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REPORT

Cerex Environmental Services

UV Hound Point Sample Air Monitor

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Technology Evaluation Report

Cerex Environmental Services UV Hound Point Sample Air Monitor

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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 TTEP. Information on NHSRC and TTEP can be found at http://www.epa.gov/ordnhsrc/index.htm.

Acknowledgments

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Abbreviations/Acronyms

AC	hydrogen cyanide
AEGL	acute exposure guideline level
CG	phosgene
CK	cyanogen chloride
Cl_2	chlorine
CW	chemical warfare
DC	direct current
DEAE	N,N-diethylaminoethanol
EPA	U.S. Environmental Protection Agency
FPD	flame photometric detection
GB	sarin
GC	gas chromatography
HD	sulfur mustard
IDLH	immediately dangerous to life and health
µg/mL	microgram per milliliter
$\mu g/m^3$	microgram per cubic meter
ms	millisecond
NHSRC	National Homeland Security Research Center
PE	performance evaluation
ppb	part per billion (by volume in air)
ppm	part per million (by volume in air)
ppm-m	ppm-meter
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
USB	universal serial bus
UV	ultraviolet

Executive Summary

The U.S. Environmental Protection Agency's National Homeland Security Research Center 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 evaluated the performance of the Cerex UV Hound point sample air monitor in detecting toxic industrial chemicals (TICs) and chemical warfare (CW) agents in air.

The UV Hound operates on the principle that, when exposed to light, gases absorb various characteristic wavelengths of the light to an extent proportional to the amount of gas in the light beam. Each gas has a unique spectral fingerprint that can be used to identify and quantify gaseous components. In the UV Hound, a xenon or deuterium lamp produces an ultraviolet light beam. Specially designed optics focus the beam and project it through the air. A receiver then collects the light and focuses it into a spectrometer. The spectrometer analyzes the wavelengths and magnitudes of the received light. The resulting single-beam spectrum (the plot of signal strength versus wavelength of light) contains all of the spectral information needed to identify and quantify the gases present in the air traversed by the light beam.

The following performance characteristics of the UV Hound were evaluated in tests with the TIC chlorine (Cl_2) as the target gas:

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

The evaluation included sampling potential indoor interferents, both with and without Cl_2. The interferents used were latex paint fumes, air freshener vapors, ammonia cleaner vapors, a mixture of hydrocarbons representing motor vehicle exhaust, and N,N-diethylaminoethanol (DEAE), a boiler water additive that can enter indoor air via steam humidification. A range of temperatures (5 to 35ºC) and relative humidities (<20 to 80%) was used to assess the effects of these conditions in detecting Cl_2.

In addition, response threshold tests also were conducted for the following TICs: hydrogen cyanide (HCN; North Atlantic Treaty Organization military designation AC), arsine (SA), cyanogen chloride (CK), and phosgene (CG), and for the CW agents sarin (GB) and sulfur mustard (HD). The UV Hound had not been tested for detection of these six chemicals before this evaluation. Detection was investigated at two concentrations, and Cerex personnel estimated quantitative detection limits based on spectral data recorded during the challenges with these chemicals.

Summary results from testing of the Cerex UV Hound are presented below for each performance parameter evaluated. Discussion of the observed performance can be found in Chapter 4 of this report.

Response Time: The UV Hound operated by compiling numerous spectra over 30-second intervals; thus, response time and recovery time were both quantized in 30-second periods. When the UV Hound responded to 10 ppm Cl_2 challenges (i.e., approximately the immediately dangerous to life and health [IDLH] level), its response times ranged from 30 to 270 seconds. Response times were higher (150 to 270 seconds) at the high-temperature/high-humidity condition. The response times for room temperature at low humidity were 30 to 150 seconds, and for room temperature/high humidity, were 30 to 90 seconds.

Recovery Time: When the UV Hound responded to Cl_2 challenges, recovery times ranged from 30 seconds to the maximum of 300 seconds allowed under the test procedures. For room temperature at low humidity, the range was 60 to 210 seconds; and, at room temperature/high humidity, it was 120 to 240 seconds. Recovery time was highest (300 seconds) at high temperature/high humidity. At high temperature/medium humidity, the recovery time was 150 seconds.

Accuracy: The UV Hound responded accurately (i.e., produced a stable green light indicating detection of Cl_2) in 21 of 46 total challenges with Cl_2. The UV Hound was 100% accurate in identifying Cl_2 in 16 total challenges delivered at 5 ºC and 50% relative humidity (RH), or at 22 ºC and either < 20% or 50% RH. However, in 30 total challenges at 35 ºC/50% RH, or at 80% RH at either 22 ºC or 35 ºC, accuracy was 10 to 20%. Failure to respond to Cl_2 challenges was the primary form of inaccuracy. Also, in one trial in the accuracy test, the UV Hound initially indicated detection of Cl_2, but stopped indicating detection of Cl_2 while the Cl_2 challenge was going on. Inspection of individual spectral results suggests that clouding of the mirrors in the optical cell by water and Cl_2 may have adversely affected detection of Cl_2 in the enclosed optical cell at these conditions.

Response Threshold: The UV Hound was able to detect CK, SA, CG, GB, and HD at challenge concentrations typically a few times the respective IDLH or AEGL-2 levels. (A quantitative estimation of detection limits for these five chemicals was conducted by the vendor; results are shown in Appendix A.) However, the UV Hound did not detect AC at 100 parts per million (ppm) (twice the IDLH level for that compound).

For Cl_2, a response threshold of 7.5 ppm was observed, as that was the lowest concentration at which the majority of trials produced a positive response. At that concentration, three of five successive challenges produced a positive indication of Cl_2 from the UV Hound.

Temperature and Humidity Effects: The effects of temperature and humidity on the UV Hound are summarized in the previous paragraphs.

Interference Effects: No interferent when tested alone produced a false positive result. Paint fumes and ammonia floor cleaner interfered with the detection of Cl_2 by producing false negative results, but air freshener vapors, engine exhaust hydrocarbons, and DEAE did not.

Other erroneous positive responses were observed when testing accuracy, and in interference testing with floor cleaner vapors, when the UV Hound indicated detection of Cl_2 while sampling clean air after the completion of a Cl_2 challenge. Other erroneous negative responses were observed in testing accuracy, cold-/hot-start behavior, and interferences, when the UV Hound stopped indicating detection of Cl_2 while the Cl_2 challenge was going on.

Cold-/Hot-Start Behavior: The UV Hound responded to Cl_2 with a stable green light in all five control (i.e., fully warmed up) challenge cycles and in all five hot temperature cold-start challenge cycles. For the cold temperature cold-start test, the UV Hound did not respond in any of the five Cl_2 challenges, almost certainly due to condensation of moisture on the mirrors in the cold optical cell. For the room temperature cold-start test, the UV Hound responded in all five of the challenge cycles within 30 to 90 seconds, but in four of the challenges, that response ceased before the Cl_2 challenge ended.

