

ECBC-TR-#####

**DOMESTIC PREPAREDNESS PROGRAM:  
TESTING OF  
SABRE 2000 HANDHELD TRACE AND VAPOR DETECTOR  
AGAINST CHEMICAL WARFARE AGENTS  
SUMMARY REPORT**

Terri L. Longworth  
Kwok Y. Ong

RESEARCH DIRECTORATE

August 2001

Approved for public release, distribution is unlimited.

Soldier and Biological Chemical Command, AMSSB-RRT, Aberdeen Proving Ground, MD 21010-5424

## Disclaimer

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorizing documents.

<b>REPORT DOCUMENTATION PAGE</b>			Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.				
1. AGENCY USE ONLY (Leave Blank)	2. REPORT DATE August 2001	3. REPORT TYPE AND DATES COVERED Final; 00 June – 00 Oct		
4. TITLE AND SUBTITLE DOMESTIC PREPAREDNESS PROGRAM: TESTING OF SABRE 2000 HANDHELD TRACE AND VAPOR DETECTOR AGAINST CHEMICAL WARFARE AGENTS - SUMMARY REPORT.			5. FUNDING NUMBERS  None	
6. AUTHOR(S) Longworth, Terri L. and Ong, Kwok Y.				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)  DIR, ECBC, ATTN: AMSSB-RRT, APG, MD 21010-5424			8. PERFORMING ORGANIZATION REPORT NUMBER ECBC-TR-	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)  Program Director, Domestic Preparedness, 5183 Blackhawk Road, ATTN: AMSSB-RTD APG, MD 21010-5424			10. SPONSORING/MONITORING AGENCY REPORT NUMBER	
11. SUPPLEMENTARY NOTES				
12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words)  This report characterizes the chemical warfare (CW) agent detection potential of the commercially available SABRE 2000 Handheld Trace and Vapor Detector. This instrument was tested against HD, GB, and GA vapors under various conditions. This report is intended to provide the emergency responders concerned with CW agent detection an overview of the detection capabilities of these instruments.				
14. SUBJECT TERMS HD Vapor testing Chemical Warfare Agent Detection GB Detector testing Interference testing GA Liquid Surface Testing IMS (Ion Mobility Spectrometry)			15. NUMBER OF PAGES 26	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT  UNCLASSIFIED	18. SECURITY CLASSIFICATION OF THIS PAGE  UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT  UNCLASSIFIED	20. LIMITATION OF ABSTRACT  UL	

Blank

## PREFACE

The work described herein was authorized under the Expert Assistance (Equipment Test) Program for the U.S. Army Soldier and Biological Chemical Command (SBCCOM) Program Director for Domestic Preparedness. This work was started in June 2000 and was completed in October 2000.

The use of either trade or manufacturers' names in this report does not constitute an official endorsement of any commercial products. This report may not be cited for purposes of advertisement.

This report has been approved for public release. Registered users should request additional copies from the Defense Technical Information Center; unregistered users should direct such requests to the National Technical Information Service.

### Acknowledgments

The authors acknowledge John Baranoski, Juan C. Cajigas, Jacob Barnhouse, and Marcia Johnson for their assistance in performing agent testing; and Frank DiPietro for his assistance in test planning, acquisition, and review.

Special thanks are extended to Dr. Reno DeBono, Dr. Yin Sun, and Mr. Tri Le, of Barringer Instruments Inc., for their expert advice and assistance during the evaluation. The authors also thank Barringer Technologies Inc., for making the test instrument available to support the evaluation.

The authors are grateful to the following members of the Expert Review Panel for Equipment Testing, for their constructive reviews and comments:

Dr. Jimmy Perkins, University of Texas School of Public Health, San Antonio, TX

Dr. Bruce A. Tomkins, Organic Chemistry Section, Chemical and Analytical Sciences Division, Oak Ridge National Laboratory, Oak Ridge, TN

Dr. Edward T. Zellers, University of Michigan School of Public Health, Ann Arbor, MI

Leo F. Saubier, Battelle Memorial Institute, Edgewood, MD

Blank

CONTENTS

1. INTRODUCTION..... 7

2. OBJECTIVE..... 8

3. SCOPE ..... 8

4. EQUIPMENT AND TEST PROCEDURES..... 8

    4.1. DETECTOR DESCRIPTION ..... 8

    4.2. CALIBRATION..... 12

    4.3. AGENT VAPOR CHALLENGE..... 12

    4.4. AGENT VAPOR QUANTIFICATION..... 13

    4.5. SURFACE CONTAMINATION SAMPLE CHALLENGE ..... 13

    4.6. FIELD INTERFERENCE TESTS ..... 13

    4.7. LABORATORY INTERFERENCE TESTS ..... 14

5. RESULTS AND DISCUSSION ..... 15

    5.1. MINIMUM DETECTABLE LEVEL ..... 15

    5.2. TEMPERATURE AND HUMIDITY EFFECTS ..... 16

    5.3. SURFACE CONTAMINATION TEST ..... 21

    5.4. FIELD INTERFERENCE ..... 21

    5.5. LABORATORY INTERFERENCE TESTS ..... 23

6. CONCLUSIONS..... 24

LITERATURE CITED..... 26

FIGURES

1. Figure 1: SABRE 2000 Handheld Trace and Vapor Detector ..... 9

2. Figure 2: SABRE 2000 Sample Card..... 9

3. Figure 3: Cross Section of the SABRE 2000 Ion Mobility Spectrometer ..... 10

4. SABRE 2000 LCD Display Indicating a Four Bar GA Detection ..... 11

TABLES

1. Minimum Detectable Level (MDL) at Ambient Temperatures and Medium RH ..... 16

2. Responses to HD Vapor Concentrations at Various Temperatures and RH..... 17

3. Responses to GA Vapor Concentrations at Various Temperatures and RH..... 19

4. Responses to GB Vapor Concentrations at Various Temperatures and RH..... 20

5. Liquid Surface Contamination Response Results ..... 21

6. Results of Laboratory Interference Tests with Agents..... 22

7. Results of Laboratory Interference Tests without Agents..... 23

8. Field Interference Testing Summary..... 24

Blank

**DOMESTIC PREPAREDNESS PROGRAM:  
TESTING OF  
SABRE 2000 HANDHELD TRACE AND VAPOR DETECTOR  
AGAINST CHEMICAL WARFARE AGENTS  
SUMMARY REPORT**

1. INTRODUCTION

The Department of Defense (DOD) formed the Domestic Preparedness (DP) Program in 1996 in response to Public Law 104-201. One of the objectives is to enhance federal, state, and local capabilities to respond to Nuclear, Biological and Chemical (NBC) terrorism incidents. Emergency responders who encounter either a contaminated or a potentially contaminated area must survey the area for the presence of either toxic or explosive vapors. Presently, the vapor detectors commonly used are not designed to detect and identify chemical warfare (CW) agents. Little data are available concerning the capability of the commonly used, commercially available detection devices to detect CW agents. Under the DP Expert Assistance (Test Equipment) Program, the U.S. Army Soldier and Biological Chemical Command (SBCCOM) established a program to address this need. The Applied Chemistry Team (ACT), formerly known as the Design Evaluation Laboratory (DEL), Aberdeen Proving Ground, Edgewood, Maryland, performed the detector testing. ACT is tasked with providing the necessary information to aid authorities in the selection of detection equipment applicable to their needs.

