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GULF WAR ILLNESSES

DOD's Conclusions About U.S. Troops' Exposure Cannot Be Adequately Supported

Statement of Keith Rhodes, Chief Technologist
Center for Technology and Engineering, Applied Research and Methods

On 8/6/04 this testimony was reissued because, beginning on page 15, the support for "Some Studies Suggest an Association between Chemical Warfare Exposure and Gulf War Illnesses" was inadvertently omitted.

June 2004

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Highlights

Highlights of GAO-04-821T, a report to Subcommittee on National Security, Emerging Threats, and International Relations, Committee on Government Reform, House of Representatives

Why GAO Did This Study

Since the end of the Gulf War in 1991, many of the approximately 700,000 U.S. veterans have experienced undiagnosed illnesses. They attribute these illnesses to exposure to chemical warfare (CW) agents in plumes—clouds released from bombing of Iraqi sites. But in 2000, the Department of Defense (DOD) estimated that of the 700,000 veterans, 101,752 troops were potentially exposed. GAO was asked to evaluate the validity of DOD, the Department of Veterans Affairs (VA), and British Ministry of Defense (MOD) conclusions about troops' exposure.

This testimony summarizes a report GAO is issuing today.

What GAO Recommends

GAO is recommending that the Secretary of Defense and the Secretary of Veterans Affairs not use the plume-modeling data for any other epidemiological studies of the 1991 Gulf War. VA concurred with our recommendation. DOD did not concur but we have clarified the recommendation to address DOD's concerns as we understand them. GAO also recommends that the Secretary of Defense require no additional plume modeling of Khamisiyah and other sites. DOD concurred with our recommendation.

The Central Intelligence Agency (CIA) did not concur with our report, stating it could not review the draft report in the time allotted.

www.gao.gov/cgi-bin/getrpt?GAO-04-821T.

To view the full product, including the scope and methodology, click on the link above. For more information, contact Keith Rhodes at (202) 512-6412 or rhodesk@gao.gov.

What GAO Found

DOD's and MOD's conclusion about troops' exposure to CW agents, based on DOD and CIA plume modeling, cannot be adequately supported. The models were not fully developed for analyzing long-range dispersion of CW agents as an environmental hazard. The modeling assumptions as to source term data—quantity and purity of the agent—were inaccurate because they were uncertain, incomplete, and nonvalidated.

The plume heights used in the modeling were underestimated and so were the hazard area. Postwar field testing used to estimate the source term did not realistically simulate the actual conditions of bombings or demolitions. Finally, the results of all models—DOD and non-DOD models—showed wide divergences as to the plume size and path.

DOD's and VA's conclusion about no association between exposure to CW agents and rates of hospitalization and mortality, based on two epidemiological studies conducted and funded by DOD and VA, also cannot be adequately supported because of study weaknesses. In both studies, flawed criteria—DOD's plume model and DOD's estimation of potentially exposed troops based on this model—were used to determine exposure. This may have resulted in large-scale misclassification.

Troops under the path of the plume were classified as exposed; those not under the path, as nonexposed. But troops classified as not exposed under one DOD model could be classified as exposed under another DOD model. Under non-DOD models, however, a larger number of troops could be classified as exposed. Finally, as an outcome measure, hospitalization rate failed to capture the types of chronic illnesses that Gulf War veterans report but that typically do not lead to hospitalization.

June 1, 2004

Mr. Chairman and Members of the Subcommittee:

We are pleased to participate in this international hearing by presenting our assessment of the plume modeling, conducted by the Department of Defense (DOD) and the Central Intelligence Agency (CIA), to determine the number of U.S. troops that might have been exposed to the release of chemical warfare agents during the Gulf War in 1990. We presented our preliminary results to you in our testimony on June 2, 2003.[1] My statement today is based on our final report, entitled *Gulf War Illnesses: DOD's Conclusions about U.S. Troops' Exposure Are Unsupported*, which is being issued today.[2]

As you know, many of the approximately 700,000 veterans of the Persian Gulf War have experienced undiagnosed illnesses since the war's end in 1991. Some fear they are suffering from chronic disabling conditions because of wartime exposures to vaccines, as well as chemical warfare agents, pesticides, and other hazardous substances with known or suspected adverse health effects. When the issue of the possible exposure of troops to low levels of chemical warfare agents was first raised, during the summer of 1993, DOD and the CIA concluded that no U.S. troops were exposed because (1) there were no forward-deployed Iraqi chemical warfare agent munitions and (2) the plumes—clouds of chemical warfare agents—from the bombing that destroyed the Iraqi chemical facilities could not have reached the troops.

This position was maintained until 1996, when DOD publicly disclosed that U.S. troops destroyed a stockpile of chemical warfare agent munitions after the Gulf War in 1991, at a forward-deployed site, Khamisiyah, in Iraq. Consequently, DOD and the CIA conducted several analyses using computer modeling, in an effort to estimate the number of troops that might have been exposed to chemical warfare agents. Recognizing that actual data on the source term—such as the quantity and purity

[1]U.S. General Accounting Office, *Gulf War Illnesses: Preliminary Assessment of DOD Plume Modeling for U.S. Troops' Exposure to Chemical Agents*, GAO-03-883T (Washington, D.C.: June 2, 2003). www.gao.gov.

[2]U.S. General Accounting Office, *Gulf War Illnesses: DOD's Conclusions about U.S. Troops Exposure Cannot Be Adequately Supported*, GAO-04-159 (Washington, D.C.: June 1, 2004). www.gao.gov.

(concentration) of the agent—and the meteorological conditions—such as the wind and the weather patterns—were not available,[3] in 1996 and 1997, DOD and the CIA conducted field-testing and modeling of the demolition of Khamisiyah, to determine the size and path of the plume, as well as the number of U.S. troops exposed to chemical warfare agents within the area of the modeled plume's path. During these initial modeling efforts, DOD also asked the Department of Energy's (DOE) Lawrence Livermore National Laboratories (LLNL) to conduct modeling. In 1997, DOD and the CIA also combined the results of five different meteorological and dispersion models into a composite simulation of the plume area. They conducted additional simulations, using meteorological and dispersal models, to estimate the path of exposure from plumes during the bombings of sites other than Khamisiyah—Al Muthanna, Muhammadiyat, and Ukhaydir. In 2000, DOD revised its modeling estimates for the destruction of chemical warfare agents at Khamisiyah, and estimated that 101,752 U.S. troops had potentially been exposed.

In response to your request, we evaluated how well conclusions—about the extent of exposure of U.S. troops and the association between CW exposure and troops' hospitalization and mortality rates—are supported by available evidence. Specifically, we have assessed the following:

1. How valid is the DOD and MOD conclusion---based on CIA and DOD plume-modeling results—about U.S. and British troops' exposure to CW agents?

2. What were the costs for the CIA's and DOD's various plume modeling efforts?

3. How valid are the DOD and Department of Veterans Affairs (VA) conclusions from epidemiological studies, based on DOD's plume modeling results, that there was no association between CW exposure at Khamisiyah and the troops' hospitalization and mortality rates?

[3]Observations were few because Iraq stopped reporting weather station measurement information to the World Meteorological Organization in 1981. As a result, data on the meteorological conditions during the Gulf War were sparse. The only data that were available were for the surface wind observation site, 80 to 90 kilometers away, and the upper atmospheric site, about 200 kilometers away.