Operational Characteristics: The prototype UV Hound and associated software were easy to set up and use after training provided by Cerex. The unit is designed to be mobile (via vehicle) rather than portable, and is also suited for fixed-site monitoring. The purchase price of the UV Hound is $49,000 to $69,000, depending on the options chosen.

Conclusion: The UV Hound detected CK, SA, CG, GB, and HD at concentrations typically a few times their respective AEGL-2 or IDLH level. However, AC could not be detected with the UV Hound at twice its IDLH level. A response threshold of about 7.5 ppm was found for Cl_2. At that level, the majority of challenges produced a stable green light response, indicating a strong fit to reference spectral data for Cl_2.

The UV Hound accurately detected Cl_2 under moderate temperature and humidity conditions (i.e., ≤ 22 ºC and ≤ 50% RH). However, higher temperature or humidity reduced accuracy to 10 to 20%, and affected response time and recovery time. The UV Hound spectral data suggest that water/Cl_2 collection on the mirrors in the optical cell reduced light transmission and detection capabilities under these conditions. Paint fumes and ammonia floor cleaner interfered with the detection of Cl_2. Erroneous positive responses were also observed when sampling clean air, and erroneous negative responses were seen when the UV Hound stopped indicating the detection of Cl_2 while the Cl_2 challenge was still going on. The UV Hound responded rapidly and accurately to Cl_2 upon startup, except after cold storage, when moisture condensed in the cold optical cell of the unit.

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 as a result of 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 test 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 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.

Under TTEP, Battelle recently evaluated the performance of the Cerex UV Hound point sample air monitor in detecting toxic industrial chemicals (TICs) and chemical warfare (CW) agents in air. This evaluation was conducted by adapting a peer-reviewed test/QA plan(1) that was developed in accordance with the requirements of the quality management plan (QMP) for TTEP.(2) Amendments to that test/QA plan(1) specific to evaluation of ultraviolet (UV) absorption instruments were established prior to this evaluation, consistent with the requirements of the TTEP QMP.(2)

This evaluation included the first assessment of the UV Hound's ability to detect certain TICs and CW agents, specifically the TICs hydrogen cyanide (HCN; North Atlantic Treaty Organization military designation AC), arsine (SA), cyanogen chloride (CK), and phosgene (CG), and the CW agents sarin (GB) and sulfur mustard (HD). For these six chemicals, the evaluation consisted solely of determining whether the UV Hound could detect the chemicals at relevant concentrations in air. This determination was based on recording spectra when challenging the UV Hound with clean air and with two challenge concentrations of each of the six chemicals. A software program was used that directly recorded individual spectra, so that results from clean air and challenge concentrations could be inspected to assess detection of these compounds. In addition, the vendor of the UV Hound analyzed the spectral data to estimate detection limits for the detected chemicals. The results of the latter analysis are presented in Appendix A of this report.

A much broader evaluation of UV Hound capabilities was conducted using the TIC chlorine (Cl_2) as the challenge chemical. Chlorine was the only target TIC for which spectral information is stored in the software library of the UV Hound, allowing it to quantify Cl_2 concentrations in air. The software program automatically compared recorded spectra to reference spectral data and displayed the measured concentration of the target chemical, along with goodness-of-fit indicators relative to the reference spectra. A green light indication on the UV Hound's laptop computer display meant a confirmed detection of Cl_2, and was triggered by a coefficient of determination (r^2) of 0.2 or greater for the spectral fit. With Cl_2 as the challenge gas, the full range of test procedures called for in the test/QA plan[1] were conducted, and the following performance parameters of the UV Hound were evaluated:

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

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 October 20, 2005 and January 3, 2006 in two phases: testing with CW agents (conducted in a certified surety laboratory at Battelle's Hazardous Materials Research Center) and testing with TICs (conducted in a non-surety laboratory at Battelle). In all evaluations, the UV Hound was operated using an internal enclosed multi-pass optical cell with a volume of about 8.8 liters and a 14.8-meter optical path length. Challenge gas flows entered and exited this cell through ¼-inch diameter ports located near the ends of the cell. The optical cell that was used in CW agent testing was removed for disposal, and an identical optical cell was installed in the UV Hound to perform the TIC testing. Evaluations with Cl_2 were conducted with challenge concentrations that were at the immediately dangerous to life and health (IDLH) level, as specified in the test/QA plan.[1] Evaluations with AC, SA, CK, CG, GB, and HD were conducted at concentrations well above the corresponding IDLH or similar levels, to increase the likelihood of detecting absorption of UV light by these chemicals. Table 1-1 summarizes the challenge concentrations used.

In response threshold tests for AC, CK, SA, and CG, the challenge concentrations were established based on the known concentrations of primary source gas mixtures and dilution using mass flow control. In the evaluations with Cl_2 and in response threshold evaluations with CW agents, challenge concentrations were confirmed by means of reference analysis of the challenge air stream. The reference method for Cl_2 was a commercial electrochemical Cl_2 sensor (Dräger MiniWarn). The reference method for GB and HD was gas chromatography with flame photometric detection (GC/FPD), using bags for air sample collection.[1]

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

Chemical	Target Concentration	IDLH or AEGL-2[(a)] Concentration
AC	100 parts per million (ppm) and 50 ppm	50 ppm ($50\ mg/m^3$)
SA	10 ppm and 5 ppm	3 ppm ($10\ mg/m^3$)
Cl_2	10 ppm	10 ppm ($29\ mg/m^3$)
CK	100 ppm and 50 ppm	20 ppm[(b)] ($50\ mg/m^3$)
CG	10 ppm and 5 ppm	2 ppm ($8\ mg/m^3$)
GB	0.15 ppm and 0.12 ppm	0.037 ppm ($0.2\ mg/m^3$)
HD	1.06 ppm and 0.79 ppm	0.09 ppm ($0.6\ mg/m^3$)

[(a)] All values in this column are IDLH levels, except that for HD an acute exposure guideline level (AEGL) is given. The AEGL-2 value of 0.09 ppm ($0.6\ mg/m^3$) for HD is that expected to produce a serious hindrance to efforts to escape in the general population, based on a 10-minute exposure.
[(b)] Estimate based on IDLH for hydrogen cyanide (AC).

