FOLLOWING TOXIC CLOUDS: SCIENCE AND ASSUMPTIONS IN PLUME MODELING

HEARING

BEFORE THE

SUBCOMMITTEE ON NATIONAL SECURITY, EMERGING THREATS AND INTERNATIONAL RELATIONS

OF THE

COMMITTEE ON GOVERNMENT REFORM

HOUSE OF REPRESENTATIVES

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FOLLOWING TOXIC CLOUDS: SCIENCE AND ASSUMPTIONS IN PLUME MODELING

MONDAY, JUNE 2, 2003

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON NATIONAL SECURITY, EMERGING THREATS AND INTERNATIONAL RELATIONS,
COMMITTEE ON GOVERNMENT REFORM,
Washington, DC.

The subcommittee met, pursuant to notice, at 1 p.m., in room 2154, Rayburn House Office Building, Hon. Christopher Shays (chairman of the subcommittee) presiding.

Present: Representatives Shays, and Turner.

Staff present: Lawrence Halloran, staff director and counsel; Kristine McElroy, professional staff member; Robert A. Briggs, clerk; David Rapallo, minority counsel; and Jean Gosa, minority assistant clerk.

Mr. SHAYS. A quorum being present, the Subcommittee on National Security, Emerging Threats and International Relations' hearing entitled, "Following Toxic Clouds, Science and Assumptions in Plume Modeling," is called to order.

What is the difference between an estimate and a guess? When plotting the path of a chemical, biological or radiological plume, the difference between a reasonable approximation and an unwarranted assumption can mean life or death.

For U.S. troops on foreign battlefields, and for civilians here at home, the science of dispersion modeling lies at the heart of current efforts to prepare for, respond to, and recover from toxic attacks. From the trenches of World War I, through last months TOPOFF2 Exercise, military planners and homeland security officials have been attempting to refine the data and calculations needed to map the trajectory of noxious clouds.

But, the variability of modeling techniques and the paucity of real-time data on weather patterns and weapon potency still makes projections too slow and limited to be relied upon for many critical decisions.

Past attempts to model plume courses and concentrations yield important lessons and warnings. In 1996, this subcommittee heard persuasive testimony that coalition bombing of Iraqi chemical weapons facilities during the first Gulf war launched plumes that traversed large portions of the combat theater.

Analysis of infrared satellite imagery and available weather data suggested broad dispersion patterns that would account for chemical agent detections at the time, detections once discounted but later deemed credible by the Department of Defense [DOD].

But subsequent modeling of U.S. demolition of chemical weapons at Khamisiyah in Iraq conducted by DOD and the Central Intelligence Agency [CIA], between 1996 and 2000, produced varied yet uniformly narrower zones of risk than seemed plausible.

So we asked the General Accounting Office [GAO], to review the Khamisiyah plume models and report on the implications of that process for Gulf war veterans and for all of those who might find themselves in the path of poisonous plumes at home or abroad in the future.

The GAO findings highlight the dangers of reaching conclusions when critical data elements remain speculative or incomplete. According to GAO, DOD lacked essential information on the quantity and physical characteristics of the agents dispersed.

Climate data was deficient. Arbitrary limits were placed on estimated plume altitudes, serious skewing downrange projections. DOD combined several in-house systems rather than select one validated modeling approach in the apparent hope that cumulative strengths would outweigh combined weaknesses. But, at some point, even that attempt, to err on the side of caution, produced more error than caution.

Drawing cohorts based on flawed DOD modeling, epidemiological studies comparing exposed and unexposed veterans may be invalid.

Once again, the benefit of any doubts about the extent of exposure risks has not gone to veterans, who now must bear the burden of proving themselves wrongly categorized by speculative Pentagon plume mapping.

The same dangers and more confront dispersion modeling applications to meet homeland security requirements. Numerous special purpose models can produce very different outcomes using the same data.

More vexing, very little data on wind and weather patterns has been captured in urban settings, the most inviting landscape for a terrorist attack. In the cold war, global and national security demanded the ability to plot the trajectory of ballistic missiles.

In the war against weapons of mass destruction, we need to be able to predict the path of toxic clouds across new battlefields abroad and here at home.

Today we examine efforts, past and present, to advance the science and perfect the art of plume modeling. Our panel of witnesses brings very impressive credentials and expertise to this discussion of a critical force projection and homeland security tool.

We welcome them and we look forward to their testimony.

[The prepared statement of Hon. Christopher Shays follows:]

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Congress of the United States

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Statement of Rep. Christopher Shays
June 2, 2003

What's the difference between an estimate and a guess?

When plotting the path of a chemical, biological or radiological plume, the difference between a reasonable approximation and an unwarranted assumption can mean life or death. For U.S. troops on foreign battlefields, and for civilians here at home, the science of dispersion modeling lies at the heart of current efforts to prepare for, respond to and recover from toxic attacks.

From the trenches of World War I through last month's TOPOFF2 exercise, military planners and homeland security officials have been attempting to refine the data and calculations needed to map the trajectory of noxious clouds. But the variability of modeling techniques, and the paucity of real-time data on weather patterns and weapon potency, still make projections too slow and limited to be relied upon for many critical decisions.

Past attempts to model plume courses and concentrations yield important lessons, and warnings.

In 1996, this Subcommittee heard persuasive testimony that Coalition bombing of Iraqi chemical weapons facilities during the first Gulf War launched plumes that traversed large portions of the combat theater. Analysis of infrared satellite imagery and available weather data suggested broad dispersion patterns that would account for chemical agent detections at the time – detections once discounted but later deemed "credible" by the Department of Defense (DOD).

But subsequent modeling of U.S. demolition of chemical weapons at Khamisiyah in Iraq, conducted by DOD and the Central Intelligence Agency (CIA) between 1996 and 2000, produced varied yet uniformly narrower zones of risk than seemed plausible. So we asked the General Accounting Office (GAO) to review the Khamisiyah plume models and report on the implications of that process for Gulf War veterans and for all those who might find themselves in the path of poisonous plumes at home or abroad.

The GAO findings highlight the dangers of reaching conclusions when critical data elements remain speculative or incomplete: DOD lacked essential information on the quantity and physical characteristics of the agents dispersed. Climate data was deficient. Arbitrary limits were placed on estimated plume altitudes, seriously skewing downrange projections. DOD combined several in-house systems, rather than select one validated modeling approach, in the apparent hope cumulative strengths would outweigh combined weaknesses. But at some point, even that attempt to err on the side of caution produced more error than caution.

Drawing cohorts based on flawed DOD modeling, epidemiological studies comparing "exposed" and "unexposed" veterans may be invalid. Once again, the benefit of any doubts about the extent of exposure risk has not gone to veterans, who now must bear the burden of proving themselves wrongly categorized by speculative Pentagon plume mapping.

The same dangers, and more, confront dispersion modeling applications to meet homeland security requirements. Numerous special-purpose models can produce very different outcomes using the same data. More vexing, very little data on wind and weather patterns has been captured in urban settings, the most inviting landscape for a terrorist attack.

In the Cold War, global and national security demanded the ability to plot the trajectory of ballistic missiles. In the war against weapons of mass destruction, we need to be able to predict the path of toxic clouds across new battlefields abroad and here at home. Today we examine efforts, past and present, to advance the science and perfect the art of plume modeling.

Our panel of witnesses brings impressive credentials and expertise to this discussion of a critical force protection and homeland security tool. We welcome them and look forward to their testimony.

Mr. SHAYS. At this time, the Chair would be happy to recognize Mr. Turner, the vice chairman of the subcommittee.

Mr. TURNER. Thank you, Mr. Chairman.

I want to thank our witnesses and our chairman for having this important hearing.

Plume modeling clearly has the potential for great usefulness in both issues of evacuation and first responders to terrorist attacks or industrial accidents. However, decisionmaking on current plume modeling may be premature.

Another issue that I think needs to be addressed, I am looking forward to testimony today, on how plume modeling, once perfected, can be communicated to first responders through Federal, State and local governments so that it may be useful when an incident may be facing them. Thank you.

Mr. SHAYS. Thank the gentleman. At this time, we will recognize our witnesses, and then swear them in and then begin the testimony.

Our witnesses, beginning, and this is the order in which you will testify as well.

Mr. Keith Rhodes, Chief Technologist, General Accounting Office; Dr. Anna Johnson-Winegar, Deputy Assistant to the Secretary of Defense for Chemical, Biological Defense Programs, Department of Defense; Dr. Donald L. Ermak, the program leader, National Atmospheric Release Advisory Center, Lawrence Livermore Laboratory. Mr. Bruce Hicks, Director, Air Resources Laboratory, National Oceanic and Atmospheric Administration; Dr. Eric Barron, Chair, Board on Atmospheric Sciences and Climate, National Research Council; and Dr. Steven R. Hanna, Adjunct Associate Professor of Harvard School of Public Health.

If you would rise. And if there is anyone—is there anyone, Dr. Winegar, you more than others, that someone might testify. Or if so, if anyone else is accompanying you that might participate, I would prefer they stand up, even if they aren't ultimately called, so we don't have to swear them in twice.

So if you would rise and raise your right hands please.

[Witnesses sworn.]

Mr. SHAYS. Note for the record, all of our witnesses have responded in the affirmative. I am going to ask Mr. Turner to take over. Mr. Rhodes, you will begin. May I just say, I am sorry, let me just make this point. We have 5 minutes. We have six panelists.

We roll over. And you can take the other full 5 minutes, but we would prefer that the rollover, that you don't go too much further into that 5 minutes. I start to get a little nervous around 7 or 8 minutes. What we are finding is all of our witnesses are now spending 10 minutes. So that would be what I would hope would happen.

STATEMENTS OF KEITH RHODES, CHIEF TECHNOLOGIST, GENERAL ACCOUNTING OFFICE; ANNA JOHNSON-WINEGAR, DEPUTY ASSISTANT TO THE SECRETARY OF DEFENSE FOR CHEMICAL, BIOLOGICAL DEFENSE PROGRAMS; DONALD L. ERMAK, PROGRAM LEADER, NATIONAL ATMOSPHERIC RELEASE ADVISORY CENTER, LAWRENCE LIVERMORE LABORATORY; BRUCE HICKS, DIRECTOR, AIR RESOURCES LABORATORY, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION; ERIC BARRON, CHAIR, BOARD ON ATMOSPHERIC SCIENCES AND CLIMATE, NATIONAL RESEARCH COUNCIL; AND STEVEN R. HANNA, ADJUNCT ASSOCIATE PROFESSOR OF HARVARD SCHOOL OF PUBLIC HEALTH

Mr. RHODES. Yes, sir. Mr. Chairman, members of the subcommittee, I am Keith Rhodes, GAO's Chief Technologist and the Director of GAO's Center for Technology and Engineering.

Although they are not with me at the table, I would like to acknowledge the study members, Jason Fong, Sushil Sharma, and James Tuitte.

I am pleased to be here today to present our preliminary assessment of the plume modeling conducted by the Defense Department, and the Central Intelligence Agency, to determine the number of U.S. troops that might have been exposed to the release of chemical warfare agents during the first Gulf war of 1990.

We will be reporting the final results of this study at a later date. As you know, many of the approximately 700,000 veterans of the first Gulf war have undiagnosed illnesses since the war's end in 1991.

Some fear they are suffering from chronic disabling conditions because of wartime exposure to vaccines, as well as chemical warfare agents, pesticides, and other hazardous substances with known or suspected adverse health effects.

Available bomb damage assessments during the war showed that of the 21 sites bombed in Iraq characterized by intelligence agencies as nuclear, biological or chemical facilities, 16 had been destroyed by bombing. Some of these sites were near the areas where U.S. troops were located.

When the issue of the possible exposure of troops to low levels of chemical warfare agents was first raised during the summer of 1993, the DOD and the CIA concluded that no U.S. troops were exposed, because, No. 1, there were no forward-deployed chemical warfare agent munitions; and No. 2, the clouds of chemical warfare agents or plumes from the bombing that destroyed the chemical facilities could not have reached the troops.

DOD and CIA maintained this position until 1996 when it became known that U.S. troops destroyed a stockpile of chemical munitions after the first Gulf war in 1991, at a forward deployed site, Khamisiyah in Iraq. This discovery prompted several modeling efforts from 1996 through 2000 by DOD and CIA, to estimate the number of troops that might have been potentially exposed to chemical warfare agents.

This modeling included field testing and modeling of bombing sites, as well as the number of U.S. troops exposed to the plume. The Department of Energy's Lawrence Livermore National Laboratory was also asked to conduct modeling.

DOD and CIA created a composite of their own individual models and conducted additional plume modeling of the bombing sites at Al Muthanna, Muhammadiyat, and Ukhaydir.

In addition, DOD used these models as the basis for their epidemiological studies regarding incidents of Gulf War Syndrome among U.S. troops returning from the first Gulf war. The dispersion of chemical agents was used to define the groups of people to be studied, those in theatre who were possibly exposed to chemical warfare agents, and those in theatre who were not.

We disagree with the DOD and CIA conclusions for the following reasons: All modeling is limited. Models are not reality. They are, at best, an approximation of what will happen, or what did happen during a specific event. The validity of the model is a function of the data that forms the basis for the model.

Thus, if you put garbage into it, you get garbage out of it. Thus, weak data inputs yield weak models, and from them weak analysis and conclusions. The DOD-CIA modeling efforts were weak in many ways: No. 1, meteorological data was incomplete and limited. For example, both the temperature at varying altitudes and over time was not complete; No. 2, the source term data, the data that defines how things reacted during the event and their potency were unknown and not reconstructed properly during field testing. For example, the purity of the agent was based on an UNSCOM report and was not consistent for all of the sites in question.

One site had an agent purity estimated as high as 50 percent, while another had a purity of only 15 percent, even through both sites were estimated to have the same agent which was manufactured at the same time.

This limitation can be seen in that even though the same inputs were used for several model runs, the outputs differed significantly.

Plume height—No 3. Plume height was arbitrarily selected to 10 meters, whereas independent field testing demonstrated that a single 1,000 pound bomb would create plume height in excess of 400 meters above the ground.

No. 4, post-war field testing done at Dugway Proving Ground did not realistically simulate the actual conditions of bombings at any of the sites. The composite model that DOD and CIA made based on their earlier analyses, produced one pattern which removed the differences from the varying models, thus giving a much smaller range of differences between the possible plumes.

The modeling and analysis executed by Livermore was discounted since it differed from the DOD and CIA analysis. Livermore did not agree for one main reason; they recognized that an atmospheric disturbance called a diffluence existed at the time of the demolition. This diffluence showed that the plume could have moved either to the north or south, or both to the north and south.

As you can see on the story board here, the green area is the DOD composite model. The yellow and light yellow areas are the Livermore model. As you can see, because of that diffluence that went directly through the center of Khamisiyah, the Livermore model shows a wider range of dispersion than what the DOD models show.

The problem is, there is no way of knowing exactly which one of these plumes is correct, or that both of them are correct, that the intersection of both of these models is correct, and therefore a much larger area was covered.

Given these uncertainties in the modeling data, we conclude that: DOD cannot know who was and who was not exposed to any level of useful accuracy, since the method, model and data of the analysis are flawed, which calls into question DOD's conclusions based upon subsequent epidemiological studies, that those who were exposed had no higher rates of illnesses than those who were not exposed.

Also, given the weaknesses in the data available for any further analysis, any further modeling efforts on this issue would not be any more accurate or helpful. We, therefore, recommend that the Congress direct the Secretary of Veterans Affairs to alter the assumptions regarding the Gulf War Syndrome to presume exposure, since many more veterans could possibly have been exposed than first estimated.

Mr. Chairman, this concludes my statement. I will be happy to answer any questions you or members of the subcommittee may have.

Mr. TURNER [presiding]. Thank you, Mr. Rhodes.

[The prepared statement of Mr. Rhodes follows:]

United States General Accounting Office

GAO

Testimony
Before the House Subcommittee on National Security, Emerging Threats, and International Relations, Committee on Government Reform

For Release on Delivery
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Monday, June 2, 2003

GULF WAR ILLNESSES

Preliminary Assessment of DOD Plume Modeling for U.S. Troops' Exposure to Chemical Agents

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

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GAO-03-833T

United States General Accounting Office June 2003

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Highlights

GULF WAR ILLNESSES
Preliminary Assessment of DOD Plume Modeling for U.S. Troops' Exposure to Chemical Agents

Highlights of GAO-03-833T, a testimony before the House Subcommittee on National Security, Emerging Threats, and International Relations, Committee on Government Reform

Why GAO Did This Study

Of the approximately 700,000 veterans of the Persian Gulf War, many have undiagnosed illnesses. The Department of Defense (DOD) and the Central Intelligence Agency (CIA) have concluded, using computer plume modeling, that no U.S. troops were exposed to hazardous substances because plumes—clouds of chemical warfare agents—could not have reached the troops. GAO was asked to assess DOD and CIA plume modeling to determine whether DOD's conclusions could be supported. GAO's final assessment will be reported at a later date.

What GAO Found

DOD's conclusion as to the extent of U.S. troops' exposure is highly questionable because DOD and CIA plume modeling results are not reliable. In general, modeling is never precise enough to draw definitive conclusions, and DOD did not have accurate information on source term (such as the quantity and purity—concentration—of the agent) and meteorological conditions (such as the wind and weather patterns), essential to valid modeling. In particular, the models DOD selected were not fully developed and validated for long-range environmental fallout; the source term assumptions were not accurate; the plume height was underestimated; the modeling only considered the effects on health of a single bombing; field-testing at Dugway Proving Ground did not realistically simulate the actual bombing conditions; and divergence in results among models.

DOD's conclusion, based on the findings of epidemiological studies–that there was no significant difference between rates of illness for exposed versus not exposed troops–is not valid. In the epidemiological studies, the results of DOD's flawed modeling served as a key criterion for determining the exposure classification—exposed versus not exposed to chemical agents—of the troops. Such misclassification is a serious problem that can have two types of effects: First, if misclassification affects both comparison groups equally (nondifferential classification–equally in the exposed and unexposed groups), it may water down the results so that important associations are missed. Second, if misclassification affects one group more than the other (differential misclassification), it may introduce bias that obscures important associations or creates false associations. Consequently, the misclassification in the studies resulted in confounding—that is, distorting—the results, making the conclusion invalid.

The full testimony, including GAO's objectives, scope, methodology, and analysis is available at www.gao.gov/cgi-bin/getrpt?GAO-03-833T. For additional information about the testimony, contact Keith Rhodes (202) 512-6412 or rhodesk@gao.gov.

June 2, 2003

Mr. Chairman and Members of the Subcommittee:

We are pleased to be here today to present our preliminary assessment of the plume modeling conducted by DOD and 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 will report the final results of this study at a later date.

As you know, many of the approximately 700,000 veterans of the Persian Gulf War have 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. Available bomb damage assessments during the war showed that of the 21 sites bombed in Iraq—categorized by intelligence agencies as nuclear, biological, or chemical facilities—16 had been destroyed by bombing. Some of these sites were near the areas where U.S. troops were located.

When the issue of the possible exposure of troops to low levels of chemical warfare agents was first raised, during the summer of 1993, the Department of Defense (DOD) and the Central Intelligence Agency (CIA) concluded that no U.S. troops were exposed because (1) there were no forward-deployed chemical warfare agent munitions and (2) plumes—clouds of chemical warfare agents—from the bombing that destroyed the chemical facilities could not have reached the troops.

This position was maintained until 1996, when it became known that U.S. troops destroyed a stockpile of chemical munitions after the Gulf War in 1991, at a forward-deployed site, Khamisiyah, in Iraq. Consequently, DOD and the CIA made several modeling efforts to estimate the number of troops that might have been potentially exposed to chemical warfare agents. But recognizing that actual data on the source term—such as the quantity and the purity (concentration) of the agent—and meteorological conditions—such as the wind and the weather patterns—were not available,[1] DOD and CIA conducted field-testing and modeling of bombing sites at Khamisiyah, in 1996 and 1997, to determine the size and path of the plume, as well as the number of U.S. troops exposed to the plume. During these initial modeling efforts, DOD asked the Department of Energy's Lawrence Livermore National Laboratories (LLNL) to also conduct modeling. In 1997, DOD and CIA also combined a number of their own individual modeling efforts into a composite and conducted additional plume modeling of the bombing sites at Al Muthanna, Muhammadiyat, and Ukhaydir. Subsequently, in 2000, DOD revised its modeling of Khamisiyah.

[1] 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.

In our testimony today, at your request, my remarks will focus on our preliminary findings of DOD and CIA plume modeling during the Gulf War. Specifically, I will address the validity of the following DOD conclusions:

- based on DOD plume modeling efforts, that the extent to which U.S. troops were exposed was minimal and
- based on findings of government-funded epidemiological studies, that there was no significant difference as to the rate of illness between troops that were exposed to chemical warfare agents versus those not exposed.

Our work thus far has involved interviews with agency officials and experts in this area, reviews of relevant documents and literature, and a review of DOD's methodology and analyses of plume modeling. Our work has been performed in accordance with generally accepted government auditing standards.

Summary

DOD's conclusion as to the extent of U.S. troops' exposure—based on DOD and CIA plume modeling—is highly questionable because the results of the modeling are unreliable. In general, modeling is never precise enough to draw definitive conclusions, and DOD did not have accurate information on source term and meteorological conditions.

We have several reasons for this assessment: First, DOD selected models that were not fully developed and validated for modeling long-range environmental fallout. Second, some of the assumptions regarding the source term data used in the modeling were not accurate—based on incomplete information, data that were not validated, and testing that did not realistically simulate the actual conditions at Khamisiyah. For example, the CIA calculated the agent purity in 1991 to be 50 percent at Khamisiyah, but 18 percent at Al Muthanna and about 15 percent at Muhammadiyat. The CIA did not independently validate or establish agent purity levels based on empirically driven analyses, and relied on UNSCOM reporting for these rates. This assessment of the agent purity rate at Al Muthanna was questioned by a DOD official. We plan to examine the validity of the methodology used to calculated the rate of degradation.

Third, the plume height was underestimated, which resulted in discounting the impact of certain meteorological conditions, such as high-speed winds at nighttime, when many of the bombings occurred. This would have a dramatic effect on the distance the chemical agent traveled. Moreover, according to an internal DOD memo, plume height in one case at Al Muthanna was arbitrarily determined by a DOD official to be 10 meters. At Muhammadiyat and Ukhaydir, plume heights were estimated to be the height of the munition or the munition stack. However, independent field-testing demonstrated that a single 1,000-pound bomb would create plume height in excess of 400 meters above the ground. Fourth, DOD, in its modeling, only considered the effect of a single bombing of the sites on the health of the U.S. troops. But DOD did not take into account the cumulative effects of repeated bombings of the sites on troops' health. Fifth, post-war field-testing done at Dugway Proving Ground, to estimate the source term data and plume height, did not realistically simulate the actual conditions of bombings at any of the sites. The simulation occurred under conditions that were not comparable to those that existed at Khamisiyah. For example, there were differing seasonal and meteorological conditions, differences in rocket construction, and lesser quantities of rockets. These differences result in multi-variable uncertainty that cannot be resolved. Finally, there was a great divergence among the various models DOD selected with regard to the size and path of the plume and the extent to which troops were exposed. Combining the results of various models masked the highly divergent predictions among the individual models regarding the size and path of the plume. The results of LLNL model which showed the largest area of coverage were disregarded and not included in the composite model.

DOD's conclusion that there were no significant differences in the rate of illness between exposed and non-exposed troops is questionnable. DOD based this conclusion on the findings of epidemiological studies, in which DOD modeling was flawed. In addition, the modeling results served as a key criterion for classifying troops that were ill and had been exposed compared with troops that were ill and determined not to have been exposed. However, the troops classified as non-exposed might have been exposed. Such misclassification is a serious problem that can have two types of effects. First, if misclassification affects both comparison groups equally (non-differential classification—equally in the exposed and unexposed groups), it may water down the results so that important associations are missed. Second, if misclassification affects one group more than the other (differential misclassification), it may introduce bias that obscures important associations or creates false associations. Consequently, the misclassification in the studies resulted in confounding—that is, distorting—the results.

Background

In March 1991, after the conclusion of the Gulf War, U.S. Army demolition units destroyed munitions at the Khamisiyah storage site—which included a bunker and an open pit—in southeastern Iraq. Later, through inspections conducted by the United Nations Special Commission (UNSCOM) in Iraq, it was discovered that hundreds of 122-millimeter rockets destroyed at Khamisiyah contained the nerve agents sarin and cyclosarin. U.S. and coalition forces also bombed many other known or suspected Iraqi chemical warfare research, materiel, storage, and production sites. According to DOD and the CIA, coalition air strikes resulted in damage to filled chemical munitions at only two facilities in central Iraq, Al Muthanna bunker 2 and Muhammadiyat, and at the Ukhaydir ammunition storage depot in southern Iraq. At Muhammadiyat, munitions containing an estimated 2.9 metric tons of sarin and cyclosarin and 15 metric tons of the chemical agent mustard were damaged during the air strikes. At Al Muthanna, munitions containing an estimated 17 metric tons of sarin and cyclosarin were damaged during the air strikes.

According to DOD, the U.S. Government did not immediately make the connection between the chemical munitions found by UNSCOM at Khamisiyah and U.S. demolition bombings there. However, in 1996, concerns raised by the Presidential Advisory Committee on Gulf War Illnesses prompted the CIA to examine this issue.[2] The CIA contracted with the Science Applications International Corporation (SAIC) to conduct the initial analysis and modeling of the bombing of chemical munitions in Khamisiyah bunker 73. The CIA's first report, published in August 1996, modeled the potential release of agents from bunker 73. The CIA and DOD jointly published a second report in September 1997. In this report, they combined the results of five different dispersions (for example, the size and path of the plume) and meteorological models to determine the extent of the plume from bombing of chemical munitions in Khamisiyah. In 2000, DOD published the results of a new modeling of the Khamisiyah site, using updated CIA source assessments and revising the hazard area.

[2] The Presidential Advisory Committee on Gulf War Veterans' Illnesses was a panel established in August 1995 to provide oversight to Gulf War illnesses investigations.

Information Needed for Modeling the Effects of Chemical Warfare Agents

In chemical plume modeling, simulations are produced that recreate or predict the size and path of the plume, including the potential hazard area, and the potential effect on the health of the exposed population. Modeling requires accurate information on

- source term characteristics, properties (for example, vapor pressure, flash point, size of particles, persistency, and toxicity information), and rate of the agent release;
- temporal characteristics of the period of release (for example, whether the initial release of chemical agent occurred during daylight hours when it might rapidly disperse into the surface air or at night when differing dispersion patterns would exist depending on terrain and the height of the release);
- accurate collection of data that drive the meteorological models, such as temperature, humidity, barometric pressure, dew point, wind velocity and direction at varying altitudes, and other related measurements of weather conditions during the modeled period;
- data from global weather models to simulate large-scale weather patterns and from regional and localized weather models to simulate the weather in the area of the chemical agent release and throughout the area of dispersion; and
- information regarding the location of potentially exposed populations, animals, crops or other assets that may be affected by releases of the agent.

Types of Models Used

The modeling of various chemical agent releases during the 1991 Persian Gulf War included global-scale 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 used included the Coupled Ocean-Atmosphere Mesoscale Prediction System (COAMPS), the Operational Multiscale Environment Model with Grid Adaptivity (OMEGA), and the Mesoscale Model Version 5 (MM5).

Transport and diffusion models (often simply called dispersion models) were also used. They project both the path of the chemical agents after release and the degree of hazard posed by the agents. For example, the modeling of various releases during the 1991 Gulf War included dispersion models, such as the Second-order Closure Integrated Puff (SCIPUFF) model along with its Hazard Prediction and Assessment Capability (HPAC) component; the Vapor, Liquid, and Solid Tracking (VLSTRACK) model; the Non-Uniform Simple Surface Evaporation Model (NUSSE); and the Atmospheric Dispersion by Particle-in-Cell (ADPIC) model.

DOD's Conclusions Regarding the Extent of Exposure of U.S. Troops Are Highly Questionable

DOD's conclusion as to the extent of U.S. troops' exposure—based on DOD and CIA plume modeling—is highly questionable because the results of the modeling are unreliable. The modeling conducted was not precise enough to draw definitive conclusions regarding the size and path of the plume. We found six reasons to question the conclusions: First, the models selected were not fully developed and validated. Second, the assumptions regarding the source term used in the modeling were not accurate. Third, the plume height was underestimated. Fourth, DOD modeling only considered the effects of a single bomb on health. Fifth, post-war field testing done at Dugway Proving Ground did not realistically simulate the actual conditions of bombing at any site. And, finally, there was a great divergence among the various models DOD selected with regard to the size and path of the plume.

The Models Selected Were Not Fully Developed and Validated

DOD and CIA officials selected in-house models for use in plume modeling (see appendix 1). In the case of Khamisiyah and other sites, DOD models—such as the VLSTRACK and HPAC/SCIPUFF dispersion models—were not fully developed and validated for environmental fallout at the time of their selection. In particular, these models were not appropriate for long-range tracking of chemical agents.

VLSTRACK was developed primarily as a tactical decision aid for predicting hazards resulting from the release of chemical and biological agents in a military environment. Modeling experts at the Naval Surface Center told us that the two-month DOD panel reanalysis and modeling was a developmental effort because existing models did not have the capability to perform the required projections. Considerations of potential illness from low-level exposure to chemical agents resulting from nerve and blister agents accidentally released in Iraq required extensive extensions and modifications to some of the methodology in VLSTRACK.

HPAC was developed jointly by the Defense Intelligence Agency and the then Defense Special Weapons Agency (now known as DTRA) and was specifically tailored to do counterproliferation contingency planning. In a 1998 scientific review and evaluation of SCIPUFF, which is an integral part of HPAC, the National Oceanic and Atmospheric Administration's (NOAA's) Air Resources Laboratory stated that SCIPUFF is probably better suited for short-range (about 10 kilometers) dispersion applications rather than for long-range transport modeling. Among the limitations cautioned regarding the use of the HPAC model are that does not provide a definitive answer due to uncertainties about transport, location, and weather.

In addition, based on the DOD modeling effort, it is evident that a group using the VLSTRACK model might receive a significantly different prediction from that of a group using the HPAC model. And neither of these models has sufficient fidelity—that is, reliability—to permit the conclusion that the actual hazard area—that is, path of the plume—is confined to the predicted hazard area. In a September 1998 memo, the Deputy to the Secretary of Defense for Counterproliferation and Chemical/Biological Defense cited a DOD panel study team, which found that the VLSTRACK and HPAC models generate hazard predictions that are significantly different from each other. The memo noted, "This occurred even when the source terms and weather inputs are as simple and as identical as possible. In operational deployment, the average model user could obtain different answers for the same threat."

