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Reports

Modeling the Chemical Warfare Agent Release at the Khamisiyah Pit

Central Intelligence Agency

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Introductory Note

As part of CIA's and DoD's continued work to support US Government efforts related to the issue of Gulf war veterans' illnesses, this paper highlights the joint CIA-DoD efforts to model the release of chemical warfare agents from the Khamisiyah pit. This modeling exercise has been a joint effort, with significant coordination among multiple agencies and hundreds of people, with expertise ranging from upper atmospheric conditions to soil characteristics. Since 21 July 1997 we have provided many briefings to Secretary Cohen and the Joint Chiefs, DCI Tenet, Senator Rudman, the staff of the National Security Council, the Presidential Advisory Committee, Congressional staffers, representatives from veterans' organizations, and the media. This report is our effort to make this information as widely available as possible.

Robert D Walpole
Special Assistant to the Director of Central Intelligence
for Persian Gulf War Illnesses Issues

Bernard Rostker
Special Assistant to the Deputy Secretary of Defense for
Gulf War Illnesses

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Modeling the Chemical Warfare Agent Release at the Khamisiyah Pit

Background

In September 1995, CIA analysts identified Khamisiyah as a key site that needed to be investigated because of its proximity to Coalition forces and the ambiguities surrounding the disposition of chemical weapons at the site; CIA informed DoD of its findings. On 10 March 1996, a CIA analyst heard a tape of a radio show in which a veteran described bunker demolition at a facility the analyst immediately recognized as Khamisiyah. He informed DoD the next morning and the PAC later that week. This identification prompted further investigation of the site, including discussions with UNSCOM.

Figure 1
Khamisiyah Storage Site, Iraq

In May 1996, Iraq told UNSCOM inspectors that US troops had destroyed chemical weapons in the pit near the Khamisiyah depot. After receiving details from UNSCOM in June, DoD was able to interview soldiers who confirmed the demolition of 122-mm rockets in the pit. We discussed this at the PAC meeting in Chicago in July 1996.

The PAC and NSC staff directed CIA to have one of its contractors model multiple chemical warfare agent releases. *Modeling* is the science and art of using interconnected mathematical equations to predict the activities of an actual event, in this case the direction and extent of the chemical warfare agent plume. Modeling is necessary because we do not know what the plume actually did. In such cases, modeling uses obtainable data--the number of rockets, weather, and so forth--to develop a best estimate of the extent of potential exposure. Our modeling efforts apply state-of-the-art atmospheric models, which consist of global-scale meteorological modeling of observational data; detailed regional meteorological modeling using regional and global-scale observations and global-scale model calculations; and transport and diffusion models simulating the contaminant transport based on the flow and turbulence fields generated by the regional model.

We quickly realized that modeling the pit presented far greater challenges than modeling Bunker 73 at Khamisiyah and other releases. We were able to model the events at Al Muthanna, Muhammidiyat, and Bunker 73 largely because we had test data from the 1960s indicating how chemical warfare agents react and release when structures in which they were stored were bombed or detonated. However, when we began to model the pit, we had significant uncertainties regarding how rockets with chemical warheads would be affected by open-pit demolition. It became clear by October that, without testing the demolition in the open, these uncertainties would remain.

We informed the PAC in November of last year and March of this year, that the proximity of US troops and the prevailing winds at the time of the event identified the associated chemical warfare agent release as a priority for further study. However, we also noted that we had significant uncertainties in attempting to characterize the event:

- Very limited and often contradictory information from two soldiers.
- Questions on the date(s) of demolition.
- Uncertainties on the number of rockets, agent purity, and amount of agent aerosolized.
- Uncertainty on agent reaction in an open-pit demolition.
- Limited weather data.
- No single model that runs weather and chemical warfare agent data simultaneously.

Figure 2
Khamisiyah Ammunition Storage Area

These uncertainties required a more intense study to determine the potential hazard area. DoD and CIA undertook an extensive effort to characterize as accurately as possible the demolition activities at the pit as well as the subsequent dispersion of the agent. This involved the aggressive analysis of any thread of information related to the noted uncertainities, as well as the formation and coordination of a technical working group consisting of modelers from the participating agencies in order to identify the extent of the release.

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Reducing General Uncertainties

Interviews With Veterans Invaluable

Working with DoD's Investigation Analysis Division, we have been able to locate and jointly interview five soldiers involved in or claiming to have been involved in the pit demolition--three more than in October of last year. We believe this constitutes at least half of those involved at the time. The participants provided key information addressing our uncertainties, including the numbers of events, munitions, and charges, as well as the placement of the charges. This information was critical to our Dugway tests and to the completion of a meaningful model.

