

USING AN ARRAY OF ION MOBILITY SPECTROMETERS IN THE FIELD FOR REAL-TIME REPORTING OF CHEMICAL VAPOR CONCENTRATION MEASUREMENTS

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ABSTRACT

Field tests were carried out where hundreds of kilograms of chemical agent surrogates were explosively disseminated to gather real time chemical concentration information at specific ground locations downwind from a CW agent attack, to assess behavior of plumes of tactical quantities of chemical agents, and to assess the use of such information for verification of cloud propagation models. Small IMS detectors were set out in arrays 0.3 to 3 km from the dissemination points. Real-time (< one second) detector responses were transmitted via RF modems to a central location. Insights into chemical cloud behavior are presented. Comparisons of actual concentration measurements and predictions using cloud travel models are discussed.

INTRODUCTION

The U.S. Army Edgewood Chemical Biological Center (ECBC), Aberdeen Proving Ground, Maryland has integrated modified, hand-held Ion Mobility Spectrometry (IMS) devices into a mini-Unmanned Aerial Vehicle (UAV) for real-time detection and identification of chemical clouds. The use of IMS technology provides an ideal approach to rapid, real-time chemical vapor detection, identification and quantification.

Preliminary testing of the detectors prior to mounting in the UAV consisted of direct observations of detector responses when they were subjected to live chemical warfare agents (CWA), CWA surrogate compounds, CWA precursors and potential interferences in a test

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chamber at ECBC. The chamber test results not only indicated that UAV mounting of the detectors was a viable undertaking but also indicated that placing an array of detectors downwind from outdoor chemical releases could be applied to determination of real time ground truth concentration measurements. Since live CWA outdoor tests are not practical in the U.S.A the chamber trials showed that IMS detection of CWA simulants is an excellent representation of IMS detections of actual CWA. Taking advantage of testing opportunities, arrays of IMS devices equivalent to those in the UAV were tested in ground applications during UAV field trials – the ground tests were secondary objectives of the trials. In the ground applications small, unobtrusive IMS detectors were set out in arrays consisting of 4, 6, 9 and 12 detectors from 0.3 km to 3 km downwind of the chemical release points. Real-time detector response information was transmitted to an upwind location using radio frequency (RF) modems.

The field trials consisted of explosive releases of hundreds of kilograms of a precursor and a surrogate chemical for chemical warfare agents; dimethyl methylphosphonate (DMMP) was the precursor and dipropylene glycol monomethyl ether (DPM) was the surrogate chemical. Single chemical and double chemical releases were accomplished. The plan for the exercise was to gather real time chemical concentration information at specific ground locations downwind from a simulated CW agent attack and to assess the value of using such information for verification of models for chemical cloud propagation.

RESULTS AND DISCUSSION

The detectors used in these tests were Lightweight Chemical Detectors (LCD), Smiths Detection, Watford, UK. Technology for these detectors was developed in large part through collaboration with and funding by ECBC. Each detector and RF modem was mounted in a container to provide partial shielding from excessive solar heat loading from the desert sun – these were not environmental tests rather tests for determination of the viability of the technology for real time ground truth concentration measurements. Air temperatures ranged from 40 to 45 C and ground temperatures from 50-55C. A separate generator powered each detector and modem – transmitted data from each detector was stored on a separate PC at a central location. A test set-up for the 12-detector array is shown in Figure 1.



Figure 1: Typical test set-up of the data center and an element of the ground-based detection array.

In July 2002 one chemical release consisted of 600 kg of DMMP and another consisted of 400 kg of DMMP and 1200 kg of DPM in two stages, 400 kg DMMP and 400 kg

DPM followed two minutes later by 800 kg DPM. For the single chemical release data was received from detectors located 0.5 km and 1.25 km on a heading of 45° true north from the dissemination point - the wind was from 205°-210° at 15-20 km per hour. DMMP concentrations ranging up to approximately 13 mg/m³ were tracked for approximately six minutes. Only 2 of 6 detectors responded because of significant RF interference in the area.