As described in the test/QA plan,[(1)] response time, recovery time, and accuracy were evaluated by alternately challenging the UV Hound with clean air and known vapor concentrations of Cl_2. It must be noted that the UV Hound reported a response every 30 seconds, based on numerous individual spectra integrated over as little as 50 milliseconds (ms) each during that interval. Thus, response and recovery times are necessarily “quantized” in 30-second intervals. Furthermore, response and recovery times were limited by the gas changeover rate in the optical cell, which was approximately one air exchange every 1.7 minutes. Each clean air and Cl_2 challenge was supplied for at least 5 minutes, and thus at least three exchanges of the optical cell volume were achieved in each challenge. Response threshold was evaluated by repeatedly stepping up from a 1 ppm Cl_2 concentration until a concentration was reached at which the majority of trials produced a stable green light response. Similar evaluations conducted over the range of 5 to 35 °C and 20 to 80% relative humidity (RH) were used to establish the effects of temperature and humidity on detection capabilities for Cl_2. The effects of potential indoor interferences were assessed by sampling selected interferences both with and without Cl_2. The interferences used were latex paint fumes, ammonia floor cleaner vapors, air freshener vapors, a mixture of gasoline exhaust hydrocarbons, and N,N-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 UV Hound unit was also evaluated with Cl_2 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. Operational factors such as ease of use, data output, and cost were assessed through observations made by evaluation personnel and through inquiries to the vendor.

QA oversight of this evaluation was provided by Battelle and EPA. As a result of scheduling conflicts, no technical systems audit (TSA) was performed during this evaluation. However, all test procedures and equipment had been subjected to TSAs in other recent evaluations conducted under the same test/QA plan.[1] A data quality audit was conducted on all data from this evaluation.

2.0 Technology Description

This report provides results for the evaluation of the UV Hound point sample air monitor. Following is a description of the UV Hound, based on information provided by the Cerex vendor. (Contact: Peggy S. Rackstraw, Vice President Sales, Cerex Environmental Services, Office: 865-777-0462, Fax: 865-777-0463, Mobile: 703-623-1524 peggy@cerexenv.com.) The information provided below was not verified in this evaluation.

Cerex air monitoring equipment is designed to continuously examine air to detect, identify, and quantify chemical airborne threats. The UV Hound (Figure 2-1) uses UV differential optical absorption broadband spectroscopy to determine the presence and concentration of target and interfering gases. Target gases include combustion gases, light chain hydrocarbons, TICs, and others. This evaluation assessed the ability of the UV Hound to also detect CW agents and several TICs for which spectral information was not previously available in the UV Hound's software library.

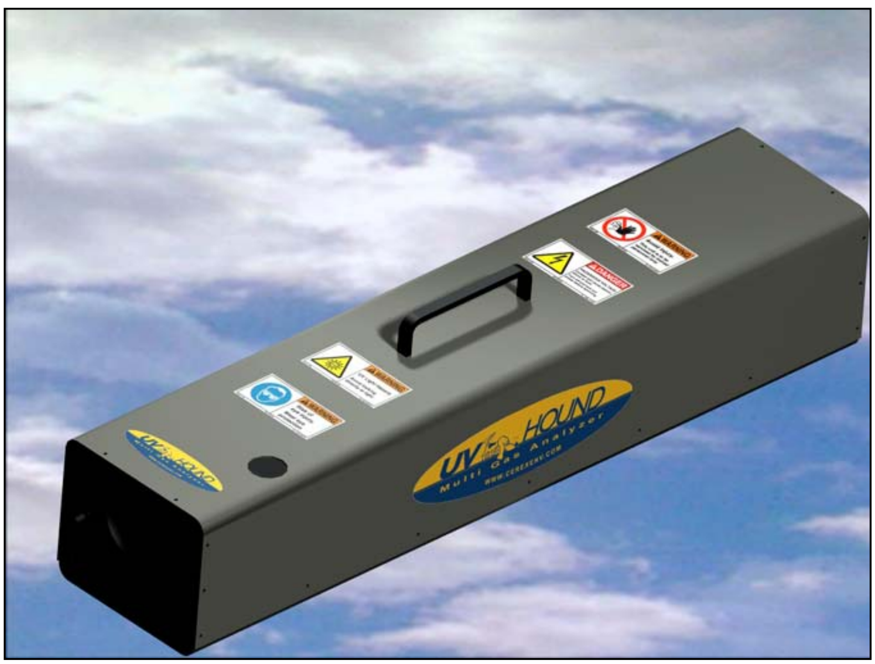

Figure 2-1. Cerex UV Hound

The UV Hound operates on the principle that, when exposed to light, gases absorb various characteristic wavelengths of light to an extent proportional to the amount of gas in the light beam. Each gas has a unique spectral fingerprint that can be used to identify gaseous components. In the UV Hound, a xenon or deuterium lamp produces a UV light beam. Specially designed optics focus the beam and project it through the air. A receiver then collects the light and focuses it into a spectrometer. The spectrometer analyzes the wavelengths and magnitudes of the received light. The resulting single-beam spectrum (the plot of signal strength versus wavelength of light) contains all of the spectral information needed to identify and quantify the gases present in the air traversed by the light beam. Quantitative analysis of the spectrum requires transformation of the single-beam spectrum to reveal the actual absorbance features—the characteristic "fingerprints" that are unique to each chemical compound.

Figure 2-2 shows spectral information illustrating the principles of detection in the UV Hound. The upper left portion of Figure 2-2 shows the typical source spectrum of a Cerex UV system that uses a deuterium light source, along with the spectral locations of characteristic absorption features of several target gases. The right-hand portion of Figure 2-2 illustrates data spectra in the atmosphere when a target gas (phosgene) is not present as well as when the gas is present, and the lower left-hand portion of Figure 2-2 shows the absorbance spectrum generated when the logarithm of the data spectrum is subtracted from the logarithm of the clean air (background) spectrum. Once absorption spectra are created, they can be compared to reference spectra (absorption spectra of known concentrations of gas) to determine the actual concentration of gas in the atmosphere. UV Hound software, running in a laptop computer connected to the spectrometer, performs this comparison and displays the calculated concentration of each target species detected, along with indication of the fit to the reference data.

