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REPORT

Environics USA Inc.

ChemPro 100 Hand-Held Chemical Detector

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Technology Evaluation Report

Environics USA Inc. ChemPro 100 Hand-Held Chemical Detector

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Notice

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Preface

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the nation's air, water, and land resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, the EPA's Office of Research and Development (ORD) provides data and science support that can be used to solve environmental problems and to build the scientific knowledge base needed to manage our ecological resources wisely, to understand how pollutants affect our health, and to prevent or reduce environmental risks.

In September 2002, EPA announced the formation of the National Homeland Security Research Center (NHSRC). The NHSRC is part of the ORD; it manages, coordinates, and supports a variety of research and technical assistance efforts. These efforts are designed to provide appropriate, affordable, effective, and validated technologies and methods for addressing risks posed by chemical, biological, and radiological terrorist attacks. Research focuses on enhancing our ability to detect, contain, and clean up in the event of such attacks.

NHSRC's team of world-renowned scientists and engineers is dedicated to understanding the terrorist threat, communicating the risks, and mitigating the results of attacks. Guided by the roadmap set forth in EPA's Strategic Plan for Homeland Security, NHSRC ensures rapid production and distribution of security-related products.

The NHSRC has created the Technology Testing and Evaluation Program (TTEP) in an effort to provide reliable information regarding the performance of homeland security-related technologies. TTEP provides independent, quality-assured performance information that is useful to decision makers in purchasing or applying the tested technologies. It provides potential users with unbiased, third-party information that can supplement vendor-provided information. Stakeholder involvement ensures that user needs and perspectives are incorporated into the test design so that useful performance information is produced for each of the tested technologies. The technology categories of interest include detection and monitoring, water treatment, air purification, decontamination, and computer modeling tools for use by those responsible for protecting buildings, drinking water supplies, and infrastructure and for decontaminating structures and the outdoor environment.

The evaluation reported herein was conducted by Battelle as part of the TTEP program. Information on NHSRC and TTEP can be found at http://www.epa.gov/ordnhsrc/index.htm.

Acknowledgments

The authors wish to acknowledge the support of all those who helped plan and conduct the evaluation, analyze the data, and prepare this report. We also would like to thank Donald Stedman of the University of Denver and John Zimmerman of EPA/ORD for their reviews of this report.

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Abbreviations/Acronyms

AC	hydrogen cyanide
CW	chemical warfare
CK	cyanogen chloride
Cl_2	chlorine
DEAE	N,N-diethylaminoethanol
EPA	U.S. Environmental Protection Agency
FID	flame ionization detection
FPD	flame photometric detection
GB	sarin
GC	gas chromatography
HD	sulfur mustard
IDLH	immediately dangerous to life and health
IMS	ion mobility spectrometer(ry)
L	liter
μg	microgram
$\mu g/m^3$	microgram per cubic meter
μL	microliter
mg/m^3	milligram per cubic meter
mL	milliliter
mm	millimeter
MSD	mass selective detection
NHSRC	National Homeland Security Research Center
ORD	Office of Research and Development
PE	performance evaluation
ppm	parts per million
ppmC	parts per million of carbon
QA	quality assurance
QC	quality control
QMP	quality management plan
RH	relative humidity
SA	arsine
THC	total hydrocarbon
TIC	toxic industrial chemical
TSA	technical systems audit
TTEP	Technology Testing and Evaluation Program

Executive Summary

The U.S. Environmental Protection Agency's (EPA's) National Homeland Security Research Center (NHSRC) Technology Testing and Evaluation Program (TTEP) is helping to protect human health and the environment from adverse impacts as a result of acts of terror by carrying out performance tests on homeland security technologies. Under TTEP, Battelle recently evaluated the performance of the Environics USA Inc. ChemPro 100 Hand-Held Chemical Detector. The objective of evaluating the ChemPro 100 Hand-Held Chemical Detector was to evaluate its ability to detect toxic industrial chemicals (TICs) and chemical warfare (CW) agents in indoor air.

The ChemPro 100 is based on Environics' open loop ion mobility spectrometry (IMS) technology and uses an improved Ion Mobility Cell™ that is designed to increase selectivity and sensitivity in detecting CW agents and TICs. It identifies agent class (Nerve, Blister, or Blood), indicates relative concentration (Low, Medium, or High), and indicates whether the concentration is increasing or decreasing.

The following performance characteristics of the ChemPro 100 were evaluated:

- Response time
- Recovery time
- Accuracy of hazard identification
- Repeatability
- Response threshold
- Temperature and humidity effects
- Interference effects
- Cold-/hot-start behavior
- Battery life
- Operational characteristics.

This evaluation addressed detection of chemicals in the vapor phase. The TICs and the respective challenge concentrations delivered to the ChemPro 100 during the evaluation were hydrogen cyanide [HCN; North Atlantic Treaty Organization military designation AC; 50 milligrams per cubic meter (mg/m^3)], cyanogen chloride (ClCN; designated CK; 250 mg/m^3), arsine (AsH_3; designated SA; 20 mg/m^3), and chlorine ($C1_2$; no military designation; 180 mg/m^3). The CW agents and concentrations were sarin (GB; 0.060 mg/m^3) and sulfur mustard (HD; 0.54 mg/m^3). These TIC and CW agent challenge concentrations were established in trial runs as producing Medium response on the ChemPro 100. The TIC challenge concentrations were equal to or greater than the Low alarm concentrations stated by the vendor. The GB and HD challenge concentrations were less than the Low alarm concentrations stated by the vendor for these agents. Two ChemPro 100 units (Units 1546 and 1811) were evaluated simultaneously with the TICs;

one unit of the ChemPro 100 (Unit 1811) was evaluated with the CW agents. The use of only one unit in testing with CW agents minimized the expense to the vendor, because that unit could not be returned to the vendor after contamination with agents. Each ChemPro 100 unit was challenged at the start of each test day with a chemical simulant sample provided by the vendor. No test procedures were initiated unless proper response to this challenge was obtained. This challenge was also repeated as needed during each test day (e.g., in the case of an unexpected response during testing) before continuing the test procedures.

The evaluation included sampling potential indoor interferents, both with and without the target TICs and CW agents. The interferents used were latex paint fumes, air freshener vapors, ammonia cleaner vapors, a mixture of hydrocarbons representing motor vehicle exhaust, and diethylaminoethanol (DEAE), a boiler water additive that can enter indoor air via steam humidification. A range of temperatures (5 to 35 ºC) and relative humidities (<20 to 80%) was used to assess the effects of these conditions.

Summary results from testing the ChemPro 100 are presented below for each performance parameter evaluated. Results reported for CK and SA are limited due to inconsistent responses, and few results for Cl_2 are reported, due to lack of response found for that chemical. Discussion of the observed performance can be found in Chapter 4 of this report.

Response Time: When the ChemPro 100 responded to challenges, the time required to respond to AC and CK was usually about 30 seconds or less, and response times for SA ranged from about 20 to 80 seconds. Response times for GB were 15 seconds or less, and for HD were usually 25 to 40 seconds, with a few results of 80 to 225 seconds. Response times for AC, GB, and HD were not consistently affected by the temperature and relative humidity (RH). These results do not include instances in which the ChemPro 100 failed to respond to TIC or CW agent challenges; those instances are addressed below under Accuracy.

Recovery Time: The time required for the ChemPro 100 to return to a baseline reading after an alarm was typically less than 50 seconds for AC, CK, SA, and HD, and less than about 15 seconds for GB, but in a few instances during evaluation with AC and HD, recovery times exceeded 600 seconds. Recovery times depended only weakly on temperature and RH, with recovery times for AC being shorter with higher temperature and lower RH. These results exclude those instances in which the ChemPro 100 did not respond to a TIC or agent challenge.

Accuracy: Of the 120 challenges with AC, GB, and HD used to assess accuracy, the ChemPro 100 responded accurately to 86, with no response to 30 challenges, and four cases of a continued alarm even when sampling clean air. Accuracy results for the target chemicals varied from one test condition to another, and (in TIC evaluation) from one ChemPro 100 unit to the other. Accuracy for AC was 100% in most conditions, but ranged from 0 to 40% under conditions of high humidity. For GB, accuracy was 80 to

100% at most conditions, but was 0% with high humidity. Accuracy for HD was 80 to 100% at some conditions, but 0 to 40% at others, with no clear dependence on temperature or RH. Accuracy for CK ranged from 0 to 100%, with different temperature and RH dependence observed from the two units. For SA accuracy ranged from 0 to 100% under different conditions (from 0 to 20% for one ChemPro 100 unit), with no apparent dependence on temperature or RH. For chlorine, only one positive response was seen from one unit in five trials on each of the two units, so the unit accuracies were 0 and 20%.

[Failure to respond to AC challenges was also observed during cold-/hot-start and battery life tests, but those observations were not used in the calculation of the accuracy results noted above.]

Repeatability: When the ChemPro 100 units responded to an AC challenge, for one unit, repeatability was perfect under all conditions of temperature and humidity (i.e., all maximum responses were Medium). For the other unit with AC, maximum response changed from Low to High as temperature increased, and from Medium to Low as RH increased. For GB, maximum responses changed from High to Medium to Low as temperature increased from low (5 °C) to room temperature to high (35 °C). No humidity effect was seen on GB repeatability, and HD response was perfectly repeatable under all conditions (all maximum responses were Low).

Response Threshold: For AC, the response threshold was between 3 and 6 parts per million (ppm) (3 and 6 mg/m^3) on both ChemPro 100 units. For CK the response threshold was between 5 and 10 ppm (12.5 and 25 mg/m^3) on one unit and between 10 and 20 ppm (25 and 50 mg/m^3) on the other. The SA response threshold was between 3 and 6 ppm (10 and 20 mg/m^3) on both units and, for Cl_2, was at or above about 60 ppm (180 mg/m^3). For GB the response threshold was about 0.002 ppm (0.01 mg/m^3), and for HD it was about 0.03 ppm (0.2 mg/m^3).

Temperature and Humidity Effects: These effects are described in the preceding summaries of other performance parameters.

Interference Effects: Ammonia cleaner and air freshener vapors produced false positive responses in nearly all trials when using either the TIC or CWA library of the ChemPro 100. Latex paint fumes produced false positives in 67 to 100% of trials in the TIC library, and in 20 to 40% of trials in the CW agent library. DEAE produced no false positive responses, and exhaust hydrocarbons produced only one false positive out of 20 trials.

[Erroneous positive responses of a different kind (i.e., alarms while the ChemPro 100 sampled clean air) were observed in a few cases during tests of accuracy with AC and CK.]

When added to challenge mixtures of AC, the interferences produced minimal false negative responses for AC with one ChemPro 100 unit. However, the response accuracy of the other unit was reduced to 40% by the air freshener vapors and to 0% by the ammonia cleaner vapors. False negative effects on CK and SA response were difficult to determine because of the variability in response for these chemicals with the two ChemPro 100 units. False negative effects on accuracy of identification for CK were seen with DEAE, and the accuracy for SA was reduced to 0 to 20% by engine exhaust hydrocarbons and DEAE. False negative responses with GB occurred primarily with ammonia cleaner and exhaust hydrocarbons. False negative responses with HD occurred with paint fumes, ammonia cleaner, and air freshener vapors. With both GB and HD, the false negatives were primarily in the form of inaccurate responses (e.g., a response of CHEM HAZARD rather than NERVE for GB), rather than no response at all. In these cases the ChemPro 100 response provides a protective warning, although the threat is incorrectly identified.

[In one challenge each with AC, GB, and HD in clean air during the evaluation of accuracy, and in two challenges with HD in interference testing, the ChemPro 100 produced a different type of erroneous negative response in clearing its alarm while the TIC or agent challenge was still ongoing.]