Scope and Methodology

To determine the validity of DOD's conclusion—that U.S. troops' exposures to chemical warfare agents were as DOD estimates suggested—based on its plume-modeling analysis, we examined the meteorological and dispersion models DOD used to model chemical warfare agent releases from the U.S. demolition of Khamisiyah and Coalition bombings of Al Muthanna, Muhammadiyat, and other sites in Iraq during the Gulf War deployment period. We evaluated the basis for the technical and operational assumptions DOD made in (1) conducting the modeling for the bombing and demolition of Iraqi sites and
(2) estimating the specific data and information used in the modeling, relating to source term, meteorological conditions, and other key parameters. We also evaluated the efforts of the CIA and DOD to collect and develop data on source term and other key parameters used in the modeling efforts.

We interviewed DOD and CIA modelers and officials involved with the modeling and obtained documents and reports from DOD's Deployment Health Support Directorate. We also interviewed and received documents from DOE officials who were involved with the modeling at LLNL. In addition, we interviewed officials and obtained documents from the Institute for Defense Analyses (IDA) concerning the IDA expert panel assessment of CIA's modeling of Khamisiyah. We also interviewed U.S. Army officials at Dugway Proving Ground, Utah, to determine how chemical warfare agents might have been released during the Khamisiyah pit area demolitions. Finally, we interviewed officials at the U.S. Army Center for Health Promotion and Preventive Medicine, to determine how specific troop unit exposures were identified, and officials of the United Nations Monitoring, Verification, and Inspection Commission (UNMOVIC), to obtain information on source term data from the United Nations Special Commission's (UNSCOM) analyses and inspections of the Khamisiyah, Al Muthanna, Muhammadiyat, and other sites.

To determine the validity of DOD's and the Department of Veterans Affairs' (VA) conclusions—based on epidemiological studies—that there was no association between Khamisiyah exposure and the rates of hospitalization or mortality, we reviewed published epidemiological studies in which hospitalization and mortality among exposed and nonexposed U.S. troops were analyzed. We also interviewed the study authors and researchers and examined the Gulf War population databases provided to the researchers by DOD in support of these studies. We interviewed Veterans Benefits Administration officials and obtained documents and reports on their analyses of DOD's population databases.

We did not examine whether plume modeling data were being used by VA to determine eligibility for treatment or compensation.

In an effort to identify the total costs associated with modeling and related analyses of chemical warfare agent releases during the Gulf War; we interviewed relevant officials and collected cost data from various DOD agencies and DOD contractors who supported the modeling efforts.

To determine the extent of British troops' exposure to chemical warfare agent-related releases during the Gulf War, we interviewed British Ministry of Defense (MOD) officials in London and at Porton Down, and reviewed U.K. Ministry of Defense reports concerning the potential effects of exposure to chemical warfare agent-related releases on British forces.

We conducted our work from May 2002 through May 2004 in accordance with generally accepted government auditing standards.

Results in Brief

DOD and MOD's conclusions, based on DOD's plume-modeling efforts regarding the extent of U.S. and British troops' exposures to chemical warfare agents, cannot be adequately supported. Given the inherent weaknesses associated with the specific models DOD used and the lack of accurate and appropriate meteorological and source term data in support of DOD's analyses, we found five major reasons to question DOD and MOD's conclusions. First, the models were not fully developed for analyzing long-range dispersion of chemical warfare agents as an environmental hazard. Second, assumptions regarding source term data used in the modeling—such as the quantity and purity of the agent—were inaccurate, since they were based on (1) uncertain and incomplete information and (2) data that were not validated. Third, the plume heights from the Gulf War bombings were underestimated in DOD's models. Fourth, postwar field testing at the U.S. Army Dugway Proving Ground, to estimate the source term data, did not reliably simulate the actual conditions of either the bombings or the demolition at Khamisiyah. Fifth, there is a wide divergence in results among the individual models DOD selected, as well as in the unselected DOD and non-DOD models, with regard to the size and path of the plume and the extent to which troops were exposed. Given these inherent weaknesses, DOD and MOD cannot know which troops were and which troops were not exposed.

The total costs for the various plume-modeling efforts to analyze the potential exposure of U.S. troops—from the demolition at Khamisiyah and the bombing of several other sites in Iraq—cannot be estimated. DOD

organizations and other entities involved with the plume-modeling efforts could provide only direct costs (that is, contractors' costs), which totaled about $13.7 million. However, this amount does not include an estimate of the considerable indirect costs associated with the salaries of DOD, VA, and contractors' staff or costs of facilities, travel, and equipment. We requested, but DOD could not provide, this estimate. In addition, the CIA would not provide direct and indirect costs for Gulf War plume modeling because, in its view, our request constituted oversight of an intelligence matter, beyond the scope of GAO authority. The CIA's contractor, the Science Applications International Corporation (SAIC), also did not respond to our request for cost data.

DOD's and VA's conclusions—that there is no association between exposures to chemical warfare agents from demolitions at Khamisiyah and rates of hospitalization and mortality among U.S. troops—also cannot be adequately supported. DOD and VA based these conclusions on two government-funded epidemiological studies, one conducted by DOD researchers, the other by VA researchers.[4] In each of these studies, flawed criteria were used to determine which troops were exposed. For example, in each study, the criteria used were based on (1) DOD plume modeling of exposures from postwar demolition of the Khamisiyah munitions depot and (2) DOD's estimates, using this modeling, of which troops were under the path of the plume. Troops under the path of the plume were classified as exposed, those not under the path as nonexposed. However, troops classified as nonexposed under one DOD model could be classified as exposed under another DOD model, thereby confounding the results. In the DOD models, a small area was identified as being under the path of the plume, resulting in a small number of troops identified as exposed. But in other modeling not selected for consideration, such as that performed at the LLNL, for example, a much larger, as well as different area, was identified as under the path of the plume, resulting in the potential classification of a larger number of troops as having been exposed. In addition, these exposed troops included different troops from those in the DOD models–that is, troops classified as exposed in the DOD selected models would have been classified as nonexposed in the other models, even though the area of coverage was much greater.

[4]G. C. Gray and others, "The Postwar Hospitalization Experience of Gulf War Veterans Possibly Exposed to Chemical Munitions Destruction at Khamisiyah, Iraq," *American Journal of Epidemiology* 150 (1999); H. K. Kang and T.A. Bullman, "Mortality Among U.S. Veterans of the Persian Gulf War: 7 Year Follow-up," *American Journal of Epidemiology* 154 (2001): 399-409.

These flaws may have resulted in large-scale misclassification of the exposure groups—that is, a number of exposed veterans may have been classified as nonexposed, and a number of nonexposed veterans may have been misclassified as exposed. In addition, in the hospitalization study, the outcome measure—number of hospitalizations—would not capture the chronic illnesses that Gulf War veterans commonly report, but which typically do not lead to hospitalization. Several published scientific studies of exposure involving Gulf War suggest an association between low-level exposure to chemical warfare agents and chronic illnesses.

In our report, we are recommending that the Secretary of Defense and the Secretary of Veterans Affairs not use the plume-modeling data for future epidemiological studies of the 1991 Gulf War, since VA and DOD cannot know from the flawed plume modeling who was and who was not exposed.

We are also recommending that the Secretary of Defense require no further plume-modeling of Khamisiyah and the other sites bombed during the 1991 Gulf War in order to determine troops' exposure. Given the uncertainties in the source term and meteorological data, additional modeling of the various sites bombed would most likely result in additional costs, while still not providing any definitive data on who was or was not exposed.