Reports of the instrument evaluations are posted in the Homeland Defense website (<http://www2.sbcom.army.mil/hld/downloads/index.htm>) for public access. Instruments evaluated and reported in 1998 and in 1999 include:

MiniRAE plus from RAE Systems, Inc.

Passport II Organic Vapor Monitor from Mine Safety Appliance Corp.

PI-101 Trace Gas Analyzer from HNU Systems, Inc.

TVA 1000B Toxic Vapor Analyzer from Foxboro Company

Draeger Colorimetric tubes (Thioether and Phosphoric Acid Ester) from Draeger Corp.

MicroFID detector from Photovac, Perkin Elmers Corp.

MIRAN Sapphire Air Analyzer from Foxboro Corp.

Mine Safety Colorimetric (HD and Phosphoric Acid) Tubes from Mine Safety Corp.

M90D1-C Chemical Warfare Detector from Environics OY, Finland

APD2000 Air Monitor from Envirotech Inc.

In 2000, the evaluation of instruments continued to include the ppbRAE Photo-Ionization Detector from RAE Systems (Sunnyvale, CA), the SAW MiniCAD mkII from MicroSensor Systems (Bowling Green, KY), UC AP2C Monitor from Proengin (France), the SABRE2000 from Barringer Instruments, Inc. (Warren, NJ), and the CAM (Type L) from Graseby Dynamics

Ltd (Herts, UK). Each of these evaluations will be reported separately. This report pertains to the evaluation of the SABRE 2000 from Barringer Instruments, Inc.

## 2. OBJECTIVE

The objective of this test is to assess the capability and general characteristics of the SABRE 2000 detector to detect chemical warfare agent vapors including liquid surface contamination testing. The intent is to provide the emergency responders concerned with CW agent detection an overview of the detection capabilities of this instrument.

## 3. SCOPE

This evaluation attempts to characterize the CW agent vapor detection capability of the SABRE 2000. Due to time and resource limitations, the investigation is only concerned with testing against Tabun (GA), Sarin (GB), and Mustard (HD) under various conditions. These representative CW agents are believed to be the most likely threats. Test procedures follow the established Domestic Preparedness Detector Test and Evaluation Protocol developed in the Phase 1 Test Report<sup>1</sup>. The test concept was as follows:

- a. Determine the Minimum Detectable Level (MDL), which is the lowest concentration level where repeatable detection readings are achieved for each CW agent tested. The current military Joint Services Operational Requirements (JSOR)<sup>2</sup> for point sampling detectors served as a guide for detection sensitivity objectives.
- b. Investigate the humidity and temperature effects on detector response.
- c. Observe the effects of potential interfering vapors upon detector performance in the laboratory and in the field.

## 4. EQUIPMENT AND TEST PROCEDURES

### 4.1 DETECTOR DESCRIPTION

Barringer Technologies, Inc., Warren, NJ, (<http://www.barringer.com/html/>) is the manufacturer of the SABRE 2000 hand held trace particle and vapor detector (Figure 1). Three units were loaned to the Domestic Preparedness program for inclusion in the detector evaluations. These units were randomly labeled A, B, and C.

The SABRE 2000 is a lightweight (approximately 6 pounds, including the batteries), handheld, portable detector that can detect, providing both audible and visual alarms, and identify specific CW agents, explosives, and narcotics. According to the Operator's Manual<sup>3</sup>, the SABRE 2000 can operate in the temperature range from 0°C to +45°C. The instrument requires either the 12V rechargeable battery or the 110V AC adapter. A fully charged battery will last approximately 1.5 hours or process up to 80 samples. The SABRE 2000 has the ability to store the results from analyses in a tabular form or as plasmagrams (graphic IMS spectrum) for later retrieval using a computer. When coupled with the computer, it is possible to immediately capture the results and display the plasmagram and other sample information.



**Figure 1: SABRE 2000 Handheld Trace and Vapor Detector**



**Figure 2: SABRE 2000 Sample Card**

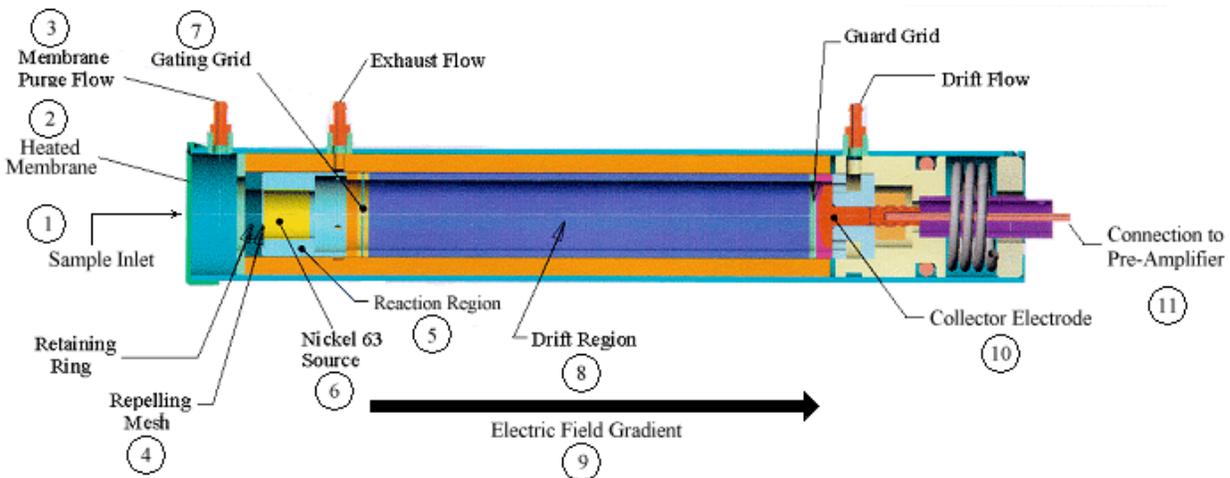
The SABRE 2000 detection technology is based on Ion Mobility Spectrometry (IMS). The instrument is not capable of providing simultaneous detection of HD and nerve agents. The SABRE 2000 operates either in positive or negative ion detection mode requiring a cartridge change to induce the positive or negative mode. Prior to operation, the appropriate mode module (positive or negative) cartridge must be installed in the instrument to detect the substance of interest. The cartridge is tightened in place using a setscrew. The positive ionization mode cartridge is programmed to detect GA, GB, GD, GF (different G nerve agents), HN3 (nitrogen mustard), VX and V<sub>x</sub> (two versions of V nerve agent). The negative ionization mode is programmed to detect HD (sulfur mustard) or L (Lewisite).