Cold-/Hot-Start Behavior: The delay time, or time to reach a ready state after start-up, was 161 seconds and 169 seconds for the two ChemPro 100 units, respectively, when started up from room temperature storage. The delay times were increased to 258 seconds and 420 seconds after storage at 5 °C. Accuracy of identification of an AC challenge was substantially reduced in initial readings after a cold start, relative to that in fully warmed up operation. For example, one unit showed no response to AC in four of five trials after start-up from cold storage, in all five trials after start-up from room temperature, and in four of five trials after start-up from hot storage. In general, response times were slightly longer, and response readings (i.e., Low/Medium/High) somewhat lower after a cold start than in fully warmed up operation.

Battery Life: One unit of the ChemPro 100 shut down after 9 hours and 53 minutes of continuous operation on battery power. The other unit shut down after 11 hours and 12 minutes.

Operational Characteristics: The ChemPro 100 has a large display that is easy to read in all light conditions provided the background light (bright blue) is used. This light is controlled from a menu within the ChemPro 100. The display indicates the response reading of the unit (hazard identity and level), what library is being used, the date and time, the audible alarm volume level, and the battery power level. A lighted status indicator is green when the unit is in ready mode, and flashing red when the unit is in alarm mode (coincident with the audible alarm). The display (when lighted) and audible and visual alarms can be readily understood by the operator, even when wearing personal protective equipment. When the ChemPro 100 detects a failure within its system, the display also indicates an error message, e.g., for air intake flow or SCCell failure. The ChemPro 100 has a “conditioning” mode that keeps the instrument from responding while the instrument stabilizes. However, the occurrence of this mode is only apparent from data displayed on a laptop computer, and is not evident to an operator using the ChemPro 100 as a hand-held device. When the temperature or humidity condition was changed, the ChemPro 100 may have entered conditioning mode and thus not responded until the conditioning mode was completed. This mode may have contributed to instances where IMS signal was observed on the laptop, but the ChemPro 100 failed to give an alarm when challenged.

Before this evaluation began, an Environics representative trained Battelle personnel to operate the ChemPro 100. The evaluation proceeded according to the vendor's recommendations, and the vendor responded promptly when information was needed during the evaluation. The list price of the ChemPro 100, as used in this evaluation, is approximately $9,500.

Conclusion: The ChemPro 100 responded correctly to AC, GB, and HD in most challenges, but responses observed with CK, SA, and Cl_2 were less reliable. However, even with AC, GB, and HD, observations included the absence of response to challenges, widely different responses from two detector units challenged simultaneously, the occasional discontinuance of a warning alarm even though a TIC or chemical agent challenge was still present, and the failure to clear an alarm even after the challenge gas was replaced with clean air. IMS signals recorded on laptop computers during testing indicated that these behaviors originated with the software that interprets the IMS signal, rather than with the IMS response itself. This finding suggests that software improvements might rectify the observed responses. Both false positive and false negative responses occurred in the presence of common indoor interferent vapors. Usually a protective warning (albeit inaccurately identified) was present in the instances of a false negative response caused by interferents. Elevated humidity generally produced less accurate responses.

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1.0 Introduction

The U.S. Environmental Protection Agency's (EPA's) National Homeland Security Research Center (NHSRC) is helping to protect human health and the environment from adverse impacts resulting from intentional acts of terror. With an emphasis on decontamination and consequence management, water infrastructure protection, and threat and consequence assessment, NHRSC is working to develop tools and information that will help detect the intentional introduction of chemical or biological contaminants in buildings or water systems, the containment of these contaminants, the decontamination of buildings and/or water systems, and the disposal of material resulting from clean-ups.

NHSRC's Technology Testing and Evaluation Program (TTEP) works in partnership with recognized testing organizations; with stakeholder groups consisting of buyers, vendor organizations, and permitters; and with the full participation of individual technology developers in carrying out performance tests on homeland security technologies. The program evaluates the performance of innovative homeland security technologies by developing evaluation plans that are responsive to the needs of stakeholders, conducting tests, collecting and analyzing data, and preparing peer-reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance (QA) protocols to ensure that data of known and high quality are generated and that the results are defensible. TTEP provides high-quality information that is useful to decision makers in purchasing or applying the evaluated technologies. It provides potential users with unbiased, third-party information that can supplement vendor-provided information. Stakeholder involvement ensures that user needs and perspectives are incorporated into the evaluation design so that useful performance information is produced for each of the evaluated technologies.

Under TTEP, Battelle recently evaluated the performance of the Environics USA Inc. ChemPro 100 Hand-Held Chemical Detector in detecting toxic industrial chemicals (TICs) and chemical warfare (CW) agents in indoor air. This evaluation was conducted according to a peer-reviewed test/QA plan[1] that was developed in accordance with the requirements of the quality management plan (QMP) for TTEP.[2] The following performance characteristics of the ChemPro 100 were evaluated:

- Response time
- Recovery time
- Accuracy of hazard identification
- Repeatability
- Response threshold

- Temperature and humidity effects
- Interference effects
- Cold-/hot-start behavior
- Battery life
- Operational characteristics.

In this evaluation, two units of the ChemPro 100 (Units 1546 and 1811) were evaluated simultaneously throughout all procedures with the TICs. In evaluating with the CW agents, only one unit of the ChemPro 100 (Unit 1811) was used, with the other kept in reserve. This approach minimized the expense to the vendor of the ChemPro 100 because the unit tested with CW agents could not be returned after testing. Results are reported for the two units separately. Each ChemPro 100 unit was challenged at the start of each test day with a chemical simulant sample provided by the vendor. No test procedures were initiated unless proper response to this challenge was obtained. This challenge was also repeated as needed during each test day (e.g., in the case of an unexpected response during testing) before continuing the test procedures.

This evaluation addressed detection of chemicals in the vapor phase, because that application is most relevant to use in a building contamination scenario. This evaluation took place between February 22 and August 11, 2005, in two phases: detection of TICs (conducted in a non-surety laboratory at Battelle) and detection of CW agents (conducted in a certified surety laboratory at Battelle's Hazardous Materials Research Center). The TICs used were hydrogen cyanide (HCN; North Atlantic Treaty Organization military designation AC), cyanogen chloride (ClCN; designated CK), arsine (AsH_3; designated SA), and chlorine ($C1_2$; no military designation). The CW agents were sarin (GB) and sulfur mustard (HD). Most evaluation procedures were conducted with challenge concentrations of the TIC or CW agent that were at or near immediately dangerous to life and health (IDLH) or similar levels, as specified in the test/QA plan.(1) Table 1-1 summarizes the primary challenge concentrations used.

Table 1-1. Target TIC and CW Agent Challenge Concentrations

Chemical	Concentration	Type of Level
Hydrogen cyanide (AC)	50 parts per million (ppm) [50 milligrams per cubic meter (mg/m^3)]	IDLH[a]
Cyanogen chloride (CK)	100 ppm (250 mg/m^3)	5 × IDLH
Arsine (SA)	6 ppm (20 mg/m^3)	2 × IDLH
Chlorine (Cl_2)	60 ppm (180 mg/m^3)	6 × IDLH
Sarin (GB)	0.011 ppm (0.060 mg/m^3)	0.3 × IDLH
Sulfur mustard (HD)	0.081 ppm (0.54 mg/m^3)	0.9 × AEGL-2[b]

(a) IDLH = Immediately dangerous to life and health; IDLH value for CK estimated from value for AC.
(b) AEGL = Acute exposure guideline level; AEGL-2 levels are those expected to produce a serious hindrance to efforts to escape in the general population. The AEGL-2 value of 0.09 ppm (0.6 mg/m^3) for HD is based on a 10-minute exposure.

The target TIC and CW agent concentrations shown in Table 1-1 were selected because they produced a Medium response from the ChemPro 100 units in initial trial runs at normal temperature and relative humidity (RH) conditions (i.e., 22 °C and 50% RH) This selection process is defined in the test/QA plan.[1] For the four TICs, the target concentrations selected are equal to or greater than the Low alarm concentrations stated by the ChemPro 100 vendor.[3] As Table 1-1 shows, the selected TIC concentrations also range from 1 to 6 times the respective IDLH concentrations for the TICs. However, for GB and HD, the target challenge concentrations in Table 1-1 are less than the Low alarm concentrations stated by the vendor, which are 0.1 mg/m^3 and 2 mg/m^3, respectively.[3] Thus, for these two CW agents, the response of the ChemPro 100 units was more sensitive than the nominal response indicated by the vendor. In considering the results of this evaluation, the relatively low concentrations of GB and HD, relative to the vendor's nominal Low alarm limits, should be kept in mind. Also, note that the vendor's information[3] states that the ChemPro 100 is suited for detecting chlorine only at absolute humidity levels below 16 g H_2O/m^3 [equivalent (e.g.) to 82% RH at 22 °C, and to 40% RH at 35 °C].

In all evaluations, the TIC or CW agent challenge concentrations were confirmed by means of reference analysis of the challenge air stream. The reference method for AC and CK was a gas chromatography method using flame ionization detection (GC/FID), with automatic sampling from the challenge air stream using a sample loop. This direct sampling approach was supplemented by collection in gas sampling bags for a few final samples. For SA the reference method was gas chromatography with mass selective detection (GC/MSD), with all sampling conducted using gas sampling bags. For Cl_2, a commercial electrochemical detector (Dräger MiniWarn) was used as the reference indicator. The reference method for GB and HD was gas chromatography with flame photometric detection (GC/FPD), using bags for sample collection.

In all testing, the sample inlet of each ChemPro 100 unit was not directly plumbed to the challenge delivery system, but sampled from a "bell" fitting through which a challenge gas flow was supplied in excess of that required by the ChemPro 100. This was done to avoid over- or under-pressurization of the units. The delivered challenge gas flows were always at least twice the inlet flow of the ChemPro 100.

As described in the test/QA plan,[1] response time, recovery time, accuracy, and repeatability were evaluated by alternately challenging the ChemPro 100s with clean air and known vapor concentrations of target TICs and CW agents. Response thresholds were evaluated by challenges with concentrations typically well below the target values shown in Table 1-1. Evaluations conducted over the range of 5 to 35 °C and 20 to 80% RH were used to establish the effects of temperature and humidity on detection capabilities. The test apparatus allowed RH to be changed rapidly; a few minutes of continuous operation was allowed to thoroughly flush all flow paths after a change in the RH (with no change in temperature). On the other hand, typically two to three hours of stabilization time were allowed after a change in the test temperature. In all cases, testing resumed only after the temperature and RH sensors in the test apparatus showed readings stabilized within the required ranges. Throughout the stabilization period after any change, the ChemPro 100 units remained enclosed in the test apparatus, sampling clean air of the target RH. The effects of potential indoor interferences were assessed by sampling selected interferences both with and without the target TICs and CW agents present. The interferences used were latex paint fumes, ammonia floor cleaner vapors, air freshener vapors, a mixture of gasoline exhaust hydrocarbons, and diethylaminoethanol (DEAE), a boiler water additive potentially released to indoor air by humidification systems. The concentrations of the interferents were checked during the evaluation by means of a total hydrocarbon (THC) analyzer, calibrated with known concentrations of propane. The ChemPro 100s also were evaluated with AC after a cold start (i.e., without the usual warm-up period) from room temperature, from cold storage conditions (5°C), and from hot storage conditions (40°C) to evaluate the delay time before readings could be obtained and the response speed and accuracy once readings were obtained. Battery life was determined as the time until ChemPro 100 performance degraded as battery power was exhausted in continuous operation. Operational factors such as ease of use, data output, and cost were assessed through observations made by test personnel and through inquiries to the vendor.

The evaluation data were subjected to multivariate and other statistical analyses, as described in the test/QA plan,[1] to characterize the performance of the ChemPro 100. The data from evaluations with AC, GB, and HD were subjected to the full set of statistical analyses; however, the data from evaluations with the other TICs were not consistent enough to support the full set of analyses, so primarily interference effects and accuracy of identification were evaluated for those TICs.

QA oversight of this evaluation was provided by Battelle and EPA. Battelle QA staff conducted a technical systems audit (TSA) and a data quality audit of all the evaluation data. A performance evaluation (PE) audit of the reference methods for AC, SA, and Cl_2 was also conducted.