We obtained comments our draft of this report from VA, DOD, and CIA. VA concurred with recommendation that VA and DOD not use the plume-modeling data for future epidemiological studies, since VA and DOD cannot know from the flawed plume modeling who was and who was not exposed. DOD did not concur with the recommendation, indicating that to them it called for a blanket prohibition of plume modeling in the future. The intent of our recommendation is only directed at epidemiological studies involving the DOD and CIA plume modeling data from the 1991 Gulf War and not a blanket prohibition of plume modeling in future. We have clarified the recommendation along these lines. DOD concurred with our second recommendation, indicating that despite enhancements in the models, uncertainties will remain. CIA did not concur with our report, indicating that it could not complete its review in the time allotted.

Background

According to the CIA, modeling is the art and science of using interconnected mathematical equations to predict the activities of an actual event. In this case, modeling was used to determine the direction

and extent of the plume from chemical warfare agents. In environmental hazard modeling, simulations recreate or predict the size and path (that is, the direction) of the plume, including the potential hazard area, and potential exposure levels are generated.

Information for Modeling

In addition to identifying the appropriate event to model, modeling requires several components of accurate information:

- the characteristics or properties of the material that was released and its rate of release (for example, quantity and purity; the vapor pressure; the temperature at which the material burns; particle size; and persistency and toxicity); temporal information (for example, whether chemical agent was initially released during daylight hours, when it might rapidly disperse into the surface air, or at night, when a different set of breakdown and dispersion characteristics would pertain, depending on terrain, plume height, and rate of agent degradation);
- data that drive meteorological models during the modeled period (for example, temperature, humidity, barometric pressure, dew point, wind velocity and direction at varying altitudes, and other related measures of weather conditions);
- data from global weather models, to simulate large-scale weather patterns, and from regional and local weather models, to simulate the weather in the area of the chemical agent release and throughout the area of dispersion; and
- information on the potentially exposed populations, animals, crops, and other assets that may be affected by the agent's release.

Types of Models Used

Various plumes during the 1991 Gulf War were estimated using global-scale meteorological models, such as the National Centers for Environmental Prediction Global Data Assimilation System (GDAS) and the Naval Operational Global Atmospheric Prediction System (NOGAPS). Regional and local weather models were also used, including the Coupled Ocean-Atmosphere Mesoscale Prediction System (COAMPS), the Operational Multiscale Environmental Model with Grid Adaptivity (OMEGA), and the Mesoscale Model Version 5 (MM5).

Transport and diffusion models were also used during the 1991 Persian Gulf War plume simulation efforts.[5] These models estimate both the path of a plume and the degree of potential hazard posed by the chemical warfare agents. Dispersion models used during the Gulf War included the Hazard Prediction and Assessment Capability (HPAC) along with its component, the Second-order Closure Integrated Puff (SCIPUFF) model; the Vapor, Liquid, and Solid Tracking (VLSTRACK) model; the Non-Uniform Simple Surface Evaporation (NUSSE) model; and the Atmospheric Dispersion by Particle-in-Cell (ADPIC) model.

DOD's Conclusion about U.S. Troops' Exposure to Chemical Warfare Agents Cannot Be Adequately Supported

DOD's conclusion about the extent of U.S. troops' exposure to chemical warfare agents during and immediately after the Gulf War, based upon DOD and CIA plume model estimates, cannot be adequately supported. This is because of uncertainty associated with the source term data and meteorological data. Further, the models themselves are neither sufficiently certain nor precise to draw reasonable conclusions about the size or path (that is, the direction) of the plumes.

In particular, we found five reasons to question DOD's conclusion. First, the models DOD and the CIA selected were in house models not fully developed for analyzing long-range dispersion of chemical warfare agents as environmental hazards. DOD and CIA officials selected several in-house models to run plume simulations. For Khamisiyah and the other Iraqi sites selected for examination, DOD selected the COAMPS and OMEGA meteorological models and the HPAC/SCIPUFF and VLSTRACK dispersion models. However, these models were not at the time fully developed for modeling long-range environmental hazards.

Second, the assumptions about the source term data used in the models are inaccurate. The source term data DOD used in the modeling for sites at Khamisiyah, as well as Al Muthanna and Muhammadiyat, contain significant unreliable assumptions. DOD and the CIA based assumptions on field testing, intelligence information, imagery, UNSCOM inspections, and Iraqi declarations to UNSCOM. However, these assumptions were based on limited, nonvalidated, and unconfirmed data concerning (1) the nature of the Khamisiyah pit demolition, (2) meteorology, (3) agent purity, (4) amount of agent released, and (5) other chemical warfare agent data. In addition, DOD and the CIA excluded from their modeling efforts many

[5]We use dispersion in this report to refer to both transport and diffusion models.

other sites and potential hazards associated with the destruction of binary chemical weapons, vast stores of chemical warfare agent precursor materials, and the potential release of toxic byproducts and chemical warfare agents from other sites.[6]

Third, in most of the modeling performed, the plume heights were significantly underestimated. Actual plume height would have been significantly higher than the height DOD estimated in its modeling of demolition operations and bombings. The plume height estimates that the CIA provided for demolition operations at the Khamisiyah pit were 0 to 100 meters. However, neither DOD nor the CIA conducted testing to support estimated plume height associated with the bombings of Al Muthanna, Muhammadiyat, or Ukhaydir. According to DOD modelers, neither plume height nor any other heat or blast effects associated with these bombings were calculated from the models; instead, these data were taken from DOD's Office of the Special Assistant for Gulf War Illnesses. In addition, according to a principal Defense Threat Reduction Agency modeler, DOD's data on plume height were inconsistent with other test data for the types of facilities bombed.

Fourth, postwar field testing at the U.S. Army Dugway Proving Ground, in Utah, to estimate the source term data did not realistically simulate the actual conditions of the demolition operations at Khamisiyah or the effects of the bombings at any of the other sites in Iraq. For field testing to be effective, conditions have to be as close to the actual event as possible, but these tests did not provide more definitive data for DOD and CIA's models. The tests did not realistically simulate the conditions of the demolition of 122 mm chemical-filled rockets in Khamisiyah. The simulations took place under conditions that were not comparable with those at Khamisiyah. There were differences in meteorological and soil conditions; the construction material of munitions crates; rocket construction (including the use of concrete-filled pipes as rocket replacements to provide inert filler to simulate larger stacks); and the number of rockets, with far fewer rockets and, therefore, less explosive materials. In addition, in the tests, the agent stimulant used had physical properties different from those of the actual agent.

[6]A binary weapon mixes two less-toxic materials to create a toxic nerve agent within the weapon when it is fired or dropped.

Finally, there are wide divergences—with regard to the size and path of the plume and the extent to which troops were exposed—among the individual models DOD selected. The models DOD used to predict the fallout from Khamisiyah and the other sites showed great divergence, even with the same source term data. While the models' divergences included plume size and paths, DOD made no effort to reconcile them. The IDA expert panel observed that the results were so divergent that it would not be possible to choose the most exposed areas or which U.S. troops might potentially have been exposed. IDA therefore recommended a composite model, which DOD adopted.[7] However, this approach only masked differences in individual model projections with respect to divergences in plume size and path. In addition, DOD chose not to include in the composite model the results of the LLNL simulation, performed at the IDA expert panel's request. The LLNL simulation estimated a larger plume size and different path from DOD's models. The IDA panel regarded the LLNL model as less capable than other models because it modeled atmospheric phenomena with less fidelity. A modeling simulation done by the Air Force Technical Applications Center (AFTAC) also showed significant divergences from DOD's composite model.