In addition, the instrument can be used to detect vapor in two different modes, particle sampling mode (sniff mode) or vapor sampling mode (pre-concentration mode). In sniff mode, the instrument can both sniff a vapor sample or monitor surface contamination to produce an analysis in 10 seconds. For particle sampling in sniff mode, a “shark-skin” sampling card (Figure 2) is used to swipe a suspected contaminated surface. This sample swab is then inserted into the particle sample card slot of the instrument (Figure 1) for thermal desorption. The desorbed vapor is drawn into the IMS cell for analysis after pressing the start button.

When the instrument is placed in its vapor sampling pre-concentration mode, a ‘vapor card’ is required in the sample card slot. The vapor is drawn directly through the instrument’s built-in pre-concentration cartridge. A sample is collected for a designated period then heat

desorbed for analysis. The operator can adjust the time of pre-concentration of the vapor sample (up to 30 seconds maximum) and this change is referred to as a “modified pre-concentration mode”.

Figure 3 shows a labeled cross section view of the basic SABRE 2000 ion mobility spectrometry (IMS) detector. The vapor sample obtained through the sample inlet (1) in the designated mode, either sniff or pre-concentration, diffuses through a heated membrane (2) and is then swept by the membrane purge flow (3) past the repelling mesh (4) into the reaction region (5).



**Figure 3: Cross Section of the SABRE 2000 Ion Mobility Spectrometer**

In the reaction region, molecules are selectively ionized using a sealed 15-millicurie Nickel-63 radioactive source (6). The ions combine with the residing chemical dopant to form ionic clusters having specific mobility. A gating grid (7) then opens, letting ions of the correct polarity enter the drift region (8). The ions are focused and accelerated by an electric field along the drift region of the IMS tube (9) to arrive at a collector electrode (10) in approximately 10-20 milliseconds.

Ions are separated according to their mass, size, and shape which affects the speed (ion mobility) at which the ions move through the drift tube toward the collector electrode. An electronic signature is produced for each ion, which is sent to the pre-amplifier (11) of the electronics. The magnitude of the collector current, as a function of time, is proportional to the number of ions arriving at that moment. The IMS detector can be extremely selective because the sample is selectively ionized and the drift time (ion mobility) of the resulting ions is very specific for an individual chemical compound.

Each chemical warfare agent produces one or more ion peaks under the SABRE 2000 operating conditions. These ion peaks are defined as channels. Channel parameters are used to determine if a particular ion peak is present. Once the SABRE 2000 determines that the

expected ion peaks are present, the unit uses the presence and channel combinations to decide if it should alarm. For example, there are typically two peaks for GA at high concentration. These two channels are labeled GA-1 and GA-2. If only the GA-2 peak is present without the associated GA-1 channel, no alarm will occur because the ion peak is not considered to originate from GA. However, if only the GA-1 channel is observed, the instrument will alarm because this ion peak is associated with low levels of GA.

The SABRE 2000 provides an audible and a visual alarm identifying the substance detected when the sample signal “matches” the required signature criteria. Figure 4 shows the liquid crystal display (LCD) response of a unit after an alarm for GA in positive mode. Both GA-1 and GA-2 peaks were detected. The GA alarm is identified next to a bar graph that indicates the strength of the detection through the number of bars lit. A list of the detected channels is displayed showing the GA-1 and GA-2 peak detection.

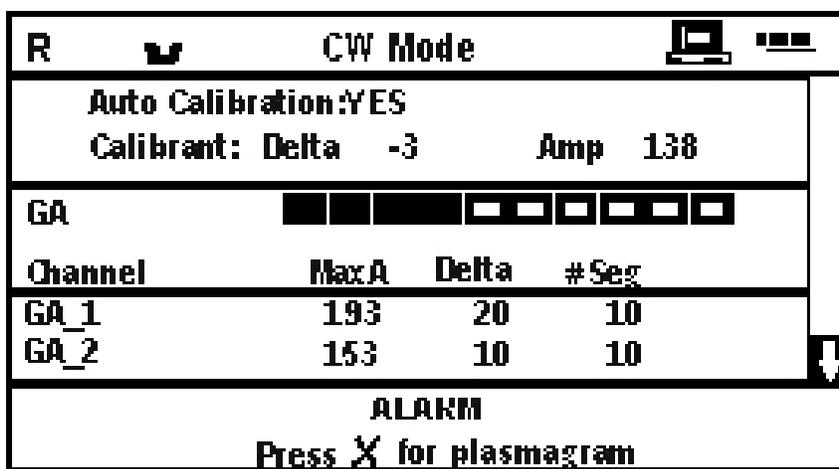


Figure 4: SABRE 2000 LCD Display Indicating a Four Bar GA Detection

Associated with each detected channel, the LCD also shows the maximum peak amplitude (MaxA), the Delta (the deviation from expected position), and the number of segments that the channel detected (#Seg). In general, higher MaxA, smaller Delta’s and higher #Seg values indicate stronger hits and higher detection confidence levels. The bar graph automatically converts the MaxA value into a visual interpretation of detection strength. One, five or ten lighted bars are relative indications of low, moderate and high agent concentration responses, respectively. The instrument is also capable of displaying the associated plasmagram for the analyzed sample. The plasmagram is a graphic display of the IMS spectrum.

After extended application in high humidity environment, the air purification cartridge located at the rear of the instrument requires replacement. The air purification cartridge removes moisture from the airflow. Moisture entering the system will significantly affect the proper functioning of the detector. The air purification cartridge should be checked regularly and replaced when necessary, for example, when the unit fails calibration verification, to avoid the effects on agent detection caused by a high humidity level.

## 4.2 CALIBRATION

Operating procedures were followed according to the Operator's Manual. After initial activation, the instrument completes a self-test and begins to warm up. This warm up procedure takes approximately thirty minutes at ambient temperature. A longer time is required for warm up after the units have been in storage or in low temperatures. The manufacturer recommends continuous operation of the instrument when possible and frequent simulant verification calibrations.