2.0 Technology Description

This report provides results for the evaluation of the ChemPro 100 hand-held chemical detector. Following is a description of the ChemPro 100, based on information provided by the vendor. (Contact: Rob Howard, Executive Vice President and General Manager, Environics USA Inc., 4401 Eastport Parkway, Port Orange, Florida 32127, rob.howard@ environicsusa.com, 386-304-5252) The information provided below was not verified in this evaluation.

The ChemPro 100 is based on Environics' open loop ion mobility spectrometry (IMS) technology. The ChemPro 100 uses an improved Ion Mobility Cell™ that is designed to increase selectivity and sensitivity in detecting CW agents and TICs. It identifies agent class (Nerve, Blister, or Blood), indicates relative agent concentration (Low, Medium, or High), and indicates whether the concentration is increasing or decreasing.

The ChemPro 100 weighs less than 700 grams (1.5 pounds) and can be powered by a rechargeable battery pack or AA batteries. The operator interface is designed to be operated using one hand. The user display provides the operator with a battery life indicator, concentration bar display, agent class, agent identification, relative time-based dose, audible alarm volume level, date, and time. The ChemPro 100 stores agent alarm information for retrieval at a later time to provide a historical log of events.

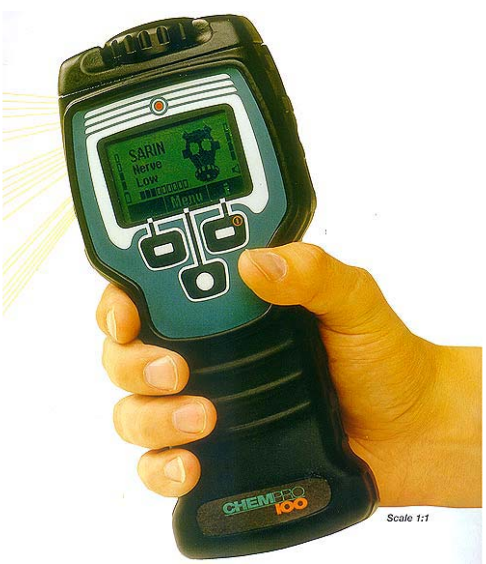

Figure 2-1. Environics USA ChemPro 100 Hand-Held Chemical Detector

The ChemPro 100, which is 102 millimeters (mm) by 229 mm by 51 mm (4 inches by 9 inches by 2 inches), is designed to be used as a personal detector, a monitor for surveying after an event, or a fixed installation detector. The ChemPro 100 is designed to operate in temperatures between -30 EC and 55 EC (between -22 EF and 131 EF). The ChemPro 100 is designed to operate continuously without the need of expendable desiccant cartridges. The ChemPro 100 has no expendables and is designed for low life-cycle and operating costs.

3.0 Quality Assurance/Quality Control

QA/quality control (QC) procedures were performed in accordance with the program QMP[2] and the test/QA plan[1] for this evaluation.

3.1 Equipment Calibration

3.1.1 Reference Methods

As noted in Chapter 1, reference methods were used to confirm the challenge concentrations of TICs and CW agents used in this evaluation. Calibration procedures for the reference and other analyses are discussed in the following paragraphs.

The GC/FID reference method for AC and CK was calibrated by preparing gas mixtures in 1-liter (L) gas sampling bags. Calibration standards for AC were prepared by diluting 1 to 4 milliliters (mL) of a certified commercial gas standard (10,000 ppm AC in nitrogen, Scott Specialty Gases) in 800 mL of high purity air in a bag. The resulting standards had concentrations of 12.5, 24.9, 37.4, and 49.8 ppm AC. Three samples from each calibration bag were injected by syringe into the GC/FID. The peak areas were recorded, and the average peak area from each set of triplicate analyses was used in a linear regression of the calibration data. Blank samples were analyzed in the same way and showed < 1 count peak areas. The regression of peak area versus AC standard concentration had the form Peak Area = 1.340 (± 0.138) · AC (ppm), with a coefficient of determination (r^2) of 0.9716. Calibration standards for CK were prepared in the same way, by diluting 1 to 4 mL of a 12,500-ppm CK compressed gas standard that had been prepared by Battelle starting from neat CK. The resulting CK concentrations were 15.6, 31.3, 46.9, and 62.2 ppm. The resulting regression had the form Peak Area = 1.333 (± 0.169) · CK (ppm), with $r^2 = 0.9725$.

The GC/MSD reference method for SA was calibrated by injecting 1, 3, 6, or 10 mL of a certified commercial 997-ppm arsine standard (Linde Gas) into 1 L of high purity air in a gas sampling bag, thereby producing standards of 1.00, 2.98, 5.95, and 9.87 ppm, respectively. The 5-mL and 10-mL glass graduated syringes used for these injections were preconditioned by filling them with the 997-ppm standard and storing them overnight. This treatment minimized loss of arsine in the syringe during standard preparation. A multipoint calibration was performed on each of the five days of testing with SA. Each multipoint calibration included one blank sample and from one to four replicate analyses at the calibration concentrations noted above (i.e., from 5 to 11 total calibration points). Response was linear, and the response to the blank samples was so small that calculated intercepts did not appreciably differ from zero; consequently the calibration plots were recalculated and forced through zero. The average of the calibration results was Peak Area = 2,529,366 (± 250,138) · (SA, ppm), where the error bar is the standard deviation of the five daily calibration slopes and is equivalent to a 9.9% relative standard deviation. For the daily calibrations, r^2 values ranged from 0.9986 to 0.9998.

Cl_2 reference analyses were conducted using a commercial electrochemical sensor (Dräger MiniWarn). The vendor-supplied calibration was used for reference determinations. The upper limit of the MiniWarn was 20 ppm, and good correspondence was observed up to that limit between the MiniWarn reading and the Cl_2 challenge concentration calculated from dilution of a certified commercial Cl_2 standard (6,015 ppm Cl_2; Praxair) in the test system. This correspondence in turn was the basis for relying on the dilution settings of the test system in preparing Cl_2 concentrations higher than 20 ppm.

Calibration standards for the CW agents GB and HD were prepared by diluting stock agent to micrograms (Φg) per mL concentrations and then injecting a 1-microliter (ΦL) volume of each standard into the GC/FPD. Calibration was based on a regression of peak area versus amount of agent injected.

For GB and HD testing, new calibration plots were prepared at least once a week during detector evaluation for a total of six GB calibrations and four HD calibrations. The concentrations of the standards used were 0.0075, 0.1, 0.25, 0.5, and 0.75 μg/mL for GB and 0.25, 0.5, 1.0, 2.5, 5.0, and 10 μg/mL for HD. Low range calibrations were used to determine agent concentrations for the response threshold and high/low tests. In all cases, agent concentrations were determined by using the most recent calibration plot. All calibration plots for both agents were linear, with r^2 values of greater than 0.99.

The THC analyzer used to document the interferent levels provided in the evaluation was calibrated by filling a 25-L Tedlar bag with a 33-ppm propane commercial compliance class standard (Scott Specialty Gases). Since propane is a three-carbon molecule, this standard constitutes a THC concentration of 99 ppm of carbon (ppmC). This standard was used for calibrating the THC analyzer throughout the evaluation. Clean air from the analytical laboratory was used for zeroing.

3.1.2 Instrument Checks

The ChemPro 100 was operated and maintained according to the vendor's instructions throughout the evaluation. Maintenance was performed according to predefined diagnostics. Daily operational check procedures were performed with vendor-supplied simulant tubes. Proper response of the ChemPro 100 to the simulant was required before the evaluation could proceed.

3.2 Audits

3.2.1 Performance Evaluation Audit

A PE audit was conducted to assess the quality of reference measurements made in the evaluation. For AC, SA, and Cl_2 the PE audit was performed once during the evaluation by diluting and analyzing a standard that was independent of the standards used during the evaluation. In each case, the primary and audit standards were diluted in exactly the same way, and analytical results were then compared, with allowance for differences in the nominal concentrations of the standards. The target tolerance for this PE audit was ±20%. No PE audit was done for CK due to the lack of an independent standard. Table 3-1 shows that the results of the PE audit were well within the target tolerance for AC and Cl_2, and slightly outside the target tolerance for SA. The SA data were reviewed, but in light of the slight exceedance of the target tolerance, no additional audits were conducted.

Independent PE audit samples do not exist for GB and HD. Instead, for the CW agents, check standards of GB and HD were prepared by individuals other than the staff conducting the reference analyses. The check standards were prepared in the same way as the reference calibration standards, i.e., by dilution of military grade agent. The results obtained for these two sets of standards were then compared. For GB, standards were prepared at concentrations of 0.75, 0.50, 0.25, and 0.1 Φg/mL. All results were within 9% for the separate standards made by two individuals. For HD, standards were prepared at concentrations of 5, 2.5, 1.0, and 0.5 Φg/mL. All results were within 15% for the separate standards made by two individuals.

Table 3-1. Performance Evaluation Audit Results

TIC	Sample	Date of Audit	Standard Concentration	Diluted Result	Agreement (%)
AC	Standard (Cylinder C74059)		10,000 ppm	45.8 ppm	
	PE Audit Std (Cylinder LL320)	3/3/05	10,000 ppm	51.5 ppm	11.1
SA	Standard (Cylinder 73486)		1090 ppm	5.9 ppm	
	PE Audit Std (Cyl. KE50368)	3/18/05	997 ppm	6.8 ppm	20.6
Cl_2	Standard (Cylinder LL23078)		6015 ppm	17.3 ppm	
	PE Audit Std (Cylinder 152836)	3/22/05	10,200 ppm	27.2 ppm	7.9

3.2.2 Technical Systems Audit

The Battelle Quality Assurance Manager conducted a TSA to ensure that the evaluation was performed in accordance with the test/QA plan(1) and the TTEP QMP.(2) As part of the audit, the Battelle Quality Assurance Manager reviewed the reference sampling and analysis methods used, compared actual evaluation procedures with those specified in the test/QA plan,[1] and reviewed data acquisition and handling procedures. No significant adverse findings were noted in this audit. The records concerning the TSA are permanently stored with the Battelle Quality Assurance Manager.

3.2.3 Data Quality Audit

At least 10% of the data acquired during the evaluation were audited. The Battelle Quality Assurance Manager traced the data from the initial acquisition, through reduction and statistical analysis, to final reporting, to ensure the integrity of the reported results. All calculations performed on the data undergoing the audit were checked.

3.3 QA/QC Reporting

Each assessment and audit was documented in accordance with the test/QA plan[1] and the QMP.[2] Once the assessment report was prepared by the Battelle Quality Manager, it was routed to the Test Coordinator and Battelle TTEP Program Manager for review and approval. The Battelle Quality Manager then distributed the final assessment report to the EPA Quality Manager and Battelle staff.

4.0 Evaluation Results

The ChemPro 100 was evaluated with the TICs AC, CK, SA, and Cl_2 and the CW agents GB and HD. Test procedures were based on sets of five challenges with a TIC or CW agent, alternating those challenges with intervals of sampling clean air.(1) Statistical approaches were used to assess the performance parameters listed in Chapter 1 for the ChemPro 100 for AC, GB, and HD, as specified in the test/QA plan.(1) Comparable statistical analyses were not conducted for the other TICs due to inconsistent detector responses with those chemicals. For those TICs, primarily interference effects and the accuracy of identification of the TIC were evaluated. Two ChemPro 100 units (Units 1546 and 1811) were used during TIC evaluation, and one ChemPro 100 unit (Unit 1811) was used during CW agent evaluation. The following sections summarize the findings of this evaluation; results for both TICs and CW agents are included for each performance parameter. Note that the target concentrations of GB and HD used in this evaluation were less than the ChemPro vendor's nominal Low alarm concentrations,(3) as described in Chapter 1.