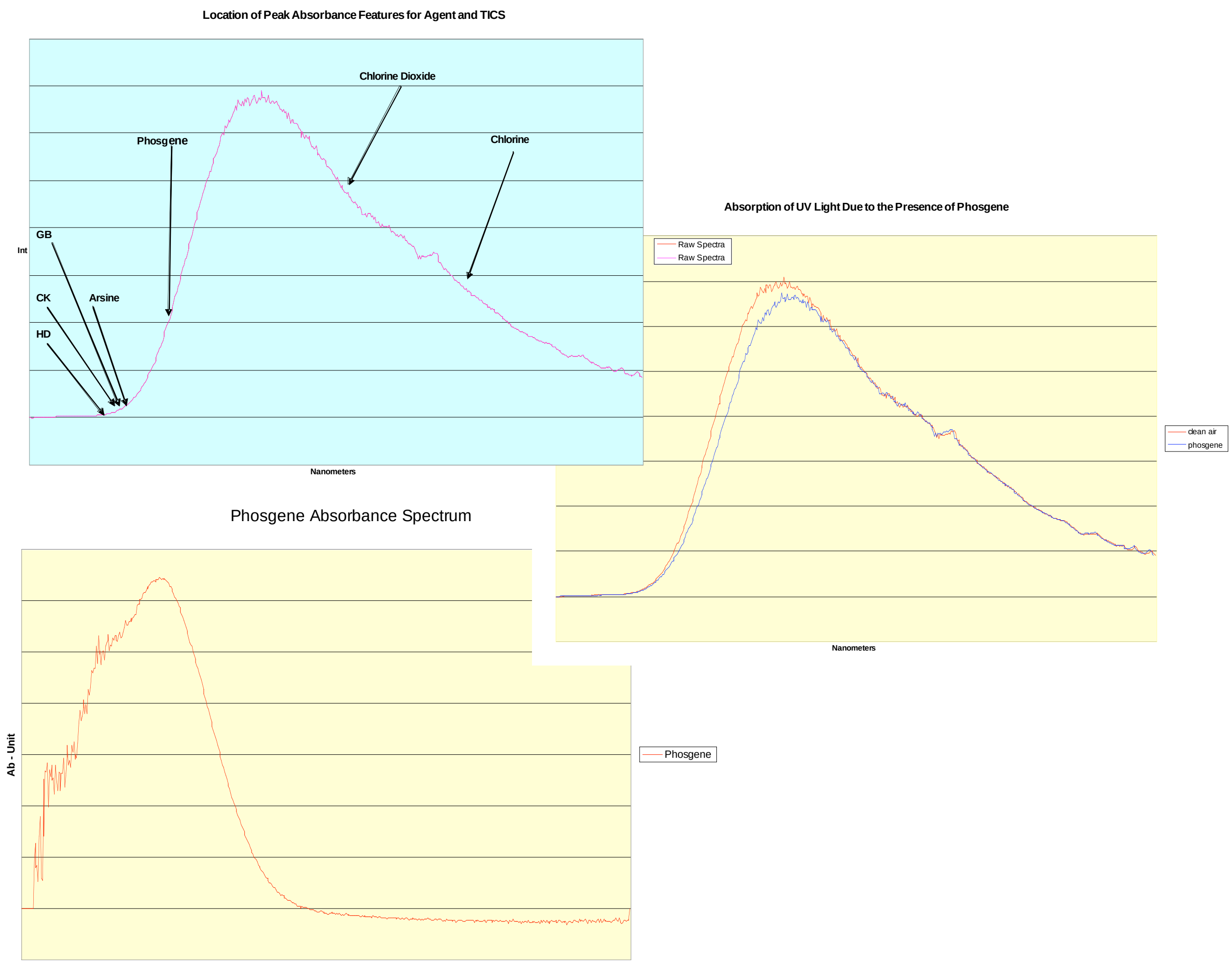

Figure 2-2. Generation of Absorbance Spectra

A positive detection of a target chemical is indicated by a green light on the laptop display, and is triggered by a coefficient of determination (r^2) exceeding 0.2 for the spectral fit. The UV Hound evaluated in this effort was equipped with two spectrometers to broaden the detected wavelength range, and thus required two laptop computers. That extended wavelength range was needed to assess the detection capabilities of the UV Hound for those six chemicals (AC, CK, SA, CG, GB, and HD) for which absorbance spectra had not been previously obtained.

The UV Hound is a mobile analytical platform designed to be mounted on a vehicle, carried into a chemical hotspot, or used as a fixed point monitoring system. The system can be DC-powered by the cigarette lighter in a vehicle and can be configured with wireless communication so that multiple systems can be networked together. The UV Hound is a portable, point-sample unit and can have an internal path-length of up to 24 meters. With a potential dynamic operating range from 0.01 to several ppm, the UV Hound is designed for quick response applications. The UV Hound may also be fitted with an optional snorkel attachment, permitting it to remain safely inside a vehicle or shelter while an air intake hose draws in outside air. The UV Hound ordinarily operates by using its own instrument case as an open flow-through optical cell, in which a fan pulls ambient air in one end of the chassis and expels it out the other end. In that mode, the flow rate at the inlet is approximately 10 cubic feet per minute. The system can also be fitted with an internal optical cell that isolates the sample gas from the surrounding area; the instrument was used in this manner for the evaluation described in this report.

The UV Hound is 7 by 8 by 35 inches in size and weighs approximately 20 pounds. The price ranges from $49,000 to $69,000, depending upon options chosen.

3.0 Quality Assurance/Quality Control

QA/quality control (QC) procedures for this evaluation were based on the program QMP[2] and the test/QA plan.[1]

3.1 Equipment Calibration

3.1.1 Reference Methods

Calibration standards for the CW agents GB and HD were prepared by diluting stock agent to micrograms per milliliter (μg/mL) concentrations and then injecting a 1-microliter volume of each standard into the GC/FPD. Calibration was based on a regression of peak area versus amount of agent injected. New calibration plots were prepared immediately prior to challenging the UV Hound. A GB calibration plot was prepared on October 26, 2005. An HD calibration plot was prepared on October 21, 2005. The concentrations of the standards used ranged from 0.25 μg/mL to 2.5 μg/mL for GB and 0.50 μg/mL to 7.5 μg/mL for HD. All calibration plots for both agents were linear, with r^2 values of greater than 0.98.

The reference measurements for Cl_2 relied upon the manufacturer's calibration of the commercial electrochemical monitor used (Dräger MiniWarn).

The THC analyzer used to document the interferent levels provided in testing was calibrated by filling a 25-liter Tedlar bag with a commercial certified 33-ppm propane standard. Since propane is a three-carbon molecule, this standard constitutes a THC concentration of 99 ppm of carbon. This standard was used for single-point calibration of the THC analyzer on each test day. Clean air from the analytical laboratory was used for zeroing the analyzer.

3.1.2 Instrument Checks

The UV Hound was operated and maintained according to the vendor's instructions throughout the evaluation. The assessment of any maintenance needs was based on predefined diagnostics in the UV Hound software; no maintenance was needed during this evaluation.

3.2 Audits

3.2.1 Performance Evaluation Audit

A performance evaluation (PE) audit was conducted to assess the quality of reference measurements made in the evaluation. For Cl_2, the PE audit was performed once during the evaluation by diluting and analyzing a standard that was independent of the standard 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%. Table 3-1 shows that the result of the PE audit was well within the target tolerance for Cl_2.

Independent PE audit samples do not exist for GB and HD. 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 0.25, 0.50, 1.0, and 2.5 μg/mL. All results were within 4% for the separate standards made by two individuals. For HD, standards were prepared at concentrations of 0.5, 1.0, 2.5, 5.0, and 7.5 μg/mL. All results were within 8% for the separate standards made by two individuals.