With regard to meteorological models, according to a 1997 memo from the Director of NOAA's Air Resources Laboratory to DOD, the selection of models was dominated by in-house, that is, DOD, models that were not well known outside of DOD. The Director noted that there were three mainstream mesoscale models available and well accepted for deriving site-specific flow conditions from large-scale meteorological information: MM5, RAMS, and Eta. At that time, OMEGA and COAMPS were too new and not well accepted outside of DOD circles. OMEGA was still under development, and a Peer Review Panel on the 1997 Khamisiyah modeling reported that there were major problems with the OMEGA model. For example, there were physically impossible aspects to the OMEGA model solutions and major errors in its simulations. For the analysis done for Khamisiyah and Al Muthanna, a DOD technical review panel found that

OMEGA consistently under-predicted surface wind speeds by a factor of 2 to 3 when compared with actual observations collected at five World Meteorological stations in the area.

The Source Term Assumptions Were Not Accurate

There were significant uncertainties in the source term used in the plume modeling at Khamisiyah. DOD and the CIA made assumptions about the source term based on field-testing, intelligence information, imagery, UNSCOM inspections, and Iraqi declarations to UNSCOM. However, these assumptions were based on incomplete information, data that were not validated, and testing that did not realistically simulate the actual conditions at Khamisiyah.

In its initial modeling of the demolition of chemical munitions at Khamisiyah, the CIA did not have accurate and precise information as to how rockets with chemical warheads would be affected by open pit demolition, compared with bunker demolition. This lack of information included the number of rockets, agent purity, and amount of agent released in the atmosphere, agent reaction in an open-pit demolition, and prevailing meteorological conditions. A DOD panel also found a lack of information,[3] that is, substantial uncertainties regarding the number of damaged rockets that might have released chemical agents and how fast the nerve agents—

[3] DOD had asked the Institute of Defense Analyses to set up a DOD-funded panel to review the modeling.

sarin and cyclosarin, which were mixed together in the rockets—were released. Some of these agents may have leaked from rockets into the soil or into the wood of the boxes that contained the rockets and evaporated over time. The panel also found that the CIA and SAIC analyses used what were essentially guesses for the lack of data. For example, the numbers of rockets were based on what was known to be there before the demolition and what was found by the UNSCOM during their inspections, but, according to a DOD panel, the numbers varied by a factor of 5 or 6.

In addition, this panel recognized that meteorological data were limited because there were relatively few observations, and these were made far from the Khamisiyah site. 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. The panel also recognized that wind patterns could contain areas of bifurcation—lines where winds move in one direction on one side and in another direction on another side—which also move over time and are different at different altitudes.

Source term assumptions on agents (sarin and cyclosarin) purity established for the four sites—Khamisiyah, as well as Al Muthanna, Muhammadiyat, and Ukhaydir—differed widely. Discrepancies between the Khamisiyah purity data and the Al Muthanna and Muhammadiyat data were not adequately resolved. The agents were assumed to be purer in February 1991 at Al Muthanna than in January at Muhammadiyat and purer still in March at Khamisiyah. In each case, agent purity was a key factor in the DOD and CIA methodology for determining the amount of agents released. Since the purity of the sarin and cyclosarin was used as a factor in calculating the amount of agents released, purity is critical in compounding the uncertainty of the modeling. For example, for modeling purposes, 10 tons of agent with a purity of 18 percent would be represented as only 1.8 tons of agent. The CIA did not independently validate or establish agent purity levels based on empirically driven analyses, and relied on UNSCOM reporting for these rates. This assessment of the agent purity rate at Al Muthanna was questioned by a DOD official, who noted in a memo, "Why we use the 18 percent purity instead of the 50 percent number available in public sources, and why we treat GF like GB when there are documents that mention the higher toxicity are not easily deferred with 'because the CIA says so.' I think the GF vs. GB numbers accepted by the EPA or CDC or whatever is the competent authority, but the purity number is problematic." We plan to examine the validity of the methodology used to calculated the rate of degradation.

In addition, according to Iraqi production records obtained by UNSCOM, the agent purity at Khamisiyah, in early January 1991, was about 55 percent. The agent subsequently degraded to 10-percent purity by the time laboratory analysis had been completed on samples taken by UNSCOM from one of the rockets in October 1991. On the basis of the sample purity and indications that the degradation rate for sarin and cyclosarin are similar, the CIA assessed that the ratio of sarin to cyclosarin when the munitions were blown up in March 1991 was the same as that sampled in October 1991—3:1. According to the CIA, assuming a conservative exponential degradation of the sarin and cyclosarin, the purity on the date of demolition, 2 months after production, was calculated to be about 50 percent.

At Al Muthanna, however, where the agent was stored in a bunker, the CIA estimated the chemical warfare agent had deteriorated to approximately 18 percent purity by the time that bunker 2 was destroyed, in early February 1991, leaving about 1600 kilograms (1.6 metric tons) of viable sarin. The CIA based its estimate on UNSCOM's analysis of Iraqi purity data and supporting information, which stated that the munitions were filled with the agent in 1988 and that the maximum purity for the 1988 agent was 18 percent in 1991. However, this assumption suggests knowledge of exact production dates and storage conditions that were not established. But UNSCOM and intelligence community reporting about the near-wartime capabilities of Iraq suggests that while the sarin produced was of poor quality, it had a maximum purity of 60 per cent.

According to CIA documents, the total amount of agent modeled to have been released at Al Muthanna was 1 kg, but, to be conservative, the amount released was assumed to be 10 kg. The reasoning given for the low amounts discharged was the heat of the explosion. The CIA assessed that far less agent would have been released in the Al Muthanna bunker because, based on U.S. field-testing using simulated bunkers, heat would build up rapidly in Iraqi bunkers made of thick reinforced concrete ceiling and walls, thereby destroying most of the agent. However, these bumkers were targeted using high explosives, such as Tomahawk missiles and laser-guided and non-guided bombs, that detonate and produce instantaneous and extreme blast forces and shock and pressure waves, as well as heat. While the CIA analysts gave great credibility to the heat, no consideration was given to either the blast effects of the munitions or to the higher altitude plumes generated with the types of munitions used.

For Muhammadiyat, DOD also provided details regarding how they derived source term characterizations for agent released using test data from Dugway Proving Grounds. However, the types of munitions used in the testing and, therefore, the resulting effects are not comparable to what munitions were actually used and their effects. At Dugway Proving Grounds, small explosive charges were placed on boxed rockets; at Muhammadiyat, the munitions were targeted using multiple high-explosive bombs. Agent purity at Muhammadiyat was estimated at 15 percent.

The Plume Height Was Underestimated

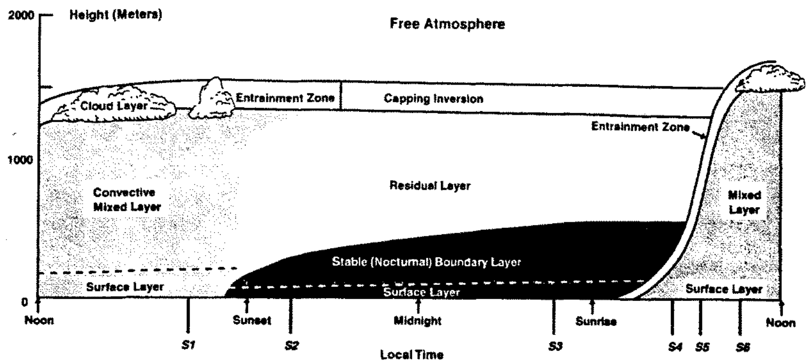
Plume heights from the explosions could be significantly higher than the plume height assumptions provided for in the modeling of Khamisiyah and other Iraqi chemical warfare sites. The plume height data the CIA provided for the demolitions at the Khamisiyah pit was 0-100 meters. However, neither the DOD nor the CIA conducted testing to establish plume heights associated with the bombings of Al Muthanna, Muhammadiyat, or Ukhaydir. DOD modelers involved with the modeling efforts told us that they did not calculate the plume height or any of the other heat or blast effects associated with the bombings of these sites because DOD had provided the modelers these data. A modeling expert from the Defense Threat Reduction Agency (DTRA) told us that DOD data on plume height was inconsistent with other test data for the types of facilities bombed. The modeling expert cited test studies conducted at White Sands Proving Grounds in New Mexico, which demonstrated plume heights would range from 300 to 400 meters in height.

Modeling experts from LLNL who participated only in the initial modeling at Khamisiyah also told us, citing studies, that they questioned how the plume height was estimated. In a pre-war analysis, LLNL projected that the smoke source cloud, immediately following the bombing of Iraqi chemical warfare agent facilities, would be characterized by a surface-based plume with a 54 meter (177 ft.) horizontal radius and a height of 493 meters (1,617 ft.). A Sandia Laboratory empirical study, performed in 1969, established a power law formula for calculating plume heights attributable to high-explosive detonations (see appendix II). Using this formula, an MK-84 or GBU-24 (942.6lb. of high explosives) bomb would generate a plume of 421 meters.

DOD applied the same assumptions about the height of the plume at Khamisiyah to model other possible chemical releases at the Al Muthanna, Muhammadiyat, and Ukhaydir sites. At Muhammadiyat, for example, DOD established a release height of 0.5 meters (roughly half the bomb height) for nerve agent and a release height of 1.0 meters (roughly half of the median height of the various bomb stacks) for blister (mustard) agent destroyed at this location. Moreover, according to an internal DOD memo, an initial cloud size of 10 meters in both lateral and vertical directions was "arbitrarily" established. No efforts were made by DOD to validate these estimates by analyzing video images that were available showing some of the plume data, particularly those taken from ground level at Khamisiyah, were used to project the characteristics of the actual plumes.

As illustrated by figure 1, disparity in plume height source data could result in vastly differing projections regarding how far the plume travels and disperses, particularly during nighttime periods when a stable (nocturnal) boundary layer emerges.

Figure 1 Boundary Layer Characteristics



Source: Roland B. Stull, An Introduction to Boundary Layer Meteorology, (Boston, MA: Klumer Academic Publishers, 1988), p. 11.

As also shown in figure 1, above the surface layer, in the stable boundary layer, the winds often accelerate to higher speeds, in a phenomenon that is called the low-level or nocturnal jet. At altitudes on the order of 200 meters above the ground, winds may reach 10-30 meters per second (22-67.5 miles per hour) in the nocturnal jet. Higher plumes than those postulated by DOD, coupled with this phenomenon, could result in the rapid transport of chemical agents until disturbed by turbulence or the return of the mixed layer sometime after dawn. However, this possibility was not taken into consideration in any of the modeling performed. Consequently, the modeling may have resulted in underestimating the extent of plume coverage. (For a detailed discussion of this issue, see appendix II.)

In addition, plume geometry associated with high-explosive discharges shows that the majority of the mass of the plume is located toward the higher altitudes, suggesting that the majority of the mass of the plume would move to higher altitues where they might be transported by these higher speed winds (see appendix III).

DOD Modeling Only Considered the Effects of a Single Bombing on Health

Iraqi chemical warfare facilities were bombed on several occasions, but DOD and CIA modeling did not reflect the cumulative effects of these repeated bombings on the amounts of agents released and on the health of troops. For example, there were 17 distinct coalition air strikes on the Muhammadiyat ammunition storage depot. While modeling was requested for the duration of 72 hours after the chemical release for Khamisiyah, DOD used only a 24-hour duration for its modeling of the bombing of Muhammadiyat. This was because at this site, unlike at others, DOD made the assumption that all of the nerve agent was released at one time and therefore modeled each air strike as if it was the only strike that caused a release. According to DOD, each model produced a freeze frame of the largest hazard area. The hazard area grows until it reaches its maximum size, which the modeling suggests is about 10-12 hours after the release.

Dugway Field-testing Did Not Realistically Simulate the Actual Bombing Conditions

DOD and the CIA also conducted post-war field-testing at Dugway Proving Ground to simulate the actual bombing conditions at Khamisiyah to derive the source term data for use in modeling. From May 1997 through November 1999, the testing center at Dugway Proving Ground conducted seven field-testings and two laboratory studies to obtain source term data for use in DOD and CIA modeling of Khamisiyah. For testing and simulation to be effective, the conditions have to be as close to the actual event as possible. However, the testing did not realistically simulate the conditions that existed during the demolition of 122-mm chemical-filled rockets in Khamisiyah and is therefore of questionable usefulness in providing inputs data for the modeling. The simulations took place under conditions that were not comparable to those that existed at Khamisiyah. During the field-testing, there were differences in seasonal and meteorological conditions; in munition crate construction material; in rocket construction, including the use of concrete-filled pipes as rocket replacements to provide (inert) filler to simulate larger stacks; the fewer numbers of rockets (and therefore explosives) in the simulations, which may have suppressed a potential chain reaction of explosions; the use of agent simulant (rather than real agent); and soil. These differences result in multi-variable uncertainty that cannot be resolved.

For example, the Dugway testing used a small sample of 32 rockets with simulant-filled warheads to conduct seven field-testings: five were single-rocket demolitions and two involved multiple-rocket demolitions. One multiple-rocket trial demolition used nine functional rockets plus three dummy rockets, while the other multiple-rocket trial used 19 functional rockets and five dummy rockets. In contrast, at the Khamisiyah pit, stacks of 122 mm rockets, estimated to total about 1,250 rockets, were detonated. Moreover, Dugway testing officials did not know whether the 122 mm rockets used during the field-testings were the same as those at the Khamisiyah pit. Dugway officials acknowledged that exploding a larger number of rockets would make a significant difference on the testing, and aerial bombing with a heavy load would have a far greater effect than was the case with the Dugway testing.

According to DOD and CIA analysts, the type of soil and wood can have a significant effect on the dispersion of the agent. However, a Dugway testing official told us that evaporation characteristics from the trials and models were uncertain. DOD and CIA estimates of the evaporation and retention rates of the chemical agent spilled on the soil may not be similar to what was actually evaporated from and retained in the pit sand at Khamisiyah. This is because while Iraqi soil was available and used in the laboratory testing, it was not used during the field-testing. Similarly, DOD and the CIA estimates of the amount of spilled agent that evaporated from and was retained in wooden crates are suspect because Dugway testing officials could not obtain actual wood from the Khamisiyah pit site for testing. The aged and possibly damp wood at Khamisiyah would absorb less agent than the new wood used at Dugway. DOD and CIA determined that only about 32 percent of the agent was released and that most leaked into the soil and wood with 18 percent of the leakage becoming part of the plume (2 percent through aerosolization and 16 percent through evaporation).

Field-testings were also conducted at a different time of the year and time of the day than the actual Khamisiyah pit event. According to Dugway officials, testing was done in May and in the early morning hours when drainage conditions prevail. The U.S. demolition of the Khamisiyah pit took place on March 10th in the late afternoon during the presence of a mixing layer. Other demolitions took place during evening and nighttime hours when the stable (nocturnal) boundary layer emerges.

Despite the uncertainties in approximating the conditions that existed even at Khamisiyah, DOD and the CIA used these data not only for the Khamisiyah modeling, but also for the modeling of other sites. At all these sites, the chemical warfare munitions would have been destroyed by air strikes with much greater quantities of high-explosive charges and under differing meteorological conditions.

Divergence in Results among the Models

DOD made no effort to resolve widely divergent modeling results among the models selected. Instead, a composite model approach was taken, which contributed to, rather than resolved, uncertainty.

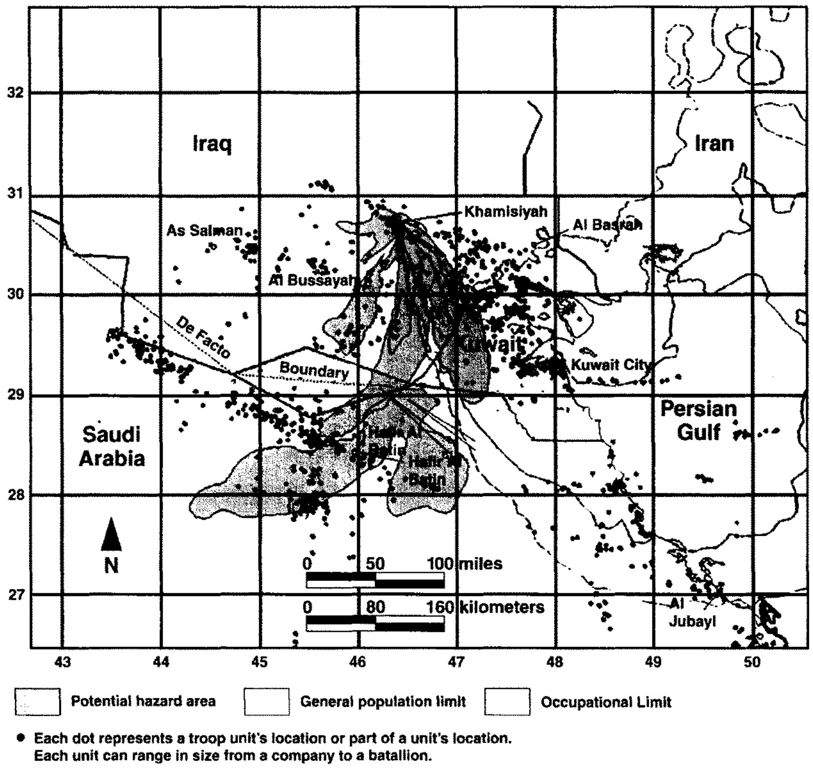
For example, the DOD panel tasked the LLNL to conduct an analysis using DOD's MATHEW meteorological model with the ADPIC dispersion model. During LLNL presentations to the DOD panel in November 1996 and February 1997, the LLNL provided a 72-hour composite projection, assuming an instantaneous release of the contents of 550 rockets containing sarin. It shows the plume covering an area extending south-southeast from the release point to the Persian Gulf, then turning eastward at the Gulf coast, and then turning northeast over the Gulf and extending northeastward across central Iran. (For a more detailed discussion of this topic, see appendix IV.)

DOD models showed significant differences from the LLNL assessment. In contrast to the LLNL modeling simulations, analysis done with the DOD models—VLSTRACK with COAMPS meteorological models and HPAC/SCIPUFF with OMEGA meteorological forecasting models—showed the plume from an instantaneous release moving first southerly, and then turning to the west-southwest. See appendix V for a 72-hour plume overlay of those composite projections published by DOD.

According to the DOD panel, no effort was made to reconcile the differences between the DOD and LLNL modeling efforts. The panel determined that the results were so different that it would not be possible to choose the most affected areas and which U.S. forces were affected. Accordingly, the panel recommended that a composite of the DOD models be used to combine the hazard areas predicted by the models. Yet we observed that even among the models selected for use by DOD, widely differing paths were evident (see appendix VI).

Assuming that a composite modeling effort is an appropriate methodology, a composite projection, including the above projections (DOD and CIA composite and LLNL), would encompass a far larger number of forces and seriously skew the outcome of any epidemiological studies done thus far, as shown in figure 2.

Figure 2: DOD Composite Projection and Lawrence Livermore National Laboratory Projection



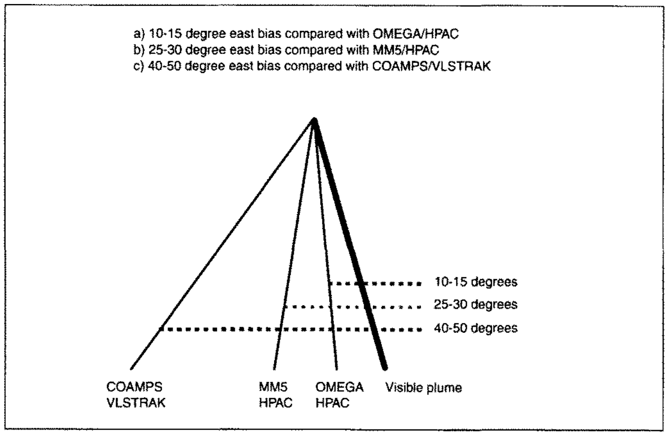
Source: GAO analysis of Department of Defense & Lawrence Livermore National Laboratory models.

Source:

A clear divergence exists in the predictions of the models. Further research was conducted to determine whether there was data available that might explain this divergence. As a result of this research, the DOD panel concluded that the divergence in the modeling outcomes may be explained by a line of diffluence (directional split) in the independently modeled 10-mm wind field data near Khamisiyah during the first 2 days of the modeling period. The precise location of this line was critical to which way the material would be transported by the wind. (See appendix VII for an illustration of this diffluence with three different data sets).

In addition, DTRA officials told us that at the time of the modeling, they conducted data-validation runs of the various models against visible smoke plumes from the oil well fires in Kuwait; the runs showed a definite bias, as shown in figure 3. According to DTRA, this validation could mean that the uncertainty involved in using these models could result in an angular shift of 10 to 50 degrees to the west. In other words, the actual area coverd could be from 10 to 50 degrees to the east of the area indicated by the model, meaning that it would cover a different population from the one in the model.

Figure 3: Validation Runs of Various Models



Source: GAO.

DOD's Conclusion from the Epidemiological Studies Is Questionnable

Given that the DOD modeling was flawed, DOD's conclusion, from epidemiological studies based on this modeling with regard to rate of illness among exposed versus not exposed, is questionnable. Nevertheless, the results of the modeling were used as a basis for determining the exposure classification—exposed versus not exposed to chemical agents—of the troops in population-based epidemiological studies. As we noted in 1997, to ascertain the causes of veterans' illnesses, it is imperative that investigators have valid and reliable information on exposure, especially for low-level or intermittent exposures to chemical warfare agents.[4] To the extent that veterans are misclassified regarding

[4] GAO, *Gulf War Illnesses: Improved Monitoring of Clinical Progress and Reexamination of Research Emphasis Are Needed*, (GAO/NSIAD-97-163, June 23, 1997).

exposure, relationships would be obscured and conclusions would be misleading.

Misclassification of study subjects in the measurement of the variables being compared is a well-recognized methodological problem in epidemiological studies. Misclassification can have two types of effects. First, if misclassification affects both comparison groups equally (non-differential—equally in the exposed and unexposed groups), it may water down the results so that important associations are missed. Second, if misclassification affects one group more than the other (differential misclassification), it may introduce bias that obscures important associations or creates false associations. Consequently, the study misclassification resulted in confounding—that is, distorting—the results, making the conclusion questionnable.

By combining the results from its individual modeling efforts, which showed different areas of coverage, and ignoring the results of the LLNL modeling, which showed much larger areas of coverage, DOD potentially may have misclassified a large number of troops truly exposed to chemical warfare agents in the putatively non-exposed group. If exposure to chemical warfare agents truly caused adverse effects resulting in increased hospitalization or death, such one-way misclassification would tend to obscure the differences in hospitalization or death rates by falsely increasing the rates in the putatively non-exposed group while not affecting the rates in the exposed group.

Based on the June 1996 plume modeling, DOD officials initially stated that only 300 to 400 troops were exposed to chemical plumes. Based on additional modeling, that number was revised to approximately 5000 on September 1996; to approximately 20,000 on October 22, 1996; and to 98,910 on July 23, 1997. DOD 2000 estimates place the number exposed at 101,752. The number from the October 22, 1997 plume model served as the basis for informing approximately 100,000 Gulf War veterans of possible exposure. This 1997 plume model was also used as the basis of at least two epidemiological studies that were published in peer-reviewed scientific journals.[6]

In 2000 DOD announced that as a result of ongoing scientific analysis, DOD's Directorate for Deployment Health Support developed a new computer model that changed the location of the Khamisiyah plume footprint. The number of service members potentially exposed remained approximately 100,000. The new 2000 model reclassified 32,627 troops as unexposed who were previously classified as exposed and classified 35,771 troops as exposed who were previously classified as unexposed. Given the weaknesses in DOD modeling and the inconsistency of data set—

[5] Gray et al., "The Postwar Hospitalization Experience of Gulf War Veterans Possibly exposed to Chemical Munitions Destruction at Khamisiyah, Iraq," American Journal of Epidemiology, vol. 150 (1999), pp. 532-540.; Kang, H.K., T.A. Bullman, "Mortality Among U.S. Veterans of the Persian Gulf War: 7-Year Follow-up," American Journal of Epidemiology, vol. 154 (2001), pp. 399-405.

representing these models—given to different researchers, there can be no confidence that the research conclusions based on these models have any validity.

Conclusions

In evaluating the limitations of the plume modeling, we concluded that even under the best of the circumstances, the results from the modeling cannot be definitive. Plume modeling can allow one to estimate what might have happened when chemical warfare agents are released in the environments. Mathematical equations are used to predict the activities of an actual event, in this case, the direction and extent of the chemical warfare agent plume. However, in order to predict precisely, one needs to have accurate information on the source term and the meteorological conditions. However, DOD did not have accurate information on the source term or on meteorological conditions.

Given these modeling flaws, the DOD modeling results should not form the basis for determining the extent of exposure of U.S. troops during the Gulf War. The models selected were not fully developed and validated for environmental fallout and the assumptions used to provide the input into the models exhibited a preferential bias for a particular and limited outcome. Yet even under these circumstances, the models failed to

[6] GAO, *Gulf War Illnesses: Improved Monitoring of Clinical Progress and Reexamination of Research Emphasis Are Needed*, (GAO/NSIAD-97-163, June 23, 1997).

provide similar conclusions. In addition, many potential exposure events were not included. It is likely that if fully developed and validated models and more realistic data for source term were included in the modeling, particularly plume height and exposure duration, the exposure footprints would be much larger and most likely to cover most of the areas where U.S. and other coalition forces were deployed. However, given the weaknesses in the data available for any further analyses, any further modeling efforts on this issue would not be any more accurate and helpful.

In particular, source term data used for modeling the release of chemical warfare agents during the Gulf War were inadequate for any model to provide, with the desired accuracy and confidence, a single definitive simulation of dispersion. Several modeling experts told us that if source term inputs into modeling assessments are not accurate, the results of the modeling would not be reliable The development of source term data was not empirically driven, but rather driven by the subjective analyses of individual intelligence agencies. No empirically driven analyses were applied to determine plume height source data from the chemical warfare agent research, production, and storage sites subjected to air strikes, and no empirically driven calculations were disclosed regarding agent purity as it affected the rate of decay of the chemical warfare agent munitions that, according to intelligence agencies reports, were produced immediately prior to the war.

Efforts to simulate events and define the source term through testing were unrealistic, conducted under inappropriate conditions and, in some cases, inappropriately applied to dissimilar events. The subjective and defective quality of much of the analyses conducted is best demonstrated by the dynamic nature of the source data over time. That is, repeated analyses resulted in continually changing conclusions and source data, despite the fact that no aspect of the actual events changed after their occurrence.

DOD completely disregarded the results from the LLNL model which provided divergent results, which were in the DOD and CIA modeling analysis. This occurred despite a high degree of divergence, even among the selected DOD models. Further, the precise plume projections of the LLNL model were excluded from DOD's composite modeling. Finally, in the DOD and CIA composite model, divergence from individual models was masked. Despite all of the uncertainties that emerged from DOD and CIA modeling, the results of the modeling were used to serve as a basis for determining the exposure status—exposed versus not exposed to chemical agents—of the troops in population-based epidemiological studies. However, given the weaknesses in DOD modeling and the inconsistency of data set—representing these models—given to different researchers, there can be no confidence that the research conclusions based on these models have any validity.

Mr. Chairman, this concludes my statement. I will be happy to answer any questions you or Members of the Subcommittee may have.

Contacts and Acknowledgments

Should you or your offices have any questions concerning this report, please contact me at (202) 512-6412 or Sushil Sharma, Ph.D., DrPH, 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 Jason Fong and Laurel Rabin. James J. Tuite III, a GAO consultant, provided technical expertise.

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Appendix I - Khamisiyah Models

On November 2, 1996, DOD requested the Institute for Defense Analysis to convene an independent panel of experts in meteorology, physics, chemistry, and related disciplines to review the Khamisiyah modeling analysis done by the CIA and its contractor, the Science Applications International Corporation. The DOD panel recommended conducting additional analyses using several DOD and non-DOD meteorological and dispersion models as shown in table 1.

Table I.1: Meteorological and Dispersion Models Used in Modeling Khamisiyah

Meteorological Model	Developer/Sponsor	Dispersion Model	Developer/Sponsor
Coupled Ocean-Atmosphere Mesoscale Prediction System (COAMPS)	U.S. Navy	Hazard Prediction and Assessment Capability/Second Order Closure, Integrated Puff (HPAC/SCIPUFF)	Defense Threat Reduction Agency
Mass Consistent Wind Field (MATHEW)	Department of Energy/Lawrence Livermore National Laboratory	Atmospheric Dispersion by Particle-in-cell (ADPIC)	Department of Energy/Lawrence Livermore National Laboratory
Mesoscale Model, Version 5 (MM5)	National Center for Atmospheric Research	Non-Uniform Simple Surface Evaporation, Version 4 (NUSSE4)	U.S. Army
Naval Operational Global Atmospheric Prediction System (NOGAPS)	U.S. Navy	Vapor Liquid Solid Tracking (VLSTRACK)	U.S. Navy
Operational Multi-scale Environment Model with Grid Adaptivity (OMEGA)	Defense Threat Reduction Agency		

Appendix II - Power Law Formula

A Sandia Laboratory empirical study performed in 1969 established a power law formula for calculating plume heights attributable to high-explosive detonations. This power law formula was derived from data on 23 test shots, ranging from 140-2,242 lbs. high explosives at U.S. Department of Energy's Nevada Test Site (National Exercise, Test, and Training Center) and provides a cloud top height at 2 minutes after detonation. Most of the shots were detonated during near neutral conditions, where the clouds continued to rise after 2 minutes; data for 5 minutes after detonation on some shots shows tops rising to nearly double the 2-minute values. The 2-minute values better represent the final cloud top heights during stable conditions.

This formula is represented as

$$\boldsymbol{h = 76(w^{1/4})}$$

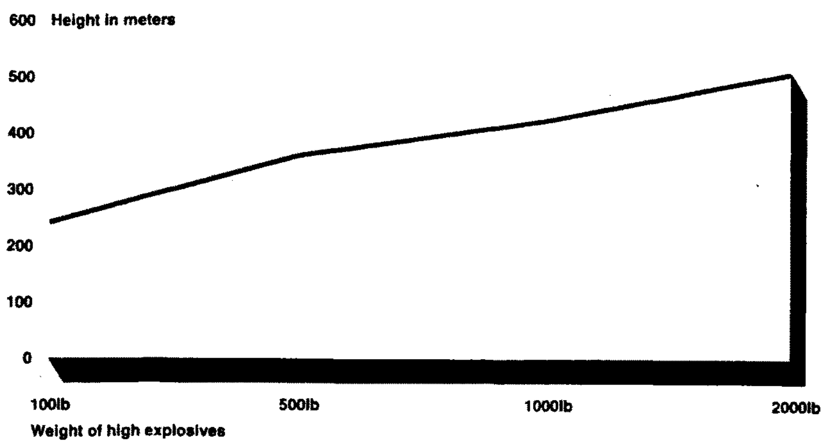
where h = height of plume in meters
and, w = weight of explosives in pounds

Using this formula, a MK-84 or GBU-24 (942.6lb of high explosives) bomb would generate a plume of 421 meters:

$$H = 76\ (942.6 \text{ pounds of high explosives})^{1/4}$$
$$H = 76\ (5.541)$$
H • 421 meters

Figure II.1 shows what the plume height trend line would be using the formula to calculate plume heights, resulting from the detonation of high explosives ranging in weight from 100 – 2,000 lbs.