MOD Relied on U.S. Plume Modeling to Determine Their Troops' Exposure to Chemical Warfare Agents

According to British officials, the MOD did not collect any source term or meteorological data during the 1991 Persian Gulf War. It also did not independently model the plume from Khamisiyah, relying instead on the 1997 DOD and CIA modeling of Khamisiyah. However, according to British MOD officials, they were reassessing the extent of British troops' exposure, based on DOD's revised 2000 remodeling of Khamisiyah. We requested from the British MOD, but did not receive, information on the findings from this reassessment.

The MOD also determined that a number of British troops were within the boundary of the plume in the DOD and CIA composite model. The MOD estimated that the total number of British troops potentially exposed was about 9,000 and the total number of troops as "definitely" within the path of the plume, however, was about 3,800. In addition, of 53,500 British troops deployed, at least 44,000 were estimated as "definitely not" within the path of the plume. However, since the MOD relied exclusively on DOD's modeling and since we found that DOD could not know who was

[7]The composite approach DOD used is also known as the ensemble approach.

and who was not exposed, the MOD cannot know the extent of British troops' exposure.

Total U.S. Plume-Modeling Costs

The DOD and CIA were the primary agencies involved in the modeling and analysis of U.S. troops' exposure from the demolition at Khamisiyah and bombing of chemical facilities at Al Muthanna, Muhammadiyat, and Ukhaydir, but several other agencies and contractors also participated. Funding to support the modeling efforts was provided to various DOD agencies and organizations, the military services, and non-DOD agencies and contractors. We collected data on the direct costs these agencies incurred or funds they spent. As shown in table 1, direct costs to the United States for modeling the Gulf War were about $13.7 million.

Table 1: U.S. Direct Costs for Modeling Gulf War Illnesses

Agency or contractor	Direct costs[a]	Work done
BAHR Inc.	$11,796	Reviewed (1) processes and technology used to produce estimates of U.S. forces potentially exposed and (2) draft reports on Khamisiyah
Central Intelligence Agency	[b]	Computer-modeling analysis
Chemical Biological Defense Command, Aberdeen Proving Ground	140,000	Wood-surface evaporative modeling and environmental data support efforts
Defense Threat Reduction Agency	870,000	Computer-modeling analyses with HPAC/SCIPUFF dispersion and OMEGA weather models
Institute for Defense Analyses	149,429	Convened a panel of experts to review Khamisiyah pit modeling analyses
Lawrence Livermore National Laboratory	60,000	Computer-modeling analyses with ADPIC dispersion and MATHEW weather models
National Center for Atmospheric Research	308,000	Computer-modeling simulations using MM5 weather model
Naval Research Laboratory	1,090,000	Meteorological analysis to identify downwind hazard assessment with NOGAPS and COAMPS weather models.
Naval Surface Warfare Center	522,000	Computer-modeling analyses with VLSTRACK dispersion and COAMPS weather models
Office of the Special Assistant to the Deputy Secretary of Defense for Gulf War Illnesses	7,980,000	Internal costs for producing case narratives for Al Muthanna, Khamisiyah, Muhammadiyat, and Ukhaydir
Science Applications International Corporation	[c]	Computer-modeling analysis
U.S. Army Center for Health Promotion and Preventative Medicine	731,000	Exposure assessment and environmental modeling to determine U.S. troops' exposed to chemical releases from multiple incidents during the Gulf War
U.S. Army Dugway Proving Ground	1,861,950	Field trials and laboratory testing using 122 mm chemical-simulant filled rockets to develop source term data for modeling
White Sands Missile Range	2,600	Missiles for testing at Dugway Proving Ground
Total	**$13,726,775**	

Sources: Agency and contractor responses provided to GAO regarding their modeling and analysis costs.

[a]Direct costs for agencies includes funding for contracts provided by the Office of the Special Assistant to the Deputy Secretary of Defense for Gulf War Illnesses.

[b]The CIA denied our request for its costs for modeling chemical releases from Khamisiyah, as well as Al Muthanna, Muhammadiyat, and Ukhaydir.

[c]SAIC did not respond to our requests for information.

DOD's and VA's Epidemiology-Based Conclusions on Chemical Warfare Exposure and Rates for Hospitalization and Mortality Cannot Be Adequately Supported

DOD and VA each funded an epidemiological study on chemical warfare agent exposure—DOD's on hospitalization rates and VA's on mortality rates. From the hospitalization study, conducted by DOD researchers, and the mortality study, conducted by VA researchers, on exposed and nonexposed troops, DOD concluded that there was no significant difference in the rates of hospitalization and VA concluded no significant difference in the rates of mortality. These conclusions, however, cannot be supported by the available evidence. These studies contained two inherent weaknesses: (1) flawed criteria for classifying exposure, resulting in classification bias, and (2) an insensitive outcome measure, resulting in outcome bias. In addition, in several other published studies of 1991 Persian Gulf War veterans, suggest an associations between chemical warfare exposure and illnesses and symptoms have been established.

DOD and VA Used Flawed Criteria for Determining Troops' Exposure

In the two epidemiological studies, DOD and VA researchers used DOD's 1997 plume model for determining which troops were under the path of the plume—who were estimated to be exposed—and which troops were not—those who were estimated to be nonexposed. However, this classification is flawed, given the inappropriate criteria for inclusion and exclusion.

In the hospitalization study, the DOD researchers included 349,291 Army troops "coded" as being in the Army on February 21, 1991. However, the researchers did not report cutoff dates for inclusion in the study—that is, they did not indicate whether these troops were in the Persian Gulf between January 17, 1991, and March 13, 1991, the period during which the bombings and the Khamisiyah demolition took place. Although we requested this information, DOD researchers failed to provide it. Finally, the total number of 349,291 troops is misleading because many troops left the service soon after returning from the Persian Gulf and therefore would not have been hospitalized after the war in a military hospital—another criterion for inclusion in the study. Moreover, the researchers did not conduct any analyses to determine what number or percentage of those who left active duty were in the exposed or nonexposed group (including uncertain low-dose exposure or estimated subclinical exposure). Given all the methodological problems in this study, it is not possible to accurately estimate the total size or makeup of the exposed and nonexposed population that may have sought or may have been eligible for care leading to military hospitalization.

In the mortality study, the VA researchers included 621,902 Gulf War veterans who arrived in the Persian Gulf before March 1, 1991. Troops

who left before January 17, 1991—the beginning of the bombing of Iraqi research, production, and storage facilities for chemical warfare agents—were included in the study. This group was not likely to have been exposed. Therefore, including them resulted in VA's overestimation of the nonexposed group.

Troops who came after March 1, 1991—the period during which Khamisiyah demolition took place—were excluded from the VA study. The Defense Manpower Data Center (DMDC) identified 696,000 troops deployed to the Persian Gulf, but the mortality study included only the 621,902 troops deployed there before March 1, 1991. This decision excluded more than 74,000 troops, approximately 11 percent of the total deployed. In addition, 693 troops who were in the exposed group were excluded because identifying data, such as Social Security numbers, did not match the DMDC database. VA researchers did not conduct follow-up analysis to determine whether those who were excluded differed from those who were included in ways that would affect the classification.

DOD and VA Used an Insensitive Outcome Measure for Determining Hospitalization Rates

Hospitalization rates—the outcome measure used in the hospitalization study—were insensitive because they failed to capture the chronic illnesses that 1991 Persian Gulf War veterans commonly report, but that typically do not lead to hospitalization. Studies that rely on this type of outcome as an end point are predetermined to overlook any association between exposure and illness.