Table 3-1. Performance Evaluation Audit Results

TIC	Sample	Date of Audit	Concentration	Result	Agreement (%)
Cl_2	Standard (Cylinder LL23078)		6,015 ppm	12.1 ppm	
	PE Audit Std (Cylinder QF 8866)	12/14/05	5,811 ppm	11.5 ppm	1.6

3.2.2 Data Quality Audit

100 percent of the data acquired during the evaluation were audited. The Battelle Quality Assurance Manager traced the data from the initial acquisition, through reduction, 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 audit was documented in accordance with the test/QA plan[1] and the QMP.[2] Once the audit 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 Test Results

With the TIC Cl_2, the UV Hound was evaluated for the performance parameters listed in Chapter 1 using the test procedures in the test/QA plan.[1] Test procedures were based on sets of five or more challenges with Cl_2, alternating with intervals of sampling clean air. Only response threshold was evaluated for the TICs AC, SA, CK, and CG and the CW agents HD and GB. One UV Hound unit was used during both TIC and CW agent evaluations; the optical cell used in CW agent testing was replaced with an identical cell before the TIC testing. The following sections summarize the findings of this evaluation; results for both TIC and CW agents are included.

For Cl_2, the software program provided with the UV Hound gave an intensity reading for the signal, an error reading in percent, an r^2 value, and a quantitative indication of the concentration every 30 seconds. The r^2 value was a measure of the "fit" of the recorded spectral data for a compound. If the r^2 value exceeded 0.2 for a challenge, a green light on the software display indicated the confirmed presence of the chemical of interest, in this case Cl_2. The occurrence of a green light was taken as the indication of accurate identification of Cl_2 in this evaluation. Results of this evaluation with Cl_2, including temperature and humidity effects, are summarized below and presented in Table 4-1. As Table 4-1 shows, accurate responses (i.e., confirmed detection of the target chemical) were observed in 21 of 46 total challenges with Cl_2. All the inaccurate responses (i.e., failure to indicate detection of Cl_2) occurred in the three tests involving high temperature (35 ºC) and/or high RH (80% RH). The tests at these three sets of conditions were repeated at the end of the evaluation (resulting in 10 total trials each) and confirmed the results seen in the original tests.

Table 4-1. Results from UV Hound Evaluation with Cl_2 at 10 ppm Concentration

TIC	Environmental Conditions	UV Hound Response	Alarms (Indicated Chemical)	Response Time Range (Seconds)	Recovery Time Range (Seconds)
Cl_2	Control (22°C – 50% RH)	Green light (5/5)	Cl_2	30	120-180
	22°C – <20% RH	Green light (6/6)	Cl_2	30-150	60-210
	22°C – 80% RH	Green light (2/10) NR (8/10)[a]	Cl_2	30-90	120-240
	35°C – 50% RH	Green light (1/10) NR (9/10)	Cl_2	60	150
	35°C – 80% RH	Green light (2/10)[b] NR (8/10)	Cl_2	150-270	300
	5°C – 50% RH	Green light (5/5)	Cl_2	30-90	30-180

NR = No response during the Cl_2 challenge.

(a) In three tests, the UV Hound displayed a green light confirming detection of Cl_2 while sampling clean air after completion of the Cl_2 challenge.

(b) In one test, the UV Hound stopped displaying a green light while the Cl_2 challenge continued.

4.1 Response Time

For all challenges conducted during this testing, the UV Hound was set to collect individual spectra over 50 ms integration intervals and average the collected spectra to provide a response every 30 seconds. This 30-second interval for response must be noted in considering the response time results in Table 4-1.

For room temperature (22 °C) at medium humidity (50% RH), the UV Hound provided a green light at the end of the first 30-second cycle for all five challenge cycles (Cl_2 challenge/clean air) conducted. The low temperature (5 °C) test with medium humidity provided five green light responses with varying response times, with the green light appearing at 30 seconds for the second challenge, 90 seconds for the final challenge, and 60 seconds for the other three challenges. The high temperature (35 °C) test with medium humidity was conducted twice for a total of 10 cycles. Nine out of 10 challenges resulted in no green light for Cl_2. The one challenge that did respond with a green light did so at 60 seconds.

For room temperature at low humidity (<20% RH), a green light appeared in all challenges within 30 seconds to 150 seconds, respectively. For this test, six challenge cycles were conducted. Three challenge cycles had response times of 30 seconds, 90 seconds, and 150 seconds, respectively. The other three challenge cycles each had a response time of 120 seconds. For the room temperature test at high humidity (80% RH), 10 challenge cycles were conducted. The UV Hound responded with a green light for two of the 10 challenges and no green light in five others. In three other challenge cycles, the green light appeared after the Cl_2 challenge was ended and the UV Hound was sampling clean air. For the two green light responses that occurred while the UV Hound was being exposed to Cl_2, the green light response times were 30 seconds and 90 seconds. For the high temperature at high humidity test, the UV Hound was exposed to 10 challenge cycles. The UV Hound responded with a green light during two cycles. In one of those cycles, the UV Hound responded with a green light at 270 seconds. In the other cycle, the UV Hound provided a response at 150 seconds; however, the response cleared (the green light went off) while the UV Hound was still being exposed to Cl_2.

Inspection of the individual UV Hound spectra recorded in the challenges conducted at 35 ºC and/or 80% RH showed that they were characterized by low signal intensities and by spectral integration times far exceeding the intended 50-ms interval. In fact, many of the spectral records reached the maximum allowable integration time of 1,000 ms. These observations are symptomatic of ineffective transmission of light from the source to the spectrometer in the UV Hound and suggest clouding or condensation on the mirrors in the optical cell at these temperature/RH conditions. The mechanism of this clouding is unknown, but presumably involves an interaction of Cl_2, water vapor, and the optical cell surfaces under these conditions. An alternative explanation—misalignment of the optical elements as a result of temperature changes—seems unlikely because frequent failures to detect Cl_2 also occurred at room temperature/80% RH. Similarly, misalignment as a result of overpressurization of the optical cells is ruled out because the gas flow rate through the optical cell was the same in all tests. Note that water vapor itself does not absorb in the UV range, so spectral interference from water is not a factor.

4.2 Recovery Time

Results of the recovery time analysis are summarized below and presented in Table 4-1.

At room temperature with medium humidity, the green light went off at 120 seconds after cessation of the Cl_2 challenge for the final challenge, 180 seconds for the second challenge, and 150 seconds for the other three challenges. The low temperature at medium humidity test also had varying recovery times with 30 seconds for the third and fourth challenges, 150 seconds for the first challenge, and 180 seconds for the second and final challenges. The high temperature at medium humidity test had only one green light response, which cleared at 150 seconds.

