We examined the relation between possible exposure to smoke from oil well fires and subsequent health events by comparing the postwar hospitalization experiences of various Gulf War exposure groups.

MATERIALS AND METHODS

Study population

The study population consisted of 405,142 regular active-duty US military personnel who were deployed to the Gulf War theater of operations for 1 or more days between August 8, 1990, and July 31, 1991, who were still in the theater of operations (8) during the time of the Kuwaiti oil well fires (February 2, 1991–October 31, 1991), and who did not remain in the Gulf region after the war. The analysis of postwar hospitalization data was limited to regular active-duty military personnel, because US Department of Defense automated hospitalization data were available for these personnel throughout the period of observation. Because active-duty personnel are rarely hospitalized outside of the Defense Department medical system (8, 35), data capture is virtually complete for this group. On the other hand, Reserve and National Guard personnel are hospitalized in military facilities only while they are on active-duty status, and since in-theater hospitalizations were not included in our study, these two groups were excluded from our analyses.

Demographic and deployment data for Gulf War veterans were provided by the Department of Defense Manpower Data Center (Monterey Bay, California) and reflected military status as of August 1, 1991. These data included a unique identifier (for linking purposes only) and information on sex, date of birth (used to determine age in years and to categorize veterans into approximate quartile groups: 17–21, 22–25, 26–31, and ≥32 years), marital status, combined race/ethnicity (White, Black, Hispanic, and "other"), service branch (Army, Navy, Marine Corps, Air Force, and Coast Guard), service type (active-duty, National Guard, and Reserve), primary occupational specialty(ies) (10 major groups defined by the Department of Defense *Occupational Conversion Manual* (36)), rank (enlisted person, warrant officer, and commissioned officer), Gulf War deployment status (deployed and not deployed), number of days spent in the Gulf theater (categorized into approximate quartiles: 1–92, 93–149, 150–197, and 198–572 days), calendar period of time stationed in the Gulf theater, and date of separation from military service.

Hospitalization data

Hospitalization data for each service member included date of admission and up to eight individual discharge diagnoses per hospitalization. Data were captured from all Defense Department military treatment facilities for the period October 1, 1988–July 31, 1999. These data were linked to deployment and demographic data using each service member's unique identifier. Diagnoses were coded according to the *International Classification of Diseases, Ninth Revision, Clinical Modification* (ICD-9-CM) (37). For these analyses, the decimal components of the ICD-9-CM diagnoses were not considered. Furthermore, as in previous reports (8, 27, 38, 39), a prewar hospitalization covariate was created to denote an individual's hospitalization for any cause during the 12 months prior to August 1, 1990. Hospitalization data from hospitals outside the Defense Department health care system and outpatient data for the time period of this investigation were not available.

Modeling of smoke from oil well fires

The Kuwaiti oil well fires began in February 1991 when Iraqi troops withdrew from Kuwait, setting fire to over half of Kuwait's 1,000 oil wells. These fires continued burning until the last fire was extinguished on November 6, 1991. To address concerns over exposure to the Kuwait oil-well-fire smoke, the US Army Center for Health Promotion and Preventive Medicine, in collaboration with the Air Resources Laboratory of the National Oceanic and Atmospheric Administration, estimated 24-hour unit emission concentration values for 15- × 15-km grid blocks (a total of 40,401 grid points) encompassing the entire Gulf War theater of operations. As in previous estimates, the Air Resources Laboratory used the Lagrangian model termed HYSPLIT (Hybrid Single-Particle Lagrangian Integrated Trajectories) (40).

Meteorologic data from the European Centre for Medium-Range Weather Forecasting (41) and the National Centers for Environmental Prediction medium-range forecast were incorporated into the HYSPLIT models. Meteorologic fields were modified to account for nonlinear radiative effects of the smoke plume on the vertical mixing of the pollutants (42, 43).

Air concentrations were calculated on a fixed, three-dimensional grid by integrating all particle estimates over the sampling time period. Model computations of carbon soot smoke and sulfur dioxide air concentrations were compared with observations from several intensive aircraft measurement campaigns, as well as with long-term ground-based breathing zone measurements. The measurements and model calculations were consistent when the results were averaged over several episodes using cumulative frequency distributions. Since the HYSPLIT model estimated unit emission concentrations, a pollutant-specific emission factor exposure table was constructed. Using the HYSPLIT modeled data, we calculated daily particulate matter exposure values for each modeled grid point. This air dispersion modeling effort enabled us to use estimates of daily particulate matter concentrations in calculating possible troop unit exposures to the oil-well-fire smoke as the troops moved within the Gulf War theater of operations.