Based on DOD's 1997 plume model, DOD's hospitalization study compared the rates for 1991 Persian Gulf War veterans who were exposed with the rates for those who were nonexposed. This study included 349,291 active duty Army troops who were deployed to the Persian Gulf. However, DOD researchers did not determine the resulting bias in their analyses, because they did not account for those who left the service.

The Institute of Medicine noted that the hospitalization study was limited to Army troops remaining on active duty and to events occurring in military hospitals. Conceivably, those who suffered from Gulf War-related symptoms might leave active duty voluntarily or might take a medical discharge. Hospitalization for this group would be reflected in VA or private sector databases, but not in DOD databases. The health or other characteristics of active duty troops could differ from those of troops who

left active duty and were treated in nonmilitary hospitals. Moreover, economic and other factors not related to health are likely to affect the use of nonmilitary hospitals and health care services.[8]

This limiting of the study to troops remaining on active duty produced a type of selection bias known as the healthy warrior effect.[9] It strongly biased the study toward finding no excess hospitalization among the active duty Army troops compared with those who left the service after the war.

Some Studies Suggest an Association between Chemical Warfare Exposure and Gulf War Illnesses

We found some studies that suggest an association between chemical warfare agent exposure and Gulf War illnesses. Each of these studies has both strengths and limitations.

Gulf War Veterans Studies

In a privately funded study, Haley and colleagues reported an association between a syndromic case definition of Gulf War illnesses, developed to model the ill veterans' symptomatic complaints, with exposure to CW agents.[10] In this study, the authors developed questionnaires on symptoms and environmental exposure identified in pilot studies of ill Gulf War veterans, similar to epidemic investigations by the Centers for Disease Control and Prevention (CDC).[11] These questionnaires were given to 249 troops from a U.S. Navy Mobile Construction Battalion that participated in the Gulf War. Factor analysis of the data on symptoms was used to derive

[8]Institute of Medicine, *Gulf War Veterans: Measuring Health* (Washington, D.C.: National Academy Press, 1999), p. 36.

[9]R. W. Haley, "Point: Bias from the 'Healthy-Warrior Effect' and Unequal Follow-Up in Three Government Studies of Health Effects of the Gulf War," *American Journal of Epidemiology* 148 (1998): 315–38.

[10]R. W. Haley and T. L. Kurt, "Self-Reported Exposure to Neurotoxic Chemical Combinations in the Gulf War," *JAMA* 277 (1997): 231–37.

[11]See Michael B. Gregg, ed., *Field Epidemiology*, 2nd ed. (New York: Oxford University Press, 2002).

a case definition identifying six syndrome factors.[12] Three syndrome factor variants found to be the most significant were (1) impaired cognition, (2) confusion-ataxia, and (3) arthro-myo-neuropathy.

Impaired cognition (syndrome 1) was associated with troops' having worn flea collars that contained chlorpyrifos.[13] Confusion-ataxia (syndrome 2), the most severe clinically, was associated with three risk factors.[14] The first was likely CW exposure; the second was the geographic location near the Saudi-Kuwaiti border around the fourth day of the air war, conducted January 18–23, 1991, when Czech chemical detection units detected sarin and mustard in ambient air near the Saudi-Kuwaiti border; and the third was side effects experienced after taking pyridostigmine. There was also a significant synergistic association between likely exposure to CW agents and the number of side effects from pyridostigmine.[15] Arthro-myo-neuropathy (syndrome 3) was associated with the amount of exposure to 95 percent DEET in ethanol insect repellent and with the number of side effects of pyridostigmine.[16]

[12]R. W. Haley and others, "Is There a Gulf War Syndrome? Searching for Syndromes by Factor Analysis of Symptoms," *JAMA* 277 (1997): 215–22. The six syndrome factors were impaired cognition, confusion-ataxia, arthro-myo-neuropathy, phobia-apraxia, fever-adenopathy, and weakness-incontinence.

[13]Impaired cognition is characterized by problems with attention, memory, and reasoning, as well as insomnia, depression, daytime sleepiness, and headache. (Study results showed relative risk 8.2, 95 percent, CI 2.9–23.5, $p = 0.001$.)

[14]Confusion-ataxia is characterized by problems with thinking, disorientation, balance disturbances, vertigo, and impotence.

[15](1) CW exposure, relative risk 7.8, 95 percent, CI 2.3–25.9, $p < 0.0001$; (2) geographic location, relative risk 4.3, 95 percent, CI 1.9–10.0, $p = 0.004$; (3) pyridostigmine side effects, dose-response trend up to relative risk 32.4, 95 percent, CI 7.8–135.0, $p < 0.0001$; (4) synergistic association, Rothman synergy statistic 5.3, 95 percent, CI 1.04–26.7, $p < 0.05$. See Jonathan B. Tucker, "Evidence Iraq Used Chemical Weapons during the 1991 Persian Gulf War," *The Nonproliferation Review* 4:3 (Spring–Summer 1997): 114–22. Center for Nonproliferation Studies, Monterey Institute of International Studies, http://cns.miis.edu/pubs (Apr. 28, 2004); and U.S. Department of Defense, Office of the Special Assistant for Gulf War Illnesses, *Coalition Chemical Detections and Health of Coalition Troops in Detection Area* (Washington, D.C.: Aug. 5, 1996). http://www.gulflink.osd.mil/czech_french/czfr_refs/n08en011/coalitn.html (Apr. 28, 2004).

[16]Arthro-myo-neuropathy is characterized by joint and muscle pains, muscle fatigue, difficulty lifting, and paresthesias of the extremities. (Results showed for exposure, dose-response effect to relative risk 7.8, 95 percent, CI 2.4–24.7, $p < 0.0001$; for side effects, dose-response effect to relative risk 3.9, 95 percent, CI 1.3–12.1, $p < 0.0001$.)

The inference that these risk-factor associations represent causal effects is supported by (1) the large, highly significant relative risks; (2) the dose-response effects; and (3) the synergistic effect of the risk factor associations with the syndromic case definition. Risk factors found not to be significantly associated with the case definition include environmental pesticides, pesticides in uniforms, antibiotic or antimalarial prophylaxis, multiple immunizations, smoke from oil well fires, fumes from jet fuel, fumes from burning jet fuel in tents, petroleum in drinking water, depleted uranium munitions, smoking, alcohol use, and combat exposure.

Another study of Gulf War veterans by Nisenbaum and colleagues, funded by CDC, examined the risk factors in 1,002 Air Force reservists.[17] They found, first, that the case definition of Fukuda and colleagues of "multisymptom illness" was strongly associated with at least one of the three chronic symptom groups fatigue, mood/cognition, and musculoskeletal pain. And, next, they found that reported exposure to CW agents was most strongly associated with the "severe illness" case definition of Fukuda and colleagues and less strongly associated with their "mild–moderate illness" case definition.[18]

Both case definitions were less strongly associated with the use of insect repellent ($p = 0.006$), the use of pyridostigmine ($p = 0.01$), and having an injury requiring medical attention ($p = 0.03$). But neither case definition was associated with smoke from oil well fires, coming under attack, seeing casualties, or having adverse health events in the family. The findings were attributed to the effects of stress but offered no empirical support for the explanation.

In a study that VA funded, Proctor and colleagues compared the exposure histories of 186 Gulf War veterans from Fort Devens, Massachusetts, and 66 from New Orleans, including 48 who deployed only to Germany. Collectively, the 252 veterans are known as the Massachusetts–New

[17]R. Nisenbaum and others, "Deployment Stressors and a Chronic Multisymptom Illness among Gulf War Veterans," *Journal of Nervous and Mental Disease* 188 (2000): 259–66.