The detection performance was verified daily and after any operational or environmental change to the instrument. The verification process requires using the confidence test sample (simulant), provided with the instrument, by following analysis procedures with the instrument in sniff mode. A verification (VERIFIC) response occurs after successful simulant exposure. The detector is then set to the desired sampling mode (either sniff mode or pre-concentration mode) and is ready for use.

## 4.3 AGENT VAPOR CHALLENGE

The agent challenges were conducted using the Multi-Purpose Chemical Agent Vapor Generation System<sup>4</sup> using Chemical Agent Standard Analytical Reference Material (CASARM) grade or the highest purity CW agents available. The vapor generator permits testing of the instrument with humidity and temperature-conditioned air without agent vapor to assure the background air does not interfere before challenging it with similarly conditioned air containing the CW agent vapor. With the instrument's sample inlet placed under the cup-like sampling port of the vapor generator, it is necessary to press the sample (round) button to initiate the sample cycle.

Agent testing followed successful start up, verification, and blank exposure to the conditioned air of the generator. Agent challenge began when the solenoids of the vapor generation system were energized to switch the air streams from the conditioned air to a similarly conditioned air containing the agent vapor. Since the SABRE does not sample continuously, the sample button must be pressed to initiate each sample collection. Each detector was tested three times under each condition. Blank samples were run after each agent exposure to ensure no residual agent remained in the instrument or the sampling cup of the vapor generator before subsequent challenges. The number of blank samples required for the instrument to clear after the agent challenge was noted.

The detectors were each tested with the agents GA, GB, and HD at different concentrations at ambient temperature (22 to 28°C) and 50% relative humidity to determine the minimum detectable level (MDL). In addition, the detectors were tested at relative humidity conditions of <5% and >90%, and temperature extremes of 0°C and +40°C to observe the potential temperature and humidity effects. Temperature extremes were based on the manufacturer's stated operating range using agent concentrations that approximated the MDL. Although HD freezes at approximately +15°C, the calculated HD volatility of 92 mg/m<sup>3</sup> at 0°C easily produces a vapor concentration higher than the 2 mg/m<sup>3</sup> JSOR detection criteria allowing the instrument to be evaluated at 0°C.

#### 4.4 AGENT VAPOR QUANTIFICATION

The generated agent vapor concentrations were analyzed independently and reported in milligrams per cubic meter ( $\text{mg}/\text{m}^3$ ) and in parts-per-million (ppm) units in the results tables. The vapor concentration was quantified by utilizing the manual sample collection methodology<sup>5</sup> for the Miniature Continuous Air Monitoring System (MINICAMS<sup>®</sup>) manufactured by O. I. Analytical, Inc., Birmingham, Alabama. The MINICAMS<sup>®</sup> is equipped with a flame photometric detector (FPD), and it was operated in either phosphorus mode for the G agents or sulfur mode for HD.

This system normally monitors air by collection through sample lines and subsequently adsorbing the CW agent onto the solid sorbent contained in a glass tube referred to as the pre-concentrator tube (PCT). The PCT is located after the MINICAMS<sup>®</sup> inlet. Then the concentrated sample is periodically heat desorbed into a gas chromatographic capillary column for subsequent separation, identification, and quantification. For manual sample collection, the PCT was removed from the MINICAMS<sup>®</sup> during the sampling cycle and connected to a measured suction source to draw the vapor sample from the agent generator. The PCT was then re-inserted into the MINICAMS<sup>®</sup> for analysis. This “manual sample collection” methodology eliminates potential loss of sample along the sampling lines and the inlet assembly when the MINICAMS<sup>®</sup> is used as an analytical instrument. The calibration of the MINICAMS<sup>®</sup> was performed daily using the appropriate standards for the agent of interest. The measured mass equivalent (derived from the MINICAMS chromatogram) divided by the total volume (flow rate x time) of the vapor sample drawn through the PCT produces the sample concentration that converts into  $\text{mg}/\text{m}^3$ .

#### 4.5 SURFACE CONTAMINATION SAMPLE CHALLENGE

The SABRE 2000 also has the capability to monitor potentially contaminated surfaces. A limited evaluation of this feature was performed using GB and HD at room temperature. Liquid agent droplets deposited on various surfaces were used to evaluate the ability of the SABRE 2000 to detect agent from a contaminated surface. Five types of surfaces including asphalt, concrete, fabric from the battle dress uniform (BDU), chemical agent resistant coated (CARC) painted slabs, and wood were tested. Five drops (each drop contains 0.2 microliters) of neat agent were transferred onto approximately  $1 \text{ cm}^2$  area of the respective surface to simulate a surface contamination density of  $10 \text{ g}/\text{m}^2$ . Approximately 15 minutes were allowed for the agent to soak into the surface before testing. The surface was then swiped with the ‘shark skin’ sampling card provided with the instrument in accordance with the manufacturer’s directions. The sampling card was then inserted into the SABRE card slot and analyzed using sniff mode. A new sampling card was used after a detection response. Blank runs were conducted between tests to ensure the instrument was clear of agent residue.

#### 4.6 FIELD INTERFERENCE TESTS

The instruments were tested outdoors in the presence of common potential interferents such as the vapors from gasoline, diesel fuel, jet propulsion fuel (JP8), kerosene, Aqueous Film Forming Foam (AFFF, used for fire fighting), household chlorine bleach, and insect repellent. Vapor from a 10% HTH slurry (a chlorinating decontaminant for CW agents), engine exhausts, burning fuels, and other burning materials were also tested. The objective was to assess the

ability of the instruments to withstand outdoor environments and to resist responding when exposed to the selected substances.

The field tests were conducted outdoors at M-Field of the Edgewood Area of Aberdeen Proving Ground in August 2000. These experiments involved open containers, truck engines, and fires producing smoke plumes, which were sampled by the detectors at various distances downwind. The instruments were carried to the smoke or fume test plume to achieve moderate but not exaggerated exposures (e.g. 0.5-2 meters for vapor fumes and 2-5 meters for smokes).

Confidence checks were performed on each detector at the beginning of each testing day and periodically between tests. The two SABRE 2000 units, one in its negative (HD) mode and the other in positive (G) mode, were exposed to each interferent for three trials using the maximum pre-concentration sampling mode (30 seconds sampling time plus 10 seconds analysis time). Testing continued with the next challenge after blank runs showed the instrument was clear of agent residue.

#### 4.7 LABORATORY INTERFERENCE TESTS

The laboratory interference tests were designed to assess the effect on the instruments of vapor exposure from potential interfering substances. The substances were chosen based on the likelihood of their presence during an emergency response by first responders. Additionally, the laboratory interference tests were conducted to assess the capability of the instruments to detect CW agent in the presence of the selected interference vapors (diesel fuel or AFFF).