In all testing with TICs, the ChemPro 100 units were operated using software library TIC 7.1, and in all CW agent tests, Unit 1811 was operated using software library CWA-7.1.0.4. One challenge with each TIC or CW agent was also conducted in the respective "opposite" library. AC and CK produced BLOOD responses in the CWA library, as expected, since those TICs are in that library. Chlorine produced no response in the CWA library, as expected, but arsine produced an unexpected BLISTER response in the CWA library. When using the TIC library, HD produced no response, as expected, but GB produced an unexpected CHEM HAZARD response.

It is important to note the nature of the inconsistent responses observed from the ChemPro 100 units with some of the TICs. Throughout all evaluation procedures, the primary data recorded from the ChemPro 100 units were the alarm indications, the High/Medium/Low readings, and the display readings identifying the detected chemical as NERVE, CHEM HAZARD, etc. These records were the primary evaluation data because these are the responses that a user of the ChemPro 100 would observe during normal hand-held operation of the instrument. However, Battelle also recorded the IMS cell signal from each ChemPro 100 unit during all evaluations, using two laptop computers in the test laboratory. It was often observed that the IMS cell signal would behave as expected during a test procedure, but the ChemPro 100 alarms and visual displays would not. For example, the IMS signal would increase when the unit was challenged with a target chemical, but the unit would not alarm or identify the chemical. In some instances, a unit would appear to reset itself during a chemical challenge and stop producing an alarm although the challenge continued, but then would sound an alarm when the challenge gas was replaced with clean air. Based on observations of the IMS cell signal, this behavior appears to be related to the software in the ChemPro 100 that interprets the IMS signal, rather than to the IMS principle itself.

Tables 4-1 and 4-2 summarize the results of the analysis of response time and other performance parameters for the TICs and CW agents, respectively. These tables show data from all evaluations for both ChemPro 100 units for illustration purposes, and the TIC and CW agent results shown are drawn from data obtained at the target concentrations (see Table 1-1).

4.1 Response Time

Results of the response time analysis are presented here, focusing on the temperature and humidity effects for AC, GB, and HD. Note that only challenges in which the ChemPro 100 actually gave a response are included in the analysis of response time. As Tables 4-1 and 4-2 show, in 120 total challenges with AC, GB, and HD, a ChemPro 100 response occurred in 86 cases, with no response in 30 cases, and otherwise erroneous responses (to AC) in four cases. The frequency of failure to respond was greater for CK, SA, and Cl_2 (23 of 60 challenges for CK, 41 of 60 challenges for SA, and 9 of 10 challenges for Cl_2).

Unit 1546 for AC – Across the three temperatures [low temperature (5 °C), room temperature (22 °C), and high temperature (35 °C)] evaluated at medium humidity (50% RH), the geometric mean time to first response was 18.0, 19.4, and 18.1 seconds, respectively. Neither the high nor low temperature average times are statistically significantly different than the room temperature condition. Across the two humidity levels [low (<20% RH) and medium] that could be evaluated at room temperature, the geometric mean time to first response was 19.2 and 19.4 seconds, respectively; again, not a statistically significant difference. Therefore, neither temperature nor humidity had an effect on time to first response for AC on Unit 1546. Unit 1546 did not respond to AC at the room temperature, high humidity (80% RH) condition.

Unit 1811 for AC – Across the three temperatures (low, room, and high) evaluated at medium humidity, the geometric mean time to first response was 15.1, 19.0, and 9.4 seconds, respectively. The high temperature average time was significantly shorter than that of the room temperature condition. The low temperature average time was not significantly different from that of the room temperature condition. Across the three humidity levels (low, medium, and high) evaluated at room temperature, the geometric mean time to first response was 18.6, 19.0, and 31.0 seconds, respectively. The high humidity average time was substantially longer than that of the medium humidity

Table 4-1. TIC Results from ChemPro 100 Evaluation

TIC	Environmental Conditions	ChemPro 100 Response	Alarms (Indicated Chemical)	Response Time Range[(a)] (Seconds)	Recovery Time Range[(a)] (Seconds)
AC	Control (22°C – 50% RH)	M	10/10 (TOXIC)	18-20	28-33
	22°C - <20% RH	M	10/10 (TOXIC)	18-20	24-27
	22°C – 80% RH	L	5/10 (TOXIC) 5/10 (NR)[(b)]	30-32	28-41
	35°C – 50% RH	M (5) / H (5)	5/10 (TOXIC) 5/10 (CHEM HAZARD)	6-21	24-600[(c)]
	35°C – 80% RH	M	2/5 (TOXIC)[(d)] 3/5 (NR)	18-20	35-36
	5°C – 50% RH	L (2) / M (8)	10/10 (TOXIC)	7-20	31-600
CK	Control (22°C – 50% RH)	M	4/10 (TOXIC) 6/10 (NR)	26-27	29-33
	22°C - <20% RH	M	3/10 (TOXIC) 7/10 (NR)	31-32	26-32
	22°C – 80% RH	L	5/10 (TOXIC) 5/10 (NR)	54-92	23-44
	35°C – 50% RH	L (4) / M (5)	9/10 (TOXIC) 1/10 (NR)	20-24	26-36
	35°C – 80% RH	M	3/5 (TOXIC)[(e)] 2/5 (NR)	23-25	21-35
	5°C – 50% RH	L (5) / M (3)	8/10 (TOXIC) 2/10 (NR)	23-29	45-57
SA	Control (22°C – 50% RH)	L	4/10 (TOXIC) 6/10 (NR)	52-77	8-10
	22°C - <20% RH	L	5/10 (TOXIC) 5/10 (NR)	35-70	12-45
	22°C – 80% RH	L	1/10 (TOXIC) 1/10 (CHEM HAZARD) 8/10 (NR)	79-83	12-41
	35°C – 50% RH	L	1/10 (TOXIC) 9/10 (NR)	38	77
	35°C – 80% RH	L (1) / H (5)	1/10 (TOXIC) 5/10 (CHEM HAZARD) 4/10 (NR)	21-82	30-94
	5°C – 50% RH	L	1/10 (TOXIC) 9/10 (NR)	53	50
Cl_2	Control (22°C – 50% RH)	L	1/10 (TOXIC) 9/10 (NR)	71	17

(a) Response and recovery time evaluated only when the ChemPro 100 showed response to the challenge.
(b) NR = No response.
(c) 600 seconds = Maximum time monitored for detector recovery time.
(d) UNIT 1811 (Response not included in table) – Alarmed and cleared during first challenge (taken as an accurate response), alarmed CHEM HAZARD High on clean air after first challenge, did not change alarm or clear for remainder of evaluation.
(e) UNIT 1811 (Response not included in table) – Alarmed as CHEM HAZARD High prior to first challenge, did not change alarm or clear for remainder of evaluation.

Table 4-2. CW Agent Results from ChemPro 100 Evaluation

CW Agent	Environmental Conditions	ChemPro 100 Response	Alarms (Indicated Chemical)	Response Time Range[a] (Seconds)	Recovery Time Range[a] (Seconds)
GB	Control (22°C – 50% RH)	M (4) / H (1)	5/5 (NERVE)	8-12	10-15
	22°C - <20% RH	M	5/5 (NERVE)	9-10	11-13
	22°C – 80% RH	-	5/5 (NR)[b]	-	-
	35°C – 50% RH	L (4) / M (1)	5/5 (NERVE)	12-15	6-13[c]
	35°C – 80% RH	-	5/5 (NR)	-	-
	5°C – 50% RH	H	5/5 (NERVE)	11-14	10-16
HD	Control (22°C – 50% RH)	L	5/5 (BLISTER)	35-42	18-22[d]
	22°C - <20% RH	L	5/5 (BLISTER)	31-34	24-30
	22°C – 80% RH	L	5/5 (BLISTER)	26-31	28-45
	35°C – 50% RH	L	1/5 (BLISTER) 4/5 (NR)	225	14
	35°C – 80% RH	L	2/5 (BLISTER) 3/5 (NR)	82-142	65-600[e]
	5°C – 50% RH	-	5/5 (NR)	-	-

[a] Response and recovery time evaluated only when the ChemPro 100 showed response to the challenge.
[b] NR = No response.
[c] During one agent challenge, the unit cleared while still being exposed to GB at 27 seconds.
[d] During one agent challenge, the unit cleared while still being exposed to HD at 67 seconds.
[e] 600 seconds = Maximum time monitored for detector recovery time.

condition. The low humidity average time was not significantly different from the medium humidity condition. Therefore, high temperature was linked to a lower time to first response while high humidity was linked to a greater time to first response for AC on Unit 1811.

Unit 1811 for GB – Across the three temperatures (low, room, and high) evaluated at medium humidity, the geometric mean time to first response was 12.2, 9.9, and 13.4 seconds, respectively. The high temperature average response time was statistically significantly greater than the room temperature condition. Across the two humidity levels (low and medium) that could be evaluated at room temperature, the geometric mean time to first response was 9.6 and 9.9 seconds, respectively. This did not represent a statistically significant difference. Unit 1811 did not respond to GB at the room temperature, high RH condition.

Unit 1811 for HD – Between the two temperatures (room and high) that could be evaluated at medium humidity, the geometric mean times to first response were 37.5 and 225 seconds, respectively. The high temperature average time was statistically significantly longer than the room temperature condition, but note that the high temperature medium RH result is based on a single response out of five trials. Unit 1811 did not respond to HD at the low temperature, medium RH condition. Across the three humidity levels (low, medium, and high) evaluated at room temperature, the geometric mean time to first response was 32.4, 37.5, and 29.0 seconds, respectively. The low humidity and high humidity average times were statistically significantly lower than the medium humidity average time to first response.

4.2 Recovery Time

Results of the recovery time analysis are presented below, focusing on temperature and humidity effects for AC, GB, and HD, and results from all tests are presented in Table 4-1 and Table 4-2. As with response time, recovery time was evaluated only when the ChemPro 100 responded to a challenge mixture. Note that in one challenge each with AC, GB, and HD, the ChemPro 100 cleared its alarm while the challenge was in progress; these cases also were excluded from the evaluation of recovery time.

Unit 1546 for AC – Of the observations across the three temperatures (low, room, and high) evaluated at medium humidity, the geometric mean recovery times were 38.7, 30.7, and 33.0 seconds, respectively. (Note that one observation at low temperature is excluded from this analysis because it did not clear within 600 seconds; its time to clear is, therefore, unknown.) From these data, the low temperature average time to clear was significantly longer than that of the room temperature condition. The high temperature average time was not significantly different from the room temperature condition. Across the two humidity levels (low and medium) that could be evaluated at room temperature, the geometric mean recovery time was 25.2 and 30.7 seconds, respectively. The low humidity average recovery time was significantly shorter than that of the medium humidity condition. Therefore, low temperature was linked to longer recovery times while low humidity was linked to faster recovery times for AC on Unit 1546. Unit 1546 did not respond to AC at the room temperature, high humidity condition.

Unit 1811 for AC – With this unit, one observation at the low temperature, medium humidity condition did not clear within 600 seconds after the completion of the challenge, and none of the observations at the high temperature, medium humidity condition cleared within 600 seconds after the completion of the challenge. These observations are excluded from the statistical analysis comparing recovery times. Of the remaining observations across the two temperatures (low and room) that could be evaluated at medium humidity, the geometric mean recovery times were 32.7 and 29.6 seconds, respectively, indicating minimal effect of temperature on recovery time for AC. Across the three humidity levels (low, medium, and high) evaluated at room temperature, the geometric mean recovery times were 25.2, 29.6, and 33.3 seconds, respectively. The low humidity average recovery time was significantly shorter than that of the room temperature, medium humidity condition. The high humidity mean recovery time was not statistically significantly different from the medium humidity condition. Therefore, low temperature was weakly linked to longer recovery times while low humidity was linked to faster recovery times for AC on Unit 1811.

Unit 1811 for GB – Of the observations across the three temperatures (low, room, and high) evaluated at medium humidity, the geometric mean recovery times were 13.4, 12.9, and 9.4 seconds, respectively. This does not represent a statistically significant difference for either the high or low temperature compared to room temperature. Across the two humidity levels (low and medium) that could be evaluated at room temperature, the geometric mean recovery times of 11.8 and 12.9 seconds, respectively; were not statistically significantly different.