[18]Association with "severe illness," adjusted OR 3.46, 95 percent, CI 1.73–6.91, $p < 0.0001$; association with "mild–moderate illness," adjusted OR 2.25, 95 percent, CI 1.54–3.27, $p < 0.0001$. See K. Fukuda and others, "A Chronic Multisymptom Illness Affecting Air Force Veterans of the Persian Gulf War," *JAMA* 280 (1998): 981–88.

Orleans cohort.[19] The case definition was a set of eight body-system symptom scores (BSS, distributed from 0 to 4), each constructed by summing the 5-point frequency-of-occurrence scales (0 = occurs never, 4 = occurs almost every day) for three symptoms typical of a particular body system. The eight body systems were cardiac, dermatological, gastrointestinal, musculoskeletal, neurological, neuropsychological, psychological, and pulmonary. Post-traumatic stress disorder (PTSD) was diagnosed with the structural clinical interviews, Clinician Administered Posttraumatic Stress (CAPS) disorder scale, or a Mississippi Scale score of >89. The symptoms were obtained from the 52-item Expanded Health Symptom Checklist, the exposure measures from an environmental exposure questionnaire and an Expanded Combat Exposure Scale (CES) questionnaire. Multiple regression analysis—controlling for age, sex, education, study site, Expanded CES score, and PTSD status—was used to develop a risk-factor model for each BSS scale.

Exposure to CW agents and debris from SCUD missiles was associated with four BSS scales; exposure to smoke from tent heaters, with three BSS scales; exposure to pesticides, vehicle exhaust, and burning human waste, with two BSS scales; the Expanded CES, with only one BSS scale; and exposure to pyridostigmine bromide (antinerve gas pills) and smoke from oil well fires, with no BSS scale. Controlling for depression scores and excluding veterans diagnosed with PTSD did not substantially affect the associations.

Three additional studies conducted with VA and DOD funding extended the risk-factor research for the Massachusetts–New Orleans cohort. The association of self-reported CW agent (nerve agent) exposure was tested with different formulations of the case definition. White and colleagues used psychological and neuropsychological tests to define illness. They found that exposure to CW agents was associated with abnormal measures of mood, memory, and attention or executive function.[20] Associations remained significant after controlling for age, sex, race, years of education, repeated grade in school, head injury, medication use, diagnosis of current

[19]S. P. Proctor and others, "Health Status of Persian Gulf War Veterans: Self-Reported Symptoms, Environmental Exposures, and the Effect of Stress," *International Journal of Epidemiology* 27 (1998): 1000–10.

[20]R. F. White and others, "Neuropsychological Function in Gulf War Veterans: Relationships to Self-Reported Toxicant Exposures," *American Journal of Industrial Medicine* 40 (2001): 42–54.

PTSD (by CAPS), diagnosis of current depression (by structural clinical interviews), active duty versus Reserve or Guard status, seeking disability rating, and Vietnam service.

Lindem and colleagues developed multiple regression models for neuropsychological test measures as case definitions of Gulf War illnesses.[21] Chemical warfare agent exposure was found to be associated with attention and executive function (continuous performance test), delayed verbal recall (California Verbal Learning Test and Visual Reproduction Test), and confusion and fatigue (Profile of Mood States). These associations remained significant when controlling for age, education, and PTSD diagnosis (by CAPS).

Wolfe and colleagues, studying 945 troops from the Massachusetts–New Orleans cohort, found that the CDC case definition of multisymptom illness was most strongly associated with having smelled a chemical odor, having taken up to 21 antinerve gas pills, or having experienced up to 10 formal alerts for CW agent attack.[22]

Kang and colleagues conducted a random sample mail survey that VA funded. Obtaining responses from 11,441 Gulf War veterans and 9,476 nondeployed Gulf War era veterans, they developed a case definition by factor analysis of symptoms measured by their questionnaire.[23] The first three syndrome factors closely resembled those that Haley and others derived (noted earlier). Finding that syndrome 2 was unique to the sample that had been deployed in the Gulf War (found in the deployed, but not the nondeployed, sample) and that the component symptoms were neurological in character, the researchers termed their syndrome 2 a possible unique Gulf War neurological syndrome. Four symptoms—blurred vision, loss of balance or dizziness, tremor or shaking, and speech difficulties—were associated with syndrome 2 only in the deployed sample. Consequently, Kang and colleagues established their case

[21]K. Lindem and others, "Neuropsychological Performance in Gulf War Era Veterans: Traumatic Stress Symptomatology and Exposure to Chemical-Biological Warfare Agents, *Journal of Psychopathology and Behavioral Assessment* 25:2 (2003): 105–19.

[22]Chemical odor, OR = 6.2, 95 percent, CI 3.9–9.9; antinerve gas pills, OR = 3.7, 95 percent, CI 2.4–5.6; formal alerts for CW attack, OR = 2.7, 95 percent, CI 2.0–3.7. See J. Wolfe and others, "Risk Factors for Multisymptom Illness in U.S. Army Veterans of the Gulf War," *Journal of Occupational and Environmental Medicine* 44:3 (2002): 271–81.

[23]H. K. Kang and others, "Evidence for a Deployment-Related Gulf War Syndrome by Factor Analysis," *Archives of Environmental Health* 57:1 (2002): 61–68.

definition as having all four of these symptoms. In the deployed sample, 277 met the case definition and 6,730 who had none of the four symptoms constituted the control group. Of a large number of risk factors analyzed, only nine were associated with the case definition, with an odds ratio greater than 3.0. Of these, perceived exposure to nerve agent had the strongest association (odds ratio 15.1, 95 percent, CI 11.5–19.9, $p < 0.000001$). This finding—a neurological syndrome appearing as the second factor in a factor analysis and being the most strongly associated risk factor, 15 times more common in ill veterans meeting the case definition than in controls—closely parallels the findings of Haley and colleagues. The finding received little notice, however, because the VA-funded mail survey did not (1) provide the odds ratio values in the table reporting the risk factor analysis results and (2) describe the finding in the text or abstract of the paper. When we noticed the finding, we manually calculated the odds ratios from the raw data in the table.

Smith and colleagues showed that hospitalization rates for several ICD-9 diagnoses were higher in veterans categorized in the Khamisiyah 2000 plume than in those not in the plume, and the association for cardiac arrhythmias was statistically significant. However, this study suffers from the same deficiencies as the earlier study that we cited: use, inappropriately, of hospitalization outcome measures rather than measures of Gulf War illness, which usually do not result in hospitalization, and use of plume modeling based on flawed data.[24]

The 2002 Kang and Bullman study has not been published in a peer-reviewed journal and therefore should not have been included in a review of the scientific epidemiologic literature. The DOD studies were invalid for two reasons: (1) Hospitalization and mortality were inappropriate outcomes because they do not measure Gulf War illnesses, which often do not lead to hospitalization, and (2) The DOD studies, no matter how powerful their techniques, could not control for the selection bias that resulted from the disproportionate early discharge of the ill Gulf War veterans soon after the Gulf War. Including only DOD hospital records of service members remaining on active duty resulted in the exclusion of veterans who left service for poor health. No amount of sophisticated

[24]T. C. Smith and others, "Gulf War Veterans and Iraqi Nerve Agents at Khamisiyah: Postwar Hospitalization Data Revisited," *American Journal of Epidemiology* 158 (2003): 457–67.

techniques can correct for this selection bias toward finding no difference.[25]

Genetics Studies

In one genetics study, Haley and colleagues found an association between the case definition of Gulf War illnesses in U.S. Gulf War veterans and low blood levels of the Q-type isoenzyme of the paraoxonase/arylesterase enzyme group (PON).[26] The PON group of enzymes is a potentially important predisposing factor in Gulf War illnesses because one of its major functions in normal body physiology is to protect the nervous system from organophosphate chemical toxins, such as pesticides and nerve agents. This finding was remarkable because the only function of Q type of the PON enzyme group is to protect the nervous system from nerve agents sarin, soman, tabun, and VX. The R-type isoenzyme has as its main function protection from organophosphate pesticides, such as diazinon, malathion, and parathion. Thus, an association between Gulf War illnesses and blood levels of only the Q-type isoenzyme of PON points specifically to nerve agent exposure. In addition, the total PON level—that is, the sum of the Q and R isoenzyme levels—was not associated with the illnesses. And the genotype (QQ, QR, or RR) was only marginally associated with them, as expected, because the level of the Q-type isoenzyme is a more important determinant of susceptibility to nerve agents than the genotype.