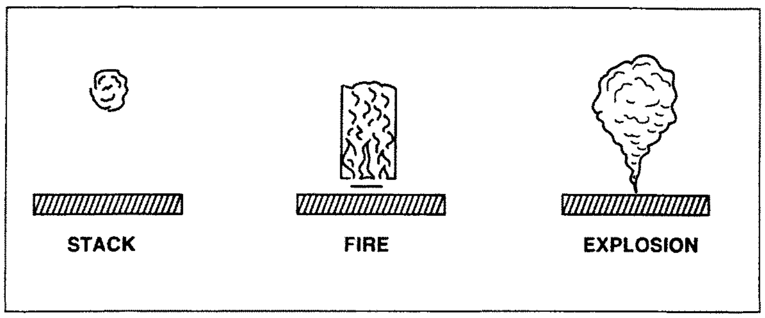
Figure II.1: Plume Height by Weight of Explosive



Appendix III – Plume Geometries and Wind Transport

As shown in figure III.1, plume geometry associated with high explosive discharges shows that the majority of the mass of the plume is located towards the higher altitudes, suggesting that the majority of the mass of the plume would move to higher altitudes where they might be transported by higher speed winds.

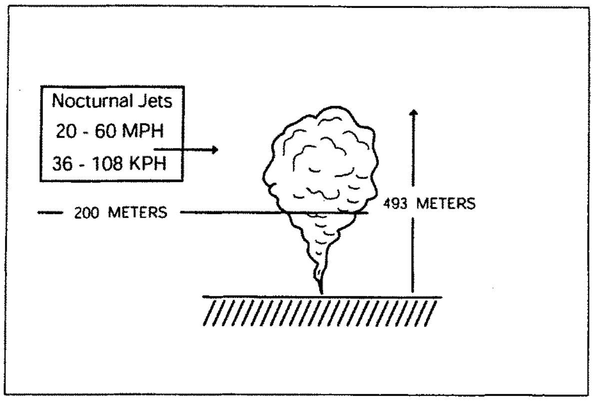
Figure III.1: Examples of Various Plume Geometries



Source: Lawrence Livermore National Laboratory.

As shown in figure 3.2, the distribution of the plume geometry may be affected by nocturnal jets.

Figure III.2: Impact of Nocturnal Jets on Plume at Higher Altitudes



Source: Lawrence Livermore National Laboratory.

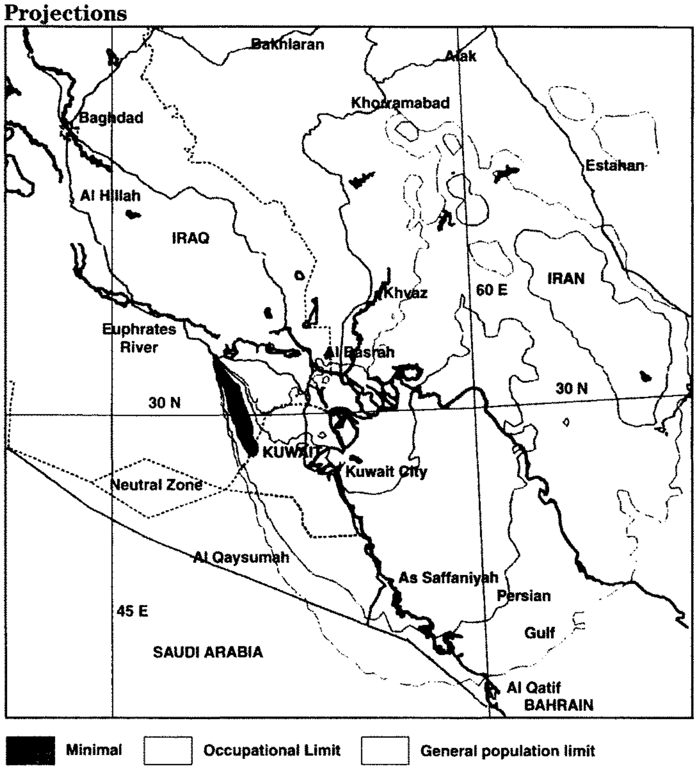
In fact, empirical studies and actual reported and observed events tend to refute DOD and intelligence agencies' assumptions and support the alternative assumption of transport by low-level jets. First, empirical testing suggests that the plume heights were much higher than postulated in the source term data. Second, no massive casualties were claimed, reported or observed in areas immediately surrounding the Iraqi chemical warfare research, production, and storage sites bombed by coalition forces. Third, since many of the bombings occurred at night, the explosive effects coupled with higher altitude plumes and the presence of a nocturnal boundary layer capable of moving hazardous materials hundreds of miles could easily account for this phenomenon, as well as the reports of chemical warfare agent detections in areas occupied by U.S. and coalition forces. Fourth, the dynamics of advection explained above may account for the reported wartime nighttime detections of very low-levels of chemical agents associated with turbulence mixing the upper and lower level atmospheric layers resulting from aircraft-related sonic booms and incoming missiles and artillery.

Appendix IV – Lawrence Livermore National Laboratory Khamisiyah Simulation

The Department of Energy's Lawrence Livermore National Laboratory (LLNL) Atmospheric Release Advisory Capability was tasked to conduct an analysis using its MATHEW meteorological model with the ADPIC dispersion model. Between 1979 and 2003, the LLNL modeling capability, known as the Atmospheric Release Advisory Capability (ARAC), now the National Atmospheric Release Advisory Center (NARAC), responded to more than 100 alerts, accidents, and disasters, and supported more than 1,000 exercises. These include assessments of nuclear accidents, fires, industrial chemical accidents, and terrorist threats.

During its presentations to the DOD panel in November 1996 and February 1997, scientists from Lawrence Livermore National Laboratory provided plume projections based on the data provided by the panel staff. A number of model projections were calculated and presented to the panel. As shown in figure IV.1, the LLNL 72-hour composite projection assuming an instantaneous release of the contents of 550 rockets containing sarin. It shows the plume covering an area extending south-southeast from the release point to the Persian Gulf, then turning eastward at the Gulf Coast, and then turning northeast over the Gulf and extending northeastward across central Iran.

Figure IV.1: Lawrence Livermore National Laboratory Composite Projections



Source: Lawrence Livermore National Laboratory, Department of Energy.

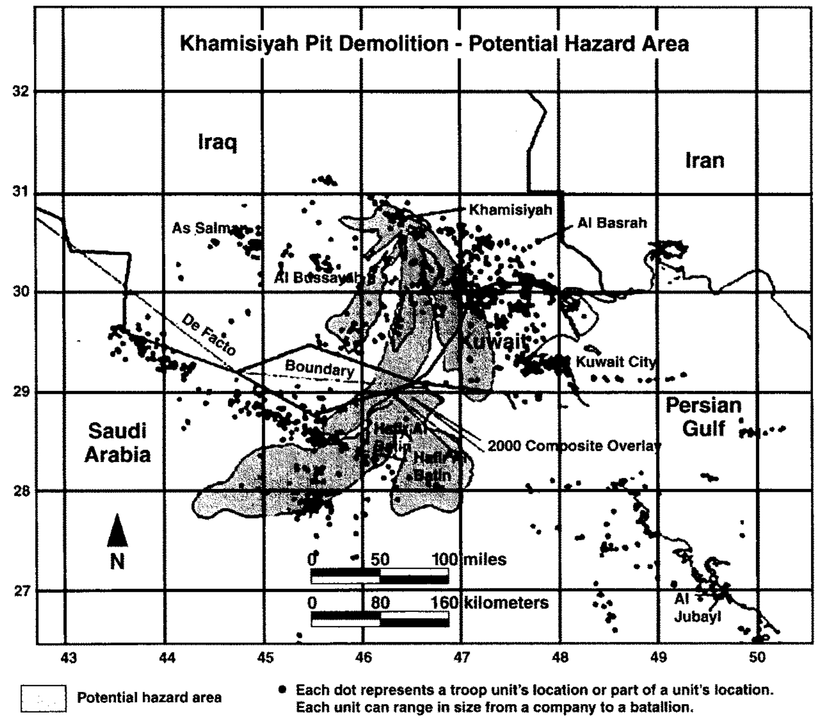
LLNL's modeling assessment shows that the 72-hour exposure due to the instantaneous release of sarin from 550 rockets covers a large hazard area. According to LLNL, agent concentration in excess of the dosage amount expected to cause "minimal effects" or symptoms on individuals covered a 2,255 square km area extending approximately 130 km south-southeast from the release point.[7] Dosages in excess of the amount that would be allowed for a worker exposed to sarin in the workplace, or the "occupational limit,[8]" were predicted over a 114,468 square kilometer area, including Kuwait City, an approximately 200 kilometer-wide area across the Persian gulf, and the higher elevations of the Zagos mountain range in Iran. The remaining area was determined to be at the "general population limit."[9]

[7] Minimal effects is the lowest concentration level that would be expected to have noticeable effects on human beings.
[8] Occupational limit is about one-tenth of the minimal effects value and is the maximum concentration level that would be allowed for a worker who could become exposed to sarin in the course of his job duties.
[9] The general population limit represents the limit below which any member of the general population could be exposed (e.g., exhale) 7 days a week, every week, for a lifetime, without experiencing any adverse health effects.

Appendix V – DOD Model Simulations

A 72-hour plume overlay of those composite projections published by OSAGWI is shown in figure V.1.

Figure V.1: DOD Composite Projection



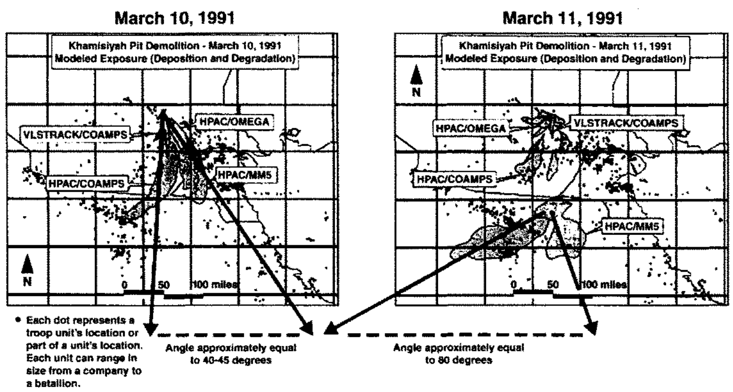
Source: Department of Defense, Office of the Special Assistant for Gulf War Issues.

Note: This projection includes the VLSTRAK and SCIPIFF/HPAC dispersion models with COAMPS, MM5, and OMEGA meteorological models.

Appendix VI – Divergence among DOD Models

Even among the models selected for use by the DOD panel, widely divergent directional outcomes were observed. As shown in figure VI.1, differences can be seen among various models for hazard areas during the first 2 days of the modeling period for Khamisiyah.

Figure VI.1 Divergence among Models Used in Constructing DOD and CIA Composite Analysis

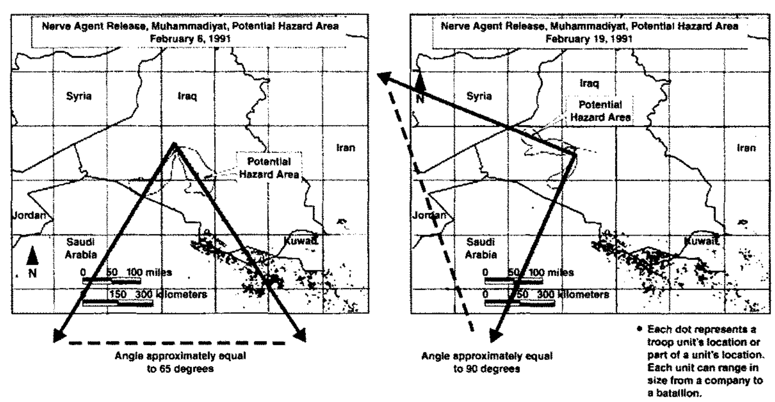


Source. Naval Surface Warfare Center.

The March 10, 1991 graphic demonstrates a 40-45 degree divergence between the HPAC/OMEGA and the HPAC/COAMPS projections while the March 11, 1991 graphic demonstrates approximately an 80 degree divergence.

The uncertainty attributed to this divergence is not limited to the Khamisiyah modeling. According to a modeling analyst involved with the modeling of Al Muthanna, the weather models used, COAMPS and OMEGA, each showed the plume going in different directions, at a 110-120 degree difference. The analyst said that COAMPS showed the plume going in a North/Northwest direction, while OMEGA showed the plume going South. Similar divergence among model predictions was also observed in the modeling of Muhammadiyat, as shown in figure VI.2.

Figure VI.2: Divergence in DOD Models for Muhammadiyat



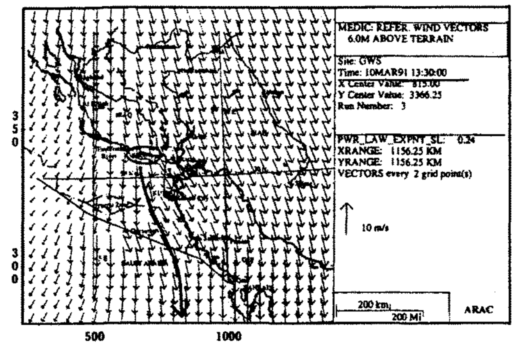
Source: Department of Defense.

Appendix VII – Divergence and Wind Field Models

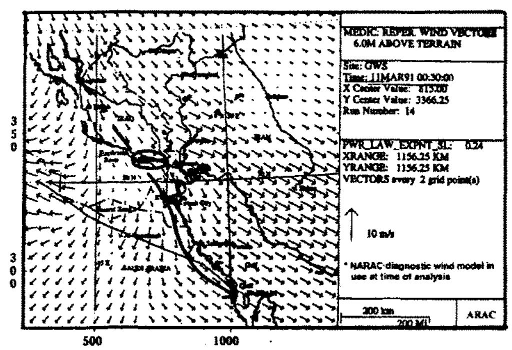
In figure VII.1, windfield vector divergence projections 6.0 meters above terrain are based on observational data processed by the Meteorological Data Interpolation Code (MEDIC) model.

Figure VII.1: Lawrence Livermore National Laboratory Diagnostic Wind Model Based on Observational Data

March 10, 1991, 13:30:00Z (16:30 local)
Based on observational data only, processed by MEDIC Model



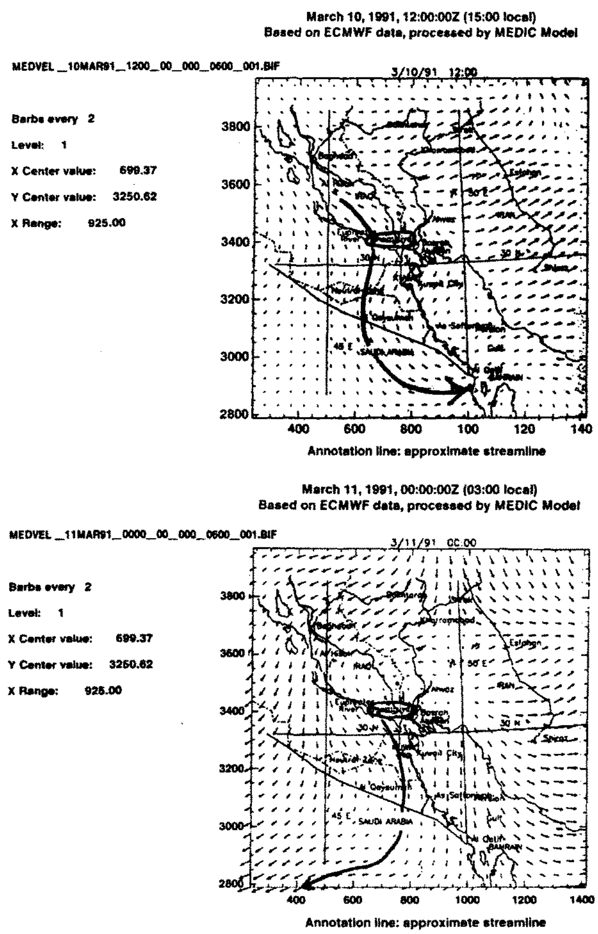
March 11, 1991, 00:30:00Z (03:30 local)
Based on observational data only, processed by MEDIC Model



Source: Lawrence Livermore National Laboratory.

In figure VII.2, the Windfield vector model based on European Centre for Medium-Range Weather Forecast (ECMWF) projections, processed by the Meteorological Data Interpolation Code (MEDIC) model, is shown.

Figure VII.2: Lawrence Livermore National Laboratory Diagnostic Wind Model Based on ECMWF Projections



Source: Lawrence Livermore National Laboratory.

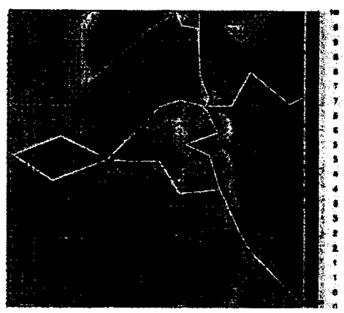
In figure VII.3, the windfield vector model is based on Coupled Ocean-Atmosphere Mesoscale Prediction System (COAMPS) Simulations at the U.S. Naval Research Laboratories.

Figure VII.3: Windfield Vector Model Based on COAMPS

NRL COAMPS Simulation: Wind analysis for 12z (15:00 local), 10 March 1991

COAMPS GRID 3, 100 X 100 X 30 5.00 km

10.0 m wind field
analysis at 1991031012
surface land sea
analysis at 1991031012

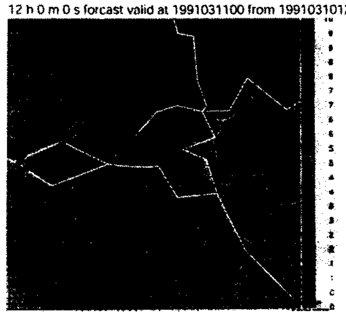


Blue Line: approximate streamline.

NRL COAMPS Simulation: Wind forecast for 00Z (03:00 local), 11 March 1991

COAMPS GRID 3, 100 X 100 X 30 5.00 km

10.0 m wind field
12 h 0 m 0 s forcast valid at 1991031100 from 1991031012
surface land sea
12 h 0 m 0 s forcast valid at 1991031100 from 1991031012



Blue Line: approximate streamline
Red line: line of diffluence
note very strong diffluence near Kamisiyah

Source: Lawrence Livermore National Laboratory.

Mr. TURNER. Dr. Johnson-Winegar.

Dr. JOHNSON-WINEGAR. Mr. Chairman and committee members, I am honored to appear today before your committee to address your questions regarding the Department of Defense efforts to model chemical, biological, radiological and nuclear weapons effects.

I am Dr. Anna Johnson-Winegar, the deputy assistant to the Secretary of Defense for Chemical and Biological Defense. In this role, I am responsible for the oversight and coordination of the Department of Defense chemical and biological defense programs.

In addition, I have served as the accreditation authority within the Department for all common use chemical and biological defense models. In my testimony today, I will provide an overview of modeling to address some of the uncertainties inherent in all models. I request that my full written statement be incorporated into the record as it answers the specific questions posed to us in advance of today's hearing.

All models and simulations are designed for specific purposes. Models are used for hazard prediction, risk analysis, operational decision support, virtual prototyping, weather forecasting and other purposes. In addition, models may be simple and easy to use, or complex and require expert users or indeed lie somewhere in between.

No one model is suitable for all purposes. Conversely, only select models are appropriate for supporting specific analyses.

Models are but a part of any analytical and decisionmaking process. While the selection of a model must be made in the context of the decision process that it will support, the actual efficacy of any model must begin with data or source terms.

For a model to represent an event accurately, detailed knowledge about the event is essential. For chemical, biological, radiological and nuclear defense analysis, key information needed includes: Weather conditions, geographic conditions, type of threat agent, concentration and purity, state of agent, type of delivery systems and type of event.

For example, dispersal from bulk storage as a result of counterforce operations, unconventional sources, toxic material accidents, etc.

Uncertainty in these areas directly affects the accuracy of the model outputs. Once source terms are defined, models may calculate submunition and debris dispersal and propagation, and vapor, liquid, solid or aerosol transport and diffusion.

The transport and diffusion of particles is only part of the overall equation. Transport and diffusion incorporates interaction of the agent with the atmosphere and with the surfaces on which the agents are dispersed. Once the agents are dispersed, analyses are required to determine the interactions between the agents and the environment, and perhaps most critically, to determine the interaction between agent and humans.

It is not sufficient to determine the quantity of agent to which an individual is exposed, the actual effects on humans must be calculated. Effects may range from no observable effects to lethal effects and everything in between.

These effects may be acute or chronic, and the response times may be immediate or delayed. A critical factor leading to the uncertainty in models is indeed the limited dosage data on human exposure to chemical or biological warfare agents.

Effects of human exposure are primarily extrapolated from animal tests, along with analysis of some limited accidental exposures. All of these factors result in some degree of uncertainty in the output from all models.

The role of models is to provide tolls to the analyst who then uses the output from the models to support decisionmaking. The analyst will incorporate risk assessment, sensitivity analysis and tradeoff analysis to account for uncertainty and to provide the most reasonable response germane to the question posed by the decisionmaker.

Even though many of the same models used to model the activities related to the 1991 Gulf war are in use today, these models, in many ways, are the same in name only. There have been numerous advances in the capabilities of the various models. These advances have been integrated into the models currently in use to support hazard prediction, operational analysis and other activities.

Each of these advances enhances the realism of the model, and enables the model to be used as a tool to provide a definitive estimate of the ground truth regarding the actual release of chemical or biological agents.

In my written statement, I have provided a number of examples of the many enhancements of the models over the last 10 years. In addition to enhancements of the models, there is a significant amount of data that must be measured. Not all data are essential for effective plume modeling.

There is always a constant tradeoff in providing the most comprehensive data versus timely information versus high resolution.

Also much of the data may be absent or estimated, because of natural variability that can only be described in a qualitative sense. Thus, even with perfect data, there will be uncertainties in an effective model because meteorology is inherently uncertain.

Plume modeling and troop location data are linked in order to estimate potential effects of exposures on personnel and on the mission. Yet, the ability to model plumes to determine hazardous areas is not Affected by the location of the units. However, the ability to analyze possible exposures to service members in those units to the hazardous content of the plume often requires plume modeling in the absence of onsite testing.

The separate data for plumes and troop location are tied together through our joint warning and reporting network, JWARN. Personnel and mission effects are then evaluated based upon the time-dependent hazard environment and the troop location in that environment.

Currently JWARN troop location and plume data are tied together in a semiautomated manner. Planned upgrades over the next few years to JWARN will automate this process. The chemical-biological defense program has significantly increased its investment in the area of modeling and simulation over the last few years.

Please be assured that the Department takes this very seriously. We understand our responsibility to provide the most accurate information possible related to transport and diffusion of these types of agents. We are indeed working very closely with other programs in the Department of Defense as well as with the other Federal agencies.

Thank you for the opportunity to address these questions, and I remain available to try to answer any further questions or concerns that the committee may have.

Mr. TURNER. Thank you, Dr. Johnson-Winegar.

[The prepared statement of Dr. Johnson-Winegar follows:]

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HOUSE GOVERNMENT REFORM COMMITTEE

STATEMENT OF

DR. ANNA JOHNSON-WINEGAR

DEPUTY ASSISTANT TO THE SECRETARY OF DEFENSE
FOR CHEMICAL AND BIOLOGICAL DEFENSE

BEFORE THE

HOUSE GOVERNMENT REFORM COMMITTEE
SUBCOMMITTEE ON NATIONAL SECURITY, EMERGING THREATS, AND INTERNATIONAL RELATIONS

U.S. HOUSE OF REPRESENTATIVES

"FOLLOWING TOXIC CLOUDS:
SCIENCE AND ASSUMPTIONS IN PLUME MODELING"

JUNE 2, 2003

FOR OFFICIAL USE ONLY
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HOUSE GOVERNMENT REFORM COMMITTEE

Statement of Dr. Anna Johnson-Winegar,
Deputy Assistant to the Secretary of Defense for Chemical and Biological Defense
Before the House Government Reform Committee
Subcommittee on National Security, Emerging Threats, and International Relations
U.S. House of Representatives
Hearing on "Following Toxic Clouds: Science and Assumptions in Plume Modeling"
June 2, 2003

INTRODUCTION

Chairman and Distinguished Committee Members, I am honored to appear before your Committee again to address your questions regarding the Department's efforts to model chemical, biological, radiological, and nuclear (CBRN) weapons effects. I am Dr. Anna Johnson-Winegar, the Deputy Assistant to the Secretary of Defense for Chemical and Biological Defense, DATSD(CBD). In this role, I am responsible for the oversight and coordination of the Department of Defense Chemical and Biological Defense Program. In addition, until recent organization changes, I have served as the authority within the Department for the accreditation of all common use chemical and biological defense models. I will elaborate on my roles and responsibilities in my testimony today. First, I will provide an overview of modeling in general to address some of the uncertainties that are inherent in all models. I will then also address several questions and concerns regarding the modeling and the supporting methodologies and analyses of events related to the 1991 Gulf War and post-war activities in Iraq. Following my comments, I welcome any questions the Committee may have and I will do my best to answer them.

OVERVIEW OF CHEMICAL AND BIOLOGICAL MODELS

As the mathematician Alfred Whitehead stated, "There is no more common error than to assume that, because prolonged and accurate mathematical calculations have been made, the application of the result to some fact of nature is certain."

All models and simulations are designed for specific purposes. Models are used for hazard prediction, risk analysis, operational decision support, virtual prototyping, weather forecasting, and numerous other purposes. In addition, they also range from simple, user-friendly models to complex models requiring expert users and support staff. No model is suitable for all purposes. Conversely, only select models are appropriate for supporting specific analyses. As examples, the DoD Chemical Biological Defense Program had a specific model developed to predict the hazard resulting from Chemical or Biological weapons used against US forces. The Defense Threat Reduction Agency (DTRA) developed a similar model to predict hazards resulting from U.S. Forces using conventional weapons against an enemy's weapons of mass destruction (WMD) manufacturing capability or stockpiled weapons. The National Center for Atmospheric Research has developed one of several modeling capabilities to predict environmental effects of pollutant releases. These models have many similarities, yet each was developed for specific purposes.

Models, however, are but a small part of any analytical and decision making process. While the selection of the analytic tool must be made in context with the decision process that it will support, the actual efficacy of any model must begin with data or source terms. For a model to represent an event accurately, knowledge about the event is essential. For CBRN effects analysis, key information needed includes weather conditions (such as temperature, humidity, wind speed, cloud cover), geographic conditions (such as topology, structures, type of vegetation), type of chemical or biological threat agent, state of agent (liquid, solid, vapor, binary agent, and types of stabilizers, buffers, etc.), type of delivery systems (e.g., spray tanks, artillery, rockets, submunitions, etc.), and type of event (e.g., dispersal from bulk storage as a result of counterforce operations, unconventional sources, toxic material accidents, etc.) Uncertainty in these areas directly affects the accuracy of model outputs.

Once source terms are defined, models may calculate submunition and debris dispersal and propagation and vapor, liquid, solid, or aerosol transport and diffusion (T&D). This is what the community typically refers to as T&D modeling. T&D of particles is only part of the overall equation. T&D incorporates interaction of the agent with the atmosphere and with the surfaces on which agents are dispersed. Once agents are dispersed, analyses are required to determine the interactions between the agents and the environment and—perhaps most critically—to determine the interactions between the agents and humans. It is not sufficient to determine the quantity of agent to which an individual is exposed; the effects on humans must be calculated. Effects may range from no observable effects to lethal effects and everything in between. Effects may be acute or chronic, and the response times may be immediate or delayed. A critical factor leading to uncertainty in models is the limited dosage data on human exposure to chemical or biological warfare agents. Effects of human exposure are primarily extrapolated from animal tests along with analysis of some limited accidental exposures.

All of these factors result in some degree of uncertainty in the output from all models. The role of models is to provide tools to the analyst, who uses the output from the models to support decision-making. The analyst will incorporate risk assessments, sensitivity analyses, and trade-off analyses to account for uncertainty and to provide the most reasonable response germane to the question posed by the decision maker to answer a question.

I will now address the specific questions asked by the Committee.

1. How were possible chemical warfare agent releases modeled in determining potential exposures in the Persian Gulf War?

A. Background

In 1996, the Central Intelligence Agency (CIA), in response to a request of the Presidential Advisory Committee on Gulf War Veterans' Illnesses, reported on computer modeling it had used to simulate possible releases of chemical warfare agents from several sites. (Modeling was necessary because there had been no measurements of such releases at the time of the war.) Because the CIA used only a single model approach, its results reflected the strengths and weaknesses of only that model. On November 2, 1996, to improve computer modeling over the earlier CIA results, the DoD asked the Institute for Defense Analyses (IDA) to convene an independent panel of experts in meteorology, physics, chemistry, and related disciplines. The panel reviewed previous modeling analyses and recommended using multiple atmospheric models and data sources to generate a more robust result than that produced by a single model. Specifically, it stated, "the combination of using more than one model and of varying the inputs provides a comprehensive approach to understanding the uncertainties contributed by the reconstruction of the meteorology...." The Special Assistant for Gulf War Illnesses agreed to conduct a new modeling effort to implement this recommendation.

To implement the recommendations of the IDA panel, the DoD and CIA asked other agencies with extensive modeling experience to participate in the modeling process. The modeling team consisted of scientists from the Defense Threat Reduction Agency (DTRA); the Naval Research Laboratory (NRL); the Naval Surface Warfare Center (NSWC); the National Center for Atmospheric Research (NCAR); and Science Applications International Corporation (SAIC) (supporting the CIA and DTRA). The purpose of this modeling effort was to identify geographical areas that could be used with population location information to identify two sub-groups: one group who was "possibly exposed" and a second group who was highly unlikely to have been exposed, or in shorter words, "not exposed". Whenever an analytical effort uses multiple methods or tools, we want to see agreement so we can gain confidence from that agreement. When agreement does not occur, as was the situation in this case, we must either choose one result as the most reasonable or the worst case or we must combine the differing results.

In this case, the analyst team decided to combine the model results by taking the union of all the "possibly exposed" areas from all the models. This decision was valid for two reasons: First, this method is the best for identifying everyone who was "possibly exposed" and second, this method produces two groups appropriate for the subsequent epidemiology studies. To believe this method produces two groups appropriate for epidemiology studies, the team did not have to believe everyone was correctly put in the right group, the team only had to believe that most of the truly exposed were in the "possibly exposed" group and very few of the truly exposed were in the "not exposed" group. The analyst team was confident that they accomplished this.