The SABRE 2000 units were tested against 1% of the headspace concentrations of vapors of gasoline, JP8, diesel fuel, household chlorine bleach, floor wax, AFFF, Spray 9 cleaner, Windex, toluene, and vinegar. The units were also tested against NH<sub>3</sub> (ammonia) at a concentration of 25 ppm. If the detector false alarmed at 1% concentration, it was tested at the 0.1% concentration of that substance. A dry air stream was saturated with the headspace vapor of the substance by sweeping it over the liquid in a tube or through the liquid in a bubbler to prepare the interferent gas mixture. Thirty milliliters/minute or 3 milliliters/minute of this vapor saturated air was then diluted to 3 liters/minute with the conditioned air at 23°C and 50% RH to produce the 1% or 0.1% concentration of interferent test mixture, respectively. The 25 ppm ammonia was derived by proper dilution of a stream from an analyzed 1% NH<sub>3</sub> vapor (10,000 ppm) compressed gas cylinder diluted with the appropriate amount of the conditioned air.

For the tests that included CW agents, the interferent test gas mixture was prepared similarly. The resultant stream of 3 liters/minute of air containing GA or HD was used as the dilution stream to blend in with 3 or 30 milliliters per minute of the substance vapor to obtain the desired 0.1% or 1% mixture of CW agent concentration in the presence of the substance vapor. The SABRE 2000 units were tested three times with each agent/interferent combination using the corresponding positive (G) or negative (H) mode. Blank runs between tests ensured the instrument was clear of agent or interference residue.

## 5. RESULTS AND DISCUSSION

### 5.1 MINIMUM DETECTABLE LEVEL

The minimum detectable level (MDL) for the SABRE 2000 instruments, A and B, are shown in Table 1 for each agent at ambient temperatures and 50% relative humidity (RH). Medium RH was chosen in lieu of dry conditions as being more representative of normal operating situations.

Results are shown for GA and GB in sniff mode, which has a response time of 10 seconds analytical time. In addition, results are shown for GA and GB in 30 second pre-concentration mode where the response time is 40 seconds (30 seconds sample collection time plus 10 seconds analytical time).

HD could not be detected in sniff mode due to chlorine peak interference in the HD window. The instrument could only give HD detection responses after technical adjustments by the manufacturer. Sampling HD in sniff mode or in 30 seconds pre-concentration mode would overwhelm the instrument and it would not produce a detection response. HD detection required a modified pre-concentration mode of 5 seconds collection time. This yielded an average response time of 15 seconds (5 seconds collection plus 10 seconds analytical time). Therefore, HD results shown in Table 1 are for the modified pre-concentration mode only. Unit C replaced Unit B during these tests due to a short circuit problem unrelated to HD detection.

MDL values were based on the lowest CW agent concentration exposure to produce three consistent responses in three independent trials. Detection response for the SABRE 2000 instrument includes the appropriate channels identifying the agent along with maximum peak amplitude (MaxA), the Delta (the deviation from expected position), the number of segments that the channel detected (#Seg), a relative bar response, and several other instrument parameters.

The current military JSOR requirements for CW agent sensitivity for point detection alarms, the Army's currently established values for Immediate Danger to Life or Health (IDLH), and the Airborne Exposure Limit (AEL) are also listed in Table 1 as references to compare the detector's performance. Army Regulation (AR) 385-61 is the source for the IDLH and AEL values for GA and GB, and the AEL value for HD. Army regulation (AR) 385-61 does not establish an IDLH for HD due to concerns over carcinogenicity.

The SABRE 2000 units exceeded the JSOR and IDLH detection levels for GA and GB in both sniff (10 second response time) and pre-concentration (40 second response time) modes. GA detection response in pre-concentration mode showed a 2 to 3 times improvement over the sniff mode detection concentration levels. Pre-concentration mode did not appreciably improve the MDL for GB. The SABRE 2000 HD detection response, using the modified 5 seconds pre-concentration mode, also exceeded the current JSOR requirement readily with an alarm time in approximately 15 seconds. The SABRE 2000, in its current configuration, could not detect the AEL values for GA, GB or HD.

**Table 1. Minimum Detectable Level (MDL) for the SABRE 2000 at Ambient Temperatures and 50% Relative Humidity**

AGENT	Concentration in milligrams per cubic meter, mg/m <sup>3</sup> , With parts per million values in parenthesis (ppm) And Response Times						
	Sniff Mode		Pre-concentration Mode		JSOR*	IDLH**	AEL ***
	Unit A	Unit B	Unit A	Unit B			
	mg/m <sup>3</sup> (ppm)	mg/m <sup>3</sup> (ppm)	mg/m <sup>3</sup> (ppm)	mg/m <sup>3</sup> (ppm)	mg/m <sup>3</sup> (ppm)	mg/m <sup>3</sup> (ppm)	mg/m <sup>3</sup> (ppm)
GA	<b>0.06</b> (0.010) in 10 seconds	<b>0.06</b> (0.010) in 10 seconds	<b>0.02</b> (0.003) in 40 seconds	<b>0.03</b> (0.005) in 40 seconds	0.1 (0.015) in 30 seconds	0.2 (0.03) up to 30 minutes	0.0001 (0.000015) up to 8 hours
GB	<b>0.06</b> (0.010) in 10 seconds	<b>0.03</b> (0.005) in 10 seconds	<b>0.05</b> (0.009) in 40 seconds	<b>0.03</b> (0.005) in 40 seconds	0.1 (0.017) in 30 seconds	0.2 (0.03) up to 30 minutes	0.0001 (0.000017) up to 8 hours
HD	-	-	<b>0.54</b> (0.08) in 15 seconds ****	<b>0.80</b> ***** (0.12) in 15 seconds ****	2.0 (0.30) in 120 seconds	None established	0.003 (0.0005) up to 8 hours

\* Joint Service Operational Requirements for detectors.

\*\* Immediate Danger to Life or Health values from AR 385-61 to determine level of CW protection. Personnel must wear full ensemble with SCBA for operations or full-face piece respirator for escape.

\*\*\* Airborne Exposure Limit values from AR 385-61 to determine masking requirements. Personnel can operate for up to 8 hours unmasked.

\*\*\*\* Units tested in modified (5 second) pre-concentration mode.

\*\*\*\*\* Unit C used in place of Unit B for these tests.