Eliminating Uncertainty Surrounding the Date

The soldiers indicated that the pit demolition occurred on 10 March 1991, coincident with the documented demolition of about 60 bunkers and 40 warehouse buildings nearby. A 10 March demolition is also supported by the fact that some of the soldiers involved in the demolition left for Saudi Arabia on 10 March, as documented by military records. According to four of the five soldiers, the event started at 4:15 p.m. local time (1315Z); one soldier remembers the pit demolition starting a few minutes after the bunker demolition. On the basis of these interviews, we assess that 13 stacks were detonated simultaneously in two groups of stacks fuzed separately. (See figure 3 for the layout of the stacks.)

Troops Working With Limited Amount of Explosives

On the basis of these interviews, we assess the soldiers used about four boxes of US C-4 explosives, which would have provided 120 charges. All soldiers indicated that there were insufficient numbers of charges to completely destroy the rockets, even with the anticipated sympathetic detonation of what they thought were high-explosive warheads. They had to use Czech detonation cord to complete the demolition.

Why the Limited Explosives Resources?

The operational planning for the demolition of the main part of the Khamisiyah depot--60 bunkers and 40 warehouses--was done in accordance with standard explosive ordinance disposal (EOD) practices for the magnitude of the demolition. However, the rockets in the pit were discovered after most of the explosives had been allocated for that main demolition. Hence, the Army personnel had to collect ad hoc resources to conduct the pit demolition. Also, given the deadlines for departure, the pit demolition could not be delayed to allow additional explosives to be delivered. In addition, many EOD personnel were scheduled to be reassigned to other important facilities. At the time, the military personnel at Khamisiyah had not received warnings about chemical weapons there, and thought they were destroying high-explosive rockets. Such a demolition would not have been as high a priority as the much larger amount of weapons in the main part of the facility.

The interviews indicate that the thoroughness of the demolition varied by stack. All the soldiers indicated that the ends of crates were broken out and the charges were placed inside (although it is possible that some charges were simply affixed to the crate exterior for the sake of expediency). They also indicated that the orientation of the rockets varied--some pointing toward the embankment, some away. The soldiers' recollections from this point vary, however. One stated that charges were placed on the side opposite the embankment and only on warheads. Another contradicted that assertion, indicating that the charges were placed at both ends of the crate with some on warheads and some on rocket sections. A third soldier indicated that in the first stack he set as many as four charges on each rocket--two on both the warhead and booster. That would have required more charges than were available. Because different soldiers used different methods on different stacks, we must assess that the placement of charges varied by stack.

Figure 3
Predemolition Photo of Pit Area Near Khamisiyah

IDA Panel Provided Meteorological Expertise

The uncertainties mentioned earlier brought modeling efforts to a halt. Former Deputy Secretary of Defense John White and former Director of Central Intelligence John Deutch asked the Institute for Defense Analysis to host a panel of experts to review the previous modeling attempts at the pit and to make recommendations for proceeding. The IDA panel consisted mostly of meteorological experts. Their expertise served as the basis for important recommendations regarding the meteorological aspects of modeling the pit release.

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Refining the Modeling Input Parameters

Number of Rockets in Pit Exceed Iraqi Declarations

Although the Iraqis declared to UNSCOM in May 1996 that 1,100 rockets were in the pit, we assess that the number was somewhat higher. The Iraqis indicated that 1,100 of the 2,160 rockets declared to have been at Khamisiyah were moved from Bunker 73 to the pit. Recent Iraqi press reports suggest that the pit contained roughly one-half of the 2,160 rockets moved to Khamisiyah (or about 1,080 rockets). However, based on the size of the crates, the varying heights of the stacks, and soldier testimonies, our best estimate of the number of rockets in the pit is 1,250. We derived an upper bound of 1,400 rockets by including uncertainty in stack width, using tight edge-to-edge packing, and assuming all stacks were the same height as the tallest of the 13.

Demolition Affected Less Than 40 Percent of the Rockets

Sometime during the year following the demolition, the Iraqis bulldozed and handcarried the remnants of the 13 stacks into seven piles. In the process, they likely damaged more of the rockets and buried others. UNSCOM inspectors recovered a total of 782 undamaged rockets: 463 taken from the surface, including 389 that were filled, 36 that were partially filled (we attibuted this partial leakage to the Iraqis in our modeling), and 38 that were unfilled; and 319 unearthed from the pit, all of which were filled. UNSCOM ensured that all were subsequently destroyed, either in place at Khamisiyah or at Al Muthanna where they were later moved.

Accordingly, our best estimate of the number of rockets damaged during the demolition is 500. This was derived by subtracting from 1,250 a total of 744 (782 found undamaged minus 38 of which were unfilled, conservatively assuming they released agent during the demolition). The result, 506, was rounded to 500. This estimate is primarily intended for illustrative purposes; the modeling effort used percentages and amounts of total agent in the pit--7,875 kg or 1,882 gallons. This means that 744 rockets' worth of agent--60 percent or 1,129 gallons--did not disperse during the demolition in March 1991 and was subsequently destroyed by UNSCOM.