B. Methodology

The DoD adopted the IDA panel recommendation to use an ensemble of weather and dispersion models combined with global data sources to assess the possible dispersion of chemical warfare agents. The methodology for modeling the release of agent was a process that used:

- A source characterization to describe the type and amount of agent released, and how rapidly it discharged. (The CIA provided the source characterization assessments.)
- Data from global weather models to simulate global weather patterns.
- Regional weather models to simulate the weather in the vicinity of the suspected agent release. (Since Iraq stopped reporting meteorological observations to the World Meteorological Organization in 1981 during the Iraq-Iran war, and since very limited onsite meteorological data were archived by the coalition forces during the 1991 Persian Gulf War, the necessary meteorological data for dispersion calculations were best simulated by state-of-the-art mesoscale meteorological models, such as COAMPS (Coupled Ocean-Atmospheric Mesoscale Prediction System), MM5 (National Center for Atmospheric Research/ Penn State Fifth Generation Mesoscale Model), and OMEGA (Operational Multiscale Environmental Model with Grid Adaptivity). These peer-reviewed and highly sophisticated models are routinely used to forecast weather.)
- Transport and dispersion models (often simply called dispersion models) to project the possible spread of the agent as a result of the simulated regional weather. (In a November 22, 1996 memorandum of the Office of Assistant to the Secretary of Defense for Nuclear and Chemical and Biological Defense Programs, Deputy for Chemical/Biological Matters, and Deputy Under Secretary of the Army (Operations Research), HPAC (Hazard

Prediction and Assessment Capability) and VLSTRACK (Chemical/Biological Agent Vapor, Liquid, and Solid Tracking Computer Model) were identified as the preferred dispersion models for DOD applications. Therefore, these two models were selected to predict dispersion patterns of the potential warfare agent releases, with meteorological inputs to be provided by the above three meteorological models.)

- A database of Gulf War unit locations to plot probable military unit locations in relation to the hazard area and estimate possible exposures. The effort to plot probable locations was not part of the modeling per se, but was an analysis required to project possible exposures.

The methodology used two types of models: weather models and dispersion models. The weather models allowed us to simulate the weather conditions in specific areas of interest by approximating both global and regional weather patterns. Based on the weather generated by a global model, a regional weather model predicted the local weather conditions in the vicinity of a possible chemical warfare agent release. Both the global and regional weather models were supplemented by actual, although quite limited, weather measurements from the Persian Gulf and surrounding regions.

The dispersion models allowed us to simulate how chemical warfare agents may have moved and diffused in the atmosphere given the predicted local weather conditions. These models combined the source characteristics of the agent—including the amount of agent, the type of agent, the location of the release, and the release rate—with the local weather from the regional models to predict how the agent might disperse. Running one dispersion model with the weather conditions predicted by each regional model resulted in a prediction of a unique downwind hazard area. Running each dispersion model with the weather from each of the different regional weather models resulted in a set of unique hazard areas. These hazard areas were overlaid to create a union, or composite, of the various projections. The composite result provided the most credible array of potential agent vapor hazard areas for determining where military units might have been exposed. This was the basic process for all of our modeling efforts.

The entire modeling process was repeatedly reviewed by government and independent experts in the field. A final academic peer-review was completed before publishing results of the modeling.

2. What models were used?

Based on several criteria, the Department used a collection of atmospheric models to assess the possible dispersion of chemical warfare agents. The IDA panel recommended basic criteria for model selection, including using high-resolution mesoscale meteorological models and transport and dispersion models that accept temporally and spatially varying meteorological fields. The IDA panel also recommended DoD use models currently sponsored by various organizations under DoD and the Department of Energy to perform additional modeling analyses. Three mesoscale meteorological models (COAMPS, MM5, and OMEGA) and two dispersion models (HPAC and VLSTRACK) were used. These models clearly did not represent all available models. However, they had all been peer reviewed, validated, and extensively used by the DoD and scientific communities.

Initially the Naval Research Laboratory (NRL) teamed with the Naval Surface Warfare Center (NSWC) to link the COAMPS meteorological model and the Vapor, Liquid, Solid

Tracking (VLSTRACK) dispersion model. The Lawrence Livermore National Laboratory (LLNL) Atmospheric Release Advisory Capability (ARAC) operated the Mass-Adjusted Three-Dimensional Wind Field (MATHEW) diagnostic meteorological model linked with the Atmospheric Dispersion by Particle-in-cell (ADPIC) dispersion model. Finally, DTRA ran the OMEGA prognostic meteorological model linked to the (Hazard Prediction and Assessment Capability/Second-Order Closure Integral Puff (HPAC/SCIPUFF) dispersion model. In addition, responding to the IDA panel's suggestion to include an established civilian mesoscale model to provide comparative results, the NRL obtained 48 hours of meteorological reconstruction generated by the MM5 mesoscale model from NCAR. Comparisons among MM5, COAMPS, and OMEGA indicated that these models produced similar reconstructions of the meteorology.

The IDA panel, chaired by Gen. (Ret.) Larry Welch and consisting of renowned scientists in the fields of meteorology and atmospheric dispersion, reviewed LLNL's initial modeling efforts, together with the initial modeling results given by COAMPS, OMEGA, HPAC, and VLSTRACK. (The MM5 mesoscale meteorological model had not been applied at that time.) The IDA panel found that while the agent transport based on both the COAMPS and OMEGA meteorological model results showed a general direction towards the west, that based on the MATHEW meteorological model results showed a general direction towards the east. A review of modeling methodologies by the IDA panel suggested that the coarse meteorology (2.5 by 2.5 degrees, or roughly 250-km resolution) used by MATHEW failed to resolve the important mesoscale features and the atmospheric boundary layer due to a lack of sufficient observational data. As a result, in its July 9, 1997 report to the DoD, the IDA panel stated it viewed LLNL's MATHEW model as less capable because it modeled atmospheric phenomena with less fidelity. The COAMPS and OMEGA results were later corroborated by another meteorological model, MM5. Another important difference between MATHEW and models such as COAMPS, MM5, and OMEGA is that the former is a "diagnostic" model, while the latter are "prognostic" models. Prognostic models are based on fundamental conservation laws of mass, momentum, and energy, and can be used to forecast weather. Diagnostic models mainly interpolate between existing data, and thus cannot be used to forecast weather. As a result, the LLNL's models were not further considered.

After the initial work performed in response to the IDA panel recommendations, the DoD established linkages between mesoscale meteorological models and dispersion models:

- MM5 → HPAC/SCIPUFF
- COAMPS → HPAC/SCIPUFF
- COAMPS → VLSTRACK
- OMEGA → HPAC/SCIPUFF

3. What were the strengths and weaknesses of the models?

The three mesoscale meteorological models (COAMPS, MM5, and OMEGA) are all quite comprehensive in treating atmospheric physics and thermodynamics. They all have been well tested in simulating atmospheric flows such as hurricanes, frontal passages, land and sea breezes, and snowstorms. This type of weather models represents the best available tools to simulate weather in the absence of onsite measurements. Areas of improvement for these models include better assimilation of high-resolution land use, soil moisture, and terrain data; better treatment of urban areas; and better quantification of model uncertainty.

OMEGA, COAMPS, and MM5 have much in common: all are three-dimensional, primitive-equation, mesoscale models solving the non-hydrostatic, compressible form of the dynamic equations and use many of the same parameterizations of physical processes (e.g., surface fluxes and moist convection).

However, these models have different features. For example, COAMPS and OMEGA are used in an operational setting, so operational constraints balance features related to data input/output considerations and objectives such as physical fidelity and numerical accuracy. As an example, COAMPS and OMEGA process observational data and perform quality control in a fully automated fashion. Conversely, MM5 is mostly used in research applications and thus contains numerous optional physical algorithms.

MM5 is widely used in research communities, COAMPS is the operational prediction model for the Navy and DoD. The basic equations of both models are based on the work of Klemp and Wilhelmson.[1] Both models use a staggered grid both horizontally and vertically. Grid nesting efficiently treats a wide range of temporal and spatial scales. On the other hand, the OMEGA grid is unstructured horizontally and adapts to both underlying surface features and dynamically evolving atmospheric phenomena. This approach achieves local accuracy of the numerical solution with a single, non-uniform grid and does not require communication between separate nesting grids.

To handle fast-moving acoustic modes and slower-moving meteorological modes, COAMPS and MM5 follow Klemp and Wilhelmson's general time-splitting algorithm. The slower modes include terms such as horizontal advection and the Coriolis force. Due to the significantly finer vertical grid spacing than horizontal spacing, semi-implicit schemes are used for integration. OMEGA's unstructured grid environment locally adapts time steps to the grid structure to satisfy a local Courant-Friedrichs-Lewy constraint, thereby increasing computational efficiency. In addition, OMEGA treats acoustic waves by applying an explicit horizontal filter and a semi-implicit vertical filter.

The planetary boundary layer (PBL) is a critical factor in controlling mesoscale weather systems. Because of the large fluxes of heat, moisture, and momentum near the earth's surface, there is generally an agreement on the need for high-resolution treatment of the physics of this layer. However, the three models apply different approaches to modeling the PBL. COAMPS and OMEGA apply a fine vertical resolution to resolve the PBL, including the stable boundary layer. In addition, they apply the level 2.5 PBL model developed by Mellor and Yamada.[2] The crucial phenomenon to resolve is the transport of mass and momentum in the PBL by large energetic eddies. Traditional local-gradient methods cannot adequately treat such a well-mixed atmosphere. Mellor and Yamada's higher-order closure methods, though computationally expensive, are capable of representing a well-mixed boundary layer. On the other hand, the lowest MM5 model computation level is approximately 40 m above ground level, with increasing layer depths above, so it is difficult for the model to properly resolve the shallow nocturnal PBL. Local-gradient theory may fail because it does not account for the influence of

[1] Klemp, J.B. and R.B. Wilhelmson, 1978: The simulation of three-dimensional convective storm dynamics. *J. Atmos. Sci.* **35**, 1070–1096.

[2] Mellor, GL and T. Yamada, 1974: A hierarchy of turbulent closure models for planetary boundary layers. *J Atmos Sci.*, **31**, 1791-1806.

large eddy transports and does not treat entrainment effects. MM5 uses non-local atmospheric boundary layer schemes that are more effective for coarser grids.

The PBL's spatial variability can result from a range of mechanisms, including topographic elevation variation, land-and-sea breeze circulation, and local contrasts in physical properties at the desert surface.

Since the model simulations' objective was to best analyze the area's meteorological conditions, use of a four-dimensional data assimilation or hindcasting was crucial. Although grid structures, numerical solvers, and PBL parameterizations all contribute to different model features, the most significant difference among the three mesoscale models is probably in their data assimilation strategies. COAMPS assimilates observations intermittently (every 12 hours) on all three grids using its previously forecasted fields as the first-guess fields. In other words, the model stops at 12-hour intervals during integration, uses the model fields as a background to generate a new objective analysis, and then restarts for the next integration period. Each restart incorporates fresh data to limit error growth. On the other hand, MM5 applies Newtonian relaxation, which gradually drives the model results toward a gridded analysis by including an extra forcing term in each governing equation. Data assimilation is performed on the outermost grid only.

The DoD modeling team used HPAC and VLSTRACK dispersion models to estimate possible hazard areas. The HPAC dispersion model is unique in that it can generate probabilistic outputs, thus providing a measure of uncertainty. The VLSTRACK dispersion model is more traditional, and generates only ensemble-mean results. If the underlying terrain is not flat, HPAC has two procedures available to internally generate mass-consistent wind fields based on the input meteorology. On the other hand, VLSTRACK is less sophisticated, and uses only a simple scheme to interpolate wind fields.

Both VLSTRACK and HPAC/SCIPUFF use the COAMPS wind field; the MM5 and OMEGA fields drive HPAC/SCIPUFF only. Even though the same meteorological fields are used, the ways the dispersion models use them are different. HPAC/SCIPUFF uses a set of artificial profiles by selecting a reduced set (i.e., 400) of horizontal grid locations from the meteorological model grid. HPAC/SCIPUFF then generates a mass-consistent gridded wind field based on refined surface topography. HPAC/SCIPUFF can use the data directly, and thus bypass the mass-consistency calculations, if these data are on a latitude/longitude or UTM grid. However, none of the mesoscale meteorological models used either of the grid systems. The alternative was to interpolate the profiles using the mass-consistency and achieving higher terrain resolution at the same time. VLSTRACK does not have an integrated meteorological model; its three-point interpolation scheme directly uses mesoscale meteorological fields.

Based on the similarity theory, the PBL's mean wind and temperature profiles and turbulence are primarily functions of the surface roughness (z0), boundary layer depth (zi), Monin-Obukhov length (L), and friction velocity (u*). Both HPAC/SCIPUFF and VLSTRACK use standard tables and equations to specify u* and z0 if they are unavailable from the meteorological model outputs.

VLSTRACK and HPAC/SCIPUFF calculate L and zi quite differently. For example, VLSTRACK does not directly calculate or use surface heat flux values (H) in modeling the PBL, but uses the Golder nomogram to establish the primary link between the meteorological conditions (captured by the PG stability class) and the Monin-Obukhov stability characterization.

As described above, HPAC/SCIPUFF specifies the PBL parameters according to the calculation mode (Simple, Observation, or Calculated). For the Observation mode, the model either directly accepts the PBL parameters in the input file or calculates them based on the PG stability class. The latter approach is comparable to the VLSTRACK implementation. The Simple mode consists of very simple diurnally variable formulae. The Calculated mode consists of detailed energy budget methods for determining the surface heat flux and prognostic equations for determining zi, thus over-riding the internal calculations of these two PBL parameters.

VLSTRACK and HPAC/SCIPUFF apply fundamentally different puff dispersion methods. VLSTRACK implements dispersion algorithms adapted from the NUSSE4 Gaussian plume model. These algorithms are derived from the classical Taylor's theory for a continuous source in a homogeneous turbulence field and provide a relationship between cloud dispersion and the velocity fluctuation statistics together with the Lagrangian time scale. The latter two are empirical parameters requiring specification. The generality of the turbulence closure methods used in HPAC/SCIPUFF provides a dispersion representation for arbitrary conditions. However, the practical application of the model requires empirical closure assumptions for higher-order correlation terms, and empirical specification of the velocity and length scales describing the atmospheric turbulence spectrum.

HPAC/SCIPUFF treats phenomena such as puff deformation and concentration fluctuation on a more rigorous theoretical basis. The equation for the concentration fluctuation provides a robust approach to producing probabilistic output. Note that the stochastic uncertainty the HPAC/SCIPUFF methodology estimates includes only contributions due to turbulent fluctuations in the atmosphere. Other sources of uncertainty such as errors in meteorological inputs and in the source term also contribute to the total uncertainty. HPAC/SCIPUFF optionally allows the specification of the meteorological uncertainty in the observational data file. However, these uncertainties were not available for input to HPAC/SCIPUFF.

4. What models would DoD use today should an event occur in a combat theater?

The Department is party to international agreements within NATO to use simplified templates for real time battlefield hazard prediction. The Department also has a limited number of locations that can use one or more of the three DoD Interim Standard Hazard Prediction Models in near real time. For NBC defense against enemy attacks, DoD uses NATO Standardization Agreement (STANAG) 2103/Quadrapartite Standardization Agreement (QSTAG) 187 on Reporting Nuclear Detonation, Biological and Chemical Attacks, and Predicting and Warning of Associated Hazards and Hazards Area. These standardization agreements cover Allied Tactical Publication (ATP)-45, which specifies procedures for hazard area estimation. For hazard areas from chemical or biological attacks on US forces, DoD uses the VLSTRACK model. For allied offensive attacks on enemy WMD targets, DoD uses HPAC. For attacks or incidents on US Chemical Demilitarization Facilities, DoD uses the Emergency Management Information System (EMIS, commonly referred to as D2PUFF). For post event analysis, the Department would perform an analysis similar to that noted in questions one and two.

The Department also has a program that will field a single hazard prediction tool throughout DoD in the near future. For the forensic analysis of a single event or a few events of high interest (as long as time was not an issue) we do as we did before; we would seek out organizations with extensive modeling experience in this area. We would likely use all of those agencies models' unless some aspect of their models' capabilities identified them as unsuitable for the event of interest. One possible starting point could be the August 2002 report by the Office of the Federal Coordinator for Meteorology, *Atmospheric Modeling of Releases from Weapons of Mass Destruction: Response by Federal Agencies in Support of Homeland Security* (FCM-R17-2002). This report identifies 29 models as potentially appropriate for use in support of homeland security.

5. Who decides what model(s) would be used?

For operational use, the Combatant Commander has the ultimate responsibility as to what is used in theater. They receive a variety of advice and guidance from various sources. For allied offensive operations during the most recent two conflicts—ENDURING FREEDOM and IRAQI FREEDOM—commanders used HPAC. In defensive applications, ATP-45 and VLSTRACK were used.

Until a recent organizational change, the DEPSECDEF and the USD(AT&L) had designated my office with this responsibility. With the April, 2003, USD(AT&L) approval of the Implementation Plan for Management of the Chemical and Biological Defense Program, the Assistant to the Secretary of Defense for Nuclear and Chemical and Biological Defense Programs, ATSD(NCB) is named the DoD Modeling and Simulation Executive Agent for M&S representations of chemical, biological, radiological, and nuclear (CBRN) weapons, weapons effects, and countermeasures (except when M&S is used by the test and evaluation community, in which case the Operational Testing Authority and/or the Director of Operational Test and Evaluation is the accrediting authority.) This DoD-wide class accreditation authority is delegated to the Joint Program Executive Office for Chemical and Biological Defense (JPEO-CBD) to oversee and approve all common use CBRN defense models and simulations; certification authority for CBRN defense data; and resolution of validation and certification issues.

6. How has modeling improved since the Persian Gulf War?

There have been numerous technical advances over the past decade in the capabilities of various models. These advances have been integrated into models currently in use to support hazard prediction, operational analyses, and other activities. Each of these advances enhance the realism of the models and enable the models to be used as tools to provide a definitive estimate of the "ground truth" regarding the actual release of chemical or biological threat agents. A summary of enhancements are:

- surface evaporation methodology
- multiple components
- horizontal and vertical cloud splitting (or diagonal)
- mass reflections within the mixing layer and/or planetary boundary layer
- fumigation into mixing layer or planetary boundary layer from above
- use of nested gridded meteorology forecast data (>10,000 locations, 16+ vertical levels, 120 hours at 1 hour intervals, 6 parameter values at each grid point, ~2 GB file size)
- representation of individual stack and/or munition locations
- ability to fix surface flux to agree with measurements

- high altitude source characterization and droplet dynamics
- high altitude meteorology characterization (GUACA, GRAM-95, other)
- eddy diffusivity estimation above the planetary boundary layer
- extension of toxicity from lethal and incapacitating effects to 8 hour workplace and 72 hour threshold exposure levels
- hazard output areas up to 600 km on a side at 5 km spacing
- map projection algorithms for geographic locations
- use of met forecast model turbulence parameters
- output in terms of probability of exceeding a given hazard level
- forest canopy and urban region bulk dispersion effects
- puff centroid rise with distance relation
- vapor deposition algorithms and vapor reaction in the air
- display of hazard contours in a variety of graphical formats, including Arc View

In recognition that a Joint Service plume model was needed to address all DoD uses: defense against enemy attacks, offensive attacks on enemy WMD targets, and attacks or incidents on US Chemical Demilitarization Facilities; DoD has begun work to bring the different modeling efforts together into one DoD acquisition program—the Joint Effects Model (JEM) program. Mature science and technology plume modeling efforts will transition to a program charged with further development, fielding, and sustainment activities. Plume models will be fully integrated into our command and control systems and will benefit from real world intelligence, meteorology, and integration into the common operational picture.

7. What sources of meteorological data are needed for effective plume modeling?

Effective plume modeling includes the integration of meteorological data with topographical, geographic, and related data. These data must be provided with a temporal frequency consistent with the time scale over which the plume modeling is calculated. The basic data needed for plume modeling include:

- wind speed and direction over domain of interest.
- air temperature and relative humidity.
- terrain elevation and land use.

It is best if the wind flow is characterized at multiple vertical levels.

Many observed and derived sources of data can be input directly into plume models. These data provide a better characterization of the boundary layer. Many times, the following data may contribute to more accurate predictions.

- vertical wind speed component positive upwards
- pressure/geopotential height
- ATP45 atmospheric stability category
- inverse Monin-Obukhov length
- turbulent kinetic energy

- surface heat flux density
- boundary layer depth
- precipitation
- surface conditions
- ground moisture
- visibility
- ceiling (Cloud cover > 5/8)
- cloud cover.

Other weather parameters, although not directly needed by the plume model, are important to the numerical weather prediction model and add accuracy to the values input to the plume model:

- cloud type
- significant weather phenomena
- sea state
- sea swell
- sea surface temperature
- amount of sea-ice
- amount of fast-ice
- sea-ice topography
- sea-ice openings

Basic terminology and data formats for weather terms are defined within the NATO Standardization Agreement (STANAG) 6022, Annex A, "Adoption of a Standard Gridded Data Meteorological Message." Meteorological data types may include climatological data, numerical weather analysis, numerical weather predictions, observations, or compound data composed of two or more of these types.

As may be evident, there is a significant amount of data that is measured. Not all data are essential for effective plume modeling. There is a constant trade-off in providing the most comprehensive data *versus* timely information *versus* high resolution. Some information can be accurately provided in real time or even predicted with some accuracy. Other data require some time to gather and describe the information accurately. While other data may be gathered accurately and quickly to provide high resolution, but may impose a massive data burden, thus making it useable only to those with access to computers with sufficient processing power. Finally, much of the data may be absent or estimated because of natural variability that could only be described in a qualitative sense (e.g., atmospheric stability may be "very" unstable.) Thus, even with perfect data, there will be uncertainties in an effective model because meteorology is inherently uncertain.

8. How are plume models tested and validated?

Within the DoD, significant and continuing efforts have been undertaken to test and validate plume models at multiple levels in order to provide a high degree of confidence in their output. To establish a common term of reference, we refer to Validation as the process of determining the degree to which a model provides an accurate representation of the real world from the perspective of the intended uses of the model.

To validate plume model outputs, the outputs have been statistically compared to thousands of small and large scale experiments and real world releases covering local, regional, and continental distances. To facilitate validation efforts, the JPEO-CBD maintains a growing database of Validated Test Data to which the models are compared across a range of variables including meteorology, agent persistency, agent toxicity, and various ground surfaces (e.g., grass, concrete). The database contains well-characterized plume information leveraging DoD and other agency investments over a period of approximately 40 years. Agent dissemination methods are validated against field tests of representative dissemination systems. In some cases the method is limited to intelligence of the threat. Lessons learned from ongoing operations, exercises, and Advanced Concept Technology Demonstrations (ACTDs) have also supported plume model validation. Lastly, plume model development is subject to multiple levels of peer reviews and reviews by independent organizations.

Data requirements to validate plume models continue to grow as the modeling requirements expand with the threat. For example, in recent years, limited experiments in urban environments and building interiors have been conducted to improve the understanding of urban wind patterns and to collect data to validate plume models. This summer, a more robust urban test is being conducted to expand our validated test database and to assess urban plume model maturity. Additional Science and Technology efforts are both planned and in progress. Efforts such as the intercept of a ballistic missile filled with agent simulant (planned) and agent persistency on surfaces (in progress) will provide essential data to validate and improve plume-modeling efforts.

To support fielding requirements, further testing of plume models is focused towards showing system effectiveness, suitability and survivability in an operational environment. To that end, Information assurance, Interoperability and Integration testing with Warning and Reporting and service Command and Control systems is planned. Because of the criticality of this area, the Director, Operational Test and Evaluation, has placed our current Joint Warning and Reporting Network (JWARN) program on oversight for operational testing. We are confident that, upon completion, we will have must thoroughly validated and tested hazard prediction capability anywhere.

9. How is plume modeling tied to troop location data?

Plume modeling and troop location data are inextricably linked in order to estimate potential effects of exposures on personnel and mission. Yet, the ability to model plumes to determine hazardous areas is not affected by the location of units. However, the ability to analyze possible exposure of service members in those units to the hazardous contents of plumes often requires plume modeling in the absence of on-site testing. The separate data for plumes and troop location are tied together through the Joint Warning and Reporting Network (JWARN). Personnel and mission effects are then evaluated based upon the time dependent hazard environment and the troop location in that environment. Currently, JWARN troop location and plume data are tied together in a semi-automated manner. Planned upgrades will automate this process.

JWARN Block I is an automated Nuclear, Biological, and Chemical (NBC) Information System. JWARN Block I is essential for integrating the data from NBC detectors and sensors into the Joint Service Command, Control, Communication, Computers, Information and Intelligence (C^4I^2) systems and networks in the digitized battlefield. JWARN Block 1 provides the Joint Force an analysis and response capability to predict the hazards of hostile NBC attacks or accidents/incidents. JWARN Block I will also provide the Joint Forces with the operational capability to employ NBC warning technology that will collect, analyze, identify, locate, report and disseminate NBC threat and hazard information. JWARN Block I is located in command and control centers at the appropriate level defined in Service-specific annexes and employed by NBC defense specialists and other designated personnel. It allows operators to transfer data from and to the actual detector/sensor/network and automatically provide commanders with analyzed data for decisions for disseminating warnings to the lowest echelons on the battlefield. It provides additional data processing, production of plans and reports, and access to specific NBC information to improve the efficiency of NBC personnel assets.

JWARN Blocks II & III completely meet the JWARN requirements for a fully automated CBRN Information System for stationary, vehicular, mobile and dispersed sensor applications that takes data directly from the sensors and generates warning and reporting information directly to the host C^4I^2 system. JWARN Blocks II & III will provide the Joint Force a comprehensive analysis capability with the use of the Joint Effects Model (JEM) which is currently under development to replace our three DoD Standard Interim Hazard Prediction tools. JWARN will also be capable of utilizing the suite of capabilities to analyze operational consequences and perform alternative course of action analyses using the suite of tools to be provided by the Joint Operational Effects Federation (JOEF). JWARN will also provide the Joint Forces with the operational capability to employ evolving warning technology that will collect, analyze, identify, locate, report and disseminate NBC threat and hazard information. JWARN will be located in command and control centers and hosted as a segment on C^4I^2 systems at the appropriate level defined in Service-specific annexes and employed by NBC defense specialists and other designated personnel. The JWARN system will transfer data automatically via hard wire or other means from and to the actual detector/sensor/ network nodes and provide commanders with analyzed data for decisions for disseminating warnings to the lowest echelons on the battlefield. It will provide additional data processing, production of plans and reports, and access to specific NBC information to improve the efficiency of NBC personnel assets.

Thank you for the opportunity to address these issues. I will try to address any additional concerns or questions the Committee may have.

Mr. TURNER. Dr. Ermak.

Dr. ERMAK. Mr. Chairman, and members of the subcommittee, thank you for the opportunity to appear before you today. My name is Don Ermak, and I lead the National Atmospheric Release Advisory Center [NARAC], at Lawrence Livermore National Laboratory.

The opinions that I present today represent my views, and I would like to focus on plume prediction and the development that is needed to address current threats to national security.

NARAC calculations for the Khamisiyah incident. NARAC is a Department of Energy and Department of Homeland Security operational support and resource center for plume modeling. Its mission is to provide timely and credible advisories to emergency managers for hazardous releases to the atmosphere.

In October 1996, the CIA asked NARAC to calculate the atmospheric dispersion of Sarin resulting from U.S. demolition activities in March 1991 at the Khamisiyah munitions storage facility.

We conducted three hypothetical release scenarios as specified by the CIA. In November, at the request of the DOD, Dr. Michael Bradley presented the NARAC results to an IDA panel on low-level exposure to chemical agents. At that meeting, we were asked to do additional simulations, and to present the results in February, which we did.

NARAC was not asked to participate in further studies. At that time, we were not convinced that all paths to understand the event had been exhausted. However, since then, several other attempts have been made.

Unfortunately, both the weather observations and the source of data appear to be inadequate for any model to provide a single definitive simulation. It is not clear to us that further analysis are warranted.

Current challenges. Recent terrorist events have heightened national concern over urban terrorism and the release of airborne, nuclear, biological and chemical agents. In response to these and other concerns, we have expanded our sources of real-time and forecast weather data, enhanced our modeling capabilities to treat biological and chemical agent releases, and the bulk effects of urban areas, and have developed Internet and Web-based communications for easy user access to NARAC.

We have also developed a state-of-the-science building scale model that simulates flow and dispersion around buildings for planning and special events. More work is needed. Both new capabilities and the expanded application of existing capabilities are needed to address this critical national security concern.

First, enhanced meteorological data networks. Atmospheric dispersion models are powerful tools. However, all dispersion models require high quality weather observations. More weather observation locations are needed for models to accurately predict plumes in urban areas.

Of particular note is the need for upper level air observations. Second, urban dispersion modeling. High fidelity, building to urban to regional scale dispersion simulations are essential for vulnerability studies, risk assessments, attribution and intelligence applications.

In addition, these models can answer important questions concerning building infiltration, command post siting, and evacuation routes for emergency response.

Third. Studies of atmospheric transitions. Many metropolitan areas are within 20 miles of an ocean or large body of water. Land-sea breezes change the direction and speed of the winds throughout the course of a day. Additional meteorological observations and improved fine scale weather prediction models are needed to provide accurate and reliable predictions in the coastal environment.

Fourth. Model evaluation. We see several key elements in model evaluation. Analytic comparisons, comparisons with field experiments, operational testing to evaluate robustness, and open literature publication and public availability to allow for scrutiny by the scientific and user communities.

While it is not practical to verify the models under all conditions, we strongly support continued field programs focused on the issues discussed above.

Fifth. A systems approach. In addition to data assimilation, weather prediction and plume dispersion models, an effective response capability needs to include dependable voice and data communications, rapid high-volume atmospheric data collection and extensive data bases of terrain, maps, population and health effects.

Of critical importance are situation awareness tools that provide emergency managers with a clear picture of the hazard. Event reconstruction capabilities that integrate observational data with prediction models are needed to estimate poorly known sources. And, finally, a highly trained multi-disciplinary staff is needed for reach-back during events.

The development of such a capability is being explored by the DOE and DHS Link program. The objective is to demonstrate the capability for providing local government agencies with NARAC capabilities in a manner that can be seamlessly integrated with appropriate State and Federal agency support. We are currently working with the cities of Seattle and New York.

In closing, let me assure you that we at NARAC are dedicated to the state-of-the-science plume prediction and emergency response support to meet the Nation's security needs. Thank you.

Mr. TURNER. Thank you.