Geographic information systems data

Troop locations for specific days were recorded using Oracle Relational Database Management System software (Oracle Corporation, Redwood Shores, California) and Intergraph Modular GIS Environment software (Intergraph Corporation, Huntsville, Alabama) on a Windows NT-based Intergraph interserve multiprocessor computer. Geographic information systems data on troop unit locations were compiled from daily data on troop unit locations and movements (27) provided by the US Armed Services Center for Unit Records Research (Springfield, Virginia).

For each day the oil well fires were burning, daily grid locations of the smoke plume were generated with the Modular GIS Environment software. Each grid point also contained information about the composition of the oil-well-fire smoke. The HYSPLIT model predicted the concentration of total suspended particulate matter at each grid point by factoring in the oil fires' extinguishment rate (44), emission rates, plume transect data (45), and ground data (46). Once a daily boundary was generated, the troop unit locations were overlaid to determine whether specific troop units had been within the plume's boundary. Particulate exposure levels were then estimated for each unit under the plume using the closest grid point on that day. Each grid point contained the concentration of particulate matter at breathing level (a height of 2 m). This analytical protocol was applied to each unit's entire duration within the theater, and it was complete when every unit in the theater of operations had been evaluated to determine possible exposure to particulate matter. Once unit exposure estimates had been completed, we used the Department of Defense Manpower Data Center's Desert Shield/Desert Storm personnel file, with starting and ending dates of deployment, to identify all individual service members assigned to each unit in order to extrapolate troop unit estimates to the level of individual members.

Estimates of exposure to the oil-well-fire smoke plume

In an effort to estimate total dose and identify a possible dose-response relation, we combined data on exposure concentration with data on duration of exposure and created a single variable for each veteran based on average daily exposure and length of exposure in days. This exposure variable was categorized as no exposure, average daily exposure of 1–260 $\mu g/m^3$ for 1–25 days, average daily exposure of 1–260 $\mu g/m^3$ for 26–50 days, average daily exposure of 1–260 $\mu g/m^3$ for >50 days, average daily exposure of >260 $\mu g/m^3$ for 1–25 days, average daily exposure of >260 $\mu g/m^3$ for 26–50 days, and average daily exposure of >260 $\mu g/m^3$ for >50 days.

Health data from the Comprehensive Clinical Evaluation Program

In response to the health concerns of Gulf War veterans, the Department of Defense instituted the Comprehensive Clinical Evaluation Program on June 7, 1994 (47). The Comprehensive Clinical Evaluation Program is a voluntary health registry established to evaluate health outcomes among Gulf War veterans who have remained on active duty, have retired from military service, or currently serve in the National Guard or Reserves. The main objective of the Comprehensive Clinical Evaluation Program is to document, diagnose, and treat conditions that may have appeared subsequent to service in the Gulf War theater (47–50). The program consists of a structured clinical evaluation protocol that includes a comprehensive medical history and physical examination. If necessary, veterans are referred to medical specialists or referral hospitals for additional diagnostic testing and/or treatment. Symptoms, patient-reported exposures, and clinical diagnoses are recorded for each participant. To ensure systematic and uniform medical evaluations, the program was initiated at 184 military health care facilities located in 39 states, eight foreign countries, and two territories, and it uses a standardized two-phase clinical evaluation process supervised by physicians who are board-certified in either family practice or internal medicine (51). Exposed and nonexposed veterans in our study were identified as participants in the Comprehensive Clinical Evaluation Program by merging of the program's database with our study population. We included the available program data from June 7, 1994–February 28, 1997.