Figure 2 shows comparisons of a cloud model prediction of surface concentration profiles with observations of DMMP concentrations at 2, 3, 4 and 6 minutes after dissemination (July 2002 tests). At 2 minutes the model predicts concentrations at 0.5 km from ground zero of >10 mg/m³ and that the concentration 1.25 km would be about 0.1 mg/m³. The prediction was reasonable at 0.5 km, a concentration of approximately 13 mg/m³ was observed at that time, but the prediction was too high for the detector located at 1.25 km since no response was observed at that location. At 3 minutes the model predicted that both detectors would be exposed to 1-10 mg/m³; the detector at 0.5 km reported 5 mg/m³ and the detector at 1.25 km had reported about 2 mg/m³ at 2.5 min, reasonable agreement between prediction and observations. At 4 and 6 min after dissemination, the model predicted that detectable clouds would have bypassed both detectors (limit of detection was approximately 0.1 mg/m³), however, the detector at 0.5 km reported significant concentrations of DMMP. The responses of the detector at 0.5 km after 3.5 minutes are caused by secondary evaporation of DMMP from the surface that was contaminated after the explosive dissemination.

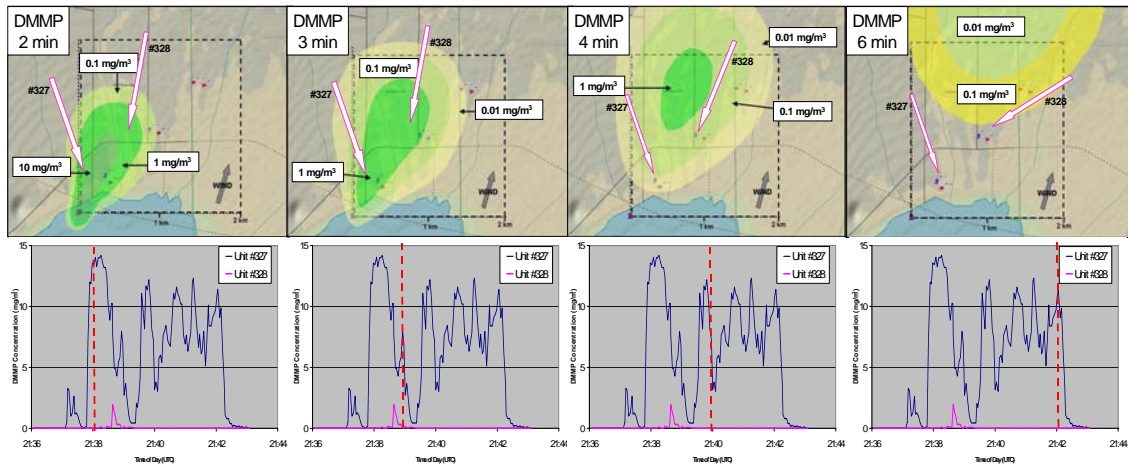


Figure 2: Predicted DMMP concentration profiles and LCD concentration measurements 0.5 km and 1.25 km downwind of the release point 2 min, 3 min, 4 min and 6 min after dissemination of 200 kg of DMMP.

In July 2003 nine detectors were set out in an array 0.5 km, 1.0 km and 2.0 km from the point of release of a mixture of DMMP and DPM. In this test 400 kg DMMP and 600 kg DPM were disseminated followed by 200 kg DPM approximately 1 hour 33 minutes later. The model predicted that the clouds would arrive at the detector locations approximately two minutes before the first detector response was noted (2 km from the release point) and the predicted maximum concentration values were about five times the maximum observed concentrations. Figure 3 shows predicted and measured values of DMMP and DPM for detector locations 1.0 and 2.0 km from ground zero. The model predicted very large concentrations arriving at the 1-km location one minute after dissemination – significantly lower concentrations were measured approximately nine minutes after dissemination. At the 2-km location, the model and detector responses nearly coincide with respect to temporal aspects for both releases but differ with respect to concentrations. Another, as yet

unexplained phenomenon, was the detector response at the 2.0 km location approximately five minutes before the detector response at 1.0 km location. One explanation is that the cloud was lofted with the dissemination and because of the extreme heat continued to rise and expand such that the cloud moved above the 1-km detector, down to the 2-km location, and that the delayed response at one km was due to secondary evaporation.