Amount of Agent per Rocket

Previous modeling efforts--completed for Bunker 73 and halted for the pit--estimated that each rocket contained 8 kg of chemical warfare agent. This was a conservative estimate based on subtracting the mass of an empty warhead from that of a full one (19 kg minus 11 kg). However, in preparation for ground demolition testing in May 1997, we analyzed Iraqi plastic inserts (figure 4) and found that they contained only 6.3 kg of agent. Our earlier estimate had included the mass of the 1.7-kg inserts.

Figure 4
SAKR-18 Inserts Obtained by UNSCOM

Agent Purity

Our best estimate of the agent purity at the time of demolition is slightly less than 50 percent (see figure 5). Iraqi production records obtained by UNSCOM indicated that the sarin/cyclosarin (GB/GF) nerve agent produced and transported to Khamisiyah in early January 1991 was about 55 percent pure. (The tests documented in the records showed purity levels ranging from 45 to 70 percent, with 55 percent being the average from 1990 test dates.) 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. On the basis of the sample purity and indications that the degradation rate for sarin and cyclosarin are similar, we assess that the ratio when the munitions were blown up in March 1991 was the same as that sampled in October 1991--3:1. Assuming a conservative, exponential degradation of the sarin/cyclo-sarin, the purity on the date of demolition two months after production can be calculated to be about 50 percent.

Figure 5
Degradation of Combined G-Agent

Establishing Initial Wind Direction

The Khamisiyah plume analysis is a retrospective analysis; hence, the opportunity for direct comparison with weather observations is limited. Several sources of imagery data, however, are available for the period 10-11 March 1991 which may provide qualitative comparison. During the May 1996 inspection of Khamisiyah, UNSCOM took GPS coordinates in the pit and recorded the location as 30û 44' 32'' N 46û 25' 52"E. An intense effort to find weather data for the area has netted good information on wind direction at the time of the explosion in March 1991. These include photography of the soot patterns created by the 10 March bunker explosions at Khamisiyah and regional-scale imagery of the Kuwaiti oilfield fire plumes.

Figure 6
Khamisiyah Bunker Soot Patterns--10 March 1991

Figure 7
Helicopter Photo of Bunker 16--September 1992

Using SPOT photography of 27 April 1991 (figure 6), analysts derived wind direction from distinct trails of windblown soot and ejecta from individual bunkers and corroborated their findings using UNSCOM helicopter color photos from October 1991 and September 1992 (figure 7). Using these sources, we have determined that the wind direction was 335° (from the north-northwest), thus initially blowing any chemical agent released from the pit to the south-southeast. The consistency of the azimuths within the 3.4-km spread of the bunker area destroyed allows us to reasonably translate the wind direction information to the pit area approximately 2 km from the bunkers. This wind direction is further corroborated by statements from one of the soldiers involved in the pit demolition, indicating that he was in a vehicle that drove through the smoke cloud in an area south to south-southeast of the pit. He reported no ill effects from the smoke.

Figure 8
Khamisiyah Bunker Soot Azimuths

In addition to the soot pattern photography, we used regional-scale imagery of the Kuwaiti oilfield fire plumes for the days immediately following the detonation to assist in corroborating modeled wind direction. These also provided an integrated measure of meteorological quantities such as low-level wind direction, low-level wind speed, vertical wind shear, and thermodynamic stability.

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Dugway and Edgewood Testing

Ground Testing Essential

During last year's modeling efforts, we noted that without ground testing we could not estimate with any degree of certainty the amount of agent released at Khamisiyah or the rate of release. In the 1970s, the US conducted additional testing on US chemical rockets to characterize the impact of terrorist actions. Unfortunately, the US tests did not measure the amount of airborne agent downwind and did not help quantify probable release parameters. Thus modelers of the pit demolition were unable to assess whether the agent would be released nearly instantaneously or over a period of days. The later scenario obviously was more dependent on weather conditions.

To resolve these uncertainties, CIA and DoD agreed in April 1997 on the need to perform ground testing before a meaningful computer simulation could be completed. We cooperated to design and implement a series of tests in May 1997 at the Dugway Proving Grounds, which gave us a much better understanding of the events at Khamisiyah. DoD provided complete logistic and administrative support for the tests.

Figure 9
Placement of C-4 Charge on Warhead, Dugway

The testing involved a series of detonations of individual rockets and some in stacks, with high-explosive charges placed the way soldiers say they placed them in March 1991. This was done to resolve questions like: how did the rockets break? what happened to the agent? were there sympathetic detonations? how much agent might have been released? We could not replicate the entire demolition of hundreds of rockets, but we did gain information critical to our modeling efforts.

First, we took special care in replicating the rockets in the pit, including:

- Using 32 rocket motors identical to those detonated in the pit.
- Manufacturing warheads based on detailed design parameters provided by UNSCOM, including precise wall thicknesses, materials, and type of burster tube explosive.