Study outcomes

We chose to examine both broad and specific health outcomes for our analyses: hospitalizations due to any cause, hospitalizations due to major ICD-9-CM diagnoses (37), and hospitalizations due to specific diagnoses thought to be the most likely manifestations of intense exposure to smoke from oil well fires. Any-cause hospitalizations did not include non-illness-related categories, such as childbirth. The 15 major ICD-9-CM categories of interest included infections and parasitic diseases; neoplasms; endocrine, nutritional, and metabolic diseases and disorders of the immune system; diseases of the blood and blood-forming organs; mental disorders; diseases of the nervous system and sense organs; diseases of the circulatory system; diseases of the respiratory system; diseases of the digestive system; diseases of the genitourinary system; complications of pregnancy; diseases of the skin and subcutaneous tissue; diseases of the musculoskeletal system and connective tissue; symptoms, signs, and ill-defined conditions; and injury and poisoning. In addition to these broad categories, we examined specific diagnoses to avoid missing a risk difference due to the possible masking effect of aggregated ICD-9-CM diagnoses. Prior to statistical modeling, we reviewed the published literature (52) and identified the following specific diagnoses as possibly being associated with smoke from oil well fires and other types of smoke exposure: asthma; ischemic heart disease; emphysema; acute bronchitis; chronic bronchitis; bronchitis not specified as acute or chronic; malignant neoplasms of the respiratory and intrathoracic organs; malignant neoplasms of the oropharynx, nasopharynx, and hypopharynx; pneumoconiosis due to silica or silicates; pneumoconiosis due to inorganic dust; unspecified pneumoconiosis; pneumopathy due to inhala-

tion of other dust; respiratory conditions due to chemical fumes and vapors; and other diseases of the respiratory system. To account for preexisting conditions, we identified any of these specific diagnoses made during a period almost 3 years prior to the start of follow-up. If a subject was found to have been hospitalized with one of the specific diagnoses of interest prior to the war, that individual was excluded from further analysis for that specific diagnosis.

To ascertain hospitalizations occurring in our study population during the period August 1, 1991–July 31, 1999, we scanned diagnostic fields in numerical order for the ICD-9-CM diagnoses of interest. Only the first hospitalization for each of the targeted outcomes was included. Men were not considered for the "complications of pregnancy" category. Hospitalizations thus captured were categorized by exposure level.

Statistical analyses

To compare the hospitalization experiences of Gulf War veterans while accounting for attrition, which was primarily due to separation from military service over the 8-year follow-up period in this population, we applied Cox's proportional hazards time-to-event modeling. Subjects were classified as having an event if they were hospitalized in any Defense Department hospital worldwide for any of the targeted conditions or outcomes. Follow-up time was calculated from August 1, 1991, until hospitalization, separation from active-duty military service, or July 31, 1999, whichever occurred first. Univariate analyses were first performed to explore the relations between the demographic, exposure, and other deployment variables and the risk of any-cause hospitalization. An exploratory model analysis was then performed to further assess the significance of the demographic, exposure, and deployment variables while simultaneously adjusting for all influential predictors of the targeted outcomes. These analyses yielded a consistent set of exposure variables and other influential covariates with p values of 0.15 or below, and these variables were then included in subsequent analyses.

Using SAS software, version 8.0 (SAS Institute, Inc., Cary, North Carolina), we calculated risk ratios and 95 percent confidence intervals for deployment status and the significant demographic variables among the 405,142 personnel with complete covariate data. The time-to-event estimates were calculated by exposure level. Using those estimates, computation and graphing of the cumulative probability of any-cause hospitalization were completed as a function of time.

RESULTS

Complete exposure, demographic, and deployment data were available for 405,142 veterans—74 percent of the approximately 550,000 active-duty deployed Gulf War veterans. Table 1 shows their demographic and military service characteristics by exposure level. Individuals were assigned to one of seven exposure groups varying in size from 3,676 to 136,513. Patterns of attrition, due primarily to separation from service, were very similar for all groups over the 8 years of observation (table 1).

Univariate analyses revealed the following predictors of postwar hospitalization: oil well smoke exposure status, marital status, age group, gender, occupational category, branch of service, race/ethnicity, pay grade, number of days in the Gulf theater, salary, length of service, and prewar hospitalization. Regression diagnostic procedures were used to assess collinearity among variables. The following variables were judged to be collinear: age and length of service, salary and pay grade, and oil well smoke exposure status and number of days in the Gulf theater. Salary, length of service, and number of days in the Gulf theater were removed from further modeling. Personnel with missing occupational data were found to be similar to those with an undesignated occupational category, so these groups were combined. Race/ethnicity was reduced to two categories, White and "other."

The adjusted risk of any-cause hospitalization for three of the six groups of veterans exposed to oil-well-fire smoke was significantly lower than the risk for the nonexposed group (table 2), although two of the three 95 percent confidence intervals were within 0.01 of including 1.0. The corresponding plots for cumulative probability of hospitalization by exposure level remained very stable and nearly parallel over the 8-year follow-up period (figure 1).