[The prepared statement of Dr. Ermak follows:]

Written Testimony of
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to the

Subcommittee on National Security, Emerging Threats, and International Security
Committee on Government Reform
House of Representatives
Congress of the United States

Hearing Entitled:
Following Toxic Clouds: Science and Assumptions in Plume Modeling

Monday, June 2, 2003
1:00 p.m. in Room 2154
Rayburn House Office Building
Washington, DC

Dr. Donald L. Ermak
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Mr. Chairman and members of the committee, thank you for the opportunity to appear before you today. I lead the National Atmospheric Release Advisory Center (NARAC) programs at the Lawrence Livermore National Laboratory (LLNL). However, the opinions that I present today represent my views and not necessarily those of the Laboratory, the Department of Energy (DOE) or the Department of Homeland Security (DHS). Today I would like to focus on plume prediction of hazardous atmospheric releases and the science and technology development in plume modeling that is needed to address challenges posed by current threats to national and homeland security.

NARAC Calculations for the Khamisiyah Incident

NARAC is the DOE and DHS operational support and resource center for plume modeling. Its mission is to provide timely and credible assessment advisories to emergency managers for hazardous releases to the atmosphere in order to help minimize the exposure of the population at risk. For over two decades NARAC has provided the DOE and other federal agencies with real-time assessments, planning support, and detailed studies of incidents involving a wide range of hazards, including chemical, biological, and radiological releases to the atmosphere.

Before I address more current issues, I will briefly review NARAC's simulations of the 1991 Gulf War Khamisiyah event. In October 1996, the Central Intelligence Agency requested NARAC to calculate the atmospheric dispersion of sarin resulting from U.S. demolition activities in March 1991 at the Khamisiyah munitions storage facility in Iraq. Three hypothetical release scenarios were specified. NARAC was requested to complete the calculations in less than one day, and we fulfilled that requirement.

In November 1996, the Office of the Secretary of Defense requested NARAC to present the results to the Institute for Defense Analysis (IDA) Panel on Low-Level Exposure to Chemical Agents. On November 20, Dr. Michael Bradley presented the NARAC calculations for three scenarios out to 24 hours. At that meeting, we were asked to do additional simulations for 21 new case scenarios, to extend the duration of the calculations to 72 hours, and to present the results at a meeting at IDA in February 1997, which we did. NARAC was not asked to participate in further studies following the February meeting.

At that time, we were not convinced that all paths to understanding the 1991 Khamisiyah event had been exhausted. However, since then, several other attempts using other models have been made to simulate the weather and plume dispersion for the Khamisiyah event. Unfortunately, both the weather observations and the sarin source data appear to be inadequate for any model to provide a single, definitive simulation of sarin dispersion from Khamisiyah, and it is not clear that further analyses are warranted.

A more complete report is included in the written testimony.

Terrorism Presents Unique Challenges for Plume Prediction

Recent terrorist events, particularly September 11th, 2001, have heightened national concern over urban terrorism and the release of airborne nuclear, biological, and chemical (NBC) agents in the urban environment. Terrorist releases of hazardous airborne material present unique threats. Potential targets are numerous and are located throughout the world in urban areas and at critical infrastructure sites. The source of the released hazardous material may be unknown or poorly known. And the hazardous area can extend from the local release location to surrounding cities and beyond.

Preparation for such an event requires appropriate emergency planning, hazard assessment, and response training at the local city and county level. During an NBC release, emergency managers and responders (fire, police, hazmat, etc.) need accurate information on the extent and effects of the airborne material to guide decisions regarding protective actions to be taken (evacuation, sheltering in place, etc.), critical facilities that may be at risk (hospitals, schools, etc.) and safe locations for incident command post siting. In addition, response teams from multiple jurisdictions (local, state, and federal) need to effectively share information regarding the areas and populations at risk.

Science and Technology Development is Needed

Effective preparation for, and response to, the release of toxic materials into the atmosphere hinges on the accurate prediction of the dispersion pathway, local concentration, and ultimate fate of the hazardous agent. Of particular concern is the threat to civilian populations within major urban areas, which are likely targets for potential attacks. Both new capabilities, and the expansion and effective application of existing capabilities are needed to address this critical national security concern.

Enhanced Meteorological Data Networks

Atmospheric dispersion models are powerful tools that can provide realistic assessments of nuclear, chemical, and biological events. However, in order to accurately predict the location of toxic clouds and to assess their effects on human health, *all* dispersion models require high-quality, three-dimensional weather observations (wind direction, wind speed, etc.). To some extent, high-resolution weather models can help "fill in the gaps" in sparse data areas, but this capability is limited by the nature of larger-scale weather systems and other factors.

Weather observations are required not only near the ground, but also in layers of the atmosphere above the ground. Ground-level and upper-air weather observations are collected routinely at airports. Additional ground-level observational data are collected by local, state, and federal agencies. However, even more weather observation locations are needed for models to accurately predict plumes in urban areas. Of particular note is the need for above-ground weather observations in urban areas.

Integrated Urban Dispersion Modeling

Accurate and timely prediction of the atmospheric dispersion of hazardous materials in densely populated urban areas is a critical homeland and national security need. High-fidelity, computationally-efficient, building-to-urban-to-regional scale dispersion simulations are essential for vulnerability studies, risk assessments, critical infrastructure protection, attribution and signature analyses, and intelligence applications. In addition to predicting concentration levels of hazardous materials, such dispersion simulations can answer questions concerning building infiltration through HVAC (heating, ventilation, and air conditioning) intakes, exits and vents, guide command post siting decisions, and aid in determining optimal evacuation routes for emergency response.

Atmospheric Transitions and the Coastal Environment

Many metropolitan areas are within 20 miles of an ocean or a large body of water such as the Great Lakes. In these coastal regions, *land-sea breezes* change the direction and speed of the winds throughout the course of a day, especially during the transitions between day and night. In fact, these transitions can completely reverse the wind direction within an hour or so. Currently available weather observation locations are too far apart to accurately characterize the three-dimensional structure of land-sea breezes, and weather prediction models often do not adequately represent their spatial structure or timing. Additional meteorological observations and improved fine-scale weather prediction models are needed to provide accurate and reliable predictions in the coastal environment.

Model Evaluation and Testing

Plume models can be evaluated in a number of ways. We see the following key components.

- Analytic comparison with known mathematical solutions to test the numerical accuracy of the model.
- Field experiment comparison to test the model in real-world situations.
- Operational testing to evaluate the usability, efficiency, consistency and robustness of the models under operational conditions.
- Open literature publication and public availability of the model to allow for scrutiny by the scientific and user communities.

Model evaluation is an ongoing activity at NARAC. While it is not practical to verify the models under all conditions, we strongly support continued field programs focused on the issues discussed above.

Systems Approach

An effective response capability must be an integrated, end-to-end system. In addition to data assimilation, weather prediction and plume dispersion models, an effective response capability needs to include dependable voice and data communications with emergency managers and first responders; rapid, high-volume atmospheric data collection and archiving; and extensive databases of terrain elevation, maps, population density, and health effects.

Of critical importance are situation awareness tools that provide emergency managers with a clear picture of the extent of the hazard and anticipated impacts so that they can make informed decisions. In this regard, event reconstruction capabilities that seamlessly integrate observational data with prediction models are needed to provide the best possible estimates of unknown sources, as well as optimal and timely situation analyses that are consistent with both models and data.

At NARAC, we believe the core of our response capability is the highly trained and experienced staff of interdisciplinary professionals. For the capability to be robust, all these elements must be available on a 24/7 basis, be able to respond to multiple simultaneous events, and have built-in redundancies. Training for end users, periodic exercises, and established procedures are also essential features.

Local Integration of NARAC with Cities (LINC)

The development of such a capability is being explored by the DOE/DHS Local Integration of NARAC with Cities (LINC) program. The objective of this program is to demonstrate the capability for providing local government agencies with NARAC atmospheric plume prediction capabilities in a manner that can be seamlessly integrated with appropriate state and federal agency support for homeland security. We are currently working with the City of Seattle, which we supported during the recent TOPOFF2 exercise, and New York City, which we supported during the Staten Island fuel fire in February of this year. Expansion to four additional cities is planned for this summer.

Commitment to National Security

In closing, let me assure you that we at the National Atmospheric Release Advisory Center are dedicated to state-of-the-science plume prediction and emergency response support in the event of an atmospheric release of hazardous material. Over the past several years, our concerns have expanded to include the atmospheric release of WMD agents and other hazardous material from terrorist activity. We have built on our historical nuclear weapons mission and developed unique expertise, capabilities and technologies to meet these emerging threats, including the threat of a biological or chemical agent release. We are committed to using our world-class scientific and technological resources – people, equipment, and facilities – to meet the nation's security needs today and in the future.

The ARAC[1] Khamisiyah Calculations
Michael M. Bradley[2], Principal Investigator
National Atmospheric Release Advisory Center (NARAC[3])
Lawrence Livermore National Laboratory (LLNL)

Initial Calculations, October 1996

Our initial calculations for the Khamisiyah incident were done on very short notice. On October 16, 1996, ARAC (the Atmospheric Release Advisory Capability at LLNL) was requested by associates in Q-Division, NAI[4] Directorate, LLNL (on behalf of the Central Intelligence Agency) to prepare model runs concerning the destruction of chemical munitions in occupied Iraq following the Gulf War. ARAC was requested to complete these calculations in less than one day. The information for the assessment was received by ARAC from Q-Division shortly before noon local time on 16 October, 1996, and the products needed to be in Washington DC by 9:00 am eastern time the following day, 17 October 1996. All information provided to ARAC concerning the assessment in regards to the source term, time and duration of release, exposure contours, and meteorological data was identical to that used by SAIC for their assessment. ARAC was provided with three release scenarios based on the number of possible chemical munitions in the ammunition dump when destroyed, and how the chemical munitions might behave at the time of destruction. We were also provided with two different meteorological records. The first was upper-air data for a large region of the Far East in text format on 3.5" disks. The second was hardcopy tracings of wind speed and direction at hourly intervals beginning at 0000 UTC on 09 March 1991 and extending to 0000 UTC 13 March 1991. The latter required manual, visual interpolation by ARAC assessors to determine the actual hourly direction and speeds. We completed the calculations and faxed copies of our plots to the CIA in less than 24 hours.

November 1996 Presentation

We were asked by the Office of the Secretary of Defense to present our results to the IDA (Institute for Defense Analysis) Panel on Low-Level Exposure to Chemical Agents on November 20, 1996. The meeting was hosted by IDA and chaired by General Welch, retired Air Force Chief of Staff, and the Director of IDA. We presented a full set of calculations for three scenarios out to 24 hours. For this set of calculations we used essentially the same meteorological data that we used for our October simulations.

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[2] Coordinator for National Security Projects, National Atmospheric Release Advisory Center L-103, P.O. Box 808, Lawrence Livermore National Laboratory, Livermore, CA 94551.
[3] At the time when the Khamisiyah calculations were accomplished, the name of the organization was ARAC. Approximately three years ago, due to an expanded mission, the organization was renamed NARAC. The DOE-sponsored ARAC Program continues to be NARAC's primary mission.
[4] Nonproliferation, Arms Control, and International Security

February 1997 Presentation

We were asked to simulate 21 case scenarios, to extend the duration of our calculations to cover a 72-hour period, and to present our results at a meeting at IDA in February 1997. The scenarios consisted of cases for 550, 325, and 100 rockets, and for instantaneous, evaporative, and a combination of 50% instantaneous and 50% evaporative releases of sarin. In each case with evaporation, the evaporation was allowed to occur over 12-hour, 36-hour, and 60-hour periods.

For this final set of calculations we used the meteorological data from the same observational sources as for the November presentation, extended out to 72 hours after the release, plus data from five additional surface stations and eight additional upper air stations that we obtained from AFCCC (Air Force Combat Climate Center). In addition, we obtained a diskette from SAIC containing surface wind data, and noted that the data for three of the stations were slightly different from what we had obtained from the hardcopy plots. We replaced the previous data with the new data on the diskette.

The results of our simulations indicated that the 72-hour exposure due to the instantaneous release of sarin from 550 rockets covered an area extending south-southeast from the release point to the Persian Gulf, then turning eastward at the Gulf coast, and then turning northeast over the Gulf and extending northeastward across central Iran. Time-integrated concentrations in excess of 0.5 mg-min/m^3 ("minimal effects level") covered a 2,255 square kilometer area extending approximately 130 km south-southeast from the release point. Dosages in excess of .05 mg-min/m^3 ("occupational limit") were predicted over a 114,468 square kilometer area, including Kuwait City, an approximately 200 km-wide swath across the Persian Gulf, and the higher elevations of the Zagos mountain range in Iran. The time-integrated concentrations from the 325- and 100-rocket scenarios covered the same area but were proportionately reduced in magnitude.

Due to changes in the wind direction over time, the totally evaporative releases resulted in simulated initial exposures to the south-southeast of Khamisiyah (as in the instantaneous release scenario), and later exposures to the northwest of Khamisiyah (even for the relatively short 12-hour evaporation scenario). In the 36-hour and 60-hour evaporation scenarios, the main exposures were to the northwest of the Khamisiyah, in a path almost centered along a straight line between Khamisiyah and Baghdad. Small areas in the higher Zagos mountain range were also exposed.

The largest simulated areal coverage (304,400 square kilometers) of time-integrated concentrations exceeding .01 mg-min/m^3, (the "general population limit") occurred for the 550-rocket scenario with 50% instantaneous release, 50% evaporative release over 36 hours.

In contrast to our simulations, calculations by the Navy Research Laboratory (NRL), using the COAMPS forecast model (and apparently later by SAIC, using the OMEGA forecast model) to predict (in a forensic sense) the wind fields, showed the plume from an instantaneous release moving first southerly, and then turning to the west-southwest. During the panel discussion at the February, 1997 IDA meeting, Dr. Kerry Emanuel, Director of the Center for Meteorology and Physical Oceanography at MIT, commented on these differences, noting that the modeled wind exhibited a line of diffluence in the general vicinity of Khamisiyah, and that the precise location of this line was critical to which way the material would be transported by the wind. He stated that an ensemble study of the problem would likely produce a bimodal distribution of results, with half the simulations showing a plume similar to ours, and other half showing a plume similar to NRL's.

Final Comments

After February 1997, we were not asked to participate in further studies of the Gulf War Syndrome. At that time, we were not convinced that all paths to understanding the 1991 Khamisiyah event had been exhausted. However, since then, several other mesoscale atmospheric models and atmospheric dispersion models have been used in attempts to simulate the weather and to calculate the transport, diffusion, and resulting sarin exposure for the event. It is not clear that further analyses are warranted.

Analyzing the Khamisiyah event is a very difficult problem, due to sparse weather data and great uncertainly regarding the amount, and nature of release, of the sarin. Although NARAC's atmospheric dispersion simulation capability is world-class, the accuracy of our simulations is limited (just as for all dispersion models) by the adequacy and accuracy of the three-dimensional atmospheric data (wind direction, wind speed, boundary layer depth, etc.) used by our models. This limitation holds not only for dispersion simulations based on observed weather conditions, but also for those based on modeled weather conditions, because the modeled weather is still ultimately based on weather observations. To some extent, mesoscale models can help "fill in the gaps" in historical observational weather data, but this capability is limited by the nature of larger-scale weather systems and other factors.

In the case of the Khamisiyah event, both the observational weather data and the sarin source data appear to be inadequate for any model to provide a single, definitive simulation of the sarin dispersion with the desired accuracy and confidence level. Given those constraints, an ensemble modeling methodology probably is the most appropriate approach for attempting to analyze the event. Perhaps enough simulations already have been accomplished to support that type of analysis.

Mr. TURNER. Mr. Hicks.

Mr. HICKS. Good afternoon, Mr. Chairman, and members of the subcommittee. My name is Bruce Hicks, and I am Director of the Air Resources Laboratory of the National Oceanic and Atmospheric Administration [NOAA]. I have been actively involved in studies of the transport and diffusion of pollutants in the atmosphere for more than 40 years, with research experience in Australia and at several U.S. laboratories. I have been with NOAA since 1980.

I recently served as the cochairman of the joint action group for the selection and evaluation of atmospheric transport and diffusion models set up by the office of the Federal coordinator for meteorology.

I have been asked to present some views regarding the current state of the science in the modeling of atmospheric dispersion. It is my pleasure to do so. I would like to show three diagrams later as I speak.

It is a major part of the mission statement of NOAA to provided forecasts to protect the public. Forecasts of atmospheric dispersion are among the capabilities that we provide.

The Chernobyl nuclear accident is an example where dispersion models were used real-time for an unfolding emergency situation. The results showed that many dispersion forecasts were quite deficient. The World Meteorological Organization concluded that there was need for a more organized provision of dispersion forecasts in the future, and hence set up a small network of international recognized dispersion forecast providers.

There are now seven of these in France, England, Canada, Russia, China, Australia, and in the USA.

In practice, Montreal serves as a back-up to the U.S. capability in NOAA and vice versa. There are 122 weather forecast officers of the National Weather Service nationwide. In the event of an incident requiring the forecast of dispersion, each of those centers is prepared to provide dispersion predictions out to at least 2 days.

The accuracy of the dispersion forecasts depends on the accuracy with which the meteorological wind fields are known. Operational weather forecasts guidance is available at 12 kilometer resolution. And the weather service forecasters are now beginning to provide rude forecast windshields at even higher resolution.

The model we use, HYSPLIT, is operationally integrated with the Weather Service's highest resolution weather prediction models, and takes advantage of greater resolution, both spatial and temporal, within the model stream at a data density higher than is generally practical for rapid external distribution.

Dispersion predictions for selected locations across the Nation are made with updated weather forecast data four times each day. For emergency events or preparations, dispersion predictions are run, on request, at 12-kilometer resolution and results are generally available within 15 minutes.

4-kilometer resolution predictions can also be run on demand. The model, HYSPLIT, is also run on remote computer systems. But, these remotely run applications rely on reduced resolution weather data to drive the dispersion calculation. All of the weather forecast officers have access to both kinds of product.

The course of product is also available via the Internet to users to who are registered by our laboratory. This is known as the real-time environmental applications and display system, READY, which is used routinely by over 1,500 registered users.

The READY system brings together dispersion models, display programs, and forecast programs generated over many years in a form that can be used by anyone. The products are used, for example, to guide response activities following industrial accidents and forest fires.

The data have been used by every long distance manned balloon venture so far. The READY System is widely known and routinely employed. The models that now make be READY were central in the activities addressing the Kuwait oil fires back in 1990 and 1991.

To us, the Khamisiyah experience was quite revealing and is worthy of some direct attention. In their scrutiny of the subject, the Office of the Special Assistant for Gulf War Illness, elected to use a small number of dispersion models, mainly from within the DOD system. There were indeed very few meteorological observations available, and hence, the dispersion codes were driven by exceedingly sparse and sometimes questionable information.

To us it is not surprising that the dispersion systems yielded different answers. Each one of these answers represented a good approach to the problem. There was no way to weigh or order these alternative depictions of the plume from Khamisiyah.

The community has now adopted the concept of ensemble modeling, in which many models are used to address the situation, and the answers are derived from analysis of all of their products. This was much like what was done for Khamisiyah, but on a larger scale.

In North America, we are not short on data, although we still have need to learn how to use the available information optimally. The shortcomings that caused the dismay about Khamisiyah should not be seen as a basis for concern necessarily in North American situations. I should point out that among other products, the READY system maintains a continuously updated plume forecast for every nuclear power plant installation in North America.

In the event of a release of radioactivity from any nuclear power plant, there is no need to start a dispersion forecast, it is always immediately available. All that is needed is a password and access to the relevant READY product.

So far, I have emphasized the long-range aspect of the problem. Much of the focus of present concern is on urban cities, and urban areas and cities. NOAA, in partnership with EPA, provides a local dispersion capability with the CAMEO/ALOHA system. CAMEO is the Computer Aided Management of Emergency Operations System. The neofield atmospheric dispersion model, provided in conjunction with CAMEO is ALOHA, the air relocations with hazardous atmospheres model.

First responders and emergency planners use CAMEO to plan for and to respond to chemical emergencies. More than 30,000 copies of this model system have been distributed to users across the country in the last year.

Over 1,000 local responders will receive training during the next year. It is for cities and urban areas that the greatest challenge exists. The monitoring stations used by the Weather Service at this time are typically located at airports, but the area of main concern is usually quite distant from the airports.

May I have the first visual, please? Is it possible? Here you will see an example of a dispersion product, showing spread of materials from Ohio across the United States. This product is based upon weather—is based upon the results of actual release of material. This is not a forecast. This is what the plume actually looks like. That is what we are trying to forecast.

In practice, though, the information that we use when we try to forecast that comes from the weather forecast officers and from largely the airports in areas.

It is the wind fields that determine the released material and where it will drift to. And it is the atmospheric turbulence that controls the rate at which dilution occurs. Both are strongly affected by the presence of buildings or other structures.

This is large scale. Now I want to talk about the smaller scale. The Nation has many atmospheric dispersion model that purport to predict the dispersion of hazardous materials released into the urban atmosphere. The capabilities are widespread across the Federal agencies.

Every one of these systems has some special quality that makes it unique. The trick now facing the atmospheric dispersion community is to determine which subset of the many dispersion systems is best suited to the latest challenges.

In a recent report, the Office of the Federal Coordinator concludes that there are 29 modeling systems running 24 by 7 within the Federal system. Of these, seven systems are used nationwide, including HYSPLIT NOAA.

Recent field studies in Salt Lake City, for example, have yielded a lot of new information. However, we do not yet know how to apply the results so that they may be applicable for some specific urban area to another, with confidence.

Consequently, there is a strong need to obtain relevant data. This is the basis for the design of what we refer to as DCNet, a program to provide Washington with the best possible basis for dispersion computation as is needed for both planning and possible response.

The problem we face is complex. The windows within a city sometimes bear little resemblance to those in the surrounding countryside, as I have already said. For small street level releases of pollutants, these local scale conditions are dominant, especially within the first minutes to hours, until entrainment above the buildings is dominant.

The presence of buildings and the street canyons separating them often causes winds that are almost random, exceedingly difficult to predict or even describe.

The flow above the urban canopy is far more describable in terms of larger scale meteorology. It is convenient to think in terms of two regimes, the street canyon flows beneath the urban canopy and the skimming flow above it.

Washington presents an excellent test bed for studies, because the urban canopy is well defined by the height constraints of the buildings. New York, for example, presents an opposite extreme.

In New York, many buildings are not only very high, but their height is quite variable. Thus, there are two reasons for focusing on the Washington metropolitan area.

Mr. TURNER. Mr. Hicks, are you near conclusion?

Mr. HICKS. Thank you. I would like to show you the next slide, which shows the array of sites presently deployed in the Washington area. There are approximately 13 locations where special instrumentation is being deployed.

And the last slide shows you the main point that I would like to reach. It shows you the window roses. It is a depiction of the wind directions from different locations across the Washington area, which has been shown by the DCNet operation. They are quite different.

Mr. Chairman, I would like to close with that. That concludes my testimony. Thank you for the opportunity. I would be happy to respond to any questions that the subcommittee might have.

Mr. TURNER. Thank you, Mr. Hicks.

[The prepared statement of Mr. Hicks follows:]

WRITTEN TESTIMONY OF

BRUCE B. HICKS
DIRECTOR, AIR RESOURCES LABORATORY
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
DEPARTMENT OF COMMERCE

BEFORE THE
SUBCOMMITTEE ON NATIONAL SECURITY, EMERGING THREAT, AND INTERNATIONAL RELATIONS
COMMITTEE ON GOVERNMENT REFORM
U.S. HOUSE OF REPRESENTATIVES

June 2, 2003

Good afternoon, Mr. Chairman and Members of the Subcommittee. My name is Bruce Hicks, Director of the Air Resources Laboratory of the National Oceanic and Atmospheric Administration (NOAA). I have been actively involved in studies of the transport and diffusion of pollutants in the atmosphere for more than 40 years, with research experience in Australia and at several US laboratories. I have been with NOAA since 1980. I recently served as the co-Chairman of the Joint Action Group for the Selection and Evaluation of Atmospheric Transport and Diffusion (ATD) Models of the Office of the Federal Coordinator of Meteorology for Meteorological Services and Supporting Research, most commonly known as the Federal Coordinator for Meteorology (OFCM). Following the events of September 11, 2001, the Federal Coordinator for Meteorology formed the Joint Action Group to include researchers, modelers, and user representatives from all Federal agencies actively employing atmospheric dispersion models for emergency response applications. The Federal Coordinator charged the Joint Action Group with the responsibility to (1) review the ATD modeling systems currently used by the Federal agencies, (2) conduct a preliminary analysis of gaps in understanding of the processes on which the modeling systems are constructed, (3) determine which operational ATD models are appropriate for use in addressing selected scenarios, (4) recommend research and development needs, and (5) review model evaluation procedures. I have been asked to present some views regarding the current state of the science in the modeling of atmospheric dispersion. It is my pleasure to do so. Three diagrams are appended, to illustrate some of the important points that I would like to make.

Concerns about atmospheric dispersion and weapons of mass destruction date back to the First World War and trench gas warfare. In the 1950s, the emphasis shifted to radioactive fallout. In the 1960s and 70s, the focus became hazardous chemicals. In the 1980s and 90s, accidents at Chernobyl and Three Mile Island occurred, and smoke and other air pollutants grew to be priority issues. Today, the main interest is in emergency response and planning. It is a major goal of NOAA to provide forecasts to protect the public; forecasts of atmospheric dispersion are among the capabilities we provide.

The modeling methods now commonly in use were developed by a small cadre of scientists, many of whom worked for my laboratory. As time progressed, the dispersion forecasting methodologies improved, partially due to the growth in computer power but also partially because of a slowly improving understanding of the atmospheric processes that cause dispersion to occur. The major processes are transport and diffusion.

The performance of dispersion models is assessed using tracers, either some trace gas that is intentionally released or a tracer "of opportunity" resulting from an accident or some other release into the air of some substance that can be measured downwind. However, the numerical comparison of model predictions with observed field data provides only a partial means for assessing model performance.

The Chernobyl nuclear accident is an example where dispersion models were used in real-time for an unfolding emergency situation, and were tested against the data sets that were collected. The results showed that many dispersion forecasts were quite deficient. The World Meteorological Organization concluded that there was need to provide for a more organized provision of dispersion forecasts in the future, and hence set up a small network of internationally recognized dispersion forecast providers. There are now seven of these Regional Specialized Meteorology Centers, distributed globally – Toulouse, France; Bracknell, England; Montreal, Canada; Oblinsk, Russia; Beijing, China; Melbourne, Australia; and Camp Springs, MD, USA. These are the centers of excellence that are internationally recognized. In practice, Montreal serves as a backup for the US capability, and *vice versa.*

The same dispersion model underpins the US, Australia, and Chinese national system – the Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model. Over the years, HYSPLIT has been extensively tested, firstly in a series of long-range tracer studies using perfluorocarbon and Krypton-85 gases, and secondly in a variety of opportunistic studies of smoke from fires, for example. Perfluorocarbons are variants on the gases used in refrigeration. They can be measured in exceedingly small concentrations. The field tests in which these tracers were used covered much of the eastern USA. The Cross Appalachians Tracer Experiment (CAPTEX) was conducted in 1983, following some initial tests in 1980. The larger-scale Across North America Tracer Experiment (ANATEX) was conducted in 1987. The first diagram attached shows how a puff of dispersing material spreads as it is transported across the eastern USA, over a four day period. These field studies were conducted by my laboratory, under sponsorship of the Department of Defense, and Department of Energy. Following the success of these field evaluations, HYSPLIT has been adopted as the standard dispersion forecasting tool used by the National Weather Service.

There are 122 Weather Forecast Offices (WFOs) of the National Weather Service, nationwide. In the event of an incident requiring a forecast of dispersion, each of these centers is prepared to provide dispersion predictions, out to at least two days. The forecasts are generated at the high-performance computing facility at the National Centers for Environmental Prediction (NCEP), which operates on a 24 X 7 basis, as do the WFOs. WFO forecasters are responsible for dissemination of dispersion output to state and local emergency managers, thus taking advantage of field forecaster experience and understanding of local weather issues. Hence, it is quite intentional that the dispersion forecasts are vectored through local regional forecast offices. However, the field forecasters are not dispersion experts; they rely on support from NOAA scientists to answer any detailed questions that might arise.

The accuracy of dispersion forecasts depends on the accuracy with which the meteorological wind fields are known. Operational weather forecast guidance is available at 12 km resolution, and NWS forecasters are now beginning to provide gridded forecast wind fields at higher resolution by means of the National Digital Forecast Database servers. The NWS maintains a large network of observing stations, at locations selected to provide nationwide coverage, including surface stations at airports (ASOS sites) and throughout communities (the modernized cooperative observer network) and many others; it also ingests a wealth of data from other federal and private sector partners. NWS routinely runs advanced numerical models to interpret the data obtained and drive the Nation's numerical weather prediction models. The HYSPLIT model is designed specifically to be driven by a comprehensive set of numerical prediction model data. HYSPLIT is operationally integrated with the NWS's highest resolution weather prediction models, and takes advantage of greater resolution-- spatial and temporal-- within the model stream at a data density higher than generally practical for rapid external distribution. Dispersion predictions for selected locations across the nation are made with updated weather forecast data four times daily. For emergency events or preparations, dispersion predictions are run on request at 12 km resolution and results are generally available within 15 minutes. Four km resolution predictions can also be run on demand. This increase in resolution requires much greater processing time-- results are available within two hours. HYSPLIT is also run on remote computer systems; however, these remotely-run applications rely on reduced-resolution weather data to drive the dispersion calculation. The use of reduced-resolution weather data in remotely-run applications is necessitated by the huge amount of numerical information involved. Because pushing this volume of data through the Internet or via some dedicated communications system takes time, today's dispersion forecasts are generated either with HYSPLIT integrated with the high-resolution weather models on the NWS mainframe computers, or by lower-resolution (40 km) data driving HYSPLIT on satellite computer systems. All of the Weather Forecast Offices have access to both kinds of product.

The coarser product is routinely made available via the Internet, to users who are registered by scientists of my laboratory. This is the Realtime Environmental Applications and Display sYstem, used routinely by over 1500 registered users for accessing and displaying meteorological data and running trajectory and dispersion models on the web server of my laboratory. The READY system brings together dispersion models, graphical display programs and textual forecast programs generated over many years into a form that is easy to use by anyone, but its primary focus is for atmospheric scientists. The products are used, for example, to guide response activities following industrial accidents and forest fires. The data have been used by every long-distance manned balloon venture so far. The READY system is widely known, and routinely employed. Evidence available to us indicates that it is the major outlet for dispersion products provided by the federal government. The models that now make up READY were central in the activities addressing the Kuwait oil fires in 1990/1991.