- Building crates based on precise measurements and UNSCOM photographs.
- Choosing a chemical agent simulant, triethyl phosphate, that closely simulates the volatility of cyclo-sarin and is often used as a simulant for sarin.
- Stacking the rockets as described by soldiers involved in the pit demolition.

Figure 10
Representation of Charges

We performed six tests at Dugway using the 32 available rockets. We began with four tests on single rockets in preparation for tests involving nine and 19 rockets. We included a few dummy warheads to increase the size of the stacks. Finally, one of the unbroken rockets from the multiple tests was dropped from an aircraft to simulate a flyout.

Flyouts

The results were very revealing. The only warheads that burst and aerosolized agent were those that had charges placed just beyond the nose of the warhead. Only the warheads immediately adjacent to the charges leaked agent. Even the rocket dropped to simulate a flyout did not disperse any simulant; it buried itself over 30 feet below the surface. The pie chart in figure 11 shows the distribution of agent from these tests among aerosolized vapor and droplets, spill into soil and wood, burning, and unaffected. Only about 32 percent of the agent was released, mostly leaking into the soil and wood. A total of 18 percent became part of the plume--two percent through aerosolization and 16 percent through evaporation (5.75 percent from soil and 10.4 percent from wood).

The Dugway testing provided a physical basis for estimating the effect of a charge on the surrounding rockets. We used pressure sensors to refine our gas dynamics models to approximate the threshold forces required to break a warhead. Gas dynamics modeling of the detonations and resultant pressure waves further bolstered our confidence that the results of the Dugway testing were realistic. This allowed development of a model to determine the effect of various placements of charges and orientations of rockets:

- Charges were placed on the ends of rockets opposite the embankment. (As cited in interviews with US soldiers.)
- Charges broke adjacent warheads but not warheads at the other end. (Dugway field testing)
- Evaporation in accordance with Dugway laboratory testing of a 3:1 mixture of sarin/cyclosarin agent at a temperature of 14 degrees C.
- Number of rocket flyouts is low (fewer than 12) with probability of leakage from the rockets minimal. (Soldier interviews and Dugway testing.)

Flyouts

Several soldiers reported seeing up to a dozen rockets flying from the pit area during the *demolition. We believe the number of flyouts was low because most of the charges were placed on the warhead area of the rocket, which would not have ignited the motor. Charges placed on the motor end probably would have caused most of the rockets to fly into the embankment. Those rockets that did fly out of the pit area generally would not have the proper stability, optimum launch angle, or even the normal thrust in some cases to go any appreciable distance.*

We modeled several rocket flyout possibilities. Although the maximum range of the rocket is 18 km, we don't believe any flew that far. Pictures after the demolition show most of the rockets have a band or clamp on the tail stabilizing fins--rockets launched without fin deployment probably would fly only 2 to 4 km. With the fins deployed, the rockets could reach 5 to 15 km.

The plume from the amount of agent released from the rocket flyouts should have been small. A drop test at Dugway Proving Grounds showed that the rocket would bury itself about 30 feet below ground level without spilling any agent. We believe that the longer range flyouts would have buried themselves also. If one of the rockets did spill the agent, the general population limit would be perhaps 50 m wide and extend downwind about 1 km. We have not shown any flyouts in our plumes because:

- *US tests on 115-mm rockets showed that most flyouts went only 200 meters and that the maximum range was 2 km--within our estimated plumes.*
- *We do not believe any actually burst.*
- *We would not be able to determine where they actually impacted.*

We feel confident that the model paradigm is consistent with UNSCOM information, soldier photos, and conservative assumptions. For example, the proportion of rockets whose agent was not affected during our ground testing (56 percent) closely matched the 708 filled rockets UNSCOM found after the demolition (56 percent). Also, examination of the three known postdemolition pit photos of the rockets show very little damage with only 4 out of 36 rockets (11 percent) showing obvious damage (figures 12 and 13).

Evaporation Testing Recognized as Critical

The large percentage of agent leaking into the soil and wood increased the importance of additional work conducted at Dugway and Edgewood laboratories. The tests were initially planned at Dugway and Edgewood to be performed on soil but, on the basis of the Dugway ground testing results, were expanded to include wood. These tests began by spilling the sarin and cyclosarin mixture onto wood and soil, respectively, and then measuring the rate at which the agent evaporated. The tests also were designed to closely replicate conditions in the pit, including:

- Sarin and cyclosarin--not simulants--were used in a 3:1 ratio.
- Soil, including some from Iraq, which was assessed to be similar to pit sand, was obtained for the tests. We tested pine, a common wood used for 122-mm rocket boxes.
- Tests simulated the wind speeds most likely present during the pit demolitions.

Different temperature ranges were used to cover the range of daytime and nighttime temperatures in the pit.