## 5.2 TEMPERATURE AND HUMIDITY EFFECTS

Tables 2, 3, and 4 show the results of the SABRE 2000 evaluation at various test conditions for agents HD, GA, and GB, respectively. Tests were conducted at ambient temperatures and RH conditions of approximately <10%, 50% and 90%. The detectors were also tested at the instrument's operational temperature extremes of 0°C and +40°C. The concentrations used to determine the temperature and humidity effects were based on the determined MDLs. Positive detection response is defined as three consistent responses in three independent trials for the agent at the temperature and relative humidity so specified. The number of alarm responses per number of trials is given in each table.

Due to an error in the firmware (which Barringer has since corrected), unit B did not produce a detection response with HD exposure even when the HD peak was clearly observed and all the parameters were set properly. Several parameters had to be changed and new firmware added to the SABRE 2000 units to enable them to detect HD.

Unit B failed to power up after testing at low temperature. It appeared that the CPU of

unit B had short-circuited. Unit C was used to continue the HD evaluations. Units A and C were used after the temperature tests to repeat some of the earlier ambient HD tests using the new parameters and firmware to reconfirm the HD detection sensitivity.

It should be noted that the firmware and parameter changes required to enable the instruments to detect the CW agents make them somewhat different from the SABRE 2000 units that were marketed for narcotic and explosive detection in circulation. Results listed below reflect test findings after the firmware changes.

Table 2 shows that the instruments successfully demonstrated HD detection response at various temperature and humidity conditions. However, at the cold temperature (0°C), the detectors experienced residual contamination effects from HD exposures. The detectors not only had difficulty clearing the residual HD but also did not clear readily after simulant checks conducted at the cold temperatures. The units required approximately 10 minutes to become sufficiently cleared between each agent exposure.

**Table 2. SABRE 2000 Responses to HD Vapor Concentrations at Various Temperatures and Relative Humidities**

Conditions		HD Concentration		5 Seconds Pre-concentration Mode*	
Temperature °C	%RH	mg/m <sup>3</sup>	ppm	Unit A	Unit C**
				15 seconds response time	15 seconds response time
				(Alarms/Trials) ***	(Alarms/Trials)
21	<5	0.58	0.09	3/3	No Alarm
		0.82	0.12	3/3	3/3
21	50	0.54	0.08	3/3	Not tested
		0.68	0.10	3/3	0/3
		0.80	0.12	Not tested	3/3
		1.95	0.30	3/3	3/3
		15.22	2.31	3/3	3/3
		31.49	4.78	3/3	3/3
21	>90	0.82	0.12	3/3	3/3
0****	0	0.60	0.09	3/3	3/3 (Unit B)
40	30	0.30	0.05	3/3	3/3

\*Modified pre-concentration mode to 5 seconds sample collection. All tests except 0°C repeated with Units A & C after new firmware and HD parameters were adjusted

\*\*Unit C replaced unit B after cold temperature tests because CPU short-circuited

\*\*\*Positive detection response is defined as three consistent responses in three independent trials

\*\*\*\*Cold tests were conducted in sniff mode with the 10 second response time using Units A & B until Unit B short-circuited

Table 3 shows that the SABRE 2000 successfully demonstrated GA detection response at the approximate MDL concentrations for ambient and high temperatures except in high humidity conditions. Relative humidity above 85% created inconsistent detection response (2 detection responses out of 3 trials) near the MDL concentrations. GA detection response at 0°C required a GA low temperature channel to be added to the instruments due to new peak identification. GA detection response at cold temperature (0°C) showed no response or inconsistent response near the MDL concentrations for Units A and B. Occasionally, during the GA evaluations, the instrument reported an extra channel response for GF, VX, GB or VERIFIC (simulant). Nevertheless, GA was also identified in each of those trials.

Table 4 shows that the SABRE 2000 successfully demonstrated GB detection response at the approximate MDL concentrations for ambient and high temperatures except in high humidity conditions. Relative humidity above 90% created inconsistent detection response (1 or 2 detection responses out of 3 trials) at MDL concentrations. GB detection response at 0°C required a GB low temperature channel to be added to the instruments to allow a response below 0.35 mg/m<sup>3</sup> due to new peak identification. In addition, the instrument false alarmed a couple of times during the background check and reported a false GA and false VX response. However, this did not affect the GB detection response.

**Table 3. SABRE 2000 Responses to GA Vapor Concentrations at Various Temperatures and Relative Humidities**

Conditions		GA Concentration		Sniff Mode		30 Seconds Pre-concentration Mode	
Temperature °C	% RH	mg/m <sup>3</sup>	ppm	Unit A 10 seconds response time	Unit B 10 seconds response time	Unit A 40 seconds response time	Unit B 40 seconds response time
				(Alarms/Trials) *	(Alarms/Trials)	(Alarms/Trials)	(Alarms/Trials)
23	<5	<b>0.01</b>	0.001	No Alarm	No Alarm	Not tested	Not tested
22		<b>0.02</b>	0.003	No Alarm	No Alarm	3/3	3/3
23		<b>0.06</b>	0.009	3/3	3/3	Not tested	Not tested
23		<b>0.08</b>	0.012	3/3	3/3	Not tested	Not tested
22		<b>0.09</b>	0.013	3/3	3/3	Not tested	Not tested
22	50	<b>0.01</b>	0.001	Not tested	Not tested	1/3	No Alarm
22		<b>0.02</b>	0.004	No Alarm	No Alarm	3/3	2/3
22		<b>0.03</b>	0.004	Not tested	Not tested	3/3	3/3
22		<b>0.04</b>	0.006	No Alarm	2/3	Not tested	Not tested
22		<b>0.06</b>	0.010	3/3	3/3	3/3	3/3
22		<b>0.45</b>	0.067	3/3	3/3	3/3	3/3
24		<b>0.57</b>	0.086	3/3	3/3	3/3	3/3
22		<b>0.82</b>	0.122	3/3	3/3	3/3	3/3
22		<b>1.10</b>	0.164	3/3	3/3	3/3	3/3
24		<b>2.50</b>	0.376	3/3	3/3	3/3	3/3
23	>90	<b>0.03</b>	0.005	No Alarm	No Alarm	3/3	1/3
24	>85	<b>0.04</b>	0.005	Not tested	Not tested	3/3	2/3
24	>85	<b>0.05</b>	0.007	2/3	2/3	Not tested	Not tested
23	>90	<b>0.08</b>	0.012	2/3	3/3	3/3	3/3
0	0	<b>0.03**</b>	0.004	No Alarm	No Alarm	No Alarm	3/3
		<b>0.05**</b>	0.007	No Alarm	1/3	2/3	Not tested
		<b>0.08**</b>	0.011	No Alarm	2/3	2/3	Not tested
40	30	<b>0.03</b>	0.005	No Alarm	No Alarm***	3/3	3/3***
		<b>0.10</b>	0.016	3/3	3/3***	Not tested	Not tested