Cox's proportional hazards modeling was completed for each of the 15 major ICD-9-CM categories, with the nonexposed group being used as the reference category. There was no evidence of a trend of increasing risk of hospitalization for veterans exposed to oil-well-fire smoke over all of the exposure groups. However, exposure level 6 showed an increase in risk of hospitalization for the category of mental disorders (risk ratio (RR) = 1.11, 95 percent confidence interval (CI): 1.03, 1.19); exposure level 3 showed an increase in risk of hospitalization for the category of skin disease (RR = 1.35, 95 percent CI: 1.03, 1.79); and exposure level 4 showed an increase in risk of hospitalization for the category of injury and poisoning (RR = 1.11, 95 percent CI: 1.05, 1.17) (table 3).

Additional modeling for the nine specific diagnoses possibly associated with exposure to oil-well-fire smoke revealed relatively small numbers of events for the specific diagnoses when stratified by the seven exposure levels. Therefore, the seven exposure categories were collapsed into two: exposed and nonexposed. Exposed personnel were found to be at statistically significantly decreased risk for ischemic heart disease (RR = 0.82, 95 percent CI: 0.68, 0.99) and at increased but not statistically significant risk for emphysema (RR = 1.36, 95 percent CI: 0.62, 2.98), acute bronchitis (RR = 1.09, 95 percent CI: 0.62, 1.90), malignant neoplasms of the respiratory and intrathoracic organs (RR = 1.10, 95 percent CI: 0.56, 2.17), malignant neoplasms of the oropharynx, nasopharynx, and hypopharynx (RR = 1.13, 95 percent CI: 0.25, 5.17), and other diseases of the respiratory system (RR = 1.45, 95 percent CI: 0.86, 2.46) (table 4). After scanning all hospitalizations in our study population, we found no hospitalization events during the study period for the diagnoses of pneumoconiosis due to silica or sili-

TABLE 1. Demographic characteristics (%) of regular active-duty Gulf War veterans in Department of Defense hospitals, by level of exposure to smoke from oil well fires, February 2, 1991–January 31, 1999

Variable	Exposure level*						
	Not exposed (*n* = 68,065)	1 (*n* = 136,513)	2 (*n* = 23,252)	3 (*n* = 3,676)	4 (*n* = 68,086)	5 (*n* = 68,968)	6 (*n* = 36,582)
Attrition							
No separation from military service	33.5	30.1	31.0	32.9	30.1	28.2	28.9
Separated from military service	66.5	69.9	69.0	67.1	69.9	71.8	71.1
Gender							
Male	95.0	94.0	93.6	95.8	95.6	95.4	93.0
Female	5.0	6.0	6.4	4.2	4.4	4.6	7.0
Age (years)							
18–22	17.3	20.1	20.5	21.7	21.9	23.7	21.4
23–27	28.8	29.8	28.0	25.4	32.0	31.4	30.2
28–33	27.3	27.4	27.9	29.6	25.6	23.7	24.1
34–65	26.6	22.8	23.6	23.3	20.5	21.2	24.3
Prewar hospitalization							
No	93.8	92.7	92.7	94.7	92.5	93.7	93.0
Yes	6.2	7.3	7.3	5.3	7.5	6.3	7.0
Marital status							
Single	45.3	46.7	46.3	46.0	48.5	49.8	46.3
Married	54.7	53.9	53.7	54.0	51.5	50.2	53.7
Military pay grade							
Commissioned officer	10.6	8.3	8.9	9.6	8.0	8.3	9.4
Warrant officer	0.9	1.4	0.9	0.7	1.7	1.4	1.5
Enlisted person	88.5	90.3	90.2	89.7	90.3	90.4	89.2
Participant in the CCEP†							
No	97.9	92.0	91.6	91.7	91.5	94.2	93.6
Yes	2.1	8.0	8.4	8.3	8.5	5.8	6.4
Race/ethnicity							
Other	30.0	36.3	34.5	32.3	33.4	34.5	33.7
White	70.1	63.7	65.5	67.7	66.6	65.5	66.3
Branch of service							
Navy/Marine Corps	65.2	22.8	12.1	2.1	26.1	54.6	48.1
Army	18.3	66.0	65.6	64.5	64.9	41.9	39.7
Air Force	16.5	11.2	22.3	33.5	9.0	3.5	12.2
Occupational category							
Electronic equipment repair	11.3	7.2	7.8	6.3	7.0	7.5	7.9
Infantry, gun crews, and seamanship	22.9	27.4	29.8	29.7	34.0	28.6	19.8
Communications and intelligence	9.8	10.8	10.7	11.2	9.1	11.2	8.9
Health care	4.6	4.5	3.1	1.8	3.4	2.2	2.9
Photography	1.9	2.4	2.1	2.7	2.2	2.1	2.3
Functional support	11.5	11.0	11.3	12.0	9.7	11.2	14.3
Electrical/mechanical equipment repair	24.0	19.7	20.0	16.0	18.1	19.6	18.9
Craftwork	4.0	3.8	2.6	3.6	2.6	2.6	5.0
Service and supply handling	7.9	10.8	10.3	11.9	9.5	11.7	14.2
Nonoccupational or missing data	2.1	2.4	2.3	4.9	4.3	3.2	5.9