In another genetics study, Mackness and colleagues reported lower blood levels of total PON in ill British Gulf War veterans than in civilian controls in a previously published study; however, they did not measure the blood levels of the Q and R isoenzymes of PON, needed for a definitive study of Haley's hypothesis.[27] This finding could indicate that ill British Gulf War veterans represented a mixture of some with low Q-type PON and others with low R-type PON. In some veterans, the illness would be associated with exposure to nerve agents; in others, with exposure to pesticides. Alternatively, the difference in total PON levels may have resulted from differences in the assays or in the veterans, since (1) the enzyme assays in

[25]H. K. Kang and T. A. Bullman, *Mortality among U.S. Gulf War Veterans Who Were Potentially Exposed to Nerve Gas at Khamisiyah, Iraq* (Washington, DC: Department of Veterans Affairs, May 2002).

[26]R. W. Haley and others, "Association of Low PON1 Type Q (Type A) Arylesterase Activity with Neurologic Symptom Complexes in Gulf War Veterans," *Toxicology and Applied Pharmacology* 157 (1999): 227–33.

[27]B. Mackness and others, "Low Paraoxonase in Persian Gulf War Veterans Self-Reporting Gulf War Syndrome," *Biochemical and Biophysical Research Communications* 276 (2000): 729–33.

the controls were performed years before those for the ill veterans and (2) the controls were civilians studied in an entirely different setting.

In yet a third genetics study, Hotopf and colleagues reported results of tests for total PON levels in blood samples—obtained in a study by Unwin and colleagues—for four groups of British troops: (1) ill veterans of the Gulf War, (2) well veterans of the Gulf War, (3) ill nondeployed veterans of the Gulf War era, and (4) ill veterans of the Bosnian conflict.[28] The case definition of illness was a score below 72.2 on the SF-36 Physical Status questionnaire. Again, the researchers did not measure the levels of the Q and R isoenzymes of PON, making the findings difficult to interpret. The researchers found a low mean level of total PON in both ill and well groups deployed to the Gulf War and higher levels in the Gulf War era and ill Bosnian groups.

The depressing of the total PON level, the researchers suggested, might be the result of some deployment-related exposures. However, instead of looking at exposure to CW agents, the researchers investigated the possible effect of multiple immunizations on total PON levels and found no evidence for it. An alternative explanation is that total PON level in both ill and well deployed veterans was the result of misclassification of veterans by the case definition. A score of 72.2 on the SF-36 scale is not a very low score, particularly in ill Gulf War veterans, and it is a nonspecific measure of illness, given that a low score indicates illness from any cause.[29] Consequently, many veterans ill from causes unrelated to the war would be misclassified as cases of Gulf War illness and, conversely, many ill from the war but with less disability would be misclassified as controls. This conclusion is supported by a nonsignificant trend showing that ill veterans who had been deployed to the Gulf War had a lower median total PON level than well veterans who had also been deployed to the Gulf War.

The many flaws of design and methodology in both British studies of PON levels do not contribute to an understanding of the PON hypothesis and leave the finding of Haley and colleagues in need of better replication.

[28]See Matthew Hotopf and others, "Paraoxonase in Persian Gulf War Veterans," *Journal of Occupational and Environmental Medicine* 45 (2003): 668-75, and C. Unwin and others, "Health of UK Servicemen Who Served in the Persian Gulf War," *Lancet* 353 (1999): 169–78.

[29]R. W. Haley and others, "Severely Reduced Functional Status in Veterans Fitting a Case Definition of Gulf War Syndrome," *American Journal of Public Health* 92 (2002): 46–47.

Animal Studies

A series of laboratory studies with animals have established the biological plausibility that brain cell damage results from low-level exposure to sarin. Husain and colleagues demonstrated in two studies at the Division of Pharmacology and Toxicology at the Defense Research and Development Establishment in Gwalior, India, that repetitive administration of low-dose sarin (approximately 0.25 LD50) daily for 10 days caused delayed onset damage to neurons in the spinal cords and brains of mice exposed by inhalation and of hens exposed by subcutaneous injection.[30]

Privately funded studies by Abou-Donia and colleagues demonstrated that combinations of organophosphates and similar cholinesterase-inhibiting chemicals in hens produce greater neurotoxic effect on brain and nerve tissue than any of the agents alone.[31] Abou-Donia's subsequent work, funded by DOD, extended the findings to synergistic combinations involving sarin at moderate concentrations (0.5 LD50).[32] A similar study by Husain and Somani, also funded by DOD, on the delayed brain effects of low-dose sarin (0.05 LD50) in combination with pyridostigmine and exercise, confirmed these findings. In particular, it demonstrated that the neuronal damage from very low doses of sarin affected primarily the basal ganglia region of the brain (striatum).[33]

A study by Henderson and colleagues, with DOD funding, found that repeated inhalation exposure to low-level sarin at subsymptomatic doses

[30]K. Husain and others, "Delayed Neurotoxic Effect of Sarin in Mice after Repeated Inhalation Exposure," *Journal of Applied Toxicology* 13 (1993): 143–45, and "A Comparative Study of Delayed Neurotoxicity in Hens Following Repeated Administration of Organophosphorus Compounds," *Indian Journal of Physiology and Pharmacology* 39 (1995): 47–50.

[31]Mohamed B. Abou-Donia and others, "Neurotoxicity Resulting from Coexposure to Pyridostigmine Bromide, DEET, and Permethrin," *Journal of Toxicology and Environmental Health* 48 (1996): 35–56, and "Increased Neurotoxicity Following Concurrent Exposure to Pyridostigmine Bromide, DEET, and Chlorpyrifos," *Fundamentals of Applied Toxicology* 34 (1996): 201–22.

[32]Mohamed B. Abou-Donia and others, "Combined Exposure to Sarin and Pyridostigmine Bromide Increased Levels of Rat Urinary 3-Nitrotyrosine and 8-Hydroxy-2'-Deoxyguanosine, Biomarkers of Oxidative Stress," *Toxicology Letters* 123 (2001): 51–58; "Disruption of the Blood-Brain Barrier and Neuronal Cell Death in Cingulate Cortex, Dentate Gyrus, Thalamus, and Hypothalamus in a Rat Model of Gulf-War Syndrome," *Neurobiology of Disease* 10 (2002): 306–26; and "Sarin: Health Effects, Metabolism, and Methods of Analysis," *Food and Chemical Toxicology* 40 (2002): 1327–33.