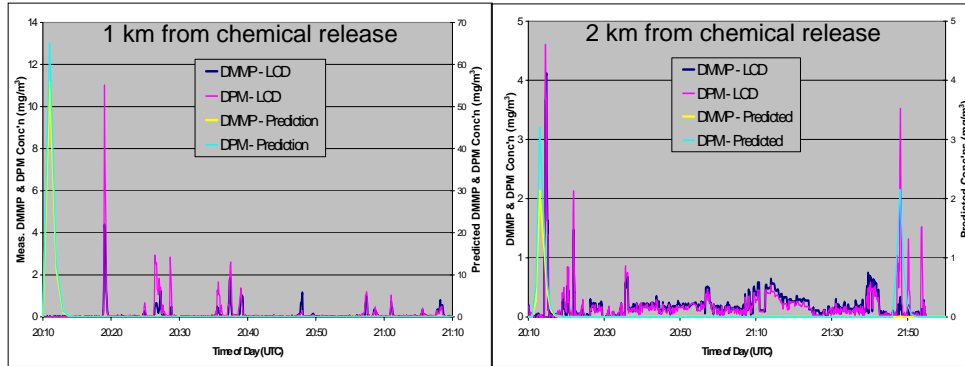


Figure 3: Detector responses to DMMP and DPM at 1 km and 2 km from the point of chemical dissemination. The 1-km plot is for 1 hour of detector response data and the 2-km plot is for 2 hours of response data. Secondary dissemination of DPM occurred 1 hr 33 min after the primary release.

In June 2004, a 12-detector array was laid out as shown in Figure 4. Detectors were located at distances of 0.5 km, 1.0 km, 2.0 km and 3.0 km from ground zero on headings of 22.5°, 45° and 67.5°.

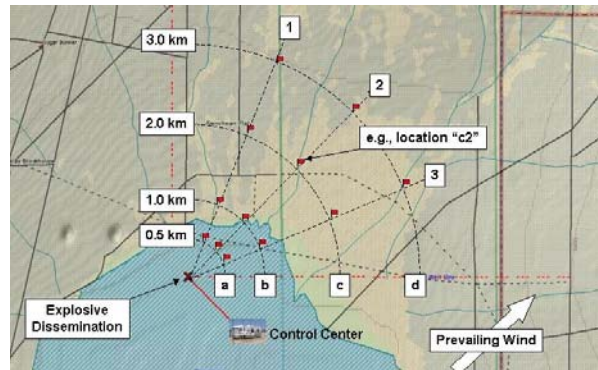


Figure 4: Detector layout for June 2004 tests

600 kg of DMMP was released in one test and 400 kg DMMP and 1200 kg DPM were released in a second test. Responses were received from all 12 detectors for varying periods during the first test and for 130 min during the second test at which time the test was terminated.

Figure 5 shows responses from all 12 detectors during the DMMP-DPM tests. As in previous tests, significant secondary evaporation was observed. The general rapid rise and fall of chemical concentrations along with occasional slow concentration variations was observed during these tests the same as in previous tests. It is fairly obvious that the wind direction was primarily toward the north-northeast in the early part of the test since the “number 1” detectors indicate the strongest response. It is interesting to note that the first responses of the “c1” and “d1” detectors at 2 km and 3 km occurred almost simultaneously.

Evaporation of the two chemicals from the site of the dissemination continued more than 2 hours. Examination of the responses at the a1, a2, and a3 locations indicate that the wind direction shifted toward the east after approximately an hour after dissemination. Termination of the tests prevented observation of the time for which detectable concentrations were being generated from the chemically contaminated surface as observed at the 0.5 km locations.

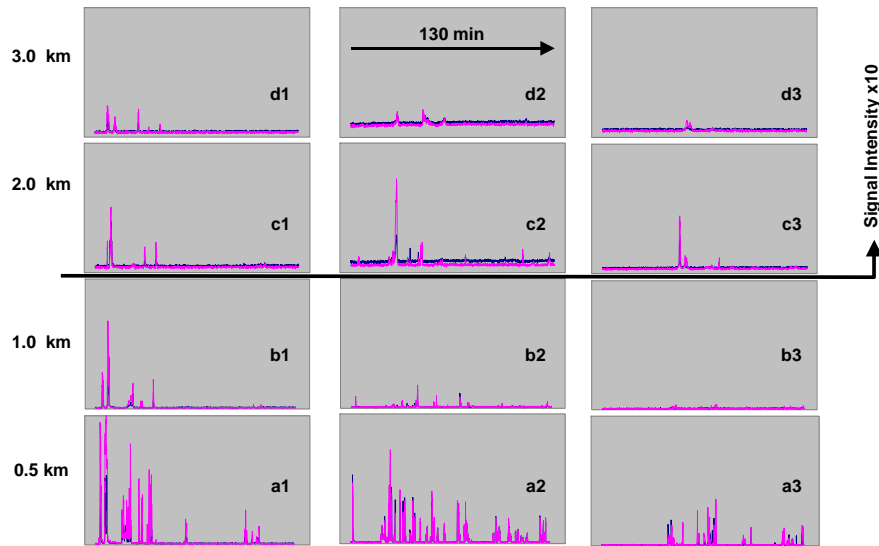


Figure 5: Detector responses from DMMP-DPM tests. Secondary evaporation was observed for more than 2 hours after the chemical release. Magenta traces are DMMP responses, blue traces are DPM responses.