Unit 1811 for HD – At the two temperatures (room and high) that could be evaluated at medium humidity, the geometric mean time to clear was 19.7, and 14.0 seconds, respectively. The high temperature time to clear was statistically significantly lower than the room temperature time to clear, but note that the high temperature recovery time is based on a single response out of five trials. Across the three humidity levels (low, medium, and high) evaluated at room temperature, the geometric mean time to clear was 26.3, 19.7, and 35.2 seconds, respectively. The low humidity and high humidity average times to clear were statistically significantly longer than the medium humidity average time to clear.

4.3 Accuracy

Results of the accuracy analysis are summarized below and presented in Table 4-1 and Table 4-2. The accuracy of a unit was defined as the proportion of trials in which the unit registered an accurate response to the challenge. The ChemPro 100 was considered accurate if it alarmed in the presence of the TIC or CW agent and correctly identified the TIC or CW agent class. This analysis was conducted for all TICs and CW agents. For the ChemPro 100, any level of response (Low, Medium, or High) and either "TOXIC" or "CHEM HAZARD" were considered by the manufacturer to be accurate for evaluating with TICs. Also, any level of response (Low, Medium, or High) and "NERVE" for GB and "BLISTER" for HD were considered by the manufacturer to be accurate for evaluations with CW agents. As noted in Section 4.1, in 30 of the 120 challenges with AC, GB, and HD, no ChemPro 100 response occurred; those 30 cases are, by definition, inaccurate responses. Lack of response and/or erroneous positive responses were also seen with CK, SA, and Cl_2.

Unit 1546 – For AC, Unit 1546 displayed 100% accuracy for the room temperature, low humidity condition as well as all three temperature conditions at medium humidity. For the room temperature, high humidity testing, 0% accuracy was observed; and for the high temperature, high humidity condition, 40% accuracy was observed. For AC, there was no observed effect of temperature at medium humidity on accuracy. There was a statistically significant effect of humidity on accuracy, with lower accuracy at high humidity.

For CK, there was no statistically significant effect for temperature at medium humidity where the accuracy values for low, room, and high temperature were 60%, 80%, and 100%, respectively. A statistically significant effect of humidity on accuracy for operation at room temperature was observed. The low humidity condition displayed accuracy of 40%, the medium humidity condition accuracy was 80%, and the high humidity condition accuracy was 0%. The accuracy of the high temperature, high humidity condition was 60%.

For SA, the unit accuracy was very low for all evaluated conditions. At room temperature and medium humidity, the accuracy was 0%. For all other temperature and humidity conditions, accuracy was 20%. Neither temperature nor humidity exhibited statistically significant effects.

For Cl_2, the only temperature and humidity condition evaluated was room temperature and medium humidity. None of five trials had a response, representing 0% accuracy. No further analysis was possible.

Unit 1811 – For AC, Unit 1811 displayed 100% accuracy for the room temperature, low humidity condition; all three temperature conditions at medium humidity; and for room temperature, high humidity. For the high temperature, high humidity condition, the unit began alarming for the first trial (judged an accurate response), but continued to alarm through the remaining four trials and the intervening clean air purges. Accuracy thus was 20% at that condition. For AC, there was no statistically significant effect for the three evaluated temperatures at medium humidity. Similarly, no significant effect was observed for the three evaluated humidity levels at room temperature.

For CK, there was a statistically significant effect for temperature at medium humidity where the accuracy values for low, room, and high temperature were 100%, 0%, and 80%, respectively. There was also a statistically significant effect of humidity on accuracy for operation at room temperature. The low humidity condition displayed accuracy of 20%, the medium humidity condition accuracy was 0%, and the high humidity condition accuracy was 100%. The accuracy at the high temperature, high humidity condition was 0%, because the unit began alarming prior to the first challenge and continued alarming through the remaining trials and the intervening clean air purges.

For SA, there was a statistically significant effect for temperature at medium humidity where the accuracy values for low, room, and high temperature were 0%, 80%, and 0%, respectively. No statistically significant effect was observed for humidity on accuracy for operation at room temperature. The low and medium humidity conditions both displayed accuracy of 80% while the high humidity condition accuracy was 20%. Oddly, while the accuracy rates at both high temperature at medium humidity (0%) and high humidity at room temperature (20%) were very low, the accuracy at the high temperature, high humidity condition was 100%.

For Cl_2, the only temperature and humidity condition evaluated was room temperature and medium humidity. Only one trial in five had a response, representing 20% accuracy. No further analysis was possible.

For GB, the unit displayed 100% accuracy for the room temperature/low humidity and room temperature/medium humidity conditions as well as the low temperature/medium humidity condition. For the room temperature/high humidity evaluation, 0% accuracy was observed with no response from the detector in any of the five trials. For the high temperature/medium humidity condition, 80% accuracy was observed. The one inaccurate test at this condition initially responded accurately with a "NERVE" response but the unit subsequently cleared during the challenge period. This test was consequently identified to not be accurate and the data for time to clear was eliminated from further analysis. However, the data for maximum response on challenge and time to first response were retained for their respective analyses. For GB, there was not a statistically significant effect of temperature on accuracy at medium humidity. There was a statistically significant effect of humidity on accuracy for operation at room temperature with the conclusion that accuracy at high humidity was significantly poorer than at low or medium humidity. This was further supported by evaluation results at high temperature/high humidity where accuracy of response was also 0%.

For HD, the unit displayed 80% accuracy for the room temperature/medium humidity condition. The one inaccurate test at this condition initially responded with a "NERVE" response but the unit subsequently cleared during the challenge period. This test was identified to be inaccurate, and the data for time to clear was eliminated from further analysis. However, the data for maximum response on challenge and time to first response were retained for their respective analyses. The low temperature/medium humidity condition had 0% accuracy while the high temperature/medium humidity condition had 20% accuracy. For these two conditions, all inaccurate trials were categorized as such because there was no response from the detector. The differences in accuracy were large enough to conclude that there was a statistically significant effect of temperature on accuracy at medium humidity. At room temperature, the low and high humidity conditions showed better accuracy (100%) than the medium humidity condition (80%) but the difference was not large enough to be statistically significant. Accuracy was 40% at the high temperature and high humidity condition.

High/Low – For the high/low test, the ChemPro 100 was challenged with either a high concentration of chemical followed by a low concentration, or a low concentration of chemical followed by a high concentration. For AC, Unit 1811 responded with either a low or medium "TOXIC" alarm at high concentration. At low concentration, the unit either did not respond or responded with a low "TOXIC" alarm. This resulted in no change in alarm level when the unit was challenged with a low concentration first, and a change in the alarm level when the unit was challenged with a high concentration first. For AC, Unit 1546 alarmed at medium "TOXIC" for all the high concentration challenges and low "TOXIC" for all the low concentration challenges. The order of the challenge did not affect the respective alarm level. For GB, Unit 1546 responded with a medium or low "NERVE" alarm at high concentration and a low "NERVE" alarm or no alarm at low concentration. There was always an accurate change in the level of the alarm for GB. For HD, Unit B responded with a low "BLISTER" alarm both at high concentration and low concentration. There was no distinction or change in alarm level between the two concentrations.

4.4 Repeatability

Results of the repeatability analysis are summarized below. As with response and recovery times (Sections 4.1 and 4.2, respectively), the evaluation of repeatability includes only those cases in which the ChemPro 100 responded to a TIC or CW agent challenge. Repeatability addressed the consistency of the Low, Medium, and High readings of the ChemPro 100.

Unit 1546 for AC – For each trial that had a response, the maximum observed response level from the ordered progression (Low, Medium, and High) was identified. Across the three temperatures (low, room, and high) evaluated at medium humidity, the maximum level of alarm (Medium) for each trial was identical. Similarly, across the low and medium humidity conditions that could be evaluated at room temperature, the maximum level of alarm (Medium) for each trial was also identical. These results show no observed effect of temperature or humidity on the maximum response for this unit.

Unit 1811 for AC – For each trial that had a response, the maximum observed response level from the ordered progression (Low, Medium, and High) was identified. A statistically significant change in maximum response was observed across temperatures with this unit. Across the three temperatures (low, room, and high) evaluated at medium humidity, the level of the maximum alarm increased with values of “Low” and “Medium” at low temperature, “Medium” for all trials at room temperature, and “High” for all trials at high temperature. A statistically significant change in maximum response was also observed across humidity conditions. Across the three levels of humidity evaluated at room temperature, the level of alarm decreased. The observed maximum responses (Medium) for all trials were identical at low and medium humidity, but the maximum response dropped to “Low” for the high humidity condition.

Unit 1811 for GB – For each trial that had a response, the maximum observed response level from the ordered progression (Low, Medium, and High) was identified. Across the three temperatures (low, room, and high) evaluated at medium humidity, the maximum level of alarm appeared to decrease with increasing temperature. The lowest temperature condition produced “High” alarms, the room temperature trials showed one “High” alarm but 4 “Medium” alarms and the high temperature condition showed only 1 “Medium” alarm and 4 “Low” alarms (one of these “Low” alarms was the trial that cleared during the challenge). This effect was statistically significant. Between the two humidity conditions with accurate responses that could be evaluated at room temperature, no significant effect was seen in maximum response level. In one case at the high temperature/medium humidity condition, the unit cleared during the challenge.

Unit 1811 for HD – For each trial that had a response, the maximum observed response level from the ordered progression (Low, Medium, and High) was identified. In all cases for HD, this response level was “Low” and therefore no temperature or humidity effects were seen in the level of response. In one case at the room temperature/medium humidity condition, the unit cleared during the challenge.

4.5 Response Threshold

Response thresholds were determined by challenging the ChemPro 100 with successively lower concentrations of TIC or CW agent until it no longer responded or the response was not maintained during a challenge. Table 4-3 provides the results for the response threshold tests for each ChemPro 100 unit. The concentrations used in each of these tests are given in the table and, for most of the TICs, are well below the concentrations used in the other evaluations. For the CW agents, the concentrations used are also below the target concentrations used in the other evaluations.

Table 4-3. Response Threshold Data for the TIC and CW Agent Evaluation

TIC/CW Agent (Concentration)	ChemPro 100 Identification Number	
	1546	1811
AC (50 ppm)	L TOXIC (2) / M TOXIC (1)	No Response (1) / L TOXIC (2)
AC (25 ppm)	L TOXIC (3)	L TOXIC (3)
AC (12.5 ppm)	L TOXIC (3)	L TOXIC (3)
AC (6 ppm)	No Response (1) / L TOXIC (2)	No Response (2) / L TOXIC (1)
AC (3 ppm)	No Response (3)	No Response (3)
CK (20 ppm)	No Response (2) / L TOXIC (3)	No Response (4) / L TOXIC (1)
CK (10 ppm)	No Response (5)	No Response (1) / L TOXIC (4)
CK (5 ppm)	No Response (3)	No Response (3)
SA (6 ppm)	No Response (4) / L TOXIC (1)	No Response (1) / L TOXIC (4)
SA (3 ppm)	No Response (3)	No Response (3)
Cl_2 (60 ppm)	No Response (5)	No Response (4) / L TOXIC (1)
GB (0.01 mg/m^3)	NA	No Response (1) / L NERVE (9)[a]
HD (0.2 mg/m^3)	NA	No Response (5) / L BLISTER (5)

[a] In six of the nine responses, the unit cleared within seconds of alarming and did not alarm again during the remainder of the GB challenge.

Table 4-3 shows that for AC, the response threshold was between 3 and 6 ppm on both ChemPro 100 units. For CK, the response threshold was between 10 and 20 ppm for Unit 1546 and between 5 and 10 ppm for Unit 1811. For SA, the response threshold was between 3 and 6 ppm for both units, and for Cl_2, the response threshold was at or above about 60 ppm as only Unit 1811 responded one time at 60 ppm.