\*Positive detection response is defined as three consistent responses in three independent trials

\*\*GA low temp channel added to units (new peaks identified) in order to detect in cold temps

\*\*\*Unit C replaced unit B for these tests because CPU short-circuited

Note: Occasionally (9 times), an extra peak would appear as a channel for GF, VX, GB, or Verific during evaluations

**Table 4. SABRE 2000 Responses to GB Vapor Concentrations at Various Temperatures and Relative Humidities**

Conditions		GB Concentration		Sniff Mode		30 seconds Pre-concentration Mode	
Temperature °C	% RH	mg/m <sup>3</sup>	Ppm	Unit A	Unit B	Unit A	Unit B
				10 seconds response time	10 seconds response time	40 seconds response time	40 seconds response time
				(Alarms/Trials*)	(Alarms/Trials)	(Alarms/Trials)	(Alarms/Trials)
23	<10	0.03	0.005	No Alarm	3/6	6/6	4/6
		0.04	0.007	No Alarm	3/3	3/3	3/3
		0.14	0.024	3/3	Not tested	Not tested	Not tested
24	50	0.02	0.003	No Alarm	No Alarm	No Alarm	No Alarm
24		0.03	0.005	No Alarm	3/3	No Alarm	3/3
24		0.04	0.007	No Alarm	3/3	No Alarm	3/3
28		0.05	0.009	2/6	3/3	4/6	3/3
24		0.06	0.010	3/3	Not tested	1/1	2/2
28		0.10	0.017	Not tested	Not tested	2/3	2/2
28		0.12	0.021	3/3	3/3	2/3	2/2
22		0.37	0.064	3/3	3/3	Not tested	Not tested
22		1.90	0.328	3/3	3/3	Not tested	Not tested
23	90	0.03	0.005	No Alarm	2/3	2/3	3/3
23		0.04	0.007	1/5	5/5	Not tested	Not tested
22		0.06	0.010	1/3	Not tested	Not tested	Not tested
0	0	0.04**	0.007	No Alarm	2/3	3/3	3/3
		0.15**	0.024	3/3	3/3	Not tested	Not tested
		0.35	0.056	3/3	3/3	3/3	3/3
40	30	0.01	0.002	No Alarm	Not tested	No Alarm	No Alarm (unit C)***
		0.03	0.006	2/3	Not tested	3/3	3/9**** (unit C)
		0.04	0.008	Not tested	3/4 (unit C)	Not tested	3/4 (unit C)

\*Positive detection response is defined as three consistent responses in three independent trials

\*\*GB low temp channel added to units (new peaks identified), to allow a response below 0.35 mg/m<sup>3</sup>

\*\*\*Unit C replaced unit B for these tests because CPU short-circuited

\*\*\*\* Unit C also displayed a false GA response and occasional false VX peaks in the background during these tests

### 5.3 SURFACE CONTAMINATION TEST

Table 5 shows the results of liquid HD and GB surface contamination tests using the SABRE 2000 in particle sniff mode. The limited evaluation indicated that the surface swab swipe was able to produce the appropriate detection response when the contaminant was absorbed on the sample swab. On rough or absorbing surfaces such as asphalt and concrete, the ability to swab the contamination is hindered. The amount of sample collected from the swipe is limited when the agent has soaked into the substrate. This resulted in failures to yield a detection response consistently for several sample swipes. Tests in GB (positive) mode occasionally indicated the presence of GF and V<sub>x</sub> on the display panel in addition to the correctly identified agent. This was attributed to the strong detection signal from the swiped sample that caused the primary detected peak to overlap into other agent peak windows.

**Table 5. Liquid Surface Contamination Detection Response Results for SABRE 2000**

Surface	HD		GB	
	Unit A Response (Alarms/Trials)	Unit C Response (Alarms/Trials)	Unit A Response (Alarms/Trials)	Unit C Response (Alarms/Trials)
Asphalt	No Alarm	2/3	3/3	3/3
Concrete	1/2	1/2	2/2	2/2
BDU	1/2	2/2	1/2	1/2
Wood	2/2	2/2	2/2	2/2
CARC	Not tested	Not tested	2/2	2/2

### 5.4 FIELD INTERFERENCE

The results for the field test exposures are presented in Table 6. False positive responses indicate that the detector alarmed in the absence of CW agent. The ambient temperature and relative humidity levels during these tests were in the range of 27-32°C and 45-80% RH, with gentle wind. During the field evaluations, unit A was set to negative (H) mode and unit C was set to positive (G) mode. Both units were tested in the 30 seconds pre-concentration mode. Adding the 10 seconds of analysis time yields a total response time of 40 seconds.

The field tests show that unit A false alarmed to five out of twenty (25%) tested substances. However, only two of the five false responses indicated HD. The other three reported Lewisite and explosives detections. Unit C false alarmed to three of the twenty (15%) test substances. Responses included false identification for three GA channels and one GB channel.

Post field test responses against HD and GA challenges showed the SABRE 2000 units to have no adverse residual effects from the field tests. Response characteristics were similar to the pre-field test results.

**Table 6. SABRE 2000 Responses to Field Interference Testing**

Interferent	SABRE 2000 Units in 30 seconds Pre-concentration Mode	
	Unit A (negative mode) 40 seconds Response time	Unit C (positive mode) 40 seconds Response time
	Alarms/Trials	Alarms/Trials
Gasoline Exhaust, Idle	0/3	0/3
Gasoline Exhaust, Revved	0/3	0/3
Diesel Exhaust, Revved	2/3*	0/3
Gasoline Vapor	0/3	0/3
Diesel Vapor	0/3	0/3
JP8 Vapor	0/3	0/3
Kerosene Vapor	0/3	0/3
AFFF Vapor	0/3	2/3**
Bleach Vapor	0/3	0/3
Insect Repellent	0/3	0/3
HTH bleach Vapor	3/3***	0/3
Burning Gasoline Smoke	0/3	0/3
Burning JP8 Smoke	0/3	0/3
Burning Kerosene Smoke	0/3	0/3
Burning Diesel Smoke	0/3	0/3
Burning Cardboard Smoke	2/3****	0/3
Burning Cotton Smoke	0/3	0/3
Burning Wood Fire Smoke	1/3*****	3/3*****
Doused Wood Fire Smoke	0/1	1/1**
Burning Rubber	1/2***	0/2

\* False responses of Lewisite  
\*\* False responses of GA  
\*\*\* False responses of HD  
\*\*\*\* False responses of NG-N (explosive) and L2 (Lewisite)  
\*\*\*\*\* False response of NGC (explosive)  
\*\*\*\*\* False responses of GA and GB

## 5.5 LABORATORY INTERFERENCE TESTS

Table 7 presents the results of testing the units with conditioned air containing either GA or HD in the presence of either diesel fuel vapor or AFFF vapor. The tests were completed at ambient temperatures and 50% RH with the SABRE 2000 units set in the 30 seconds pre-concentration mode. The units showed no false response when exposed to either 0.1% or 1% AFFF vapor or 1% diesel vapor.