Figure 11
Agent Disposition in Gallons

The plot in figure 14 presents the results of the Dugway laboratory tests, which provided the more conservative results of the two laboratories. Of particular interest, most of the chemical warfare agent evaporated during the first 10 hours. Thereafter, with a significantly decreased surface area from spillage, the release was slow, and significant portions of the agent stayed in the soil and wood. In addition, tests of the soil at Edgewood indicated that about one-eighth of the agent degraded in the soil in the first 21 hours.

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Using an ``Ensemble'' of Models

While multiple efforts already discussed significantly reduced uncertainties in the input parameters for modeling the chemical warfare agent release, uncertainties in the results of long-range transport and diffusion also arose because of the relatively limited meteorological data in the region, the complexity of the modeled phenomena, and limitations and differences in the various models. To address these uncertainties, the DoD/CIA modeling team used a variety of models in several different combinations as recommended by the Institute for Defense Analysis review panel.

Figure 12
Postdemolition Photo of Stack 9 in Pit at Khamisiyah

The models chosen are highly versatile advanced atmospheric and transport and diffusion modeling systems. Because all models have relative strengths and weaknesses, we used multiple models to reconstruct the event. This strategy also helped identify any model-induced (as opposed to data-induced) uncertainties. Figure 15 depicts the interrelationship of the models in this effort.

Meteorological Reconstruction

Determining accurate regional-scale meteorological fields for several days is crucial for modeling the transport of nerve agent in the atmosphere. Because a comprehensive set of local and regional observed weather conditions was not available, the IDA panel recommended using several different wind field modeling techniques to assess the sensitivity and robustness of dispersion results. Accordingly, the DoD/CIA team attempted to reconstruct the weather conditions on 10 to 13 March 1991 to the highest fidelity possible. This reconstruction consisted of regional (mesoscale) weather model predictions with data assimilation of all available observations, including those from global-scale (synoptic) sources. The meteorological reconstruction drew upon the following:

- Operational global observational data (although relatively sparse in the Persian Gulf region) available during March 1991.

- Additional observational data from the Persian Gulf region not operationally available in March 1991. These data include delayed Saudi surface and rawinsonde (formerly known as *radiosonde*) data, declassified surface data collected by USAF and Special Forces in the Khamisiyah region, declassified Navy Ship Data, and satellite data.
- Archived global forecast fields generated by GDAS during March 1991 using operational data, or global reanalysis with a current model (NOGAPS) assimilating operational data mentioned in the first two bullets. These analyses combined observational data with results of global forecast models at six-hour intervals to predict wind fields at local and regional levels.
- Local and regional predictions, using three independent models: COAMPS, OMEGA, and MM5. These models use large-scale observations and calculations from the global GDAS and NOGAPS models to initialize and set boundary conditions. Using these initial constraints and local effects, these models predict the wind speeds and directions at any point in the region. (Local effects include such influences as moisture variations due to marshes, local terrain, and the Persian Gulf sea breeze.) All models used by the DoD/CIA team include planetary boundary layer dynamics because they dominate the transport and diffusion of the agent cloud.

Figure 13
Debris From 9-Rocket Demolition at Dugway

Figure 14
Total Sarin and Cyclosarin

Figure 15
Multiple Mathematical Models/Modelers Used in Various Combinations

Several variations using the meteorological models were conducted to investigate the relative contributions of observational data and global-scale predictions to the dispersion of the agent from the pit. For example, NRL performed multiple variations of the meteorology with the NOGAPS/COAMPS pairing. These included a "baseline" run, where the NOGAPS global input to COAMPS was held constant; "data denial" runs, where meteorological observation data were ignored; and a "random perturbation" run, where generated local "observations" were randomly changed to represent observational error. In order to examine other model-induced effects, both OMEGA and MM5 were initialized with different global-scale drivers; OMEGA driven by GDAS (in addition to NOGAPS) and MM5 driven by GDAS and ECMWF.

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Validation of Predicted Meteorological Results Against Observations

The low-level wind directions generated by the multiple meteorological variations were compared to the soot vectors described earlier. The predictions from the models were generally consistent for a majority of variations.

Smoke dispersion from the Kuwati oilfield fires also was used to test the consistency of the meteorological variations with observed data. Figure 16 shows satellite imagery of these smoke plume trajectories over the Persian Gulf region on 11 March 1991. The heat from the fires caused the smoke to rise rapidly and to be transported in the planetary boundary layer as well as the troposphere. Because the smoke absorbed heat from the sun as well, only an indirect comparison could be made with the model predictions, which do not include this effect. Most of the resulting smoke trajectories capture the general characteristics of the oilfield fires.

On the basis of the results of the comparison to soot patterns and the oilfield fires, the NOGAPS/COAMPS, GDAS/OMEGA, and GDAS/MM5 linkages were chosen as the baseline simulations for the dispersion calculations. These simulations gave the most realistic predictions, given their consistency with observed weather conditions.