* Exposure level 1: average daily exposure of 1–260 μg/m³ for 1–25 days. Exposure level 2: average daily exposure of 1–260 μg/m³ for 26–50 days. Exposure level 3: average daily exposure of 1–260 μg/m³ for >50 days. Exposure level 4: average daily exposure of >260 μg/m³ for 1–25 days. Exposure level 5: average daily exposure of >260 μg/m³ for 26–50 days. Exposure level 6: average daily exposure of >260 μg/m³ for >50 days.

† CCEP, Comprehensive Clinical Evaluation Program.

cates, pneumoconiosis due to inorganic dust, unspecified pneumoconiosis, or pneumopathy due to inhalation of other dust.

DISCUSSION

In late February 1991, during Operation Desert Storm, more than 600 oil wells were ignited by the Iraqi army as it fled Kuwait. The resulting fires burned through November 1991, producing a visual effect of dramatic proportions. The global community feared profound changes in meteorologic patterns, significant environmental impact, and adverse health effects among those exposed to the smoke and pollution. Although the environmental consequences of the burning oil wells did not reach the proportions initially predicted, public concern over the possible health effects of exposure

TABLE 2. Adjusted risk ratios for postwar hospitalization from any cause among regular active-duty Gulf War veterans in Department of Defense hospitals, February 2, 1991–January 31, 1999

Variable	No. of subjects	%	No. hospitalized	%	Risk ratio	95% confidence interval
Level of exposure to smoke from oil well fires*						
Not exposed†	68,065	16.8	12,990	19.1		
1	136,513	33.7	27,242	20.0	0.99	0.97, 1.01
2	23,252	5.7	4,454	19.2	0.93	0.90, 0.97
3	3,676	0.9	709	19.3	0.92	0.85, 0.99
4	68,086	16.8	13,731	20.2	1.03	1.00, 1.05
5	68,968	17.0	12,317	17.9	0.97	0.94, 0.99
6	36,582	9.0	7,001	19.4	1.01	0.98, 1.04
Gender						
Male†	383,207	94.6	71,963	18.8		
Female	21,935	5.4	6,481	29.6	1.53	1.49, 1.57
Age (years)						
18–22†	83,858	20.7	13,980	16.7		
23–27	122,157	30.2	20,056	16.4	0.95	0.93, 0.98
28–33	106,144	26.2	21,959	20.7	0.95	0.93, 0.97
34–65	92,983	22.9	22,449	24.1	1.17	1.14, 1.20
Prewar hospitalization						
No†	377,119	93.1	70,736	18.8		
Yes	28,023	6.9	7,708	27.5	1.60	1.56, 1.63
Marital status						
Single†	191,281	47.2	32,272	16.9		
Married	213,861	52.8	46,172	21.6	1.01	0.99, 1.02
Military pay grade						
Commissioned officer†	35,494	8.8	6,510	18.3		
Warrant officer	5,508	1.4	1,443	26.2	1.34	1.26, 1.42
Enlisted person	364,140	89.8	70,491	19.4	1.50	1.46, 1.55
Participant in the CCEP‡						
No†	378,422	93.4	68,048	18.0		
Yes	26,720	6.6	10,396	38.9	1.40	1.37, 1.43
Race/ethnicity						
Other†	138,038	34.1	27,856	20.2		
White	267,104	65.9	50,588	18.9	1.10	1.08, 1.11
Branch of service						
Navy/Marine Corps†	151,409	37.4	11,321	7.5		
Army	207,775	51.3	43,779	21.1	1.22	1.20, 1.24
Air Force	45,958	11.3	9,344	20.3	1.01	0.98, 1.03
Occupational category						
Electronic equipment repair†	32,468	8.0	5,874	18.1		
Infantry, gun crews, and seamanship	111,115	27.4	20,022	18.0	1.09	1.06, 1.13
Communications and intelligence	41,528	10.3	7,870	19.0	1.03	0.99, 1.06
Health care	14,982	3.7	4,230	28.2	1.32	1.27, 1.37
Photography	8,961	2.2	1,919	21.4	1.07	1.01, 1.12
Functional support	45,513	11.2	9,583	21.1	1.01	0.97, 1.04
Electrical/mechanical equipment repair	81,171	20.0	15,105	18.6	1.02	0.99, 1.05
Craftwork	14,040	3.5	2,781	19.8	1.15	1.10, 1.21
Service and supply handling	42,622	10.5	8,253	19.4	1.08	1.04, 1.12
Nonoccupational or missing data	12,742	3.2	2,807	22.0	1.19	1.13, 1.24