The Khamisiyah experience was quite revealing, and is worthy of some direct attention. In their scrutiny of the subject, the Office of the Special Assistant for Gulf War Illness (OSAGWI) elected to use a small number of dispersion models, mainly from within the DoD system. There were few meteorological observations available, and hence the dispersion codes were driven by exceedingly sparse and sometimes questionable information. It is not surprising that the dispersion systems yielded different answers. Each one of these answers represented a good approach to the problem. There was no way to weigh or order these alternative depictions of the plume from Khamisiyah. Consequently, it was decided to err on the side of caution and to assume that every prediction was equally likely. This is far from an optimal way to proceed, but in the lack of meteorological observations a better approach would be hard to conceive. There were few data, and there was no basis to select one model conclusion instead of another. For remote locations like the Khamisiyah case, the situation today has not improved greatly. We are still at the mercy of the meteorological forecasts, and if there are no observations to drive the forecasts then these forecasts are highly vulnerable. The community has now adopted the concept of ensemble modeling – in which many models are used to address the situation and the answers are derived from analysis of all of their products. This is much like what was done for Khamisiyah, but on a larger scale. The DOD has a good suite of models, which are tailored for combat applications, and they have been upgraded since the Persian Gulf War. However, they will continue to suffer from the lack of meteorological observation data, which can limit their effectiveness.

In North America, we are not short on data, although we still have need to learn how to use the available information optimally. The shortcomings that caused concern in the Khamisiyah case should not be seen as a basis for concern about North American situations.

Among other products, READY maintains a continuously updated plume forecast for every nuclear power installation in North America. In the event of a release of radioactivity from any nuclear power plant, there is no need to start a dispersion forecast. It is always immediately available. All that is needed is password access to the relevant READY product.

The discussion so far relates to long-range transport and diffusion of pollutants. However, the focus of current concern is on places where people live or congregate, or where there are buildings or other structures or institutions of national importance. Attention is mainly on urban areas and cities. NOAA, in partnership with EPA, also provides a local dispersion capability with the CAMEO/ALOHA system. CAMEO is the Computer-Aided Management of Emergency Operations system. The near-field atmospheric dispersion model provided in conjunction with CAMEO is ALOHA – the Areal Locations of Hazardous Atmospheres model. First responders and emergency planners use CAMEO to plan for and respond to chemical emergencies. The system integrates a chemical database and a method to manage the data, an air dispersion model, and a mapping capability. Responders can use CAMEO to access, store, and evaluate information critical for developing emergency plans. ALOHA allows the user to estimate the downwind dispersion of a chemical cloud based on the toxicological/physical characteristics of the released chemical, atmospheric conditions, and specific circumstances of the release. ALOHA also assists the user in estimating the amount of toxic chemicals entering the atmosphere by modeling a variety of release scenarios – discharges from tanks or pipelines as well as evaporating puddles. ALOHA makes use of local wind speed and direction observations or automated measurements.

NOAA, in collaboration with EPA, has delivered more than 30,000 copies of CAMEO and ALOHA to users across the country in the last year, providing communities and first responders with a tool that helps them prevent, prepare and respond to local emergencies. Over 1000 local responders will receive CAMEO/ALOHA training during the next year as part of joint NOAA, EPA, and Office of Domestic Preparedness efforts.

It is for cities and urban areas that the greatest challenge exists. Cities and urban areas influence wind fields considerably, in ways that the standard monitoring stations of the NWS do not yet detect well. These monitoring stations are typically located at airports, but the area of main concern is usually quite distant from the airports. We need to consider many possible emergency scenarios, and we must prepare for them with the fervent hope that our preparations will never be tested. To these ends, we need modeling systems that can be used to describe the dispersion of trace gases, biological agents, and radioactivity through the air, over distances that are intermediate between the regional scales of the HYSPLIT variety of dispersion models, and the ALOHA variety of near-field capabilities. In reality, wind fields are affected by the presence of buildings in ways that are not yet fully understood. Consequently, we tend to rely on the acquisition of actual data rather than on the predictions of wind fields based on some preferred numerical model. It is the wind fields that determine where released materials will drift, and it is atmospheric turbulence that controls the rate at which dilution occurs. Both are strongly affected by the presence of buildings or other structures, in ways that are often quite random.

The nation has many atmospheric dispersion models that purport to predict the dispersion of hazardous materials released into the urban atmosphere. The capabilities are widespread across the federal agencies, state and local authorities, academia, and the private sector. Every one of these systems has some special quality that makes it unique. The trick now facing the atmospheric dispersion community is to determine which subset of the many dispersion systems is best suited to the latest challenges. In the OFCM report, Atmospheric Modeling Releases from Weapons of Mass Destruction: Response by Federal Agencies in Support of Homeland Security, the Joint Action Group identifies 29 modeling systems running 24 x 7 within the federal system. Of these, seven systems are used nationwide including HYSPLIT and ALOHA. These are roughly equally split between the military and civilian agencies.

Sorting out which might be the best proved impossible, because each has special strengths to address the particular issues for which it was initially intended, and each suffers from specific weaknesses, the most important of which were documented as research and development needs in the report. The OFCM report stated, therefore, that there is no existing "best capability" suitable for widespread application. Nor is it likely that any such generalized model will be developed in the near future. Instead, we need to learn how to access the suite of capabilities now in use, and to select from it the capabilities best suited to situations that may arise. The margin of error in the models can be significant and is dependent on the scenario and the availability of reliable meteorological input data. The OFCM continues to work on these issues through its Federal coordinating infrastructure and in collaboration with the academic community and private sector through workshops and forums.

There is a practical reality that complicates the situation substantially. Most available modeling systems have been developed on the basis of understanding generated in field studies over grass or desert, completely in the absence of buildings or other large surface structures. The application of current concern centers on cities and urban areas, where the buildings will cause changes in wind fields that are not yet well understood. There are research programs presently underway to investigate the dispersion characteristics of urban areas. Recent field studies in Salt Lake City, for example, have yielded a lot of new information. However, we do not yet know how to apply the results applicable for some specific urban area to another, with confidence. Consequently, there is a strong need to obtain relevant data, based on measurements in the situations of actual importance.

This is the basis for the design of DCNet – a program to provide Washington with the best possible basis for dispersion computation, as is needed for both planning and possible response.

The problem we face is complex. The winds within a city sometimes bear little resemblance to those of the surrounding countryside. Emphasis for weather forecasting is on larger-scale patterns, and therefore observations of wind and temperature in cities below the level of tall buildings have not been weighted heavily in weather forecast models. For small, street-level releases of a contaminant, these local-scale conditions are dominant, especially within the first minutes to hours, until entrainment above the buildings is significant. The presence of buildings and the "street canyons" separating them often causes winds that are almost random, exceedingly difficult to predict or even describe. The flow above the "urban canopy" is far more describable in terms of larger scale meteorology. It is convenient to think in terms of two regimes – the street canyon flows beneath the urban canopy and the "skimming flow" above it. Washington presents an excellent testbed for studies, because the urban canopy is well defined by the height constraint on the buildings. New York, for example, presents an opposite extreme. In New York, many buildings are not only very high, but their height is quite variable.

There are thus two major reasons to focus attention on the Washington metropolitan area. First, the attention is needed because, the attacks of 9/11 demonstrate it to be a target. Second, the urban landscape lends itself to the application of new science, so that greatly improved capabilities are feasible. But there is a third reason that makes Washington so attractive. In 1983, a year-long study was conducted here, largely replicating the sort of situation that some people fear we might be confronting. In the 1983 study, minute amounts of harmless but very easily detected trace gases were released from a number of locations around the beltway. Several trace gases were used, all variants on the fluorocarbons used in refrigeration. This METRopolitan Experiment ("METREX") has provided a baseline of understanding not present anywhere else. METREX was a NOAA program, specifically designed to test how well dispersion models perform in an urban area like the District of Columbia. The news was not good – the predictions were very poor. But there was some good news as well – the models appear to describe the statistics of the behavior quite well. That is, they fail to reproduce the fine details of what is going on, but they succeed in describing the probability that some particular range in exposures will be encountered. Based on this experience, the current program addresses the statistical description of urban dispersion directly. The statistical approach, rather than focusing on predicting the most accurate snapshot of concentration of contaminant at a specific time and place, better supports the goal of dispersion predictions – to help decision makers assess the likelihood that people will be harmed.

With the experience of METREX behind them and the recognition that Washington is now an attractive target, NOAA scientists have deployed an array of meteorological stations in the downtown area. These stations report not only the wind speed and direction, but also the intensity of the turbulence. Sonic anemometry is used. Sonic anemometers measure the speed of sound along three axes, and derive from these data the wind speed along these axes with great accuracy and frequency. A measurement frequency of ten times per second is typical. The instruments are mounted on 10 m towers, mostly on the tops of buildings where data on the skimming flow can be obtained. The second figure attached gives some details of the current deployment. One of the most visible locations can been seen on the roof of the National Academy of Sciences. Data are analyzed by computers on each tower and are transmitted to a central analysis location every fifteen minutes. The data already show the dangers inherent in assuming the relevance of nearby airport data. The third figure attached shows the differences in the distribution of wind speeds and directions across the downtown area. If airport data were used to address the case of a dispersion situation on the Mall, then the answers would be wrong.

For obvious reasons, the Washington downtown system is referred to as "DCNet." It is proposed that the operation should be extended to cover the greater DC Capital Region. The system is a demonstration of capabilities that now exist and are ready for deployment. The trial system enables a user to identify a source location with the click of a mouse, and define the downwind area of potential high risk using observations from the DCNet system. There is no long wait involved. Results can be generated almost instantaneously. In practice, this new generation of dispersion system relies on access to the best available weather forecast data as well as the information from dedicated arrays of sensors like DCNet. There are, of course, many other sources of meteorological information that could be accessed (highway sensors operated by Departments of Transportation, for example). There are additional data available from radars and from other remote sensing sources. A challenge to the research community is to sort out how best to make use of data from all available origins.

It has already been emphasized that the main goal of DCNet is to refine our understanding of how hazardous trace gases and particles are dispersed across the kind of area where people work and live. To this end, the operational systems that are now being improved are viewed not as being final developments, but as continuously evolving capabilities with continuing upgrades as improved understanding warrants. A major concern is that an incorrect forecast could lead to decisions that do more harm than good. To demonstrate the accuracy of the forecasts, a new round of tracer studies will be required.

The Washington exercise is seen as a prototype of what could eventually be a nationwide program. There is testing and development ahead, well before any decisions about wider deployment are made. In the meantime, the system now in place offers this area an unparalleled capability to plan for possible attacks, and to respond if one were to occur.

On the regional scale, weather forecasting and dispersion forecasting systems are becoming increasingly integrated. There are already model systems that combine the two, and it is the present intention to install one of these modeling frameworks as the nation's premier forecasting tool in the near to intermediate future. This new model framework is known as the Weather Research and Forecasting model (WRF). Once WRF is up and running, there will be no need for self-standing dispersion codes that access meteorological data from elsewhere and compute dispersion from those data. It can be said that we are presently operating in a stop-gap mode while the National Weather Service, working with the Department of Defense and a variety of other agencies, refines its next generation of forecasting model. In the future, the dispersion forecasts will be a far more routine product than at the moment. Moreover, these dispersion products will make full use of the remote probing data base that is now becoming a mainstream part of the national meteorological observing system (such as advanced RADAR and sonic anemometry). Other agencies will be able to access the products using the real-time and streamlined communications systems on which the NWS relies. In the meantime, the NOAA operational systems already provide state-of-the-art forecasts of dispersion and are ready for refinement to address specific situations of special concern.

Thank you, Mr. Chairman and Members of the Subcommittee. This concludes my testimony for today. Thank you for the opportunity to testify, and I would be happy to respond to any questions that the Subcommittee may have.

Mr. TURNER. Dr. Barron.

Dr. BARRON. Good afternoon. My name is Eric Barron. As Chair of the National Research Council's Board on Atmospheric Sciences and Climate, I am here today to discuss the Board's new report, entitled "Tracking and Predicting the Atmospheric Dispersion of Hazardous Material Releases: Implications for Homeland Security."

There are three phases to addressing deliberate release of hazardous materials, such as chemical, biological or nuclear agents. Preparedness, response, and recovery and analysis.

The atmospheric sciences contributes to all three. In the preparedness phase, we can enable risk assessment, improve training exercises and aid in evaluating outcomes associated with potential sites of hazardous release. The preparation for the Salt Like City Olympics is a good example of this mode of operation.

In recovery and analysis, atmospheric models and observations can be used to examine exposure levels. Such assessments were utilized extensively following both Chernobyl and September 11th in both real-time and in terms of recovery.

Response is a much greater challenge, because time is of the essence and vulnerable regions such as major cities present special challenges. In every one of those phases, improvements in capability are warranted, but it is particularly in the area of response that the needs of first responders and emergency managers do not seem to be well satisfied by existing capabilities.

Our capacity to meet these challenges rests on three interconnected elements: Atmospheric dispersion models that predict the path and spread of hazardous agents, observations of the plume and local meteorological conditions, and effective coordination among the relevant atmospheric science and emergency response communities.

The committee recommends that we establish a nationally coordinated effort for the support and evaluation of existing models and development of new modeling approaches. The Office of the Federal Coordination for Meteorology has taken some important initial steps in this regard.

As a part of this effort, the report concludes that we must focus on operational and specifically urban use of these models, develop model solutions that specifically quantify confidence levels and the nature of variability of the predictions, enhance our ability to assimilate meteorological, primarily wind, temperature and moisture, and CBM sensor data into models, conduct urban field programs and wind tunnel simulations to better evaluate and to better develop models, and to focus on rigorous and independent model intercomparisons and evaluations.

In terms of observations, the committee recommends that we conduct comprehensive surveys of existing observational networks and work to improve those networks, especially around key vulnerable areas. Here the most important points are to improve our ability to identify the source and the plume, characterize low-level winds, characterize the depth and intensity of atmospheric turbulence, and identify areas of potential degradation and dry or wet deposition of the harmful agents, to explore supplementing existing radar network with short-wave length radars that enable better meteorological observations and better identification of the plumes.

To continue to develop airborne and surface mobile observation platforms with a focus on rapid deployment and accessibility, and to conduct field programs with the objective of using observations to test and modify dispersion and missile scale transport models.

The committee is also concerned that emergency managers need a more realistic understanding of the uncertainties associated with dispersion prediction, and the atmospheric sciences community should have a better understanding of the needs of responders. In particular, the committee recommends Table Top event simulation exercises convened on a regular basis to bring together response teams and members of the atmospheric sciences community to help establish and exercise a common set of data interface and decision support protocols.

And, two, a more carefully crafted management strategy with a strong center of coordination and clear lines of responsibility. We suggest a single point of contact to connect emergency responders to appropriate modeling centers for immediate assistance.

In at least one urban area, a fully operational dispersion tracking and forecasting system should be established. This should be a comprehensive system designed as a test bed for understanding and improving our capabilities, and providing the basis for a much broader national implementation.

As a final point, it should be emphasized that robust atmospheric observing systems and high resolution atmospheric modeling systems will be used for many other important purposes, to support severe weather warnings, for air quality forecasting, and of course for tracking the accidental release of some hazardous material.

Such multiple uses will help justify costs and ensure that the systems are regularly maintained and evaluated. I would like to thank the subcommittee for this invitation to testify, and I would be happy to answer any questions.

Mr. TURNER. Thank you, Dr. Barron.

[The prepared statement of Dr. Barron follows:]

TRACKING AND PREDICTING THE ATMOSPHERIC DISPERSION OF HAZARDOUS MATERIAL RELEASES: IMPLICATIONS FOR HOMELAND SECURITY

Statement of

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before the

National Security, Emerging Threats, and International Relations Subcommittee
Government Reform Committee
U.S. House of Representatives

JUNE 2, 2003

Good afternoon, Mr. Chairman and members of the Subcommittee. Thank you for this opportunity to testify. I am Eric Barron, Dean of the College of Earth and Mineral Sciences and a Professor of Geosciences at Pennsylvania State University. I am the current Chair of the National Research Council's Board on Atmospheric Sciences and Climate (BASC). As you know, the National Research Council is the operating arm of the National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, and was chartered by Congress in 1863 to advice the government on matters of science and technology.

The BASC recently produced the report "Tracking and Predicting the Atmospheric Dispersion of Hazardous Material Releases: Implications for Homeland Security". This report was produced as part of a major initiative launched by the National Research Council after September 11, 2001, to provide guidance to the federal government on scientific and technical matters related to counter-terrorism and homeland security. I am here today to discuss the findings and recommendations from this report.

Atmospheric scientists and emergency managers have long been concerned with tracking and predicting the atmospheric dispersal of hazardous agents that are accidentally released from industrial sites, energy facilities, and transport vehicles. Today, the terrorist threat carries with it the possible use of weapons of mass destruction, including the deliberate release of chemical / biological / nuclear (C/B/N) agents. Our ability to track the dispersal of these agents has become a critical element of terrorism planning and response. Because it is impossible to anticipate all possible scenarios for airborne release of a C/B/N agent, and in many cases, the exact source location or nature may not be known initially, dispersion modeling systems must be capable of providing useful information even in the absence of some basic input information. This presents a tremendous technical challenge.

Our capacity to meet this challenge rests upon three interconnected elements: 1) atmospheric dispersion models that predict the path and spread of the hazardous agents, 2) observations of the plume and of local meteorological conditions, and 3) effective communication and coordination among the relevant atmospheric science and emergency response communities. The following is an overview of the committee's key findings and recommendations related to each of these three elements.

Dispersion Modeling: Capabilities and Needs

Dispersion modeling systems range from the relatively simple to the highly complex, and they can potentially be used to assist emergency management personnel in the following stages of an event:

- *preparedness stage*: for predicting the outcome of possible C/B/N release scenarios.
- *response stage*: for evaluating the hazard zone in the minutes to hours after an event occurs.
- *recovery and analysis stage*: for assessing human health and environmental impacts in the days to months after the event occurs.

For each of these stages, different dispersion modeling capabilities are required. For preparedness activities (e.g., training for response to threats against specific events such as the Olympics, or specific targets such as a nuclear power plant), existing dispersion models appear to satisfy many of the needs of the emergency response community. Likewise, for post-event recovery and analysis (e.g., reconstructing the dispersal paths of radioactive material released from the Chernobyl reactor accident; or assessing what communities were exposed to smoke plumes from the World Trade Center fires), existing models also seem to provide useful support. However, in the case of immediate response to unanticipated emergency events, where fast-response models are required, the needs of emergency management do not seem to be well satisfied by existing capabilities. There is clearly room for improvement in the dispersion models currently in operational use.

The committee's primary concern is that emergency managers need a realistic understanding of uncertainties associated with a dispersion model prediction; and at present, the uncertainties in most atmospheric dispersion forecasts are not well bounded. Most atmospheric dispersion models predict only the ensemble-average dispersion pattern (that is, the average over a large number of realizations of a given dispersion situation) and not the event-to-event variability about that average. As a result, a forecast from even a very sophisticated dispersion model may have large single-event errors. This represents substantial human health risks when emergency managers must use this information to determine appropriate response actions. **Thus, new approaches are needed for modeling individual hazardous releases, to quantify not only the average downwind concentration distribution of the hazardous plume, but that also to provide some measure of the expected event-to-event variability in that situation.**

Other recommendations for improving modeling capabilities include the following:

- **It is necessary to learn how to more effectively assimilate into models data from meteorological observations and C/B/N sensors, especially as the quality and availability of these data increase.**

- **Urban field programs and wind-tunnel urban simulations should be continued, to improve our understanding of dispersion in different weather regimes and release scenarios, and to allow for the testing, evaluation, and development of modeling systems.**

- **Many currently used models are not well designed for complex natural topographies or built urban environments; and likewise, the effects of urban surfaces are not well accounted for in most meteorological models. Development work in this area should be enhanced.**

- **There is a need for independent, quantitative review and intercomparison of the various models used for operational response to C/B/N events. Most evaluations carried out to date have been largely qualitative in nature.**

Observations: Capabilities and Needs

The basic observations required for tracking and predicting the dispersion of a hazardous agent include:
- identification of the hazardous agent source and plume
- characterization of low-level winds (to follow the plume trajectory)
- characterization of the depth and intensity of atmospheric turbulence (to estimate plume spread)
- identification of areas of potential degradation and dry/wet deposition of the hazardous agents

The committee found that existing observational systems need to be used more effectively, and enhanced in a number of specific ways to become more useful in the context of tracking and predicting dispersion of hazardous agents. Recommendations include the following:

- **A comprehensive survey of the capabilities and limitations of currently existing observational networks should be conducted, followed by action to improve these networks and access to them, especially near areas deemed most vulnerable to terrorist attacks.**

- **There should be an evaluation of the potential for supplementing the national Doppler radar network with sub-networks of short-range, short-wavelength radars, which can be useful for estimating boundary layer winds, monitoring precipitation, and possibly tracking some C/B/N plumes.**

- **Wind and temperature profilers (which measure variations of wind and temperature with height) provide important information for response to C/B/N attacks and should become an integral part of fixed-observational networks.**

- **Mobile observational platforms such as Unmanned Aerial Vehicles, and portable scanning lidars and radars can be used to characterize wind, temperature, turbulence in areas where other platforms cannot easily reach. There should be continued development of these technologies, and plans developed to make such instruments rapidly available for timely use in vulnerable areas.**

- **Local topography and the built environment lead to wind patterns that can carry contaminants in unexpected directions. Efforts should be made to systematically characterize local-scale windflow patterns in areas deemed to be potential terrorist targets, with the goals of optimizing the design of observational systems and educating forecasters about local flows.**

Management and Coordination: Capabilities and Needs

There are numerous federal agencies that operate dispersion modeling systems, including DOE, DoD, NOAA, EPA, FEMA, and the Nuclear Regulatory Commission. In addition, it seems likely that the new Department of Homeland Security could eventually augment or subsume some of the activities currently residing in other federal agencies. The committee did not make specific recommendations about agency leadership responsibilities. However, we do feel that a more carefully crafted management strategy, with a strong center of coordination and clear lines of responsibility, is essential to ensure further progress in the development and effective operation of dispersion modeling systems. **Thus we recommend that a nationally coordinated effort be established for the support and systematic evaluation of existing models, and research and development of new modeling approaches.**

Emergency responders need to better understand the strengths and weaknesses of existing observational and dispersion modeling tools; and in turn, atmospheric scientists need to better understand how dispersion forecasts are used in emergency response situations. **Thus we recommend that joint training exercises (perhaps most usefully, in the form of tabletop event simulation exercises) should be convened regularly to bring together emergency responders and atmospheric scientists, to establish and exercise protocols for information exchange and decision support.**

Currently, emergency responders face a confusing array of seemingly competitive atmospheric transport model systems supported by various agencies, and in many cases, they do not have a clear understanding of where to turn for immediate assistance. Emergency responders do not enjoy the luxury of in depth analysis and comparison of differences among competing atmospheric models; they need immediate, definitive support without excessive complexity or confusion. **Thus we recommend that a single federal point of contact should be established (e.g., a central clearing house with a 1-800 phone number) that could be used to connect emergency responders to appropriate dispersion modeling centers for immediate assistance.**

In closing, we emphasize that much can be done with better use of existing observational networks and modeling systems, but additional resources likely will be required to strengthen the capabilities of many communities. It should be noted, however, that robust atmospheric observing systems and high-resolution atmospheric models could be used for other important purposes: for instance, to support severe weather warnings and air quality forecasting. Using these observational and modeling resources for multiple purposes would help justify costs and ensure that the systems are regularly maintained and evaluated.

Mr. TURNER. Dr. Hanna.

Dr. HANNA. I would like to thank the subcommittee for asking me to testify. My name is Steven Hanna, and I am with the Harvard School of Public Health. And I represent a person who has done research on turbulence and dispersion modeling for many years.

I am representing myself, so my opinions are my own, based on the science. I am probably the only person sitting here that doesn't have a staff backing me up ready to provide things.

I have looked at a lot of government dispersion models over the years. That is probably the reason I have been asked to testify, including EPA, Department of Defense, NOAA, and other types of modeling systems.

I was the chair of a three-member peer review committee of the Khamisiyah modeling exercise for several years. And I must say, our conclusions about how good the exercise was are somewhere in between the two speakers on the other end of the table.

I would like to first review some fundamental facts about transport and dispersion models. One has been mentioned before, is that much of the history of this field comes from chemical, biological agents from needs in World War 1.

One interesting aspect of them, is you run them in a forward or backward mode. If you know what the source is, you can calculate what is going to happen to people.

On the other hand, if you don't know where the source was, you can use observations of concentrations in order to try to triangulate back to where the source might have been.

Another fundamental fact is also substances move in a similar manner, the chemical agents, biological agents, other types of tracers are dispersed through the atmosphere similarly, and you can use the same types of models.

The difference between emergency response and other types of more routine models is that the emergency response has to run fast, and needs to have capability of bringing data into the system.

Another difference between chemical agents and biological agents in the way they can be run and interpreted, because there is an immediate effect of a chemical agent, so you can do emergency response modeling, but with biological agents, it requires 2 weeks later before people start showing up at emergency rooms. But, you can still do planning studies.

The uncertainties have been addressed by the others, and you can think of it in terms of weather forecasts. We all know how certain weather forecasts are, and the same thing applies to transfer and dispersion models, because there the material is moving in the atmosphere.

I would like to point out that over the past 10 years there have been great improvements to DOD, DOE and other dispersion modeling systems so that many of them are now capable of modeling things with state-of-the-art science.

A couple of major issues. I feel that the government assessments have been ignoring the many valuable models available from the industries. The chemical processing plants and oil refinery industries have developed many very good models that I don't see being used or considered.

Another issue is I see a—it is quite unclear on who runs which model when we have several agencies who are running models for emergency response. And I have seen those written down. But I have a hard time myself deciding this, and I think there needs to be more definition.

Another issue is, I believe with some of the models that are out there for use by the general public or by the military, that we need more consistency in user guidance. I see 100 different users getting different answers when they run the same model against the same scenario.

We need better field tests. Most of our field tests so far are what you would call fair weather. When we do an experiment, if it starts raining, the experimentalists pack up and go back to their hotel rooms. And real releases are just as likely to be during rain or when a front is going through. So we need more comprehensive studies.

As for urban city areas, there is much discussion about the variability in the city. But, on the positive side, because of all of the buildings, there is a lot of mixing, and we find that in some aspects, especially at moderate distances, you can do quite well with modeling in cities.

However, you do need the local observations because you obviously need to know which way the wind is blowing as the primary determinant.

And my final comment is on the Gulf war. I believe that it was a reasonable program, the results were reasonable. However, seemed in many cases to be a compromise, and instead of being a long-term basic research effort, it seemed to be carried out in short bursts of 2-week subtasks rather than over a longer-term period.

Thank you and I would be willing to answer further questions.

Mr. TURNER. Thank you, Dr. Hanna.

[The prepared statement of Dr. Hanna follows:]

Testimony on "Following Toxic Clouds: Science and Assumptions in Plume Modeling"

Steven R. Hanna

2 June 2003

My name is Steven Hanna. I am an Adjunct Associate Professor at the Harvard School of Public Health, a Research Professor at George Mason University, and president of Hanna Consultants. For the past 38 years, my career has emphasized plume modeling, beginning with my graduate research in Meteorology at Penn State, continuing with 14 years' experience at NOAA's Atmospheric Turbulence and Dispersion Laboratory in Oak Ridge, TN, and followed by 18 years' experience with environmental consulting firms in Massachusetts. For the past six years, I have held concurrent appointments at Harvard and at George Mason University, and have carried out related research studies through my consulting company. Throughout this period I have developed and evaluated plume models and studied air pollution meteorology for a wide range of applications and for a mix of government and industrial sponsors. Because of this broad experience, I am often called upon to carry out independent assessments of plume models and have chaired several peer review committees for plume models such as the EPA's new AERMOD model. From 1997 through 2001, I chaired the peer review committee for the plume modeling done for the Gulf War. For nine years (1989-1998), I was the Chief Editor of the *Journal of Applied Meteorology*, where I made the final publication decision for over 1000 manuscripts.

Because of my broad experience in developing and evaluating emergency response plume models for industry and government over the past 20 years, I am familiar with the models and scenarios used by a wide array of groups. I am not linked with a particular model or group and can offer unbiased opinions on the models' capabilities and on their strengths and weaknesses.

Before answering the questions listed in my invitation letter, I wish to point out that plume models are sets of mathematical and/or computer equations that are used to estimate the location and magnitude of concentrations or dosages (concentrations summed over time) due to releases of contaminants to the atmosphere. Combined with information on health effects, the results of the plume model can be used to make emergency response decisions in real time. Other uses of plume models are to carry out planning exercises or determine the effects of a past incident. The type of contaminant (e.g., gas, particles, aerosol) does not usually matter to the calculations, since all dilute gases and small particles are transported and dispersed alike. In the case of large particles (i.e., diameters larger than about 100 micrometers) or large releases of dense gases (e.g., a rupture of a ten ton chlorine tank), there have been special plume formulas developed that are used as options in most hazardous gas models.

My answers to the 14 questions asked in my invitation letter are given below:

Question 1 – What are the types of dispersion models?

Dispersion models are applied when hazardous materials are emitted to the atmosphere at an assumed mass per unit time over an assumed period of time. All dispersion models are similar in that they calculate two basic characteristics of the emitted material – 1) the speed and direction that the plume moves with the wind, and 2) the dispersion or lateral and vertical spread due to turbulence in the atmosphere. Simple fast-running models called Gaussian plume models have been successfully applied for many decades. Examples are the EPA's ISC model and NOAA's CAMEO/ALOHA. Slight modifications to these simple models have been made to account for changes in wind speed and direction with time, and the resulting models are called Lagrangian puff models, which form the basis for applied modeling systems such as the EPA's CALPUFF, NOAA's HYSPLIT, and DTRA's HPAC/SCIPUFF models. A related model based on Lagrangian particles is DOE's NARAC system. In addition to the many government-sponsored models, there is a class of high-quality models developed by the chemical and oil industries for application to accidental releases of hazardous chemicals (e.g., hydrogen fluoride, chlorine, or propane) to the atmosphere, where algorithms are needed to handle high-velocity aerosol jets and dense gases. The above models are most commonly used for emergency response since they can be run relatively quickly. Another widely-used modeling system that requires much more time is a three-dimensional grid model such as the EPA's Models3/CMAQ, which is applied to urban and regional ozone, particle, and toxics problems. At the far end of the spectrum of complexity are the Computational Fluid Dynamics (CFD) models, which are often applied in research mode to groups of urban buildings and are based on small three dimensional grids and which can take hours or days to run on a large computer.

Question 2 – What are the types of emergency response models?

Several types of emergency response models are in use by different groups, but the fundamental requirements are that the model must be run quickly and easily. The three-dimensional grid models discussed under Question 1 do not satisfy these requirements. Examples of the more commonly-used emergency response models that do satisfy these requirements are the Lagrangian Gaussian puff models HPAC/SCIPUFF (from DTRA), HYSPLIT (from NOAA) and VLSTRACK (from the Navy), the Lagrangian particle model NARAC (from the DOE), and several Gaussian plume/puff models with dense gas capabilities (CAMEO/ALOHA from NOAA, HGSYSTEM from the chemical and oil companies, and SAFER/TRACE and PHAST from consulting companies servicing primarily the nuclear and chemical industries).