Both units detected GA in the presence of the 1% diesel vapor. The 1% AFFF vapor appears to affect the GA detection sensitivity of the instrument. A slightly higher than the determined MDL concentration was needed for both units to produce the GA detection response. However, when the AFFF concentration was lowered to 0.1%, both units detected GA at the MDL concentration.

The results indicate that unit A was able to detect HD in the presence of either diesel vapor or AFFF vapor. However, unit C was inadvertently tested below its MDL for HD therefore did not respond at this concentration.

**Table 7. SABRE 2000 Laboratory Interference Results with GA and HD**

Agent	Interferent	Concentration		SABRE 2000 Units in 30 seconds Pre-concentration Mode	
		mg/m <sup>3</sup>	ppm	Unit A Response (Alarms/Trials)	Unit C Response (Alarms/Trials)
GA	1% Diesel	0.03	0.005	2/2	2/2
	1% AFFF	0.04	0.006	0/2	0/2
	1% AFFF	0.10*	0.016	2/2	2/2
	0.1% AFFF**	0.03	0.005	2/2	2/2
HD	1% Diesel	0.35***	0.054	2/2	0/2
	1% AFFF	0.35***	0.054	2/2	0/2

\* Slightly higher GA concentration required before detection under the 1% AFFF influence  
 \*\* At AFFF concentration lowered to 0.1%, both units detected GA at the MDL  
 \*\*\*HD concentration is below MDL for Unit C.

Laboratory evaluations to determine if other potential interferent compounds would cause the detector to false alarm are summarized in Table 8. Tests were conducted using unit A in positive mode and unit C in negative mode. The detectors were set to the 30 seconds pre-concentration mode (30 seconds sampling with 10 second analytical time). The interferent vapor concentrations were generated at the 1% saturation level. These tests did not include use of CW agent and were conducted at ambient temperature with 50% RH. No detection responses (false alarms) were observed in the negative mode. In positive mode, only one false GA response occurred during the evaluations and it occurred for one of three exposures to toluene.

**Table 8. SABRE 2000 Laboratory Interference Results without Agents  
(1% Saturation at Ambient Temperature and 50% Relative Humidity)**

Interferent	Unit A (Positive mode)	Unit C (Negative mode)
	30 Pre-concentration mode	30 Pre-concentration mode
AFFF	No Alarm	No Alarm
Bleach	No Alarm	No Alarm
Diesel	No Alarm	No Alarm
Floor Wax	No Alarm	No Alarm
Gasoline	No Alarm	No Alarm
JP8	No Alarm	No Alarm
Spray 9	No Alarm	No Alarm
Toluene	GA (1/3)*	No Alarm
Vinegar	No Alarm	No Alarm
Windex	No Alarm	No Alarm
Ammonia (25 ppm)	No Alarm	No Alarm

\*False GA response for one out of three trials.

## 6. CONCLUSIONS

Conclusions are based solely on the results observed during this testing. Aspects of the detectors, other than those described, were not investigated.

Civilian first responders and HAZMAT personnel use Immediate Danger to Life or Health (IDLH) values to determine levels of protection selection during consequence management of an incident. The threshold sensitivity of the SABRE 2000 is better than the current IDLH and JSOR sensitivity requirements for the CW agents tested. All response times were the same, either 10 or 40 seconds, depending on the selected mode of operation. The units detected both GA and GB at concentrations lower than the JSOR and IDLH levels in both sniff

and pre-concentration modes. HD detection sensitivity also exceeded the JSOR requirements when operated in the modified 5 seconds pre-concentration mode. The SABRE 2000 could not meet the AEL detection requirements for GA, GB, or HD.

The instruments demonstrated CW agent vapor and surface contamination monitoring for HD, GA, and GB at most of the conditions tested. However, there were several concerns uncovered during the evaluation. The primary problem was the initial inability to detect HD consistently. Several revisions of firmware and parameter changes by the manufacturer were required to arrive at the final test configuration. It is important to note that the tested SABRE 2000 units, because of the needed changes, are not the same instruments currently used for narcotic and explosive detection.

In addition, the instrument exhibited inconsistent responses to GA and GB near the MDL in high humidity conditions. As stated by the manufacturer, moisture causes problems with instrument response and the internal air purification cartridge needs to be checked regularly and replaced when necessary.

Cold temperature caused erratic behavior of the instrument responses at the MDL and necessitated longer recovery times. The instrument required additions by the manufacturer of new GA and GB low temperature channels to the algorithm for detection response at MDL concentrations at 0°C. Since the SABRE 2000 does not have airflow through the system continuously, only after it is physically put into its sampling cycle does the airflow begin, the clearing of less volatile substances in cold temperature required a number of sampling cycles, which extended the recovery time.

The ability to detect agent in the presence of a potentially interfering vapor, when the vapor itself does not cause a false alarm, has been demonstrated. Tests in the controlled laboratory environment and results of the field interferent tests showed only a few false responses to the interference substances tested.

## LITERATURE CITED

- 
1. Longworth, Terri L. et al, Testing of Commercially Available Detectors Against Chemical Warfare Agents: Summary Report, ECBC-TR-033, U.S. Army Chemical Research, Development and Engineering Center, Aberdeen Proving Ground, MD, May 1999, UNCLASSIFIED Report.
  2. ATCD-N, MEMORANDUM, Subject: Joint Service Operational Requirement (JSOR) for the Automatic Chemical Agent Detector Alarm (ACADA), HQDA United States Army Training and Doctrine Command, Fort Monroe, Virginia, 3 August 1990.
  3. SABRE 2000 Operator's Manual, Barringer Technologies, Inc., Warren, NJ, 2000.
  4. Ong, Kwok Y., Multi-Purpose Chemical Agent Vapor Generation System, ERDEC-TR-424, U.S. Army Chemical Research, Development and Engineering Center, Aberdeen Proving Ground, MD, July 1997, UNCLASSIFIED Report.
  5. Ong, Kwok Y. et al, Analytical Methodology for Quantitative Determination of O-ethyl-S-(2-Diisopropylaminoethyl) Methylphosphonothiolate (VX), ERDEC-TR-476, U.S. Army Chemical Research, Development and Engineering Center, Aberdeen Proving Ground, MD, March 1998, UNCLASSIFIED Report.