At room temperature with low humidity, five of the six cycles had a recovery time of 60 seconds. The final challenge had a recovery time of 210 seconds. At room temperature with high humidity, the two recovery times were 120 and 240 seconds. At high temperature with high humidity in the one test where the UV Hound still had a green light at the end of the Cl_2 challenge, the UV Hound recovery time was recorded as 300 seconds, which was the maximum time allowed in the test procedure for the alarm response to stop after the end of a Cl_2 challenge. In the case where the UV Hound cleared while still being challenged with Cl_2, that clearance occurred 60 seconds after the UV Hound began alarming to the presence of Cl_2.

4.3 Accuracy

Results of the accuracy analysis are summarized below and are based on the data presented in Table 4-1. The UV Hound was considered accurate if it confirmed the presence of Cl_2 by displaying a green light, indicating a close fit to the reference spectral data, and continued to display that indication until the Cl_2 challenge stopped.

Accuracy was defined as the proportion of trials in which the unit registered an accurate response to the challenge. The UV Hound was 100% accurate at room temperature and medium humidity, room temperature and low humidity, and low temperature and medium humidity (total of 16 challenges). The UV Hound was 20% accurate at the room temperature/high humidity condition, and 10% accurate at the high temperature/medium humidity and high temperature/high humidity conditions (total of 30 challenges). At the latter condition, one response was judged inaccurate because the confirmed indication of Cl_2 stopped during the Cl_2 challenge.

High/Low—The high/low test evaluated the response of the UV Hound to alternating higher or lower concentrations of the target chemical (Cl_2). In this high/low test, when a higher challenge (10 ppm) was delivered first, the UV Hound intensity response did not decrease when the challenge was then switched to a lower concentration (5 ppm). However, when the lower challenge was delivered first, the UV Hound intensity response did increase when the challenge was then switched to the higher concentration. In four out of the six challenge cycles (two high/low/clean air and two low/high/clean air), the UV Hound responded with a green light within 60 to 120 seconds. The final high/low and low/high cycles did not provide green light responses. Recovery times for the four challenge cycles that produced responses ranged from 60 to 240 seconds.

4.4 Response Threshold

For the TICs AC, CK, SA, and CG and the CW agents GB and HD, the detection capabilities of the UV Hound were assessed by challenges with the concentrations shown in Table 1-1. The aim of this evaluation was to assess whether these chemicals could be detected by the UV Hound, as the UV Hound had not been challenged with these chemicals before. The result of this evaluation was that CK, SA, CG, GB, and HD all produced detectable spectral response at both of the respective challenge concentrations shown in Table 1-1. Thus, the UV Hound, as tested, is capable of detecting these five chemicals at the challenge concentrations, which were typically a few times the respective IDLH or AEGL-2 level. However, no response was observed in either challenge with hydrogen cyanide (AC).

The vendor of the UV Hound also performed a quantitative evaluation of the spectral data from the response threshold tests for CK, SA, CG, GB, and HD. The results of that evaluation are presented in Appendix A.

A response threshold test was also conducted for Cl_2 by starting at a low concentration (1 ppm) and stepping the concentration up until the UV Hound responded with a green light for the majority of the challenge cycles at a concentration. At 1 ppm and 2 ppm, the UV Hound showed no green light response. At 5 ppm, one of four cycles produced a green light. At 7.5 ppm, the UV Hound responded with a green light in three of the five cycles within 120 to 180 seconds. This result indicates a response threshold for Cl_2 of approximately 7.5 ppm.

4.5 Temperature and Humidity Effects

The effects of temperature and humidity on the UV Hound are summarized in Sections 4.1 through 4.3.

4.6 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 concentrations of paint fumes, floor cleaner vapors, air freshener vapors, and gasoline exhaust hydrocarbons were monitored by a total hydrocarbon monitor and maintained at 10, 10, 1, and 2.5 parts per million carbon (ppm C), respectively.[(1)] DEAE was delivered from a compressed gas standard and diluted to a concentration of 10 parts per billion (ppb) carbon (ppb C).[(1)] The effect of these interferences on the UV Hound response to Cl_2 is summarized below and in Table 4-2.

Because of the reactivity of Cl_2, the potential existed for reduction of the delivered Cl_2 challenge level due to reaction with the interferent vapors. To avoid this, the Cl_2 level was monitored with the electrochemical sensor at the outflow port of the UV Hound’s optical cell, as well as at the inflow, and the delivered Cl_2 standard flow was increased as necessary to maintain approximately 10 ppm Cl_2 in the cell. Such an adjustment was needed only when using the ammonia floor cleaner as interferent. There was no indication that the electrochemical sensor responded to any reaction product of ammonia with the floor cleaner vapors.

Table 4-2. Interference Effects

TIC or CW Agent	Interferent	UV Hound Response	Alarms (Indicated Chemical)	Response Time Range (Seconds)	Recovery Time Range (Seconds)
Cl_2	Control	Green light (5/5)	Cl_2	30	120-180
	Paint Fumes	Green light (1/5)[(a)] NR (4/5)	Cl_2	120	-
	Floor Cleaner	NR (10/10) [(b)]	-	-	-
	Air Freshener	Green light (5/5) [(a)]	Cl_2	30-90	30
	Gasoline Engine Exhaust	Green light (5/5)	Cl_2	30-90	0-120
	DEAE	Green light (5/5) [(a)]	Cl_2	30-120	30-150

NR = No response.
(a) In one or more trials, the UV Hound stopped displaying a green light while the Cl_2 challenge continued.
(b) In two trials, the UV Hound displayed a green light confirming detection of Cl_2 while sampling clean air after completion of Cl_2 challenge.

4.6.1 False Positive

A false positive was defined as a response from the UV Hound when challenged with an interferent in air in the absence of a TIC or CW agent. None of the five interferents produced a false positive in the five trials conducted for each interferent.

A different type of erroneous positive response was observed in a few challenges with Cl_2, when the UV Hound showed a confirmed identification of Cl_2 while the optical cell was being purged with clean air after the end of a Cl_2 challenge. Such occurrences are noted in Section 4.1 through 4.3. Similar erroneous positive responses were also noted after challenges with Cl_2 and interferences together, as noted in Table 4-3 and described below in Section 4.6.2.

4.6.2 False Negative

A false negative response was defined as a reduction or elimination of response to Cl_2, when Cl_2 and the interferent were present together in the challenge. In the control test (i.e., Cl_2 challenge with no interferent), the UV Hound identified the Cl_2 challenge in all tests with a stable green light response within 30 seconds.

For the paint fumes with Cl_2, the UV Hound responded with a green light in only one out of five challenge cycles at 120 seconds. That response then cleared before the end of the Cl_2/interferent challenge.