For GB, the response threshold was around 0.01 mg/m^3 for Unit 1811. The ChemPro 100 responded to nine out of 10 challenges at that concentration; however, in six of those cases, the unit stopped responding within seconds after first responding, while still being challenged with GB. For HD, the response threshold was around 0.2 mg/m^3 for Unit 1811 as it responded to five out of 10 challenges with HD at that concentration.

4.6 Temperature and Humidity Effects

The effects of temperature and humidity on the ChemPro 100 are summarized in Sections 4.1 through 4.4.

4.7 Interference Effects

Five interferents (latex paint fumes, ammonia floor cleaner vapors, air freshener vapors, gasoline engine exhaust hydrocarbons, and DEAE) were used in the evaluation. The effect of these interferences on the ChemPro 100 response is summarized below and in Table 4-4. This table summarizes results from both ChemPro units for illustration purposes, but does not include false positive readings.

False Positive – A false positive response was noted if the ChemPro 100 responded and provided an alarm in the presence of an interferent alone (i.e., in the absence of a TIC or CW agent). A false positive was defined as any alarm under those conditions.

Other erroneous positive responses were observed during testing of accuracy (Section 4.3) in the form of alarms that occurred during sampling of clean air. These are noted in the footnotes of Table 4-1.

Unit 1546 (false positive) – In the TIC library, a false positive rate of 100% was observed for paint fumes, ammonia cleaner, and air freshener. Engine exhaust and DEAE did not produce any false positives in the three separate trials conducted for each interferent.

In the CW agent library, a false positive rate of 100% was observed for ammonia cleaner and air freshener. Paint produced a false positive rate of 40%. Engine exhaust produced a false positive rate of 20%. DEAE did not produce any false positives in the three separate trials conducted for this interferent in the CW agent library.

Unit 1811 (false positive) – In the TIC library, a false positive rate of 67% was observed for paint fumes, 80% for ammonia cleaner, and 100% for air freshener. Engine exhaust and DEAE did not produce any false positives in the three separate trials conducted for each interferent.

Table 4-4. Interference Effects

TIC or CW Agent	Interferent	ChemPro 100 Response	Alarms (Indicated Chemical)	Response Time Range (Seconds)	Recovery Time Range (Seconds)
AC	Control	M	10/10 (TOXIC)	18-20	28-33
	Paint Fumes	H	9/10 (CHEM HAZARD) 1/10 (NR)[a]	17-20	66-93
	Floor Cleaner	H	5/10 (CHEM HAZARD) 5/10 (NR)	15-18	31-45
	Air Freshener	M (5) / H (1)	6/10 (CHEM HAZARD) 4/10 (NR)	19-21	13-20
	Gasoline Engine Exhaust	L (4) / M (4)	8/10 (TOXIC) 2/10 (NR)	21-25	13-23
	DEAE	L (7) / M (1)	8/10 (TOXIC) 2/10 (NR)	20-23	17-29
CK	Control	M	4/10 (TOXIC) 6/10 (NR)	26-27	29-33
	Paint Fumes	L (3) / M (5)	5/10 (CHEM HAZARD) 3/10 (TOXIC) 2/10 (NR)	19-108	18-57
	Floor Cleaner	M (4) / H (3)	7/10 (CHEM HAZARD) 3/10 (NR)	17-19	19-44
	Air Freshener	M (2) / H (3)	5/10 (CHEM HAZARD) 5/10 (NR)	18-26	17-26
	Gasoline Engine Exhaust	L (2) / M (5)	5/10 (CHEM HAZARD) 2/10 (TOXIC) 3/10 (NR)	25-83	26-62
	DEAE	L	3/10 (TOXIC) 7/10 (NR)	25-35	18-27
SA	Control	L	4/10 (TOXIC) 6/10 (NR)	52-77	8-10
	Paint Fumes	M (2) / H (2)	4/10 (CHEM HAZARD) 6/10 (NR)	31-64	146-340
	Floor Cleaner	L (3) / M (7)	10/10 (CHEM HAZARD)	19-24	36-74
	Air Freshener	M	10/10 (CHEM HAZARD)	21-26	33-95
	Gasoline Engine Exhaust	L	1/10 (TOXIC) 9/10 (NR)	67	11
	DEAE	-	6/6 (NR)	-	-
GB	Control	M (4) / H (1)	5/5 (NERVE)	8-12	10-15
	Paint Fumes	H	5/5 (NERVE)	9-10	145-508
	Floor Cleaner	M (2) / H (3)	5/5 (CHEM HAZARD)	15-18	18-19
	Air Freshener	M	3/5 (NERVE) 2/5 (CHEM HAZARD)	12-20	12-23
	Gasoline Engine Exhaust	L	1/5 (CHEM HAZARD) 4/5 (NR)	26	6
	DEAE	L	5/5 (NERVE)	12-16	6-12
HD	Control	L	5/5 (BLISTER)	35-42	18-22[b]
	Paint Fumes	L (2) / M (1) / H (2)	2/5 (NERVE) 3/5 (CHEM HAZARD)	10-71	35-600[c]
	Floor Cleaner	 L (1) / M (4)	1/5 (BLISTER) 4/5 (CHEM HAZARD)	18-32	20-44[d]
	Air Freshener		5/5 (CHEM HAZARD)	22-25	35-46
	Gasoline Engine Exhaust	M	5/5 (BLISTER)	27-35	19-21
	DEAE	L L	5/5 (BLISTER)	39-51	8-16

(a) NR = No response.
(b) During one agent challenge, the unit cleared while still being exposed to HD at 67 seconds.
(c) 600 seconds = Maximum time monitored for detector recovery time.
(d) During one agent challenge, the unit cleared while still being exposed to HD at 118 seconds.

In the CW agent library, a false positive rate of 100% was observed for ammonia cleaner and air freshener. Paint produced a false positive rate of 20%. DEAE did not produce any false positives in the three separate trials conducted for this interferent. Engine exhaust false positive testing was not conducted for this unit because the detector stopped functioning before the tests could be run.

False Negative – A false negative response was noted if the presence of an interferent masked the presence of a TIC or CW agent and the ChemPro 100 provided a lower response or did not respond to the TIC or CW agent. Changes in response, response time, and recovery time due to interferences are discussed in the following paragraphs.

Other erroneous negative responses (i.e., the failure to respond to a TIC or CW agent challenge in clean air) are discussed under accuracy (Section 4.3), and also occurred during testing of cold-/hot-start behavior (Section 4.8) and battery life (Section 4.9). In addition, the few instances in which the ChemPro 100 cleared its alarm while a TIC or CW agent challenge was in progress (Sections 4.2, 4.3, and below in this section) are also erroneous negative responses.

Unit 1546 (false negative) – For this unit, the accuracy in detecting AC in the presence of the interferents was similar to the accuracy without the interferent. Accuracy was 100% for the non-interferent evaluation as well as for the evaluations with paint and ammonia cleaner. The accuracy for the evaluations with air freshener, engine exhaust, and DEAE as interferents was 80%. Thus, no overall accuracy effect was observed when interferent was added to the AC.

The interferents did exhibit a statistically significant effect on the maximum level of response observed for AC. All five responses for the non-interferent evaluation reached a Medium alarm level, as did all four of the responses for the engine exhaust evaluation and three of the four responses for the air freshener evaluation. The paint and ammonia cleaner tests each saw five of five alarms at the High level. DEAE had three of its four observations at the Low alarm level.

The geometric mean time to first response to AC for the non-interferent evaluation was 19.4 seconds. Paint and ammonia cleaner results displayed statistically significant shorter average response times. For paint, the average time was 17.8 seconds, and for ammonia cleaner, the average time was 16.4 seconds. At 19.5 seconds and 20.8 seconds, the response times for air freshener and DEAE, respectively, were comparable to that for no interferent. Only engine exhaust showed a statistically significant longer response time, at 24.3 seconds.

The geometric mean recovery time for the non-interferent AC evaluation was 30.7 seconds. The air freshener, engine exhaust, and DEAE all produced shorter recovery times with estimates of 17.2 seconds, 21.0 seconds, and 21.7 seconds, respectively. At 35.5 seconds, the mean recovery time for ammonia cleaner was not statistically significantly different from the non-interferent value. Only paint as an interferent produced a longer recovery time at 84.8 seconds.

The accuracy in detecting CK in the presence of the interferents varied by interferent. Accuracy was 80% for the non-interferent. For paint, ammonia cleaner, air freshener, and engine exhaust, the accuracy was 100%. With DEAE as an interferent, the accuracy was 0%.

The accuracy in detecting SA in the presence of the interferents varied by interferent. Accuracy was 0% for the non-interferent and for paint, engine exhaust, and DEAE. For ammonia cleaner and air freshener, the accuracy was 100%.

Unit 1811 (false negative) – For this unit, there was some variability in the accuracy of response for AC for this unit with different interferents. The evaluation without interferent had 100% accuracy. An accuracy of 80% was observed for the evaluations with paint, engine exhaust, and DEAE as interferents. Only 40% accuracy was observed for the evaluation with air freshener as an interferent, and 0% accuracy was observed for the ammonia cleaner evaluation. Thus, a statistically significant effect of interferents on the accuracy of detection of AC was observed.

The interferents also exhibited a statistically significant effect in the maximum level of response observed for AC. All five responses for the non-interferent evaluation reached a Medium alarm level, as did both responses for the air freshener evaluation. By contrast, all four responses for the paint evaluation showed a maximum response at the High level and all four responses for both engine exhaust and DEAE showed a maximum response at the Low level.

The geometric mean time to first response to AC for the non-interferent evaluation was 19.0 seconds. At 18.5 seconds and 20.5 seconds, the response times for paint and air freshener, respectively, were comparable to that with no interferent. Both engine exhaust and DEAE showed slightly longer response times than the non-interferent tests. The engine exhaust time was 22.2 seconds, while the DEAE response time was 21.7 seconds. With no accurate responses, the time to first response of ammonia cleaner could not be analyzed.

The geometric mean recovery time for AC for the non-interferent evaluation was 29.6 seconds. The air freshener, engine exhaust, and DEAE all produced shorter recovery times with estimates of 13.5 seconds, 14.9 seconds, and 19.5 seconds, respectively. With no accurate responses, the recovery time for ammonia cleaner could not be analyzed. Only paint as an interferent produced a longer recovery time at 75.3 seconds.

The accuracy in detecting CK in the presence of the interferents varied by interferent and was clearly subject to the variability in ChemPro 100 response noted above. Accuracy was 0% for the non-interferent evaluation, and also for air freshener. For ammonia cleaner and engine exhaust, the accuracy was 40%. With paint and DEAE as interferents, the accuracy was 60%.

The accuracy in detecting SA in the presence of the interferents varied by interferent. Accuracy was 80% for the non-interferent and for paint. For ammonia cleaner and air freshener, the accuracy was 100%. With engine exhaust as an interferent the accuracy was 20%, and accuracy was 0% for DEAE as an interferent.

The accuracy of Unit 1811 in detecting GB was not the same for all interferents evaluated. The detector exhibited a range of different behaviors for the interferents evaluated in the presence of GB.

- Paint – All five trials responded to the challenge with the appropriate “NERVE” response. However, when the challenge was terminated and clean air passed into the system in each of the trials, the unit produced a Low-level “CHEM HAZARD” alarm. Since this spurious alarm was after completion of the challenge (where the correct alarm was observed) and the unit subsequently cleared, these trials were ultimately counted as accurate.
- Ammonia Cleaner – All five trials responded to the challenge, but in each case with the inaccurate “CHEM HAZARD” response. Since no “NERVE” response was observed, these trials were all counted as inaccurate.
- Air Freshener – Three of the five trials responded accurately to the challenge with a “NERVE” response. The other two trials exhibited an inaccurate “CHEM HAZARD” response and were counted as inaccurate.
- Engine Exhaust – One of the five trials responded to the challenge with the inaccurate “CHEM HAZARD” response, while the other four trials resulted in no response at all. Hence, accuracy was determined to be 0%.
- DEAE – All five trials responded accurately to the challenge in the presence of this interferent.