Modeling the Transport and Diffusion of Chemical Warfare Agent

All transport and diffusion models used in this effort (SCIPUFF, VLSTRACK, and NUSSE4) characterized the detonation using 13 stacks distributed over a 300-meter-long line. For modeling purposes, the masses associated with each stack were considered to be spaced at even intervals. The initial release height was assessed to have been about one meter, or about halfway up the stacks. The release from all stacks was judged to have occurred simultaneously. Each of the 13 stack locations resulted in an initial 6-kg vapor puff and an initial 6-kg liquid droplet mass. The liquid droplets had a mean size of 550 microns. The models (SCIPUFF, VLSTRACK, NUSSE4) then followed the agent cloud according to their respective algorithms.

Model Selection

We chose these models on the basis of several criteria. First, the level of fidelity had to be adequate to resolve important features of the event. For example, the transport and diffusion models had to be able to accept updates from weather models at intervals on the order of every hour. Also, operational regional weather models must handle planetary boundary layer transport and resolve the effects with sufficient fidelity to meet the requirements for the Khamisiyah event. Secondly, the models must have been subjected to various stages of validation against known analytic solutions, well-studied idealized atmospheric flows, and observational data. Where appropriate, nonlinear simulations from the models should have been compared with results from other models accepted in the meteorological community. Thirdly, the transport and diffusion models must have demonstrated previous application to chemical warfare agent dispersion problems and include a satisfactory agent database. Finally, the models must be off-the-shelf, configured to respond to the rapid timetable and data needs imposed by the humanitarian urgency of this project.

Establishing linkages between weather and transport models is critical and was emphasized by the IDA panel. Attempts by CIA's contractor, SAIC, in 1996 to model the pit used the analytical linkage between the OMEGA weather model and the VLSTRACK transport and diffusion model to drive the NUSSE4 transport and diffusion model. NUSSE4 had an established but unique ability to handle multiple agents, which was the case with the Khamisiyah rockets. Efforts to expand the analysis of the pit in 1997 focused on enhancing other linkages. The Defense Special Weapons Agency (DSWA) linked the OMEGA and COAMPS mesoscale models and SCIPUFF--a DSWA transport and diffusion model. SCIPUFF has been demonstrated and validated in a test series at the White Sands Missile Range. The Naval Research Laboratory (NRL) teamed with the Naval Surface Weapons Center (NSWC) *to link the COAMPS model with the VLSTRACK dispersion model, which is widely used in the Navy and elsewhere in the military for tactical analyses and can accommodate varying meteorology. VLSTRACK was validated against sets of field trial data from at least 60 reports on chemical and biological agent and simulation releases. Recently it has also been the subject of an independent review by the National Oceanographic and Atmospheric Agency (NOAA).*

In response to the IDA Panel's suggestion that an established non-DoD local and regional weather model be included in the effort to provide comparative results, NRL was also able to secure 48 hours of meteorological reconstruction generated by the MM5 model from the National Center for Atmospheric Research (NCAR).

The relative droplet mass is small--about 19 gallons--and the liquid droplets that comprise about half the initial chemical warfare agent cloud settle to the ground quickly. Once the liquid droplets reach the ground they spread, and the surface area from which the agent can evaporate increases. The subsequent release of agent, which comprised the bulk of the agent released into the atmosphere at Khamisiyah, included the evaporation from the liquid contamination as well as the persistent (over several days) evaporation from the absorbed liquid pools and saturated wood at the stack locations. Evaporation from wood and soil has been incorporated into each of the models to reflect the evaporation curves from the Dugway/Edgewood test results. The specific results from the Dugway evaporation tests (rather than the Edgewood results) have been used in order to err on the side of conservativism.

Figure 16
Meteorological Satellite Image of Kuwaiti Oil Fire Plumes, 11 March 1991

In addition, the diminution of the ground-level vapor agent concentration as it is transported downstream is entirely due to assessed changes in regional meteorological conditions, basically shifting winds and turbulent mixing. Depletion mechanisms such as agent degradation (for which modelers could not agree on a rate), photolysis, and vapor deposition were not used. The combined effect of these phenomena would be to diminish and limit the extent of the plume especially in the case of long-range transport, perhaps by as much as 40 percent. In addition, scattered rain showers in the area on 11 March, which could have caused additional hydrolysis, were not incorporated into our modeling effort because we could not be confident of their location. This more conservative approach is warranted, given that the primary value of the modeling effort was to provide medical and epidemiological researchers with this important tool.

Estimate of the Plume: A Composite of Multiple Models

Uncertainties in the plume's trajectory are heavily dependent on the amount of meteorological data available. In addition, performing similar trajectory analyses with different dispersion models could lead to different conclusions. Therefore, the DoD/CIA modeling group chose to present a composite or union of five different meteorological/dispersion simulations--representing the outermost perimeter of all models overlayed--in order to define the extent of the plume. These five simulations, all of which use the baseline meteorological fields, are:

- NOGAPS/COAMPS/SCIPUFF.
- GDAS/OMEGA/SCIPUFF.
- GDAS/MM5/SCIPUFF.
- NOGAPS/COAMPS/VLSTRACK.
- GDAS/OMEGA/NUSSE4.