[33]K. Husain and S. Somani, "Delayed Toxic Effects of Nerve Gas Sarin and Pyridostigmine under Physical Stress in Mice," *Journal of Burns and Surgical Wound Care* 2 (2003): 2–19.

(0.1 LCt50) for 5 or 10 days, with or without heat stress, produced no immediate effects.[34] But at 30 days after exposure to sarin, damage was produced to cholinergic receptors in several brain regions, including the basal ganglia. In the same study, Henderson and colleagues identified evidence of an autonomic nervous system injury affecting the function of T-cells in the immune system as well.[35] In addition, chronic abnormalities of neuronal metabolism in the basal ganglia have been implicated in ill Gulf War veterans by several investigators through the use of magnetic resonance spectroscopy.[36]

Two recent laboratory studies at the U.S. Army Medical Research Institute of Chemical Defense, Aberdeen Proving Ground, support the animal studies. Scremin and colleagues demonstrated that moderate doses of sarin (0.5 LD50) in combination with pyridostigmine bromide produced prolonged elevations in rats' cerebral blood flow but that neither agent alone had a prolonged effect on cerebral blood flow.[37] A companion study, by Roberson and colleagues, demonstrated that repeated administration of sarin to guinea pigs in doses of 0.2 or 0.4 LD50 produced no immediate ill effects on behavior, weight, body temperature, flinch threshold, or EEG brain wave activity. But at 100 days postdosing, abnormal brain function was found, indicating neurochemical or pathological brain cell changes that affect behavior.[38]

[34]R. F. Henderson and others, "Response of F344 Rats to Inhalation of Subclinical Levels of Sarin: Exploring Potential Causes of Gulf War Illness," *Journal of Toxicology and Industrial Health* 17 (2001): 294–97 and 18:1 (2002): 48.

[35]See Henderson and others, "Response of Rats to Low Levels of Sarin," and "Subclinical Doses of the Nerve Gas Sarin Impair T Cell Responses through the Autonomic Nervous System," *Journal of Toxicology and Applied Pharmacology* 184 (2002): 82–87.

[36]See R. W. Haley and others, "Brain Abnormalities in Gulf War Syndrome: Evaluation by ^{1}H Magnetic Resonance Spectroscopy," *Radiology* 215 (2000): 807–17, and "Effect of Basal Ganglia Injury on Central Dopamine Activity in Gulf War Syndrome: Correlation of Proton Magnetic Resonance Spectroscopy and Plasma Homovanillic Acid," *Archives of Neurology* 57 (2000): 1280–85, as well as D. J. Meyerhoff and others, "Reduced N-Acetylaspartate in the Right Basal Ganglia of Ill Gulf War Veterans by Magnetic Resonance Spectroscopy," *Proceedings of the International Society of Magnetic Resonance Medicine* 9 (2001): 994.

[37]O. U. Scremin and others, "Effects of Chronic Exposure to Low Levels of Cholinesterase Inhibitors on Cerebral Blood Flow," paper for the Society for Neuroscience Meeting, Orlando, Florida, 2002.

[38]Melinda Roberson and others, "Depression of Cholinesterase Activity by Low-Dose Sarin Exposure May Lead to Persistent Changes That Influence Behavior," Society for Neuroscience, Washington, D.C., Program no. 205.3 (Abstract, 2002).

Conclusions

In evaluating the plume models used, the results from the DOD and CIA modeling can never be definitive. Plume models can allow only estimates of what happens when chemical warfare agents are released in the environment. Such estimates are based on mathematical equations, which are used to predict an actual event—in this case, the direction and extent of the plume. However, in order to predict precisely what happens, one needs to have accurate data on relative to both source term and meteorological conditions. DOD had neither of these.

Given the unreliability of the input data, the lack of individual troop location information, and the widely divergent results of the simulations conducted based on varying models, DOD's analyses cannot adequately estimate the extent of U.S. troops' exposure to chemical warfare agents and other related releases. In particular, the models selected were not fully developed for projecting long-range environmental fallout, and the assumptions used to provide the source term data were inaccurate or flawed. Even when models with the same source term data were used, the results diverged. In addition, the models did not include many potential exposure events and exposures to some key materials—for example, binary chemical weapons, mustard agent combustion by-products, and chemical warfare agent precursor materials. It is likely that if models were more fully developed and more credible data for source term and meteorological conditions were included in them, particularly with respect to plume height as well as level and duration of exposure, the hazard area would be much larger and most likely would cover most of the areas where U.S. troops and Coalition forces were deployed. However, given the lack of verifiable data for analyses, it is unlikely that any further modeling efforts would be more accurate or helpful.

The results of DOD's modeling efforts were, nonetheless, used in epidemiological studies to determine the troops' chemical warfare agent exposure classification—i.e., exposed versus nonexposed. As we noted in 1997, to ascertain the causes of veterans' illnesses, it is imperative that investigators have valid and reliable data on exposure, especially for low-level or intermittent exposures to chemical warfare agents.[39] To the extent that veterans are misclassified as to exposure, relationships will be obscured and conclusions misleading. In addition, DOD combined the

[39]U.S. General Accounting Office, *Gulf War Illnesses: Improved Monitoring of Clinical Progress and Reexamination of Research Emphasis Are Needed*, GAO/NSIAD-97-163 (Washington, D.C.: June 23, 1997).

results of individual models that showed smaller plume size and ignored the results of the LLNL which showed much larger plume size and divergent plume path. Given the uncertainties in source term data and divergences in model results, DOD cannot determine or estimate—with any degree of certainty—the size and path of the plumes or who was or who was not exposed.

Recommendations for Executive Action

In our report, we are recommending that the Secretary of Defense and the Secretary of Veterans Affairs not use the plume-modeling data for future epidemiological studies of the 1991 Gulf War, since VA and DOD cannot know from the flawed plume modeling who was and who was not exposed.

We are also recommending that the Secretary of Defense require no further plume-modeling of Khamisiyah and the other sites bombed during the 1991 Persian Gulf War in order to determine troops' exposure. Given the uncertainties in the source term and meteorological data, additional modeling of the various sites bombed would most likely result in additional cost, while still not providing DOD with any definitive data on estimating who was or was not exposed.

We obtained comments on a draft of this report from VA, DOD, and CIA. VA concurred with the recommendation that VA and DOD not use the plume-modeling data for future epidemiological studies, since VA and DOD cannot know from the flawed plume modeling who was and who was not exposed. DOD did not concur with the recommendation, indicating that to them it called for a blanket prohibition of plume modeling in the future, where the limitations of the 1991 Gulf War may not apply. The intent of our recommendation is only directed at epidemiological studies involving the DOD and CIA plume modeling data from the 1991 Gulf War and not a blanket prohibition of plume modeling in the future. We have clarified the recommendation along these lines. DOD concurred with our second recommendation, indicating that despite enhancements in the models, uncertainties will remain. CIA did not concur with our report, indicating that it could not complete its review in the time allotted.

If you or your staff have any questions about this testimony or would like additional information, please contact me at (202) 512-6412 or Sushil Sharma, Ph.D., Dr.PH., at (202) 512-3460. We can also be reached by e-mail at rhodesk@gao.gov and sharmas@gao.gov. Individuals who made key contributions to this testimony were Venkareddy Chennareddy, Susan Conlon, Neil Doherty, Jason Fong, Penny Pickett, Laurel Rabin, and Katherine Raheb. James J. Tuite III, a GAO consultant, provided technical expertise.

Keith Rhodes, Chief Technologist
Center for Technology and Engineering
Applied Research and Methods

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