For the ammonia floor cleaner vapors with Cl_2, 10 challenge cycles were conducted. In two cycles, the green light came on after the Cl_2/interferent challenge was complete and the UV Hound was sampling clean air. In the other eight challenges, no green light responses occurred. The UV Hound’s intensity readings for this test varied widely from large negative intensities to large positive intensities.

When Cl_2 was tested in the presence of air freshener vapors, the UV Hound responded with a green light within 30 to 90 seconds for all five challenge cycles. However, in four of the five cycles, the UV Hound green light then went out prior to completing the Cl_2/interferent challenge cycle. The time from first response to clearing of the green light was 120 seconds in most cases.

For the gasoline engine exhaust interferent with Cl_2, the UV Hound green light came on in all five cases within 90 seconds, and three of the five cycles responded within 30 seconds. The green light remained on until the Cl_2/interferent challenge was replaced with clean air. The recovery times ranged from 0 to 120 seconds.

For Cl_2 in the presence of DEAE, a green light was recorded for all five challenge cycles. The response times ranged from 30 to 120 seconds. In one of the five challenge cycles, the green light went out prior to completing the Cl_2/interferent challenge. For the other four challenge cycles, the green light indication remained stable until the clean air challenge began, and recovery times ranged from 30 to 150 seconds.

These results show both actual false negative responses, i.e., failure of the UV Hound to identify the Cl_2 challenge in the presence of the interferent, and another type of erroneous negative response, in which the UV Hound's accurate identification of Cl_2 ceased while the Cl_2/interferent challenge continued. The former were observed with floor cleaner vapors and latex paint fumes, and the latter with air freshener vapors, latex paint fumes, and DEAE. Neither was observed with engine exhaust hydrocarbons. The latter type of erroneous negative response was also observed during testing of cold-/hot-start behavior, as described in Section 4.7.

4.7 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 4-3 illustrates the data obtained in testing for cold-/hot-start effects, showing the start condition, sequential experiment number, response reading, response and recovery times, and indicated chemical.

In the control test, the UV Hound responded to each Cl_2 challenge with a confirmed (i.e., stable green light) identification within 30 seconds after the start of the challenge, and cleared within 120 to 180 seconds after the Cl_2 challenge ended.

For the room temperature cold-start test, the UV Hound was held at room temperature overnight. The UV Hound was turned on at 10:02 a.m. and the first test was conducted at 10:03 a.m. The UV Hound responded with a green light in all of five challenge cycles. However, in four of the five cycles, the UV Hound's green light went out prior to completing the Cl_2 challenge.

For the cold-temperature, cold-start test, the UV Hound was stored overnight at 5 to 8 °C. The UV Hound was removed from the cold storage at 8:43 a.m., and the first challenge was conducted at 8:47 a.m. Testing personnel noted that almost immediately the scan times of the UV Hound increased greatly. The green light did not come on during any of the five Cl_2 challenges, and the intensity readings of the UV Hound continuously decreased as the challenge cycles were conducted. It is highly likely that

Table 4-3. Start State Effects

UV Hound Unit	Start Condition	Experiment Number	UV Hound Response	Response Time (Seconds)	Recovery Time (Seconds)	Alarm (Indicated Chemical)
	Control	1	Green light	30	150	Cl_2
		2	Green light	30	180	Cl_2
		3	Green light	30	150	Cl_2
		4	Green light	30	150	Cl_2
		5	Green light	30	120	Cl_2
	Room Temperature (Cold Start)	1	Green light	90	-[a]	Cl_2
		2	Green light	60	-[a]	Cl_2
		3	Green light	60	30	Cl_2
		4	Green light	30	-[a]	Cl_2
		5	Green light	60	-[a]	Cl_2
	Cold Temperature (Cold Start)	1	NR[b]	-	-	-
		2	NR[b]	-	-	-
		3	NR[b]	-	-	-
		4	NR[b]	-	-	-
		5	NR[b]	-	-	-
	Hot Temperature (Cold Start)	1	Green light	60	150	Cl_2
		2	Green light	30	180	Cl_2
		3	Green light	30	210	Cl_2
		4	Green light	30	150	Cl_2
		5	Green light	60	120	Cl_2

(a) Green light indication ceased before end of Cl_2 challenge.
(b) No response, likely due to condensation of moisture on the mirrors in the optical cell.

this behavior was the result of moisture condensing on the cold surfaces of the mirrors in the optical cell, thereby obscuring the UV light beam, as the moisture content of the challenge air (at 22 ºC and 50% RH) exceeded the saturation vapor pressure at the temperature to which the UV Hound had been cooled overnight. This suggestion is supported by the return of the UV Hound to normal operation after it had warmed in the laboratory.

For the hot-temperature, cold-start test, the UV Hound was held overnight at approximately 40 °C. The UV Hound was removed from storage at 8:28 a.m., and the first test was conducted at 8:30 a.m. The UV Hound produced a stable green light in all five of the challenge cycles within 30 to 60 seconds. The recovery time after completing the challenge cycle was 120 to 210 seconds.

4.8 Operational Characteristics

The UV Hound tested was a prototype, in that a second spectrometer had been installed to extend the wavelength region detected. This was done to evaluate detection of the four TICs and two CW agents that had not been detected previously by the instrument. Each spectrometer was connected to a laptop computer with a universal serial bus (USB) cable. Two types of software were used, a basic program for recording raw spectral data, and an advanced program that compared recorded spectra to a library of spectral reference data to identify and quantify selected TICs. The former software was used for evaluating response thresholds for AC, CK, SA, CG, GB, and HD; the latter software was used in all evaluations with Cl_2. The UV Hound and software were easy to set up and use after training provided by Cerex.

The UV Hound operation was simple. The deuterium lamp and internal fan were turned on by connecting the electrical power cord to the UV Hound itself. Each of the two spectrometers was powered by its respective laptop computer. All control of the UV Hound was through the laptop software, which always started correctly and performed reliably. The instrument manual was well written and clear, including its instructions for use of the software.

The UV Hound is most suited for monitoring at a fixed site to detect or diagnose chemical contamination. Its reliance on a laptop computer for control and data acquisition limits its portability, though it is designed for mobile operation aboard a vehicle.

5.0 Performance Summary

Summary results from the evaluation of the Cerex UV Hound are presented below. Discussion of the observed performance can be found in Chapter 4 of this report. All results are from testing one UV Hound unit.

Response Time: The UV Hound operated by compiling numerous spectra over 30-second intervals; thus, response time and recovery time were both quantized in 30-second periods. When the UV Hound responded to 10 ppm Cl_2 challenges (i.e., approximately the IDLH), its response times ranged from 30 to 270 seconds. Response times were higher (150 to 270 seconds) at the high-temperature/high-humidity condition. The response times for room temperature at low humidity were 30 to 150 seconds, and for room temperature/high humidity, were 30 to 90 seconds.