* Exposure level 1: average daily exposure of 1–260 μg/m^3 for 1–25 days. Exposure level 2: average daily exposure of 1–260 μg/m^3 for 26–50 days. Exposure level 3: average daily exposure of 1–260 μg/m^3 for >50 days. Exposure level 4: average daily exposure of >260 μg/m^3 for 1–25 days. Exposure level 5: average daily exposure of >260 μg/m^3 for 26–50 days. Exposure level 6: average daily exposure of >260 μg/m^3 for >50 days.

† Reference category.

‡ CCEP, Comprehensive Clinical Evaluation Program.

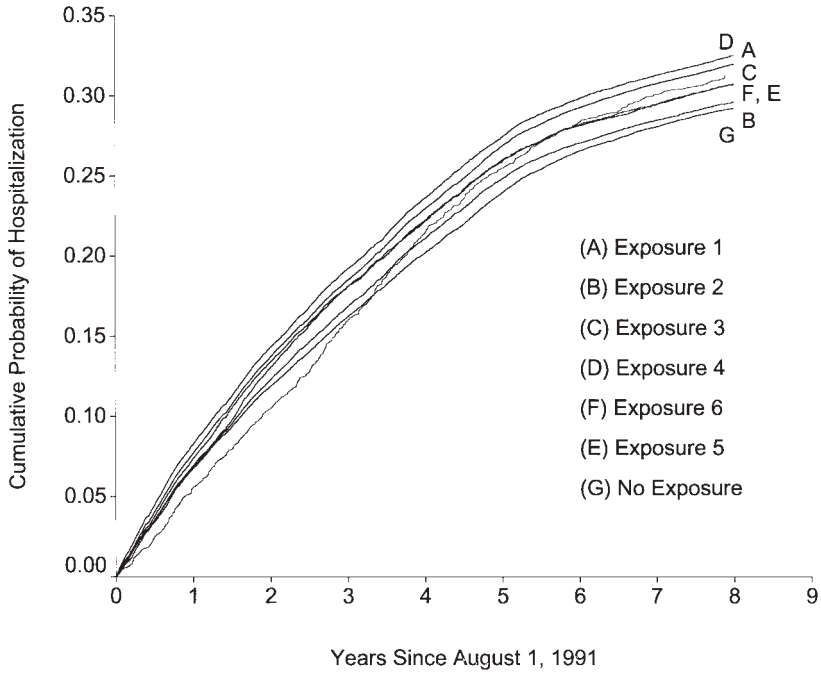

FIGURE 1. Probability of postwar hospitalization for any cause in a Department of Defense hospital during the period August 1, 1991–July 31, 1999 among regular active-duty Gulf War veterans, by level of exposure to smoke from oil well fires. Categories of exposure: not exposed; exposure level 1: average daily exposure of 1–260 μg/m³ for 1–25 days; exposure level 2: average daily exposure of 1–260 μg/m³ for 26–50 days; exposure level 3: average daily exposure of 1–260 μg/m³ for >50 days; exposure level 4: average daily exposure of >260 μg/m³ for 1–25 days; exposure level 5: average daily exposure of >260 μg/m³ for 26–50 days; exposure level 6: average daily exposure of >260 μg/m³ for >50 days.