One of the most important observations from these tests is that there are significant departures of experimental measurements of chemical concentrations from chemical concentration predictions. In addition, the detector responses are far from monotonic as might have been expected from plume predictions. Concentrations can increase very rapidly and decrease to baseline just as quickly. Also, concentrations can increase very slowly and decrease slowly or rapidly. Concentrations are highly dependent on local micro-meteorological conditions. Figure 6 shows rapid and slow concentration increases. These temporal concentration variations could only have been determined using a detector with a very short time response time, a detector such as the LCD. The LCD can generate up to 2 or 3 ion mobility spectra per second. In these tests the LCD was set up to acquire sample for a period of about 100 milliseconds and to report detection information at 5-second intervals – the entire sampling, signal processing and data transmission process requires approximately 300 msec. The detector response information indicates that it is essential for a CWA detection system to respond rapidly so as not to miss clouds that could pass by a slower detection system undetected.

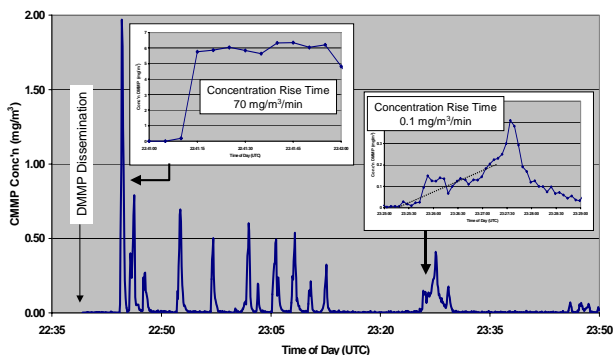


Figure 6: Temporal variations of chemical concentrations after realistic releases of CWA surrogate compounds.

Figure 7 shows comparative effects of “fast” and “slow” detection systems – these detectors were co-located 1.0 km from ground zero. The fast system, the LCD, yields concentration information at 5-second intervals while the other system, a miniaturized Gas Chromatograph (GC) with a Surface Acoustic Wave (SAW) detector operates at 3-minute intervals. The GC-SAW system essentially missed the first “wave” of chemical passing over the detector location. Each point on the GC-SAW curve results from a 1-minute pre-concentration step, a 1-minute chromatogram and a 1-minute clearing process. An integration of the maximum amount of chemical under the maximum response of the LCD and the maximum response of the GC-SAW yields approximately the same mass of sample but the instantaneous concentration indication differs by about an order of magnitude.

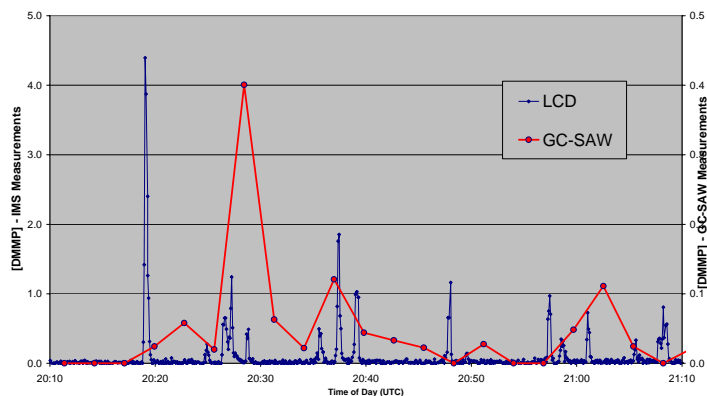


Figure 7: Comparison of “fast” and “slow” detection systems – the detectors were co-located 1.0 km from ground zero.

CONCLUSIONS

Realistic ground truth measurements require fast detection devices – concentrations can increase rapidly from 10’s of $\text{mg}/\text{m}^3/\text{min}$ or very slowly, of the order of $0.1 \text{ mg}/\text{m}^3/\text{min}$. Slower detectors can result in non-detections or significant delays in detections of potentially dangerous quantities of chemicals.

Cloud models do not accurately predict concentrations at specific points on the ground nor do they accurately predict the arrival times of clouds at specific points or duration of detector responses after a chemical release.

Cloud models are “integrating” indicators of point concentrations whereas the fast detection systems indicate realistic ground truth concentrations information in real time, with approximately 1-second time constants

Local micro-meteorological conditions control vapor concentrations at point locations.

The Lightweight Chemical Detector Ion Mobility Spectrometer is a viable instrument for assessing point concentrations in the field in real time.