In examining the individual interferent accuracy rates, only the ammonia cleaner and engine exhaust accuracy rates were statistically significantly different than the non-interferent evaluation.

After determining that the interferents did seem to affect the accuracy of identifying GB, further analysis was performed on the maximum response level, time to first response, and recovery time for each interferent compared to the non-interferent evaluation. In the instances where the ChemPro 100 responded but produced an inaccurate response, the maximum response level, time to first response, and time to clear from the inaccurate responses are also provided.

The interferents showed a statistically significant effect on the maximum level of response observed from Unit 1811 for GB. Four of the five responses for the non-interferent evaluation reached a Medium alarm level and one reached a High alarm level. The interferents appeared to affect the maximum response differently:

- Paint as an interferent strengthened the maximum response level to a high alarm for all trials.
- Ammonia cleaner alarmed two trials at medium and three at high but as “CHEM HAZARD” rather than “NERVE” in each case.
- Air freshener alarmed at medium for all five trials but in two cases as “CHEM HAZARD” rather than “NERVE.”
- Engine exhaust seemed to cancel the response except in one trial where a low “CHEM HAZARD” response was observed.
- DEAE appeared to reduce the maximum alarm level as all five trials exhibited a low alarm level.

The geometric mean time to first response to GB for the non-interferent evaluation was 9.9 seconds. Ammonia cleaner, air freshener, engine exhaust, and DEAE displayed statistically significant longer average response times. For ammonia cleaner, the average time was 15.6 seconds. For air freshener, the average time was 15.2 seconds. For engine exhaust, the average time was 26.0 seconds. For DEAE, the average time was 13.9 seconds. At 9.4 seconds, the average response time for paint was comparable to no interferent.

The geometric mean recovery time for GB for the non-interferent evaluation was 12.9 seconds. Paint displayed statistically significant longer average recovery time at 236 seconds. At 18.8, 15.7, 6.0, and 9.5 seconds, the recovery times for ammonia cleaner, air freshener, engine exhaust, and DEAE, respectively, were not significantly different from the non-interferent evaluation.

The accuracy of Unit 1811 in detecting HD was not the same for all interferents, and the detector exhibited a range of different behaviors for the interferents:

- Paint – All five trials responded to the challenge but two of them with the “NERVE” response and three with the “CHEM HAZARD” response when the accurate response to HD is “BLISTER.” Therefore, this unit showed 0% accuracy in the presence of paint.
- Ammonia Cleaner – All five trials responded to the challenge, in four cases with the inaccurate “CHEM HAZARD” response and in the fifth case with the correct “BLISTER” response, but in that case the unit subsequently cleared while the challenge was going on. All these responses were judged inaccurate; therefore, this unit showed 0% accuracy in the presence of ammonia cleaner.
- Air Freshener – All five trials responded to the challenge but all with the incorrect “CHEM HAZARD” response. Therefore, this unit showed 0% accuracy in the presence of air freshener.
- Engine Exhaust – The unit showed 100% accuracy despite the presence of this interferent.
- DEAE – The unit showed 100% accuracy despite the presence of this interferent.

In comparing the individual interferent accuracy rates, paint, ammonia cleaner, and air freshener accuracy rates were all statistically significantly lower than that for the non-interferent evaluation.

After determining that the interferents did seem to affect the accuracy of identifying the HD agent, further analysis was performed on the maximum response level, time to first response, and recovery time for each interferent compared to the non-interferent evaluation. Note that these analyses did incorporate data from trials determined to be inaccurate if such data were appropriate. For example, the time to first response analysis uses data from trials that recorded an alarm, even if it was the incorrect alarm type.

The interferents exhibited a statistically significant effect on the maximum level of response observed from Unit 1811 to HD. All five responses for the non-interferent evaluation reached a Low alarm level as did all five responses for both the engine exhaust and DEAE evaluations. The other three interferents generally showed higher alarm levels. Four responses for the ammonia cleaner evaluation showed a maximum response at the medium level with the incorrect alarm designation of “CHEM HAZARD.” The air freshener evaluation had five incorrect “CHEM HAZARD” responses, which all reached a medium alarm level. Of the five responses to paint, two trials alarmed at the high level for “NERVE,” two alarmed at the low level for “CHEM HAZARD,” and one alarmed at the medium level for “CHEM HAZARD.”

The geometric mean time to first response to HD for the non-interferent evaluation was 37.5 seconds. At 26.1, 23.8, 28.9, and 44.4 seconds, the response times for paint, air freshener, engine exhaust, and DEAE, respectively, were comparable to no interferent. At 20.9 seconds, ammonia cleaner showed statistically significantly shorter average response time than that of the non-interferent evaluation.

The geometric mean recovery time for HD for the non-interferent evaluation was 19.7 seconds. At 25.8, 40.0, 19.6, and 10.6 seconds, the recovery times for ammonia cleaner, air freshener, engine exhaust, and DEAE, respectively, were comparable to no interferent. At 107 seconds, paint showed statistically significantly longer average recovery time than that of the non-interferent evaluation.

4.8 Cold-/Hot-Start Behavior

Analysis of the effects of insufficient warm-up time, under start-up conditions ranging from cold (5 to 8°C) to hot (40°C), are summarized below. Table 4-5 illustrates the data obtained in evaluating for cold-/hot-start effects, showing the ChemPro 100 units used, the start condition, delay time, sequential experiment number, response reading, response and recovery times, and alarm indication. Such evaluation was conducted only with AC at the IDLH concentration.

Table 4-5. Start State Effects

ChemPro 100 Unit	Start Condition	Delay Time (Seconds)	Experiment Number	ChemPro 100 Response	Response Time (Seconds)	Recovery Time (Seconds)	Alarm (Indicated Chemical)
1546	**Control**	NA	1	M	20	32	TOXIC
			2	M	19	29	TOXIC
			3	M	20	32	TOXIC
			4	M	19	33	TOXIC
			5	M	19	28	TOXIC
	Room Temperature (Cold Start)	169	1	NR[a]	-	-	-
			2	NR	-	-	-
			3	NR	-	-	-
			4	NR	-	-	-
			5	NR	-	-	-
	Cold Temperature (Cold Start)	258	1	L	23	19	TOXIC
			2	NR	-	-	-
			3	NR	-	-	-
			4	NR	-	-	-
			5	NR	-	-	-
	Hot Temperature (Cold Start)	225	1	NR	-	-	-
			2	NR	-	-	-
			3	NR	-	-	-
			4	M	19	19	TOXIC
			5	NR	-	-	-
1811	**Control**	NA	1	M	18	32	TOXIC
			2	M	20	30	TOXIC
			3	M	19	28	TOXIC
			4	M	20	30	TOXIC
			5	M	18	28	TOXIC
	Room Temperature (Cold Start)	161	1	NR	-	-	-
			2	L	31	32	TOXIC
			3	L	28	26	TOXIC
			4	L	29	28	TOXIC
			5	L	31	28	TOXIC
	Cold Temperature (Cold Start)	420	1	NR	-	-	-
			2	NR	-	-	-
			3	NR	-	-	-
			4	NR	-	-	-
			5	NR	-	-	-
	Hot Temperature (Cold Start)	169	1	NR	-	-	-
			2	L	22	23	TOXIC
			3	L	20	23	TOXIC
			4	L	21	23	TOXIC
			5	NR	-	-	-

[a] NR = No response.

Unit 1546 – Delay time is the time it took the ChemPro 100 to achieve a ready state after powering the unit on. For the room temperature cold start, the delay time was 169 seconds. For the cold temperature cold start, the delay time was 258 seconds. For the hot temperature cold start, the delay time was 225 seconds.

All five trials with AC with the ChemPro 100 Unit 1546 fully warmed up (i.e., the control condition) produced a response. For the cold-start evaluations, only one of the five trials for cold storage, none of the trials for room-temperature storage, and only one of the five trials for high-temperature storage exhibited any response to the AC challenge. Thus, each cold-start condition exhibited statistically significant degradation in accuracy compared with the fully warmed-up control condition for this unit.

Unit 1811 – For the room temperature cold start, the delay time was 161 seconds. For the cold temperature cold start, an initial error message, "Error – Check Air Intake," was observed. At that point, the unit was restarted. At 200 and 330 seconds, additional error messages, "Functional Exception D003," were observed. The unit then showed a ready state at 420 seconds. For the hot temperature cold start, the delay time was 169 seconds.

All five trials with AC at the fully warmed-up control condition produced a response. For the cold-start evaluations, none of the five trials for cold storage, four of the five trials for room-temperature storage, and three of the five trials for hot storage exhibited a response to the AC challenge. For this unit, only the cold-storage condition exhibited a statistically significant degradation in accuracy compared with the fully warmed-up start condition.

When an alarm did occur from a cold start, its maximum level was always Low, while the maximum level observed from the control condition was a Medium in all five trials. This shows that the standard condition and the cold-start conditions do not have the same level of maximum response.

When an alarm did occur from a cold start, it was likely to take longer to occur. With a geometric mean of 21.0 seconds, the time to first response for a cold start from hot storage was slightly longer than that from the control condition (geometric mean of 19.0 seconds). The response delay for the cold start from room temperature was even greater (geometric mean of 29.7 seconds), and, thus, substantially longer than that from the control condition.

The geometric mean recovery time for the cold start from room temperature (28.4 seconds) was not significantly different than for the control condition (29.6 seconds). However, the recovery time for the cold start from hot storage (23.0 seconds) was significantly shorter than in the control condition.

4.9 Battery Life

The ChemPro 100 can be powered by a battery pack or AA batteries. The battery life evaluation was conducted by placing a fully charged battery pack provided by the vendor in the ChemPro 100. The ChemPro 100 was then powered on and allowed to warm up fully according to the manufacturer's directions. The battery life evaluation was conducted by successive challenges with AC at IDLH concentration delivered for 5 minutes every half hour, and the results are shown in Table 4-6. Unit 1811 frequently failed to respond to the AC challenge during the battery life evaluation, and Unit 1546 did so on two occasions, as shown by the entries of “No Response” in Table 4-6. For Unit 1546, the battery indicator went from full to 3 bars at 2 hours and 45 minutes after powering on. Then, the low battery alarm began at 9 hours and 50 minutes, and the unit shut down at 9 hours and 53 minutes after powering on. For Unit 1811, the battery indicator went from full to 3 bars at 3 hours and 15 minutes after powering on. The battery indicator then went from 3 bars to 1 bar at 10 hours. The 1-bar indicator began flashing at 11 hours. Then, the low battery alarm began at 11 hours and 10 minutes, and the unit shut down at 11 hours and 12 minutes after powering on.

Table 4-6. Responses Recorded from the ChemPro 100 in Battery Life Evaluation[(a)]

		ChemPro 100 Identification Number			
		1546		1811	
Test	Time	Response (Response Time in Seconds)	Battery Indicator	Response (Response Time in Seconds)	Battery Indicator
Start-up	0815				
1	0830	M TOXIC (19)	Full	No Response	Full
2	0900	M TOXIC (18)	Full	No Response	Full
3	0930	M TOXIC (20)	Full	No Response	Full
4	1000	M TOXIC (18)	Full	No Response	Full
5	1030	M TOXIC (18)	Full	No Response	Full
6	1100	M TOXIC (20)	3 bars	No Response	Full
7	1130	M TOXIC (19)	3 bars	M TOXIC (28)	3 bars
8	1200	M TOXIC (19)	3 bars	No Response	3 bars
9	1230	M TOXIC (19)	3 bars	M TOXIC (28)	3 bars
10	1308	M TOXIC (18)	3 bars	No Response	3 bars
11	1330	M TOXIC (20)	3 bars	No Response	3 bars
12	1400	No Response	3 bars	No Response	3 bars
13	1430	M TOXIC (18)	3 bars	No Response	3 bars
14	1500	M TOXIC (20)	3 bars	No Response	3 bars
15	1530	L TOXIC (22)	3 bars	No Response	3 bars
16	1600	No Response	3 bars	No Response	3 bars
17	1630	M TOXIC (21)	3 bars	M TOXIC (29)	3 bars
18	1700	M TOXIC (21)	3 bars	No Response	3 bars
19	1730	M TOXIC (19)	3 bars	M TOXIC (18)	3 bars
20	1800	M TOXIC (19)	3 bars	M TOXIC (19)	3 bars
	1805		Low Battery Alarm		
	1808		**Power Off (9 hours, 53 minutes)**		
21	1815				1 bar
22	1830			M TOXIC (21)	1 bar
	1900			M TOXIC (19)	1 bar
	1915				1 bar (flashing)
	1925				Low Battery Alarm
	1927				**Power Off (11 hours, 12 minutes)**

[(a)] All battery life tests were conducted with AC as the challenge TIC at the IDLH concentration of 50 ppm (50 mg/m^3).