Note that, in addition to the standard "source modeling" mode of predicting concentrations or dosages from a given source, the plume models can also be operated in "reverse or receptor-modeling" mode if the source location and magnitude are not known. In the latter situation, observations of concentration or dosage at two or more positions can be combined with the plume model to triangulate a best guess of the position and magnitude of the source.

Question 3 – What are the strengths and weaknesses of these models?

The major strength of the models mentioned above is that they have all been evaluated and "calibrated" with the eight or ten major sets of data from field experiments so that we can be confident that they produce results that agree with observations within a factor of about two for some simple release scenarios. Models such as HPAC/SCIPUFF, HYSPLIT, and NARAC are based on up-to-date science. The models for the chemical industries are applicable to a broader range of release types, including dense gases and aerosol jets.

The major weakness of these models is that any real source release is nearly always more complicated than the simple scenarios studied in the field and wind tunnel experiments on which the models are based. Real sources tend to be variable in time and space, to occur in non-ideal locations such as next to a building near a river, and to occur at times when the atmosphere is variable or rapidly changing or it is raining. Consider Bhopal, Three Mile Island, Chernobyl, and Khamisiyah, which all took place during non-ideal meteorological conditions with poorly-known sources.

Question 4 – What are the deficiencies in emergency-response or real-time models?

Several deficiencies were mentioned in my answer to Question 3. In addition, there are problems due to a lack of nearby meteorological data such as wind speed and direction and stability. Usually the models are developed and tested using highly-instrumented field experiments. However, in a real emergency application, the only available wind speed may be from an airport 20 km away.

Another deficiency is related to the need to clearly communicate the uncertainty in the model predictions. HPAC/SCIPUFF is the only model that includes an estimate of the uncertainty along with its forecasts. However, it is important for decision-makers to know that, even in the best of conditions, the model predictions can be expected to be accurate only within a factor of about two. Also, any uncertainties in the source term are directly translated into uncertainty in the modeled concentrations or dosages.

A deficiency in the OFCM review of emergency response models is that the useful models developed by the oil and chemical industries were generally ignored just because they were not developed by government agencies. Models such as HGSYSTEM, developed by a consortium of industries such as Shell and ExxonMobil, are in the public domain and account for a much wider range of chemical plant accident scenarios and source types than the government models. These industry models generally also include models for source emissions, such as flashing jets from pressurized HF tanks, or evaporation from LNG spills.

There are problems in knowing which agency is responsible for applying plume models to be used for emergency response decisions in some scenarios. The lines are fuzzy and responsibilities not entirely clear.

Question 5 – How can these deficiencies be improved?

The models should be improved to cover a wider range of meteorological scenarios and source scenarios, including difficult topics such as a chemical agent release that varies in time over 30 minutes and position over 5 km (e.g., a release from a moving truck) during a morning rush-hour with the sun rising.

The expected uncertainties of models should be explained as part of the training, and the uncertainty of a specific emergency response prediction should be included in the prediction. For example, if the model predicts that the plume will move towards the east, the decision makers should know that there is a chance that the plume will move towards the west.

The government agencies and the oil and chemical industries should work together so that the government models make optimum use of the scientific developments by the industries. Furthermore, the various agencies with plume models should decide the mechanism whereby different agencies will take the lead for running their models for certain scenarios so that it is clear which agency is responsible. It then follows that the various models should give fairly consistent results so that there are not large differences in emergency response actions taken by different agencies to the same release scenario.

Question 6 – What sources of data are needed for effective plume modeling?

The details of the source (location, mass release rate, duration, temperature and composition) are needed, since the accuracy of the plume model is no better than the accuracy of the source inputs. Information on land-use and nearby complex terrain or buildings is useful. Wind and stability inputs are necessary and should be from an unobstructed location as close to the source as possible. In combat zones and in remote sites where observed winds are unlikely to be available, meteorological forecast models can be run to provide wind inputs, although actual observations are preferred if available. Locations of critical populations are needed so as the focus the predictions on specific areas. Sometimes remote sounders are available that can provide real-time observations of winds for input to the plume models or of concentrations for use in refining (calibrating) the predictions.

Question 7 – How are plume models tested and validated?

Over the past few decades, there have been several field and laboratory (e.g., wind tunnel) experiments where tracer gas or small particles are released at a known rate, winds and stability are measured on-site, and concentrations or dosage are measured by numerous sampling instruments. Some of the field experiments carried out by DOE and by industry involved releases of hazardous gases and aerosols such as HF and ammonia. Some of the DOD experiments involved "real" scenarios such as exploding bunkers but used tracer gases. The field experiments are preferred over the laboratory experiments because they more closely represent actual release scenarios. However, the field experiments are relatively expensive (several million dollars for a several day study with 10 to 20 release trials).

In most cases, it does not matter what is used as a tracer, since most contaminants in the atmosphere are transported and diffused in the same manner. Most of the recent experiments used SF_6 as a tracer. Because of the costs and the difficulties, these experiments usually produce limited amounts of data and are carried out under relatively ideal conditions. If it rains or if a front goes through, the experimentalists pack up and go home. The total data archive of useful field experiments consists of about 20 or 30 experimental campaigns with about 10 to 50 individual trials per campaign. I have evaluated many models with most of these available data sets and am one of the few persons who have compared models from a variety of agencies and industries with the same data sets.

The model outputs that are evaluated depend on the needs of the decision makers. For example, sometimes all that is needed is the maximum distance to which a toxic concentration extends, while other times the need is for the precise spatial coverage of toxic concentrations. The models are generally evaluated by looking at the relative mean bias (e.g., the model overpredicts by 70 % on average) and the relative scatter (e.g., an individual prediction could be up to a factor of three high or low). We often determine whether differences between models are significant. For example, when we evaluated the EPA's CALPUFF model versus DTRA's HPAC model versus the Navy's VLSTRACK model with the Dipole Pride 26 field data from the Nevada Test Site, we found that all three models performed fairly well (i.e., relative mean biases less than a factor of two and relative scatters less than about a factor of 3 or 4). In fact because of natural variability in the atmosphere, it is unlikely to have a model that consistently performs better than this.

Question 8 – What are the challenges for developing sound models for cities?

Cities obviously are unique and every building is different and has its own special shape, roof structures, porches, nearby landscaping, etc. However, it is impractical in emergency response models to try to model the effects of each windowsill and HVAC system. The current approach by many agencies is to develop simplified three-dimensional models for the areas right around individual buildings or in specific street canyons, and then use simplified "urban canopy" models for the plume after it is transported past the first two or three buildings. We find that the urban boundary layer is well-mixed due to the effects of the buildings, making it possible to derive straightforward general relations. These relations are now being developed and tested using recent field experiments in Salt Lake City, Los Angeles, and San Diego. An extensive tracer experiment is planned in Oklahoma City for this July and should help refine and test these models.

Our recent evaluations of HPAC with the Salt Lake City data used several optional wind inputs, covering the range from only the airport winds to the complete set of special wind observations in the city, with the surprising result that the model performance was not best for optimum wind inputs. Further study of this issue is needed since there may be compensating errors.

Question 9 – What models should be used in the event of a chemical, biological, or radioactive release into the air?

As stated in paragraph three of my introduction, the same models can be used for chemical, biological, and radioactive releases, since all of these substances disperse in the atmosphere in the same manner. The most widely-used real-time models used for emergency response are the DOE NARAC model, the DTRA HPAC/SCIPUFF model, the NOAA HYSPLIT and CAMEO/ALOHA models, and several models used in the chemical industries (e.g., SAFER, PHAST, CHARM, HGSYSTEM). The EPA's AERMOD and CALPUFF models are excellent state-of-the-art models that could be used for emergency response, although they are currently used primarily for regulatory applications.

Question 10 – What is the margin of error for these models?

The plume models listed under Question 9 have similar performance measures (i.e., margins of error), and further improvement is probably limited by natural uncertainties in the atmosphere – the same uncertainties that cause weather forecasts to never be exactly correct.

The margin of error is less for well-defined scenarios and is more for poorly-defined scenarios. For field experiments where the source is well known and there is extensive on-site meteorology, the relative mean bias for a good model is less than about 30 or 40 % and the relative scatter is about 100 %. For real-world emergency response scenarios, the relative mean bias would be about a factor of two or three and the relative scatter would be about a factor of five to ten. However, this uncertainty of the plume model is still less than the uncertainty for the emissions rate or for the exposure and risk components of the model.

Question 11 – How were possible chemical warfare agent releases modeled in determining potential exposures in the 1991 Persian Gulf War?

From 1997 through 2001, I was the chair of the Peer Review Committee for the plume modeling of Khamisiyah. The plume modeling procedure was hampered from the start due to a deficiency in information on the source emissions rate and an almost complete lack of meteorological data in Iraq. The modeling methodology changed several times during this period as models were upgraded. For example, the OMEGA (DTRA) and COAMPS (Navy) mesoscale meteorological model went through several modified versions over the course of the study. The MM5 meteorological model was also applied in order to generate wind fields over the modeling domain. These meteorological models had to be used because of the lack of wind observations. Two plume models (DTRA's HPAC/SCIPUFF and the Navy's VLSTRACK) were applied, using best estimates of the source emissions and using the outputs of the mesoscale meteorological models. In order to account for the uncertainty, the researchers ran the two plume models separately using the wind inputs from the three meteorological models. The end product of each meteorological model and plume model combination was a map containing a set of dosage contours for three or four dosage limits based on health effects. An advisory committee decided to use the total area coverage of the contours predicted by the six model combinations (three meteorological models and two plume models) in order to define the area of possible health effects for U.S. troops.

Question 12 – What were the strengths/weaknesses of these models?

It is hard to tell what the strengths and weaknesses of the models were because there were no data whatsoever to use for comparisons. The Kuwait oil fire observations were of little relevance because those plumes rose to a much higher elevation. However, it was obvious that the three meteorological models often produced differences in wind direction of 30 or more degrees and differences in wind speeds of a factor of two, causing the plume paths to often diverge by 30 or more degrees and the cloud speeds to diverge significantly. The two plume models produced further differences. Our opinion is that the HPAC/SCIPUFF plume algorithms are slightly more state-of-the-art than VLSTRACK, although VLSTRACK has an excellent data base for CBN source emissions scenarios

Question 13 – What models should DOD use today should an event occur in a combat theater?

My answer has two parts. First, of the available DOD models, HPAC/SCIPUFF is probably the recommended model because of its state-of-the-science algorithms, its good performance against available field data, its useful graphical outputs, and its implementation within the context of DOD modeling centers and procedures. Second, there are other models available from other agencies and industries that are just as good technically and perhaps better in some areas, but which are not specifically formatted for DOD use. These models include the EPA's AERMOD and CALPUFF systems, the DOE's NARAC system, NOAA's HYSPLIT system, and industrial models such as HGSYSTEM. Even the simple NOAA CAMEO/ALOHA modeling system has been shown to agree well with observations, and includes technical details such as dense gases. In addition, the European Union, Australia, and other non-US countries have excellent models available such as the UK ADMS model. Thus I recommend that DOD review and consider making use of the other excellent models that are available.

Question 14 – How has modeling improved since the Persian Gulf War?

If we assume that the year 1991 should be used as the base year for comparisons, then there have been major improvements in DOD plume models. Prior to 1991, DOD models were primarily Gaussian plume and puff models from the 1960's, and had not been updated in years. DTRA's HPAC/SCIPUFF model has been developed during the time period since 1991 and enhancements are continuing. Other advanced emergency response models such as the DOE NARAC system, the EPA AERMOD and CALPUFF models, and the NOAA HYSPLIT system have also become available during this time. As a result of problems evident during the Chernobyl release, plume models for radiological releases have been improved and data communications enhanced so that these models can be confidently used in real-time for emergency response. In all of the above cases, the improvements have primarily concerned the improved specifications of wind fields and the improved measurements of wind fields and communication of data. Additional improvements have involved parameterization of wind flow and dispersion in urban areas, using recent field experiments such as the 2000 field study in Salt Lake City.

Further comments -

There is much variability in plume model predictions. I believe that an advanced plume model should be able to demonstrate improved performance over a simple baseline plume dispersion model. This is the same as saying that a new weather forecast model should be able to do better than simple estimates such as climatology or persistence.

There is currently much research underway on development of detailed Computational Fluid Dynamics (CFD) models which can predict the variation of concentrations over small time scales (one second) and over small grid volumes (about 1 m^3). Many persons say that, as computers improve, the CFD models can eventually be practical for emergency response use. These persons stress the CFD models' usefulness in urban scenarios. However, it is not clear whether these models' predictions will be any more accurate than the predictions of models such as HPAC or NARAC, with the problems arising due to the large natural variability of the atmosphere. Personally, I feel that CFD models are overkill, but is possible that I may be proven wrong over the long run. And certainly CFD models are capable of producing impressive detailed color graphics for use by emergency responders. Of course another use of CFD models is as a "data base" for development of simplified parameterizations in model such as HPAC.

Mr. TURNER [presiding]. We will now turn to a series of questions—before we turn to questions, we actually want to ask unanimous consent that all members of the subcommittee be permitted to place any opening statement in the record, and that the record remain open for 3 days for that purpose.

Without objection, it is so ordered. Also, I ask for further unanimous consent that all witnesses be permitted to include their written statements in the record. Without objection, it is so ordered.

We will go first to questions from our chairman, Chairman Shays.

Mr. SHAYS. Thank you. Also I have a unanimous consent, Mr. Chairman. The GAO request for this work was submitted jointly by this committee and Senator Robert Byrd of West Virginia, and I ask unanimous consent that a statement by Senator Byrd be included in the record.

Mr. TURNER. Without objection, so ordered.

[The prepared statement of Hon. Robert C. Byrd follows:]

Statement of Senator Robert C. Byrd
Government Reform Committee
Hearing on Plume Modeling
June 2, 2003

Mr. Chairman, Representative Kucinich, I appreciate the opportunity to address the Committee on the issue of computer modeling of toxic plumes of debris from the bombing of Iraqi chemical weapons plants and ammunition storage sites.

On the surface, this hearing appears to be about a technological issue: how well the computer systems of the Department of Defense and other government agencies are able to perform complex mathematical operations to predict how shifting winds and changing temperatures might affect the movement of a cloud of a particular substance.

But this technological subject is at the heart of how the Department of Defense and the Department of Veterans Affairs have responded to Gulf War Illness, the crippling complex of symptoms that has affected thousands of our troops who served in the Persian Gulf in 1990 and 1991. One in seven Gulf War veterans have reported suffering from undiagnosed illnesses. While this fact has largely disappeared from newspaper headlines, the need to care for those who suffer from Gulf War Illness remains.

In 1991, after Saddam Hussein had withdrawn his forces from Kuwait, U.S. and British soldiers set about destroying large caches of weapons in Iraq. One such depot, near the city of Khamisiyah, was filled to the rafters with the most lethal cocktails of chemical weapons, so powerful that a single drop could kill within minutes. This facility was destroyed by our troops, using a large amount of explosives, throwing a huge cloud of smoke and nerve agents into the air.

Years later, as complaints of Gulf War Illness began to receive more attention, the Department of Defense conducted plume modeling studies to try to recreate the movement of this, and other, similar, toxic clouds. Using some of the most advanced computer systems available, the Department produced an impressive-looking study that found that the plume of chemical weapons from Khamisiyah may have enveloped as many as 100,000 troops. On the basis of this fact and others, Representative Shays and I offered legislation in 1998 to provide the Secretary of Veterans Affairs with the authority to presume service connection – and therefore to provide health care and compensation – to the affected veterans. That legislation, the Gulf War Veterans Act of 1998, was included in the Omnibus Appropriations bill of that year.

Last year, Chairman Shays and I wrote to the General Accounting Office to request a review of these plume studies by the Department of Defense. The GAO analysis considered a large number of factors, such as the assumptions used in the plume models – wind direction, air temperatures – and the appropriateness of using these models to determine the soldiers' exposure to low levels of chemical weapons.

The results of the GAO study are, in one word, shocking. Important data, such as the size of the plume and wind direction and speed were not necessarily based on actual measurements made in 1991. Some of this data appears to be little more than guesswork. This means that the high-tech computer models of how toxic clouds may have exposed our troops to chemical agents have no solid basis in fact.

The inescapable conclusion from this analysis is that the Pentagon's estimate that only 100,000 troops may have been exposed to chemical agents after the demolition of the depot at Khamisiyah has no basis in fact or observation. It is increasingly clear that several hundred thousand troops may have been exposed to low levels of chemical warfare agents, carried by winds for hundreds of miles from their source.

Despite the unreliability of the plume models, the Department of Defense and the Department of Veterans Affairs to this day use these same models as a basis for judging whether a veteran of the 1991 war against Iraq who suffers from an undiagnosed illness should have priority access to the VA health care system.

Mr. Chairman, it took twenty years before our government understood the devastating effects of Agent Orange. It took decades to recognize the health effects of nuclear weapons tests that subjected our troops to heavy doses of radiation. We should not forget that many veterans of the first war in the Persian Gulf continue to live with illnesses that are attributable to their service to our country, and we should ensure that they have access to the health care that they deserve.

Moreover, this nation should take from the Persian Gulf a lesson about the security of our nation and how we formulate decisions about entering into conflict. The presence of chemical and biological weapons dictates a different view of the battlefield. The goal of detection, containment, and destruction of weapons of mass destruction is logical and laudable. But, in the aftermath of the Persian Gulf war, we have learned a thing or two about the risks associated with accomplishing that goal through military might.

What we are seeing is that low dose exposure to these weapons is not generally resulting in the immediate injury or death. Instead, it results in an increasingly debilitated battlefield force, long-term post-war illnesses in services members, and birth defects among their children and future generations.

The United States stands united behind our troops when they take to the fields of battle. This commitment must extend to supporting our veterans who have returned home with injuries or illnesses. And yet, the Department of Defense and the Department of Veterans Affairs, over the past twelve years, have jumped through hoops to find explanations – like the faulty plume modeling studies that are to be examined in this hearing – why some veterans suffering from Gulf War Illness should not enjoy the full benefits of health care and compensation that are promised to others who have been injured in the line of duty. This must be corrected. We must support our promises to our veterans.

This Congress has, at the urging of myself and Congressman Shays, provided the Secretary of Veterans Affairs with the authority he needs to correct this deplorable situation and to live up to the words of President Abraham Lincoln in his second inaugural address that form the motto of the Department of Veterans Affairs: "to care for him who shall have borne the battle, and for his widow, and his orphan…" I urge the Secretary to heed this report, to understand the pain and suffering among our veterans these flawed studies have allowed, and to correct this situation as quickly as possible. We should do no less for our nation's veterans.

Mr. SHAYS. I thank all of our six witnesses for their attendance. In preparation for this hearing, I really wrestled with whether this is an art or a science. So I would like, if an art is 1 and a science is 10, where on the scale are we? I would like each of you to tell me. Is the projection of a plume an art or a science? Is it a 1 or a 10 or somewhere in between?

Mr. Rhodes.

Mr. RHODES. Thank you, Mr. Chairman.

I guess the way I would characterize it is that it is a genuine science. The interpretation of what you do with what comes out of the model can be more art even though the underlying science is a 10. It is real science. It is mathematics.

Mr. SHAYS. But when you are done, what do I have? Do I have more science or more art?

Mr. RHODES. Depends on what you were able to put into the model. If you are able——

Mr. SHAYS. Under the best conditions, what do I have?

Mr. RHODES. You still don't have reality. I mean, you still do not have reality today. So you still have an estimate, so it is not going to be——

Mr. SHAYS. It is not going to be a mathematical certainty.

Mr. RHODES. It is not going to be a mathematical certainty. It will be mathematical, but it will not be a certainty.

Mr. SHAYS. Maybe I need to ask the question differently. So you have succeeded in not giving me a number. You have basically told me it is a science, but there is no certainty, and the outcome is like an art, and it is only as good as what you put in. I understand that part. I am going to come back.

Dr. Winegar, what do you think?

Dr. JOHNSON-WINEGAR. I certainly agree in a qualitative sense that it is more of a science than an art. I would certainly want to characterize it as a science that is rapidly improving, and that any answer given today would certainly only be a snapshot in time as to how much of a science it is in comparison, for example, of what was done 10 years ago or, even more to the point, what we will be able to do 10 years from today.

So I clearly put modeling and simulation in the area of science.

Mr. SHAYS. Dr. Ermak.

Dr. ERMAK. I would agree with the past statements that the study of the atmosphere is a science. Like all sciences, there are things that are unknown. So I think that where the—perhaps the shift between science and art comes in is in the application of that, and that probably varies, depending on the application. In emergency response, where you cannot bring in—where time limits our response, and all the resources of the research, and you do not have all the time to make this type of a prediction, then I think there is more art.

Mr. TURNER. Mr. Hicks.

Mr. HICKS. In my judgment, it is a 7, and the science is trying to turn it into an 8.

Mr. SHAYS. The last part I missed.

Mr. HICKS. The research is trying to turn it into an 8.

Mr. SHAYS. OK. Thank you.

Dr. BARRON. It is science on its way to becoming even better science. If you took the best case of extensive observations, a great deal of time to begin to do multiple simulations, create ensembles, understand something about uncertainties, I would say it was in the 7 to 8 range, in talking about confidence, not whether it is a science or not. In the worst case of very poor observations and the need for immediate response, then the confidence goes way down.

Mr. SHAYS. OK. Dr. Hanna.

Dr. HANNA. I would give it an 8 if you have a lot of data. If you are in a place like Khamisiyah, I would bring it down to a 6 or so. But in all cases, there is a lot of uncertainty.

Mr. SHAYS. Thank you very much for your response. Remembering that, I am looking at three shades of color, green, and an olive green and a more yellow. They are all plumes, projections of plumes, correct?

Mr. RHODES. Yes, they are.

Mr. SHAYS. They are the same incident, correct?

Mr. RHODES. Yes, they are.

Mr. SHAYS. Defense is green?

Mr. RHODES. Deep green, yes.

Mr. SHAYS. Deep green.

Livermore is the more yellow.

Mr. RHODES. Yes, and the olive green around. The Defense composite is the one that drives down into Saudi Arabia, and Livermore is the one that moves up to Iran.

Mr. SHAYS. Actually the yellow is blown out by the dark green, because the Khamisiyah, as I look at it, is at the very top.

Mr. RHODES. Yes. If you look at the highest point of the green composite, that is the side of Khamisiyah.

Mr. SHAYS. The only certainty, at least with these two, is that the plume went south rather than north?

Mr. RHODES. Yes, initially. But as you can see from the Livermore model, it does turn and then start to move north.

Mr. SHAYS. Correct. Originally started down.

Mr. RHODES. Yes.

Mr. SHAYS. This may seem less of a focus for our other witnesses, but we have had 10 years of hearings on the whole issue of Gulf war illnesses in this committee, and we didn't know about Khamisiyah until we had a witness who actually had a video of blowing it up, and the Defense Department heard of our hearing that we were going to have the next week on Tuesday, notified the press at 12 noon on Friday that there would be a 4 o'clock press hearing in which they said our troops were exposed to defensive chemical weapons, because they had denied that our troops had ever been exposed, and then we were getting in the word game of offense/defense.

What is important to me here in this issue is that I believe that Defense basically looked at the soldiers who were under the dark green; is that correct?

Mr. RHODES. That is true.

Mr. SHAYS. We made some presumption that anyone who could confirm that they were in the green, dark green, area had some exposure to chemical defensive exposure to chemicals; is that correct?

Mr. RHODES. That is true.

Mr. SHAYS. If, in fact, we use the Livermore model, then all of the assumptions about who was exposed and who wasn't exposed become very different, correct?

Mr. RHODES. Yes, sir.

Mr. SHAYS. So it is your recommendation, and I don't want it to get lost, but it is your recommendation that what happened? I want you to repeat it. It is on page 5. You say, "We, therefore, recommend"——

Mr. RHODES. We, therefore, recommend that the Congress direct the Secretary of Veterans Affairs to presume exposure, that those in theater are presumed exposed, because outside of that green area, those people in the area that the Livermore model shows should be exposed, and therefore, we are presuming—we are recommending that you direct the Secretary of Veterans Affairs to presume exposure of all veterans in that area, the total area, not just the composite area.

Mr. SHAYS. Now, for the purpose of this hearing, we have two interests, I have at least two interests, but one is we still have to care about our veterans who were in the first Gulf war, because I felt shortly after the war DOD and the Department of Veterans Affairs didn't care enough about them. I take it they care now about them. So that is one issue.

The other issue is just understanding this whole art to science, which I understand is more of a science, depending on the data, and understanding its impact in any future war and battle, and also to understand it domestically, because there is an absolute certainly that someday, somewhere in the United States, American civilians and all who are here in the United States in that particular area will be exposed to some chemical, biological, radioactive, nuclear, whatever. So it is very important. In other words, the work you do is very important, and some of you spend your mornings, noons, and nights thinking about this one issue. Thank you for doing that.

But if you could just deal with this issue here right now, I would like you, Dr. Johnson-Winegar, to tell me how you react to what Mr. Rhodes has said and Dr. Ermak, as well as, Mr. Hicks and Dr. Hanna, if you would react to that.

Let me just say also, Dr. Johnson-Winegar, one, I appreciate you participating. I have said in the past, but it is to your credit that you are so into participating in a larger panel because it makes us have better dialog, and we do thank you for that. Also I want to say that your statement clearly was comprehensive. It would have probably taken you 20 minutes to go through, so I want to thank you that you did not do that, but I am also thankful that you took each question we asked and responded to it in a very thorough way, and we appreciate that.

Having said that, could you react to what Mr. Rhodes said?

Dr. JOHNSON-WINEGAR. Certainly. Let me just make two comments. First of all, the area that is shown in green, which is referred to as the DOD estimate, is, in fact, really a composite of information that was generated from using a number of different model systems, and the DOD did call upon IDA, the Institute for Defense Analysis, an independent organization, to review that data. The data was then subsequently reviewed yet again by scientists who are eminent in the field, some of whom are here today. So we have peer review accreditation of the work that was done.

With regard to the apparent discrepancy between the DOD prediction and that run by the Lawrence Livermore model, I believe that the real answer is in what is being done with that information, and it is certainly my understanding that veterans are being treated based on symptomatology and not based solely on where they were geographically located; in other words, whether they were "in the plume" or "not in the plume." So I think that the bottom line is we certainly appreciate your concerns, and I want to reinforce the concerns from the Department of Defense for all those veterans. Clearly, we agree with the premise that they should be treated based on potential exposure.

Mr. SHAYS. I will come back, Dr. Johnson-Winegar. Thank you. Dr. Ermak.

Dr. ERMAK. Yes. When I look at this chart, I see this as an example of the uncertainty that often results from dispersion models and, in particular, the large uncertainty that can result when there is inadequate initial data on which to make the dispersion calculation. I will stop there.

Mr. HICKS. Yes. My comments on this are colored by the fact that I was a member of the team that reviewed the Department of Defense work to start off with.

Mr. SHAYS. I consider that helpful. I mean, thank you for saying that, but now react.

Mr. HICKS. We delved very deeply into the assumptions that were made in that analysis, and I have not had the opportunity to do the same thing to the Lawrence Livermore analysis. I can't imagine what I would find if I were to do so, but at the moment I would say that I agree with Dr. Ermak that these are examples of how the plume forecasts are at the mercy of the assumptions that you make.

Mr. SHAYS. OK. Thank you.

Dr. BARRON. This wasn't a specific part of the National Research Council's investigation, so the report doesn't—whatever I say is outside the nature of that report. But I think that is the perfect answer. When you have inadequate observations, especially to initiate models, you can expect widely different simulations from the plume models.

Dr. HANNA. This is exactly what we see in any sort of modeling exercise like this, and it makes me wonder why stop at five models? If we put 70 models up there, we would probably cover the entire 360 degrees.

Mr. SHAYS. But having said that, then for me as a policymaker who has to be concerned about veterans, I sent to—along with others in the first Gulf war, I look at that and I say that we can't be any more certain that the DOD model, based on a number of models put together, or the Livermore, is more accurate, and, therefore, it would strike me that we would have to give the presumption to the veteran that they were, in fact, exposed.

Dr. HANNA. Well, I would interpret in a probability sense that there is a higher probability of people being affected in the middle of that group of plumes and lower probability at the outside of it.

Mr. SHAYS. Right. The problem is—and I will get to questions about plumes of chemical, biological or radiological, and I will have some questions there—but the problem that differs for you and then for us is that men and women risk their lives in battle, and we don't really know where the plume was. That is really what—and yet we are trying to say we do, and we give a presumption if you are under the green, but if you are not under the green, you don't get the presumption. So that is a huge, a huge issue, at least for the committee.

Thank you, Mr. Chairman. I will have some more questions.

Mr. TURNER. Well, I certainly appreciate the testimony of all of the members of our panel, and some of the words that I wrote down that each of you used as you were describing this process is "uncertain," "variable," "errors," "limited data," or "estimates."

Keeping in mind that the wind has always been used as an analogy for ever-changing and unpredictable, I know that what you are attempting to do is something that is very different than what our expectation is.

Also in understanding the science application of it, it is clear that what you are approaching is the theoretical, and many people are appearing to look at this information on a nontheoretical basis, and real decisions are being made, decisions concerning exposure levels, evacuation plans, response. It seems that some of these decisions are certain and conclusive, but in listening to your testimony today, it would seem to me that each of you agree—and that is going to be my question to you—it seems that each of you agree that making any certain and conclusive decisions based upon this data would be incorrect; that the processes are scientific, they are improving, and they are certainly important to our overall safety and our planning. But we are currently looking at a process that may have a margin of error of 100 percent.

So I would ask if that is true, if my impression is that each of you, though committed to the process and its importance, would also agree that certain and conclusive decisions should not be made based upon any of the current modeling outputs.

Mr. Rhodes.

Mr. RHODES. I don't know that I would go that far. If I am thinking about urban evacuation, for example, you have to evacuate, and in the process of modeling, the application of the model to understand the best probability of escape route to move people away from the dispersion, that may be the only tool you have until you have extremely good chemical detectors deployed throughout an urban area or something like that.

Mr. TURNER. Excuse me, Mr. Rhodes. Saying it is the only tool you have is different than saying that it is going to be accurate.

Mr. RHODES. Yes, that is true.

Mr. TURNER. I understand that we may not have anything else, I understand the importance of it, but it does appear to me that each of you are saying, as each of you review each other's data and other types of processes, that drawing any real certain and conclusive decisions as a result of modeling is currently not advisable.

Mr. RHODES. Real certainty. "Certain" is the operative term there. Certain decisions, I would say, have to be couched in understanding that you are making—you are using a model to establish probability, and, therefore, the certainty of what you are doing, as I said, if it is the only tool available to you, then you may have to accept your probability, but it is not going to be perfect.

Mr. TURNER. Dr. Johnson-Winegar.

Dr. JOHNSON-WINEGAR. Thank you.