Turbulence-induced uncertainty is inherent in an atmospheric modeling effort. It particularly affects the predicted dosage levels. Models generally account for this by predicting that there is a 50-percent probability that a specific dosage level will fall within a given contour. In our effort, we modified the models to broaden the contours so that they predict that there is a 99-percent probability that a specific dosage will fall within a given contour, further increasing our confidence in the outcome.

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The Plume and Potential Troop Exposure

Dosages, Concentrations, and Limits

We decided to depict two levels of potential exposure in our modeling (note: a dosage is the amount or concentration of the agent to which a person at that location is exposed over a specific period of time):

- *First noticeable effects.* This is the dosage that would be expected to cause watery eyes, runny nose, tightness of chest, muscle twitching, sweating, and headache. Increasingly higher dosages would produce vision impairment, imcapacitation, and death.
- *General population limit.* The dosage below which the general population, including children and older people, could be expected to remain 72 hours with no effects. (See figure 17 on toxicity.)

Figure 17
Sarin Toxicity

To understand the magnitude difference between the levels, note that the general population limit dosage (.01296 milligram-minute per cubic meter) is one-eightieth of the dosage expected to produce noticeable effects (1 mg-min/m3). But the area between these levels, which we will call the area of low-level exposure for this report, is the area for which medical research is needed. The exposure at Khamisiyah was relatively brief, measured in hours, not weeks, as would be the case with low-level occupational exposures. The coordinated efforts of VA, DoD, and HHS are ensuring research into better understanding this exposure issue.

Last Year's 50 Kilometers and 20,000 Troops

Last October, when it became clear that meaningful modeling of a potential release from the pit had come to a halt, DoD used the first noticeable effects limit to define a circle around

Khamisiyah. On the basis of available literature and discussions with experts, DoD determined that one would have expected to see noticeable effects within 25 km of the demolition. Given the uncertainties at the time, DoD doubled that, and it was assessed that roughly 20,000 troops were within the 50-km circle so defined. DoD used this assessment as a basis for mailing almost 20,000 surveys in an attempt to get additional information from the people that had been near Khamisiyah at the time of the demolition. DoD received 7,400 responses to the surveys, with over 99 percent showing no physical effects that could be correlated with exposure to the chemical warfare agent sarin.

Figure 18 depicts the Kuwaiti Theater of Operations with last year's 50-km circle around Khamisiyah and DoD's current understanding of military unit locations. Each dot represents where company-size units were located based on DoD's S3-G3 conferences. These conferences helped develop much better fidelity on the locations of troops, allowing DoD to move from battalion-level accounting to company-level accounting. While that has been completed for all of XVIII Airborne Corps, it is not complete for the VII Corps. The S3-G3 conference for VII Corps is scheduled for September. The analysis that follows uses battalion-level data for the VII Corps; with more refined data the numbers are likely to be slightly lower.

Figure 18
Unit Locations
10 March 1991
Khamisiyah Pit Demolition

The Plume Over Four Days

A closer look at the area with figure 19 shows the area of first noticeable effects on the first day (from 4:15 p.m. on 10 March 1991 to 3:00 a.m. on 11 March). This area is well within DoD's 50-km first-effects area from last year's survey effort.

The next map (figure 20) shows a closer view of the first-effects portion of the plume, which is about 20 km long and five km wide. No military units were located under the first-effects portion of the plume, which is consistent with the lack of reported effects and with DoD's survey results, which had over 99 percent of the respondents showing no signs of physical effects that could be correlated with exposure to sarin. The troops that performed the demolition had evacuated the area. As stated earlier, we know that one soldier involved in the demolition drove briefly through the smoke from the explosion. He had no ill health effects.

The small, 1.5-km-long peanut shape near the pit represents the area where DoD believes chemical alarms would have gone off had they been used. A note of caution, however: all plume areas depicted in this report are based on dosage levels--concentrations over time. The alarms are designed to go off based on concentrations, recycling every 20 seconds, that would cause incapacitation or death.

Figure 19
Day 1
10 March 1991 Modeled Exposure
Khamisiyah Pit Demolition

The offshoot portion of the plume is a product of using a composite or union approach in our modeling. While all five models produced first effects plumes for the first day that pointed south; one model also depicted a portion of the plume moving to the southeast. Our inclusion of the latter model graphically illustrates our approach in drawing the outer boundary of the overlaid plumes.