TABLE 3. Adjusted risk ratios for postwar hospitalization in major three-digit ICD-9-CM* categories and by estimated exposure to smoke from oil well fires among regular active-duty Gulf War veterans in Department of Defense hospitals, August 1, 1991–July 31, 1999

ICD-9-CM codes	Major diagnostic categories	Exposure level†					
		1 (*n* = 136,513)	2 (*n* = 23,252)	3 (*n* = 3,676)	4 (*n* = 68,086)	5 (*n* = 68,968)	6 (*n* = 36,582)
001–139	Infections and parasitic	0.93	0.87‡	0.85	0.97	0.91	0.95
140–239	diseases	0.98	0.96	0.77	0.94	0.90	0.93
240–279	Neoplasms						
	Endocrine, nutritional, and	0.89‡	0.94	0.81	0.87‡	0.84‡	0.84‡
280–289	metabolic diseases	0.97	0.89	1.06	0.92	0.98	0.90
290–319	Blood diseases	1.03	1.10	1.08	0.97	0.99	1.11‡
320–389	Mental disorders	0.94	0.95	0.79	0.96	0.94	0.94
	Nervous system diseases						
390–459	Circulatory system diseases	0.95	0.88‡	1.15	0.87‡	0.90‡	0.92
460–519	Respiratory system	0.98	0.99	0.69‡	0.98	0.97	0.98
520–579	diseases	0.97	0.94	1.02	0.94	0.92‡	1.04
	Digestive system diseases						
580–629	Genitourinary system diseases	0.97	0.91	0.85	0.97	0.91‡	0.95
630–676	Complications of pregnancy	0.92	0.86‡	0.48‡	1.00	0.97	0.84‡
680–709	Skin diseases	0.98	0.95	1.35‡	1.01	0.87‡	0.89
	Musculoskeletal system						
710–739	diseases	0.96	0.91‡	1.01	1.03	0.97	1.00
	Symptoms, signs, and ill-						
780–799	defined conditions	0.93	0.97	0.97	0.92‡	0.90‡	0.98
800–999	Injury and poisoning	1.01	0.94	0.85	1.11‡	1.00	1.01

* ICD-9-CM, *International Classification of Diseases, Ninth Revision, Clinical Modification*.

† Exposure level 1: average daily exposure of 1–260 μg/m³ for 1–25 days. Exposure level 2: average daily exposure of 1–260 μg/m³ for 26–50 days. Exposure level 3: average daily exposure of 1–260 μg/m³ for >50 days. Exposure level 4: average daily exposure of >260 μg/m³ for 1–25 days. Exposure level 5: average daily exposure of >260 μg/m³ for 26–50 days. Exposure level 6: average daily exposure of >260 μg/m³ for >50 days.

‡ Statistically significant difference from the reference group (no exposure).

TABLE 4. Adjusted risk ratios for postwar hospitalization due to selected ICD-9-CM* diagnoses, by estimated exposure to smoke from oil well fires, among regular active-duty Gulf War veterans in Department of Defense hospitals, August 1, 1991–July 31, 1999

ICD-9-CM code(s)	Specific diagnosis(es)	Exposure status		Risk ratio	95% confidence interval
		Not exposed (n = 68,065)	Exposed (n = 337,077)		
493	Asthma	135	745	0.90	0.74, 1.10
466	Acute bronchitis	16	93	1.09	0.62, 1.90
491	Chronic bronchitis	11	45	0.78	0.38, 1.57
160–165	Malignant neoplasms of the respiratory and intrathoracic organs	10	49	1.10	0.56, 2.17
146–148	Malignant neoplasms of the oropharynx, nasopharynx, and hypopharynx	2	10	1.13	0.25, 5.17
492	Emphysema	8	48	1.36	0.62, 2.98
410–414	Ischemic heart disease	156	585	0.82	0.68, 0.99
506	Respiratory conditions due to chemical fumes and vapors	4	13	0.71	0.23, 2.17
519	Other diseases of the respiratory system	17	137	1.45	0.86, 2.46

* ICD-9-CM, *International Classification of Diseases, Ninth Revision, Clinical Modification*.

to the smoke plume remained strong and was fueled by early media reports of illnesses among Gulf War veterans. The potential long-term health effects of smoke-plume exposure have yet to be characterized.