I would certainly like to characterize it as what I view as a continuum across the certainty to noncertainty. And as more data becomes available and the models become more robust, you can certainly put more confidence in the output of that data, which can then be used to make these kinds of decisions. I would certainly like to envision it in sort of a phased approach or perhaps a tiered approach in that perhaps an immediate decisionmaking process is going to be less certain, but that as more information becomes available, for example, more data points on either the meteorological conditions or more information that is known about the particular source. And while that might not be available in, say, for example, the first 15 minutes, it may be available in a matter of a few hours. And again, as was pointed out earlier, specifically in the case of biological agents, some of the epidemiological and symptomatic data may not be available, as a matter of fact, for several days.

So what we may have to do is an iterative process, where we run the first model, we use what data we get from that, what output, to make some presumptive decisions. We do it again at some other point, whether that is hours or minutes later; it depends on how many sources we have for data coming in, how quickly that can be analyzed.

Please bear in mind that while I am certainly not the subject matter expert and would defer to many of the others here, many of these models are indeed very complex and may take, as a matter of fact, hours at very large supercomputers to be able to do the generation. So we may indeed have to refer to what I like to characterize as a phased approach to using the modeling data to help us make those kinds of decisions.

Dr. ERMAK. I believe that the uncertainty is very much correlated with the amount of information that we have or the data in order to do our simulations. When there is very little data, the uncertainty becomes high, and when there is considerable data, we can then bring that uncertainty down to a bounds that we find acceptable.

For the purposes of emerging response, I think there is also another set of data that we have not talked much about, and that is sensor data of the agent or hazardous material that has been released. Today there is considerable effort going on to develop and to disseminate sensors for chemical, biological and nuclear material, or nuclear radiation. The use of this data can be used to help reduce the uncertainty in real-time responses.

Our experience in many different types of events has been that initially when an event occurs, the uncertainty is quite large. While we might have access to the real-time meteorological data, we know very little about the source, but we are able to predict the pathway in which the cloud may be going. From this, first responders can go out, make measurements or collect data that would help to verify the initial plume and also help us to quantify how much material is being released. We find these latter stages are an iterative process in which as more data becomes available, we are able to make more and more certain calculations of the dispersing plume.

Mr. HICKS. From my perspective, the key word here is "probabilistic." All the models produce answers that are, in fact, statistical in their very nature, so they are probabilistic answers. The trick, I think, is that we have to learn how to predict the boundary of an area, defining where 10 percent of the population at least will receive a dangerous dose. In this application, I am not quite sure how that would be applied. However, I do concur with what was said here to my right.

Dr. BARRON. Well, I think there will always be a level of uncertainty, but I like to think about what the future might be like. I suspect that we will get to the point where we will see a distribution of instruments, say, within an urban environment that is sufficiently detailed to characterize the main features of the flow through that particular city. And then if you can imagine an operational mode of forecasting that goes along with that process for day in and day out, you are learning from the—applying the discipline of forecasting to that region day after day, or combining it with experiments and test cases, I think that what you will discover is that not only will we be able to do a much better job, but you will be able to communicate the level of uncertainty. Often it is not a matter of whether or not you can eliminate completely that uncertainty, but if you have an understanding of the level of uncertainty, then you can make sure you don't put people in harm's way or you have a much better estimate.

So I really see this as sort of a transition between research, which has been the history of much of this problem, moving into this operational phase for which you bring this discipline of forecasting to this mode, to this mode of operation day in and day out, to the point where you become a service, which means the stakeholders are at the table, and you have learned from each other, atmospheric scientists from that community of responders and responders in terms of what the atmospheric science community can deliver, and you can give a good estimate of what that level of uncertainty is. Then I think you have accomplished a great deal.

Dr. HANNA. Concerning our confidence in the models, I would like to point out that the EPA uses just about these same types of models thousands of times over the past 20 or 30 years to make decisions about emissions controls for plants, which has then been followed up by observations about the plants, and these models have been shown to be reasonable for those thousands of applications, which is similar to this application.

Concerning acceptance criteria and looking at all of the various comparisons with observations, it seems like once a model gets within 30 or 40 percent of the observation, that is what can be considered an excellent substance criteria, but that is if you have a lot of onsite data. Once you get to a situation like Khamisiyah with hardly any meteorological data or anything else, I suppose it degrades to a factor of 5 or so. But we do have a lot of evidence of model accuracy that is built up over the years.

Mr. TURNER. I appreciate your answers. The reason why I ask the question is we have had testimony in front of us that relates to the issue of what happens when these models that you are working with get in the hands of others, because we have had individuals who have testified that we can predict the plume as a result of a specific incident, and each of you being experts in the field are saying that of course they are useful, they certainly are better than anything else that we have, they give us information that is necessary to determining how to react, but yet they are not specifically conclusive and should not be absolutely relied upon. I wanted to hear your responses, as I know that we have heard in other hearings individuals talking about the absolute prediction of plume incidence.

One other question that came out of Mr. Hicks' testimony. You have in your written statement, "The coarser product is routinely made available via the Internet to users who are registered by scientists of my laboratory. This is the Realtime Environmental Applications and Display System, used routinely by over 1,500 registered users for accessing and displaying meteorological data and running trajectory and dispersion models on the Web server of my laboratory."

One of the things that we have been hearing about also in this committee is issues of tracking data and the types of access that individuals have to data. So one of the things that I would like to know both from you specifically, for example, what types of reviews do you have of who is having access to this information, and what they are using it for, but also from the other panelists as to this information that you receive gets specific enough that your models are able to predict with accuracy, to what extent do we need to be concerned about having a classified nature to the outcomes of your work?

Mr. Hicks.

Mr. HICKS. Yes. Immediately after the September 11 incident, we closed down access to the Web operation except to users who were either from a dot mil origin or from a NOAA origin. We then opened it up to registered people. In other words, we went through the process of checking out the credentials on people as they came in. Only the coarsest data are available that way. The 40-kilometer Web data are used, and they are made available. The fine-scale stuff, the fine-scale data that are necessary, for example, for predicting what might happen in Washington, DC, New York City and so on, those data are not then made available through that source.

Mr. TURNER. Do you track also then what people are doing with the data that you do provide to them? Are you aware of what—because it said access to your server. You do know what people are doing with the information you are providing?

Mr. HICKS. Yes. We keep track of the runs that are made, and we make sure that we know exactly who is using them for what.

Mr. TURNER. Other members of the panel, any concerns that you might have about the information being available to individuals that might use it to cause more harm than good?

Mr. RHODES. Well, it is a genuine concern. It is on the same scale as imagery. If you are going to Space Imaging, and you get a photograph from outer space, it is at a certain granularity. One of the conundrums associated with it, however, is that this is math. There are lots of people on the planet who can do the math without having to come to NOAA. So even though they may not have access to the fine-grain information, you raise a legitimate concern about how much information do you want to disperse to whom, because then the tool is now turned as a tool for your opponent.

Mr. TURNER. Anyone else want to speak on that issue?

If not, Mr. Chairman.

Mr. SHAYS. Thank you. It would strike me that it is much more difficult to predict where a plume has gone than it is later to reconstruct it and say where it has been; is that accurate or not? Mr. Rhodes.

Mr. RHODES. I hate to sound like a broken record, but it depends on where you had the information. If you can reconstruct the information, reconstruct source term, meteorological data from the time of the event, then after the fact it will be easier to reconstruct if you didn't have that information at the time of the event or a priori.

One of the concerns about the Khamisiyah event in and of itself is that the data are limited, and, as you know, Iraq quit submitting meteorological data to the World Meteorological Organization in I believe it was 1981. So no one was able to collect meteorological data except from sites that were distant from the Khamisiyah site. So unless you can get that detailed data up front, or after the fact, then the reconstruction is difficult.

Mr. SHAYS. Anyone choose to add to that?

Dr. BARRON. If you have good knowledge of the source term and good meteorological observations, then in hindsight you have the advantage that you have the time to run multiple realizations of models, and, therefore, you can have an ensemble that gives you a better sense of the probability of the distribution, if you have the data to work with. Whereas if you were looking actually during an event, and you were working to respond quickly, you might not have the time for multiple realizations.

Mr. SHAYS. OK. I am going to use Dr. Johnson-Winegar's explanation on page 2 of her statement when she is talking about the variables. She said basically, weather conditions are an obvious factor, such as temperature, wind speed, cloud cover and so on; geographic conditions, such as topography structures, type of vegetation, type of chemical, biological, or biological threat agent; and the state of the threat agent. Is that all one part, Dr. Johnson-Winegar, or is that two? It said the type of chemical or biological threat agent and the state of agent, the fifth?

Dr. JOHNSON-WINEGAR. Yes. They are separate.

Mr. SHAYS. OK. And then the type of delivery systems and the type of event.

Would you add anything to that as I went through it, which is—let me just deal with No. 3, which is the type of chemical or biological threat agent. Is a chemical or a biological harder to model, or is there no difference?

Dr. JOHNSON-WINEGAR. I will start out, and my esteemed colleagues can chime in. I think it gets back to the issue that we have made repeatedly in today's discussion, the source data, and so currently I would assess the fact that our overall state of knowledge about chemical weapons is more defined and more well understood than the biological agents, so that is just one piece of the information.

Mr. SHAYS. How about radioactive, radiological?

Dr. JOHNSON-WINEGAR. I think that is even better than chemical. We know more about that, and I would put that in a more advanced stage than chemical. And I am speaking primarily of what are known as the traditional chemical warfare agents. If, as a matter of fact, you would want to expand that definition to everything including toxic industrial chemicals and toxic industrial materials that may be a greater concern for a civilian incident than a military incident, then obviously our total body of knowledge goes down somewhat.

But with regard to the biological agents in particular, that is where I assess that we have some of the largest data gaps in knowing things about the various types of agents and, in particular, as I mentioned later on in my statement, the actual effects on humans via aerosol exposure of many of these biological agents. We have limited ability to extrapolate from animal studies and certainly in many cases no human effects data of many of the biological agents. So that brings us back to the point that all members of the panel have made, without being assured of a lot of the source data, then that has an impact on the output from the model, to be sure.

Mr. SHAYS. Does anyone else on the panel want to speak to the issue of chemical, biological and radiological?

Dr. HANNA. In my statement I mention the difference between biological and chemical in that you don't know that there was a biological release in general, so you can't really do an emergency response calculation, and there is some research centers around the country that think that atmospheric modeling is not of much use to biological incidents.

Mr. SHAYS. I sense that. But what about radiological or chemical in general?

Dr. HANNA. Well, chemical you know that there was a release, and radiological you also tend to know that there was a release.

Mr. SHAYS. But do they respond basically the same way?

Dr. HANNA. Yes. They would transport and disperse the same way.

Mr. SHAYS. What I am trying to understand is—in the end is that if we know the weather conditions—I mean, we have a sense of the topography, but if we know—and the type of vegetation, those are fairly obvious. We can make some quick assumptions about that. But weather is obviously going to be one big variable. Is forecasting the weather a science or an art? And it is a science, but its impact in the end is an art, from my standpoint.

What I am just trying to understand is where are the big challenges in those six key types of information: the weather, geographic condition, what type of agent, you know, chemical or biological, the issue of the state of the agent, the type of the delivery system and the type of event? It just strikes me that weather is—I have always assumed that weather was the biggest element, and in the end, obviously, the concentration of the material in terms of its impact on the populace is going to be obviously not just the weather. I understand that part of it.

But what I am really wrestling with right now is—help me out here. What becomes the biggest challenge to people in your field? Is weather the key?

Dr. HANNA. Well, I think people that do comprehensive modeling with emissions, then transfer and dispersion, and then risk assessment believe that the emissions and the risk assessment are the largest challenges, that probably the weather is—of those three is what we know the best. However, when you are worried about wind direction, as in the Khamisiyah example, I think we have—we really need to know the wind direction in order to do the troop assessments that you are talking about.

Mr. SHAYS. I mean, we have done the tabletop. Once we knew what we were dealing with, a chemical, and what type of chemical, the key thing was—we asked—we wanted to know which way the wind was blowing and how fast the wind was blowing and what was the humidity. I gather that has something to do with its—what, what would humidity tell us? So it is mostly wind.

Dr. BARRON. Well, humidity could affect a particular agent, like a mustard agent or a nerve agent; it would affect the deposition if there was rainfall, the deposition of the agent out of the atmosphere. That is the reason why having that humidity and precipitation elements are valuable.

Mr. SHAYS. What I am surprised about is I am not seeing a lot of people jump in here. Why are you not trying to help me out?

Dr. BARRON. Well, I think there are a lot of uncertainties. My view is that urban meteorology or anyplace with complex topography and an observational suite which is less dense than the scale of the circulation that would be going through buildings, and very little practice at obtaining this discipline of forecasting within that region, that is a substantial problem. We have little experience, and this is a vulnerable region of the country. So I believe that is a substantial challenge, along with the other elements.

Mr. HICKS. If I may come in, the first two you mentioned, the weather and the geography, the geography is important. The topography is important because it affects the wind direction as much as anything else. So that is tied in intimately with the weather, the meteorology of the problem.

Our perspective at the moment is that the key thing we have to worry about is to make sure we can do what we say we can do in the areas where people actually live, where people will be affected, and that is, we are finding, a very, very difficult thing to do. The urban areas are difficult to address, because the buildings do interfere with the wind so much. I think in Dr. Johnson-Winegar's language that would be topography.

Mr. SHAYS. Anybody else?

Dr. ERMAK. I would say that I think weather is an important uncertainty, and especially in the urban areas, both because of the complexities of dealing with the flows around urban areas and because that is where our populations are located. I think we need both additional data such as the Washington DCNet that was being set up in other urban areas to support our work there, and I think we also need research into urban dispersion modeling and understanding the flows in these areas.

Other areas, I think, that create uncertainties have to do with the fact that many of these agents are not in a gaseous form, but either in an aerosol or a particulate, and understanding these could have a dramatic impact on how far they disperse downwind and where they settle onto the ground. So that is another.

And I think particularly with biological, a third thing that must be—that is not well known is viability. Because the agent is in the atmosphere and it travels downwind doesn't mean that a person who was exposed to it and is still alive that it could cause illness and other difficulties to the person. So I think that is another area where research is needed.

Mr. RHODES. I would say I guess there is a variation on weather, but understanding the time, the duration of the event, if something occurs at sunset and extends into the evening, if something occurs in the middle of the night, if something occurs at dawn, these are factors that have to be worked in, because now you have temperature layers that are different. Talking about a source term and talking about saying—making the statement "I understand the chemical" is an extremely broad statement, because that means—for example, in Khamisiyah that meant you understood how many rockets, of what type, in what container, in what configuration; and they were blown up with what; how much was ejected; was it in a pit, was it in a bunker; was it at night, was it during the day.

So there is an awful lot of data that, when we are talking about the data that we need, the source term data, there is a tremendous amount of data that we need. If this is an evaporative chemical; is it a persistent chemical? As you heard 2 weeks ago in our discussion about Wallingford, anthrax at less than a 5-micron diameter operates as a vapor, and as you saw there were 3 million spores underneath the No. 10 machine, and yet we found spores 25 feet above it in the high bay. So does it settle? And when it settles, is it stable? I mean, all of those factors are involved. But the time of day when something occurs is extremely important, because then you understand what the varying temperatures are between the ground, which may still be warm, and the air that is cooled in the desert, for example.

Mr. SHAYS. You could make an argument if the plume is like the Livermore plume, it seems to be broader. You could potentially make an argument, it would seem to me, based on science ultimately, that though more people were exposed, the concentration may be so much less that the exposure isn't serious; whereas if it happens to be the more concentrated plume, that it is likely—but obviously, then, we want to know what was blown up at Khamisiyah. I understand all of those factors.

Mr. RHODES. I guess one of the following points leveraging off of what Dr. Johnson-Winegar said, looking at Dr. Hailey's work down in Texas, trying to establish what is minimal exposure, what symptoms, what conditions are expressed over time based on what exposure, that is a key item, so that even though you are talking about the olive green and the yellow area, those people may just express symptoms later, like ALS or something like that.

Mr. SHAYS. Would you all react to this, because I am trying to sort this out. Based on a number of hearings our committee has had, tell me if I am on the right track or not. Obviously, for our veterans, we want to reconstruct where the plumes went, and we want to know the impact of the plumes, the concentration of exposure and so on. But in our fighting this war on terrorism, the bigger need is to be able—at the moment of an attack to be able to have a sense of who is potentially in danger and who isn't, and where you are safe and where you are not safe. And so it seems to me that what we are really trying—and maybe we gain from reconstructing the past. I mean, we do, but it seems to me our primary efforts should be—and this committee's primary effort and the government's primary effort should be on how can we have more accurate projection of plumes when there is an attack so that we are sending people to safety and we are treating the people who may need to be treated. Is that a fair statement? Does anybody disagree with that?

The reporter cannot take a nod and a shake. So the bottom line, I am seeing a lot of heads go up and down. Anyone want to say it better for the sake of me and the reporter?

Dr. ERMAK. Let me come in for a moment. I agree with you completely. What we most recognize, I feel, is that we do have a lot of meteorological information available. The models that are available today are making good use of part of that information. We have to get to the point where we can mine the total information body, the total network of information.

Mr. SHAYS. So we can instantly say that most of the time the wind direction goes this way most of the time, or when the temperature is this, and this time of year, so we could almost turn to the computer and make an assumption. If we didn't have, you know, some accurate, present information, we would just go historically and make assumptions; is that what you are saying to me? If you could tie this in, if you would, with your issue of the urban sensors.

Mr. HICKS. Yes. What I am trying to say is that in the final product, every emergency manager would have the ability, would have the information in front of him that would draw not only upon the best weather forecast information available, but also upon those data sets that are within his own area, and they may be the Department of Transportation's data, they may be the Environmental Protection Agency's data, they may be data from private sources. These data have to be, to my mind, exercised. We have to learn how to make use of all of the data sets that are available out there, because a lot of data are available in urban areas that are not being used at this time.

Mr. SHAYS. Anybody want to add to that?

Dr. JOHNSON-WINEGAR. What I would like to add to that is with regard to your comment on what the government can and should do to increase our predictive capabilities, I certainly think that is a very important aspect. Some of the things that the Department of Defense has been doing and is investing in for the future includes such things as improving the sensitivity and specificity of the various types of sensors that can be deployed either for military use or for civilian use, and that goes to the things that are being used in BioWatch and a number of other different scenarios.

Also we talked about low-level effects. We have embarked upon a very ambitious program to look at low-level, i.e., subacute, impacts of a number of the different chemical agents known to us.

Third, I would like to point out our program in what is called agent fate and the fact that there are, again, a number of assumptions that are used as to whether agents would be absorbed into various surfaces, concrete, sand, whatever, and what is the possibility of either reaerosolization in the case of anthrax spores, for example, or off-gassing when the climatic conditions may change or something like that. These again just point to a lot of the unknowns.

I am sorry that the whole panel keeps coming back to that point, but it is a very important point to make to you, that with regard to what we know about the source term data, what is the agent going to be? What kind of form is it going to be? How is it going to be impacted by the meteorological, as was mentioned earlier, in high humidity or in rain, or, as was also mentioned, the time of day, the inversion layers in the air? All of these things have to be fed into the model. These are all areas that are crying for an additional investment in the research programs, and I think that we can be proud of the investment the Department of Defense is making in some of those areas.

Mr. SHAYS. Let me be clear and just make one last point before I am all set with my questions.

The Department of Defense, though, is not—its focus is not on terrorist attacks in urban areas in the United States; is that correct? I mean, whatever work you are doing, you are doing more on the battlefield than you are in an urban setting, correct?

Dr. JOHNSON-WINEGAR. Well, our primary emphasis is on the battlefield, but I think in many areas, the information is easily transferable to an urban setting. For example, agent fate, you know, is it going to be absorbed into the concrete on the street, probably the same type of data would be generated as to would it be absorbed into a runway on an airfield.

Mr. SHAYS. This is my last point. When we had our hearing on the issue of anthrax as it related to our government buildings here and in the post office in Wallingford, they did—twice they tested in the facility. They did not believe it was where they tested. When Ottilie Lundgren died, they went back and they found it. And one of the points that was made to us was that had they known it was there, they would have found it, but it was so small. I mean, what they were looking for is such a small—it is difficult to find it, and the bottom line was had they known it was there, we would have been we know it is here, now we have to find it, as opposed to it is probably not here, and they did the test, and they didn't find it. When they knew it was there, they did find it. That is my point.

We know that there will be chemical, biological, heaven forbid maybe even a nuclear attack on the United States. We know that a prime target is a place like New York City. So if we knew—like right now you just knew that sometime soon there would be an attack, a chemical attack, say, on Times Square, would it take us—do you agree that we would probably very quickly, in preparation, be able to prepare for it, know the way the wind basically goes, and be able to say not what is going to happen 10 or 20 miles down, but what is going to happen 15 blocks away?

My point is if you knew it was going to happen, do you think that we would be making a lot faster progress? Do you understand the question?

Dr. ERMAK. Allow me to answer that. If you knew or thought—perhaps a better way to put it is there was a high probability that something might happen, or you had information that it might, you can, of course, do a better job of preparing for it. At NARAC, we have been involved in situations such as that where at certain places certain events were occurring, and it was anticipated that this might happen.

Now, in all of the events that we supported, there was not a release. However, we were able to bring much more of our resources to bear on to that situation, both in the collection of data and in the running of more high-fidelity models to address it. So I would think—I would say at least yes; the answer is if you knew that an event might be occurring, you could be much better prepared in having plume predictions with greater fidelity and accuracy.

Mr. SHAYS. I am taught to observe, and one of the things I am observing is that you all do work that no one knows much about or really cares that much about, and they should. And I had this sense that, you know, you just kind of plod through this, you have done it for years, and you keep doing it. I guess I would like there to be a higher sense of urgency. I would like to feel a higher intensity level. I would like to feel like—you know, someday you all are going to be on TV having to respond to some attack somewhere, and they are going to ask you about this boring thing called the plume, and you are going to try to explain it to people, and then you are going to think when you go home, my God, if we just did a little more a little bit sooner, it might have helped. That is kind of my sense of what I am gaining from this hearing.

I am set to relinquish my time unless someone wants to make a comment.

Dr. HANNA. I think I would like to second what Bruce Hicks said. There is no substitute for wind observations in the urban area, and there are a number of them that are already in and being proposed for the Washington area, for the New York area, and there is the urban atmospheric observatory being proposed for New York right down in the Times Square area. And you just have to have those local wind observations to tell you which way the plume is going to go, because you don't want to use the Baltimore airport wind or the LaGuardia wind or something.

Dr. BARRON. I would just like to add that the Board on Atmospheric Sciences and Climate report wasn't one that was requested, it was one that the atmospheric sciences community felt that this was essential to begin to take these steps; for instance, instrumentation and modeling of a city to work on the forecasting, gain experience, do model intercomparisons so you would know which model was accomplished in what particular facet. So that was entirely our intent was to provide a path for how atmospheric sciences could best address the issue that you raised.

Mr. HICKS. And I would like to volunteer that neither the DCNet in Washington, DC, or the Urban Atmosphere Observatory up in

New York were generated top-down. They were both generated by the scientists recognizing there is a real problem here, and we had better start addressing it fast or else we will get into trouble. We are trying to dig our way out of a hole, and do it fast.

Mr. SHAYS. Thank you, Mr. Chairman.

Mr. TURNER. I don't have any other questions, but we do have some questions from our counsel.

Mr. HALLORAN. Thank you. I just want to first ask for a couple things for the record from Dr. Winegar, if I could.

Your statement describes the J–1 process as semi-automated. I wonder if we have a more complete explanation of what is automated and what is not, in some more detail, on what the plans are to automate that system.

Dr. JOHNSON-WINEGAR. I will be happy to take that for the record and provide you more details of the various phases of the full integration of J–1.

Mr. HALLORAN. Thank you. Your statement early on says that, until recent reorganizations, you were the party responsible to accredit models. Who does it now?

Dr. JOHNSON-WINEGAR. Under the recent reorganization, my immediate boss, Dr. Dale Klein is now the accreditation authority, because his purview reaches across nuclear, as well as chemical and biological. So I believe that is the appropriate person.

Mr. HALLORAN. Thank you.

Mr. Rhodes, briefly, to what do you attribute DOD's limiting of the plume height or altitude in their modeling? What drove that?

Mr. RHODES. I have no answer for that. I believe it was—as we understand from the documentation, it was an arbitrarily set value, and it was described as an arbitrarily set value.

Mr. HALLORAN. I see. Was it in your testimony or someone else's that described the videotapes that we had seen here of that event looked to show plumes higher than that.

Mr. RHODES. It was actually in our document, in our further testimony and in our subsequent report, talking about the thousand-pound bomb estimate and plume being as high as 400 meters. That was us.

Mr. HALLORAN. Thank you.

And finally, Dr. Ermak, could you just briefly tell us about your experiences in TOPOFF 2 and what the reported problems were with the plume applications and modeling in that exercise scenario?

Dr. ERMAK. Yes. We participated in TOPOFF 2 in two ways. One was in direct support to the city of Seattle and the surrounding area, and the other was through the Federal Government, through the Department of Homeland Security and the Department of Energy. I think one of the points that I think came out of that, it is not only important to have the accurate data and accurate model predictions, but also important is to be able to rapidly provide emergency managers and the first responders with that information, and to provide that information in a way that they can readily use it.

As an example, during that exercise we had one of our staff in the city of Seattle supporting the Fire and Emergency Operations Center people in Seattle in the use of our system that was being tested. He was also available to answer questions that came from, say, the mayor or other public officials. And this was very, very useful. And so that says also that in addition to—and he emphasizes the need for information that is in a form that they can use to make their decisions.

Mr. HALLORAN. And what is the impediment to that? I mean, it just came in a form that he didn't understand, or no one was willing to make a definitive call as to what it really meant?

Dr. ERMAK. No. I think, sometimes for example, just a plume picture is not readily understandable, say, by a policymaker or decisionmaker. And so putting that into terms in which they can understand it, understand the reliability of it is, is very, very helpful to them.

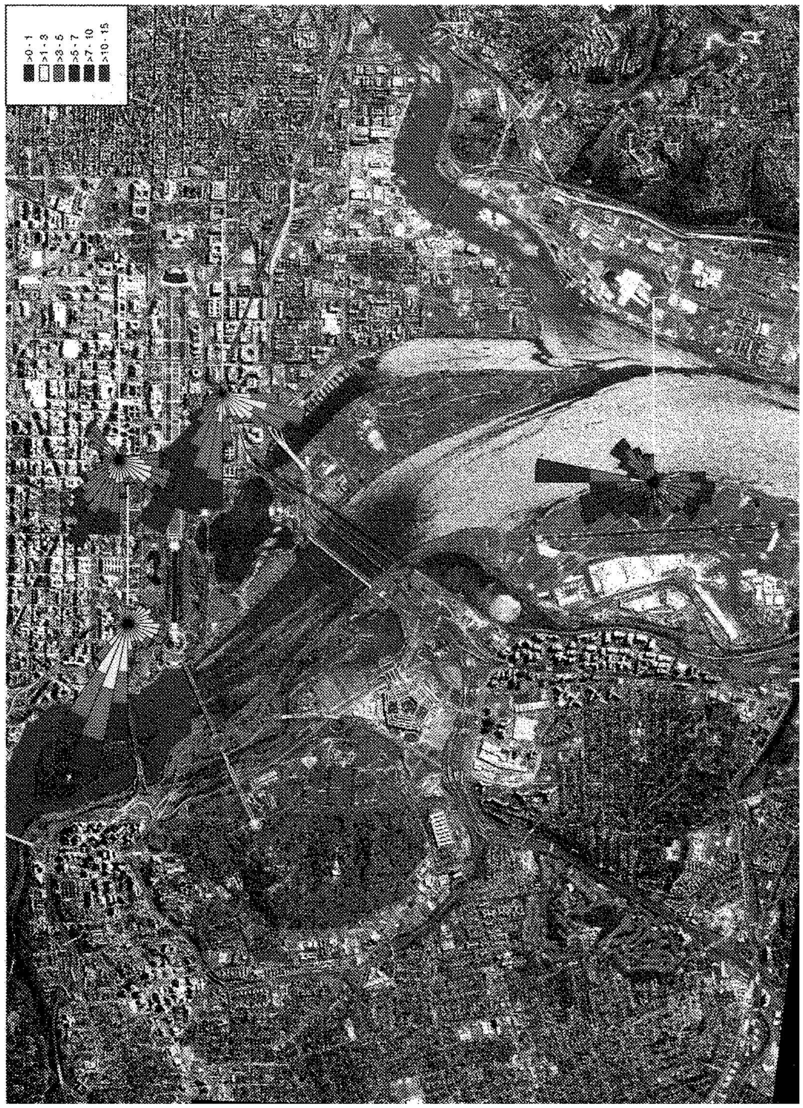
Mr. HALLORAN. Thank you, Mr. Chairman.

Mr. TURNER. Thank you. I want to thank each of you for participating in this. Certainly the work that you are doing is important and very complex, and we respect the expertise that you bring. I think the issue before the committee has focused somewhat on how that information is used. And as our chairman has raised the issue of, as you look to modeling, what resources are going to be necessary for your success.

With that, I want to ask if anyone has anything else they would like to add to the record? Hearing none, I want to thank you again for your participation, and thank our chairman. We will be adjourned.

[Whereupon, at 3:01 p.m., the subcommittee was adjourned.]

[Additional information submitted for the hearing record follows:]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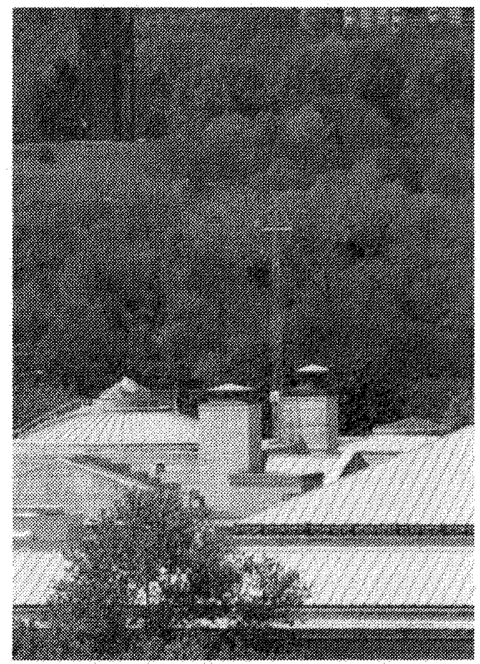
DCNet Status

Some sites are already set up, starting with downtown Washington –

1,2 Department of Commerce
3 The National Academy
4 National Arboretum
5 Silver Spring SSMC-III
6. DOE – Forrestal Building
7 Naval Research Labs
8,9 The Pentagon
10 DC Municipal Building
11 Veteran's Administration

12 Hart Senate Building
13 National Zoo



The DCNet tower on the roof of the National Academy of Sciences, Constitution Avenue.

ANATEX – NOAA regional perfluorocarbon tracer study, 1987

This shows how a puff diffuses as it is transported downwind for four days.