The next map (figure 21) shows the first-effects plume for the second day. It is an area about six km across and six km deep. This is the result of a smaller area being generated by the evaporation of agent from the soil and wood. This evaporation is a critical component of the plume, making up almost 90 percent of the plume. We would not have expected the evaporation from the wood without the Dugway testing. We had thought there would be an instantaneous release into the atmosphere with some evaporation from the soil, but the Dugway testing showed that the spill into the wood and subsequent evaporation would be a very important factor.

By the third day, as the next map (figure 22) shows, the evaporation is not producing dosage levels above the first noticeable effects limit. However, the evaporation makes the low-level event last a few days.

Figure 20
Day 1
10 March 1991 Modeled Exposure
Khamisiyah Pit Demolition

Figure 23 depicts the low-level exposure area, extending to the general population limit, for the first day. The wind has driven the chemical cloud south-southwest, extending almost 300 km and into Saudi Arabia. This potentially exposed almost 19,000 troops to low levels of chemical warfare agent. Remember that this plume is the composite of five models; the plumes from each individual model predicted smaller exposure areas. We used the composite approach to increase our confidence that the resulting plume would be our best estimate of the potential area covered, taking into account individual model biases. This approach was critical for notifications and for future epidemiological studies. However, we do not expect that everyone under the composite plume was exposed.

The map for the second day (figure 24) shows the effects of significant wind changes, thickening the plume and shifting it toward the west. This is the day of the highest potential low-level exposure, possibly affecting 79,000 troops, including some at King Khalid Military City. The initial cloud continued to move downrange, and the constant evaporation of agent from the sand and wood continued to refresh the plume, sending new tendrils from the pit.

By the third day (figure 25), the agent in the atmosphere in the south had dispersed to levels below the general population limit. Evaporation continued to feed the plume, which, because of additional wind changes, was moving several directions, predominantly up the Euphrates valley. Up to 3,300 troops were exposed on this day.

Figure 21
Day 2
11 March 1991 Modeled Exposure
Khamisiyah Pit Demolition

The map for the fourth day (figure 26) shows a small plume from evaporation moving to the northeast, potentially exposing two battalions of troops there, about 1,600. After that, any additional evaporation did not exceed the general population limit.

Figure 22

Day 3
12 March 1991 Modeled Exposure
Khamisiyah Pit Demolition

The table reflects the daily totals. As already indicated, no units appear to have been exposed to dosages causing first noticeable effects. Moreover, the daily numbers for low-level exposure do not sum to the total exposed population, because some troops would be counted on multiple days. The total, eliminating double-counting, is nearly 99,000.

US Forces Potentially
Exposed to Nerve Agent *Number of troops by day*

Date	Day	First Noticeable Effects	Low Level(a)
March 10	1	0	18,814
March 11	2	0	79,058
March 12	3	0	3,287
March 13	4	0	1,638

(a) Because people are counted on multiple days, the numbers do not sum to the total exposed population of **98,910.**

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Next Steps

Epidemiological Work

The plume developed by our modeling efforts constitutes our best estimate of the potential exposure and will become a critical input for continued medical and epidemiological research. The concentrations and dosages people were potentially exposed to are essential to some of that work. The maps in this paper reflect only two levels of dosage and were developed using one location for a unit each day, even though we know they were moving. For the detailed epidemiological work ahead, each plume's dosage contours will be provided, and DoD will develop profiles for individual units that show their exposure over time--both with the concentration they had at any point in time and with the cumulative dosage. That will become a part of the ongoing medical research program. The number of troops who have been exposed to very low levels remain a concern, both immediately and in the long run. We need to understand, through our epidemiological and medical work, the effects of low-level chemical exposure for our veterans now and for the future.

Figure 23
Day 1
10 March 1991 Modeled Exposure
Khamisiyah Pit Demolition

Continued Support to the Veterans

DoD has sent two different letters of notification. The first were to the 99,000 that were under the composite plume, indicating that we believe they may have been exposed to low levels of chemical warfare agent. Current medical assessments suggest that there are no long-term health consequences, but that if veterans have any concerns, they should contact DoD or VA. The second letter went to those who received one of the 20,000 surveys last year but were not under our modeled plume. That letter indicates that our best assessment suggests that they were not exposed.

As we have stated, if anyone who served in the Gulf has any concern about their health, whether they were at Khamisiyah or not, they should be examined at a DoD or VA facility. Hotline numbers are 1-800-796-9699 and 1-800-PGW-VETS, respectively. We will answer questions and ensure that the callers get the medical treatment they need and deserve. Those desiring to contact CIA for questions on modeling or other issues in which intelligence support could help, call the Agency's Public Affairs number: (703)482-0623.

Figure 24
Day 2
11 March 1991 Modeled Exposure
Khamisiyah Pit Demolition

Figure 25
Day 3
12 March 1991 Modeled Exposure
Khamisiyah Pit Demolition

Figure 26
Day 4
13 March 1991 Modeled Exposure
Khamisiyah Pit Demolition

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