As part of our continuing efforts to assess plausible associations among potential Gulf War exposures and health outcomes, we examined the hospitalization experience of US military personnel potentially exposed to oil-well-fire smoke. These exposure-outcome relations were evaluated using Defense Department databases containing demographic, service history, and troop unit location and movement information linked with sophisticated geographic information systems smoke-plume modeling data. Our study allowed estimates of the degree of possible exposure to oil-well-fire smoke in 405,142 Gulf War veterans. The health events of interest for this group of veterans included hospitalization at any Defense Department treatment facility for any cause, hospitalization for any illness in one of 15 major ICD-9-CM categories, and hospitalization due to any of nine selected diagnoses over an 8-year observation period.

The thick oil-well-fire smoke plumes provided dramatic visual evidence of gross air pollution, with smoke being the most obvious product of combustion, as well as the most complex. Although smoke can be thought of as just partially combusted carbonaceous material, in reality it is a complex mixture of organic and inorganic compounds, such as sulfur dioxide, nitrogen oxides, benzene, hydrogen sulfide, and acidic gases, as well as particulate matter (52). The health effects attributable to the known chemicals and particulates from oil well fires to which Gulf War veterans were potentially exposed have been previously reviewed (52). The seven exposure categories we created were assigned to military units operating in proximity to the burning oil fields, and the data were extrapolated to individuals attached to those units.

Acquiring precise and reliable data on exposure at the individual level is one of the most challenging aspects of epidemiologic studies of this type. The limitations of epidemiologic studies that use group exposure data and individual outcome data have been discussed previously (27, 53, 54). Quantitative estimation of other known, potentially confounding behavioral and environmental exposures at the individual level was not feasible for this study. Thus, it is possible that exposure to tobacco use, fine desert dust, exhaust from diesel equipment, and other war-related exposures may have influenced some of the risk findings.

The choice of hospitalization as the measure of health effects also had some inherent limitations. Our analyses were limited to morbidity severe enough to require admission to a Defense Department hospital for inpatient care. Because outpatient data were not available, our study did not examine the full spectrum of health effects. Additionally, hospitalization data were only available for Gulf War veterans who remained on active duty or retired with medical benefits after the end of the war. However, rates of service attrition were found to be comparable across all seven exposure levels, including persons not exposed to the oil well fires. Previous studies have reported similar results when rates of attrition among Gulf War veterans were compared with those of their nondeployed counterparts (9, 10, 27). Furthermore, although the distributions of demographic variables across the exposure levels were similar (table 1), it is possible that personnel in direct combat roles, as a group, are more physically fit than support personnel and thus are less likely to be hospitalized postdeployment. This could explain why risk of hospitalization overall (table 2) and risk for several major diagnostic categories (table 3) tended to be lower in the exposed than in the unexposed. More research is needed in order to identify and quantify this effect. However, the fact remains that exposure to oil-well-fire smoke based on objective, quantitative data was not found to be positively associated with hospitalization. Lastly, the observation period of 8 years may not have been long enough for all long-term health effects of oil-well-fire smoke exposure to manifest.

Despite these limitations, our study had a number of unique strengths. To our knowledge, it was the first to study

possible associations between exposure to oil-well-fire smoke and postwar hospitalizations. We used sophisticated modeling techniques to quantify and integrate data from disparate sources to estimate concentration and duration of exposure to oil-well-fire smoke. Hospitalizations are an objective outcome measure, in contrast to self-reported symptoms or illnesses. Hospitalization data are very complete for active-duty military personnel, because these persons have ready access to essentially free medical care in Defense Department facilities. Since active-duty personnel seldom seek medical care outside the Defense Department health care system, we are confident that we captured virtually 100 percent of the most serious health outcomes (8, 35). In addition, our large study population permitted robust risk estimates, and the study had considerable statistical power to detect even small differences in hospitalization risk across exposure categories and among demographic groups. This makes it very likely that if true differences in hospitalization risk existed between exposed veterans and nonexposed veterans, we would have detected them.

In summary, the results of this study do not support the theory that Gulf War veterans are at increased risk of hospitalization due to exposure to oil-well-fire smoke. Using both broad and specific categories of health outcomes and searching for a dose-response effect, we found no evidence of an association, particularly a cause-effect relation, between exposure to oil-well-fire smoke and increased hospitalization risk. Our findings are consistent with those of other studies of health outcomes following Gulf War military service that have been carried out to date (8–13). The findings support the conclusion of the 1998 RAND Corporation review (52)—namely, that adverse health effects would not be expected in Gulf War veterans as a result of exposure to the Kuwaiti oil well fires.

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