Recovery Time: When the UV Hound responded to Cl_2 challenges, recovery times ranged from 30 seconds to the maximum of 300 seconds allowed under the test procedures. For room temperature at low humidity, the range was 60 to 210 seconds; and, at room temperature/high humidity, it was 120 to 240 seconds. Recovery time was highest (300 seconds) at high temperature/high humidity. At high temperature/medium humidity, the recovery time was 150 seconds.

Accuracy: The UV Hound responded accurately (i.e., produced a stable green light indicating detection of Cl_2) in 21 of 46 total challenges with Cl_2. The UV Hound was 100% accurate in identifying Cl_2 in 16 total challenges delivered at 5 ºC and 50% RH, or at 22 ºC and either < 20% or 50% RH. However, in 30 total challenges at 35 ºC/50% RH, or at 80% RH at either 22 ºC or 35 ºC, accuracy was 10 to 20%. Failure to respond to Cl_2 challenges was the primary form of inaccuracy. Also, in one trial in the accuracy test, the UV Hound initially indicated detection of Cl_2, but stopped indicating detection of Cl_2 while the Cl_2 challenge was going on. Inspection of individual spectral results suggests that clouding of the mirrors in the optical cell by water and Cl_2 may have adversely affected detection of Cl_2 at these conditions.

Response Threshold: The UV Hound was able to detect CK, SA, CG, GB, and HD at challenge concentrations typically a few times the respective IDLH or AEGL-2 levels. (A quantitative estimation of detection limits for these five chemicals was conducted by the vendor; results are shown in Appendix A.) However, the UV Hound did not detect AC at 100 ppm (twice the IDLH level for that compound).

For Cl_2, a response threshold of 7.5 ppm was observed, as that was the lowest concentration at which the majority of trials produced a positive response. At that concentration, three of five successive challenges produced a positive indication of Cl_2 from the UV Hound.

Temperature and Humidity Effects: The effects of temperature and humidity on the UV Hound are summarized in the previous paragraphs.

Interference Effects: No interferent when tested alone produced a false positive result. Paint fumes and ammonia floor cleaner interfered with the detection of Cl_2 by producing false negative results, but air freshener vapors, engine exhaust hydrocarbons, and DEAE did not.

Other erroneous positive responses were observed when testing accuracy, and in interference testing with floor cleaner vapors, when the UV Hound indicated detection of Cl_2 while sampling clean air after the completion of a Cl_2 challenge. Other erroneous negative responses were observed in testing accuracy, cold-/hot-start behavior, and interferences, when the UV Hound stopped indicating detection of Cl_2 while the Cl_2 challenge was going on.

Cold-/Hot-Start Behavior: The UV Hound responded to Cl_2 with a stable green light in all five control (i.e., fully warmed up) challenge cycles and in all five hot temperature cold-start challenge cycles. For the cold temperature cold-start test, the UV Hound did not respond in any of the five Cl_2 challenges, almost certainly due to condensation of moisture on the mirrors in the cold optical cell. For the room temperature cold-start test, the UV Hound responded in all five of the challenge cycles within 30 to 90 seconds, but in four of the challenges, that response ceased before the Cl_2 challenge ended.

Operational Characteristics: The prototype UV Hound and associated software were easy to set up and use after training provided by Cerex. The unit is designed to be mobile (via vehicle) rather than portable, and is also suited for fixed-site monitoring. The purchase price of the UV Hound is $49,000 to $69,000, depending on the options chosen.

Conclusion: The UV Hound detected CK, SA, CG, GB, and HD at concentrations typically a few times their respective AEGL-2 or IDLH level. However, AC could not be detected with the UV Hound at twice its IDLH level. A response threshold of about 7.5 ppm was found for Cl_2. At that level, the majority of challenges produced a stable green light response, indicating a strong fit to reference spectral data for Cl_2.

The UV Hound accurately detected Cl_2 under moderate temperature and humidity conditions (i.e., $\leq$ 22 ºC and $\leq$ 50% RH). However, higher temperature or humidity reduced accuracy to 10 to 20%, and affected response time and recovery time. The UV Hound spectral data suggest that water/Cl_2 collection on the mirrors in the optical cell reduced light transmission and detection capabilities under these conditions. Paint fumes and ammonia floor cleaner interfered with the detection of Cl_2. Erroneous positive responses were also observed when sampling clean air, and erroneous negative responses were seen when the UV Hound stopped indicating the detection of Cl_2 while the Cl_2 challenge was still going on. The UV Hound responded rapidly and accurately to Cl_2 upon startup, except after cold storage, when moisture condensed in the cold optical cell of the unit.

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, as amended for testing of UV absorption instruments.

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

Appendix A:
Detection and Quantification Limits Calculated by the Vendor of the UV Hound Based on Spectral Data Recorded in Response Threshold Tests

As described in Sections 1.0 and 4.4 of the report, for AC, CK, SA, CG, GB, and HD, the detection capabilities of the UV Hound were assessed by challenging the UV Hound with two concentrations of each TIC or CW agent. Cerex personnel compared the recorded spectra with spectra from clean air challenges, and calculated detection limits for each chemical detected. The results are shown in Table A-1 for each chemical that could be detected. Note that both minimal detection limit and quantification limit are shown in Table A-1. Detection limit is defined as the concentration that would produce a response equal to three times the standard deviation of the baseline response. Quantification limit is the concentration that would produce a response equal to nine times the standard deviation; i.e., quantification limit is three times detection limit. The units of ppm-meters (ppm-m) shown in Table A-1 reflect the importance of both chemical concentration and optical path length in contributing to the detection of a target chemical.

Table A-1. Detection Limits Estimated by Cerex for the UV Hound

TIC/CW Agent	Detection Limit (ppm-m)	Quantification Limit (ppm-m)	Minimum Sample Path (meters)[a]
CK	111	332	16
SA	3.0	9.0	3.0
CG	1.8	5.3	2
GB	0.054	0.16	4.7
HD	0.69	2.1	23

ND = No detection.
NA = Not applicable.
[a] Minimum path length needed to achieve the limits shown.

The calculated detection and quantification limits shown in Table A-1 can be converted to corresponding concentrations in air, by dividing the values shown in ppm-m by the path length of the cell (i.e., 14.8 meters). When this calculation is performed, the resulting detectable and quantifiable concentrations for SA, CG, and GB are lower than the respective IDLH levels listed for these compounds in Table 1-1. For CK and HD, the resulting detectable concentrations are lower, and the resulting quantifiable concentrations slightly higher, than the respective IDLH level and AEGL-2 listed for these compounds in Table 1-1. Overall, the results in Table A-1 suggest that the UV Hound is capable of detecting these chemicals at concentrations near or below their immediately dangerous levels.