4.10 Operational Characteristics

General performance observations noted during this evaluation were:

- Instrument Operation—The ChemPro 100 has a large display that is difficult to read in low light conditions but very easy to read when the background light (bright blue) is used. This light is controlled from a menu within the ChemPro 100. The display indicates the state of the unit, what library is being used, the date and time, the volume level, and the battery power level. Controls were easy to use, and, when lit, the display was easily readable, even if the operator was wearing personal protective equipment.

- Instrument Indicators—The ChemPro 100 has one lighted indicator to show the status of the detector. This indicator is green when the unit is in ready mode and flashing red when the unit is in alarm mode. When the ChemPro 100 alarms to a challenge, it will sound an audible alarm and flash the red indicator light. The audible alarm has a volume control. The visual and audible alarms were strong and readily noticeable. The unit can also identify the type of chemical which caused the alarm. When the ChemPro 100 detects a failure within its system, the display indicates the type of failure.

- Warm-Up—The ChemPro 100 took about 2.7 to 7 minutes to reach a ready state after being turned on, whether starting from room temperature storage, cold (5 to 8 °C) storage, or hot (40 °C) storage conditions.

- Batteries—The ChemPro 100 can operate on a rechargeable battery pack or AA batteries.

- Errors—Error messages occurred over the course of evaluating the ChemPro 100. Several of these error messages were ‘Functional Exception D03’. Also, there were errors for air intakes and SCCell failure.

- Conditioning Mode—The ChemPro 100 has a conditioning mode that is only indicated on a laptop computer if connected to the ChemPro 100. The occurrence of this mode is not shown on the display of the unit itself. The ChemPro 100 could enter conditioning mode and would not sample until conditioning mode was completed. The length of time that the instrument is off line in this mode would be unknown to an operator using it as a hand-held instrument.

- Vendor Support—Before the evaluation, a vendor representative trained Battelle employees to operate the ChemPro 100. Evaluating proceeded according to the vendor’s recommendations. The vendor responded promptly when information was needed during the evaluation.

- Cost—The list price of the ChemPro 100 plus the Standard Accessory Kit is approximately $9,500.

5.0 Performance Summary

Summary results from evaluation of the ChemPro 100 are presented below for each performance parameter evaluated. Full evaluation of test results was conducted for AC, GB, and HD. Results reported for CK and SA are limited due to inconsistent responses, and few results for Cl_2 are reported, due to lack of response found for that chemical. Discussion of the observed performance can be found in Chapter 4 of this report.

Response Time: When the ChemPro 100 responded to challenges, the time required to respond to AC and CK was usually about 30 seconds or less, and response times for SA ranged from about 20 to 80 seconds. Response times for GB were 15 seconds or less, and for HD were usually 25 to 40 seconds, with a few results of 80 to 225 seconds. Response times for AC, GB, and HD were not consistently affected by the temperature and RH. These results do not include instances in which the ChemPro 100 failed to respond to TIC or CW agent challenges; those instances are addressed below under Accuracy.

Recovery Time: The time required for the ChemPro 100 to return to a baseline reading after an alarm was typically less than 50 seconds for AC, CK, SA, and HD, and less than about 15 seconds for GB, but in a few instances during evaluation with AC and HD, recovery times exceeded 600 seconds. Recovery times depended only weakly on temperature and RH, with recovery times for AC being shorter with higher temperature and lower RH. These results exclude those instances in which the ChemPro 100 did not respond to a TIC or agent challenge.

Accuracy: Of the 120 challenges with AC, GB, and HD used to assess accuracy, the ChemPro 100 responded accurately to 86, with no response to 30 challenges, and four cases of a continued alarm even when sampling clean air. Accuracy results for the target chemicals varied from one test condition to another, and (in TIC testing) from one ChemPro 100 unit to the other. Accuracy for AC was 100% in most test conditions, but ranged from 0 to 40% under conditions of high humidity. For GB, accuracy was 80 to 100% at most test conditions, but was 0% with high humidity. Accuracy for HD was 80 to 100% at some test conditions, but 0 to 40% at others, with no clear dependence on temperature or RH. Accuracy for CK ranged from 0 to 100%, with different temperature and RH dependence observed from the two units. For SA accuracy ranged from 0 to 100% under different test conditions (from 0 to 20% for one ChemPro 100 unit), with no apparent dependence on temperature or RH. For chlorine, only one positive response was seen from one unit in five trials on each of the two units, so the unit accuracies were 0 and 20%.

[Failure to respond to AC challenges was also observed during cold-/hot-start and battery life tests, but those observations were not used in the calculation of the accuracy results noted above.]

Repeatability: When the ChemPro 100 units responded to an AC challenge, for one unit, repeatability was perfect under all conditions of temperature and humidity (i.e., all maximum responses were Medium). For the other unit with AC, maximum response changed from Low to High as temperature increased, and from Medium to Low as RH increased. For GB, maximum responses changed from High to Medium to Low as temperature increased from low (5 °C) to room temperature to high (35 °C). No humidity effect was seen on GB repeatability, and HD response was perfectly repeatable under all conditions (all maximum responses were Low).

Response Threshold: For AC, the response threshold was between 3 and 6 ppm (3 and 6 mg/m^3) on both ChemPro 100 units. For CK the response threshold was between 5 and 10 ppm (12.5 and 25 mg/m^3) on one unit and between 10 and 20 ppm (25 and 50 mg/m^3) on the other. The SA response threshold was between 3 and 6 ppm (10 and 20 mg/m^3) on both units, and for Cl_2 was at or above about 60 ppm (180 mg/m^3). For GB the response threshold was about 0.002 ppm (0.01 mg/m^3), and for HD it was about 0.03 ppm (0.2 mg/m^3).

Temperature and Humidity Effects: These effects are described in the preceding summaries of other performance parameters.

Interference Effects: Ammonia cleaner and air freshener vapors produced false positive responses in nearly all trials when using either the TIC or CWA library of the ChemPro 100. Latex paint fumes produced false positives in 67 to 100% of trials in the TIC library, and in 20 to 40% of trials in the CW agent library. DEAE produced no false positive responses, and exhaust hydrocarbons produced only one false positive out of 20 trials.

[Erroneous positive responses of a different kind (i.e., alarms while the ChemPro 100 sampled clean air) were observed in a few cases during tests of accuracy with AC and CK.]

When added to challenge mixtures of AC, the interferences produced minimal false negative responses for AC with one ChemPro 100 unit. However, the response accuracy of the other unit was reduced to 40% by the air freshener vapors and to 0% by the ammonia cleaner vapors. False negative effects on CK and SA response were difficult to determine because of the variability in response for these chemicals with the two ChemPro 100 units. False negative effects on accuracy of identification for CK were seen with DEAE, and the accuracy for SA was reduced to 0 to 20% by engine exhaust hydrocarbons and DEAE. False negative responses with GB occurred primarily with ammonia cleaner and exhaust hydrocarbons. False negative responses with HD occurred with paint fumes, ammonia cleaner, and air freshener vapors. With both GB and HD, the false negatives were primarily in the form of inaccurate responses (e.g., a response of CHEM HAZARD rather than NERVE for GB), rather than no response at all. In these cases the ChemPro 100 response provides a protective warning, although the threat is incorrectly identified.

[In one challenge each with AC, GB, and HD in clean air during the evaluation of accuracy, and in two challenges with HD in interference testing, the ChemPro 100 produced a different type of erroneous negative response in clearing its alarm while the TIC or agent challenge was still ongoing.]

Cold-/Hot-Start Behavior: The delay time, or time to reach a ready state after start-up, was 161 seconds and 169 seconds for the two ChemPro 100 units, respectively, when started up from room temperature storage. The delay times were increased to 258 seconds and 420 seconds after storage at 5 °C. Accuracy of identification of an AC challenge was substantially reduced in initial readings after a cold start, relative to that in fully warmed up operation. For example, one unit showed no response to AC in four of five trials after start-up from cold storage, in all five trials after start-up from room temperature, and in four of five trials after start-up from hot storage. In general, response times were slightly longer, and response readings (i.e., Low/Medium/High) somewhat lower after a cold start than in fully warmed up operation.

Battery Life: One unit of the ChemPro 100 shut down after 9 hours and 53 minutes of continuous operation on battery power. The other unit shut down after 11 hours and 12 minutes.

Operational Characteristics: The ChemPro 100 has a large display that is easy to read in all light conditions provided the background light (bright blue) is used. This light is controlled from a menu within the ChemPro 100. The display indicates the response reading of the unit (hazard identity and level), what library is being used, the date and time, the audible alarm volume level, and the battery power level. A lighted status indicator is green when the unit is in ready mode, and flashing red when the unit is in alarm mode (coincident with the audible alarm). The display (when lighted) and audible and visual alarms can be readily understood by the operator, even when wearing personal protective equipment. When the ChemPro 100 detects a failure within its system, the display also indicates an error message, e.g., for air intake flow or SCCell failure. The ChemPro 100 has a "conditioning" mode that keeps the instrument from responding while the instrument stabilizes. However, the occurrence of this mode is only apparent from data displayed on a laptop computer, and is not evident to an operator using the ChemPro 100 as a hand-held device. When the temperature or humidity condition was changed, the ChemPro 100 may have entered conditioning mode and thus not have responded until the conditioning mode was completed. This mode may have contributed to instances where IMS signal was observed on the laptop, but the ChemPro 100 failed to give an alarm when challenged.

Before this evaluation began, an Environics representative trained Battelle evaluation personnel to operate the ChemPro 100. Evaluating proceeded according to the vendor's recommendations, and the vendor responded promptly when information was needed during the evaluation. The list price of the ChemPro 100 plus the Standard Accessory Kit is approximately $9,500.

Conclusion: The ChemPro 100 responded correctly to AC, GB, and HD in most challenges, but responses observed with CK, SA, and Cl_2 were less reliable. However, even with AC, GB, and HD, observations included the absence of response to challenges, widely different responses from two units challenged simultaneously, the occasional discontinuance of a warning alarm even though a TIC or chemical agent challenge was still present, and the failure to clear an alarm even after the challenge gas was replaced with clean air. IMS signals recorded on laptop computers during testing indicated that these behaviors originated with the software that interprets the IMS signal, rather than with the IMS response itself. This finding suggests that software improvements might rectify the observed responses. Both false positive and false negative responses occurred in the presence of common indoor interferent vapors. Usually a protective warning (albeit inaccurately identified) was present in the instances of a false negative response caused by interferents. Elevated humidity generally produced less accurate responses.

6.0 References

1. *Technology Testing and Evaluation Program Test/QA Plan for Evaluation of Portable Ion Mobility Spectrometers for Detection of Chemicals and Chemical Agents,* Version 1, Battelle, Columbus, Ohio, February 2005.

2. *Quality Management Plan (QMP) for the Technology Testing and Evaluation Program (TTEP),* Version 1, Battelle, Columbus, Ohio, January 2005.

3. Library Datasheet for SOCOM Update 3 Libraries, CP100V2-LIB-V1-TEK310105-GasDet31-CWA-7104_TIC-71_Precursor-71-Library Datasheet-Final-RCM-2-8-05.doc, Environics, Mikkeli, Finland, February 8, 2005.