March 2001

Environmental Technology Verification Report

SPECTREX INC. SAFEYE 420 ULTRAVIOLET OPEN-PATH MONITOR

Prepared by

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ETV ETV ETV

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Environmental Technology Verification Report

ETV Advanced Monitoring Systems Center

Spectrex Inc. SafEye 420 Ultraviolet Open-Path Monitor

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Notice

The U.S. Environmental Protection Agency (EPA), through its Office of Research and Development, has financially supported and collaborated in the extramural program described here. This document has been peer reviewed by the Agency and recommended for public release. Mention of trade names or commercial products does not constitute endorsement or recommendation by the EPA for use.

Foreword

The U.S. 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 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.

The Environmental Technology Verification (ETV) Program has been established by the EPA to verify the performance characteristics of innovative environmental technology across all media and to report this objective information to permitters, buyers, and users of the technology, thus substantially accelerating the entrance of new environmental technologies into the marketplace. Verification organizations oversee and report verification activities based on testing and quality assurance protocols developed with input from major stakeholders and customer groups associated with the technology area. At present, six environmental technology areas are covered by ETV. Information about each of the environmental technology areas covered by ETV can be found on the Internet at http://www.epa.gov/etv/.

Effective verifications of monitoring technologies are needed to assess environmental quality and to supply cost and performance data to select the most appropriate technology for that assessment. In 1997, through a competitive cooperative agreement, Battelle was awarded EPA funding and support to plan, coordinate, and conduct such verification tests for "Advanced Monitoring Systems for Air, Water, and Soil" and report the results to the community at large. Information concerning this specific environmental technology area can be found on the Internet at http://www.epa.gov/etv/07/07_main.htm.

Acknowledgments

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List of Abbreviations

AMS	Advanced Monitoring Systems
API	Advanced Pollution Instrumentation
CEM	continuous emission monitor
CO_2	carbon dioxide
EPA	U.S. Environmental Protection Agency
ETV	Environmental Technology Verification
FIO	flame ionization detector
GC	gas chromatograph
GC/FID	gas chromatography/flame ionization detection
Hg	mercury
m	meters
MDL	minimum detection limit
N_2	nitrogen
ND	neutral density
NH_3	ammonia
NIST	National Institute of Standards and Technology
NO	nitrogen oxide
ppb*m	parts per billion meters
ppm	parts per million
ppm*m	parts per million meters
QA/QC	quality assurance/quality control
QMP	Quality Management Plan
RSD	relative standard deviation
TSA	technical systems audit
UV	ultraviolet

Chapter 1
Background

The U.S. Environmental Protection Agency (EPA) has created the Environmental Technology Verification (ETV) Program to facilitate the deployment of innovative environmental technologies through performance verification and dissemination of information. The goal of the ETV Program is to further environmental protection by substantially accelerating the acceptance and use of improved and cost-effective technologies. ETV seeks to achieve this goal by providing high quality, peer-reviewed data on technology performance to those involved in the design, distribution, permitting, purchase, and use of environmental technologies.

ETV works in partnership with recognized standards and testing organizations; with stakeholder groups that consist of buyers, vendor organizations, and permitters; and with the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests (as appropriate), collecting and analyzing data, and preparing peer-reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

The EPA's National Exposure Research Laboratory and its verification organization partner, Battelle, operate the Advanced Monitoring Systems (AMS) Center under ETV. The AMS Center recently evaluated the performance of optical open-path monitors for use in ambient air or fence line measurements. This verification report presents the procedures and results of the verification test for the Spectrex Inc. SafEye 420 ultraviolet (UV) open-path monitor.

Chapter 2
Technology Description

The objective of the ETV AMS Center is to verify the performance characteristics of environmental monitoring technologies for air, water, and soil. This verification report provides results for the verification testing of the SafEye 420. The following description of the SafEye 420 is based on information provided by the vendor.

The SafEye 420 is an alarm system that detects ammonia, aromatics, and, hydrogen sulfide, using a high-intensity UV flash source. The detector's three-sensor design includes two absorbed and one reference band sensor. Depending on the gas to be monitored, the band range of the sensors can be tailored with a dip switch to meet specific absorption zones.

The SafEye 420 is made up of two components: a flash source and a detector. These components can be separated to measure ambient gas concentrations over a path length from 1 to 140 meters. The flash source projects a wavelength (specific for the type of gas to be measured) to the detector over an unobstructed line of sight. The beam is attenuated when a hazardous gas traverses it at any point along its path. The detector measures the amount of attenuation by means of two narrow-band sensors and compares this information to a third reference sensor input that is not affected by the subject gas or environmental factors.

The detector's microprocessor software interprets the data and provides output signals in terms of parts per million meters (ppm*m). The detector transmits the data via a 4 to 20 mA signal or an RS485 port or, if a pre-set gas concentration is exceeded, closes one of three contacts.

All the SafEye models (ultraviolet and infrared) are approved for industrial applications by international standards: CENELEC explosion-proof enclosures (per EN 50014, 50018, and 50019), Underwriter's Laboratory, and Factory Method (Class I Division 1, Groups B, C, and D and Class II Division 1, Groups E, F, and G).

Figure 2-1. Spectrex SafEye 420 UV Open-Path Monitor

Chapter 3
Test Design and Procedures

3.1 Introduction

This verification test was conducted according to procedures specified in the *Test/QA Plan for Verification of Optical Open-Path Monitors*.[1] The test was designed to challenge the SafEye 420 in a manner simulating field operations and was modeled after Compendium Method TO-16.[2] The monitor was challenged in a controlled and uniform manner, using an optically transparent gas cell filled with known concentrations of a target gas. The gas cell was inserted into the optical path of the monitor during operation under field conditions, simulating the presence of the target gas in the ambient air.

The monitor was challenged with the three target gases commonly measured by this monitor at known concentrations, and the measurement results were compared to the known concentration of the target gas. The gases and concentrations used for testing the SafEye 420 are shown in Table 3-1. The verification was conducted by measuring the three gases in a fixed sequence over three days. The one-day sequence of activities for testing the monitor for a single gas is shown in Table 3-2.

Table 3-1. Target Gases and Concentrations for Testing the SafEye 420

Gas	Concentration Level	Target Gas Concentration (ppm*m)[a]	Equivalent Gas Cell Concentration[b] (ppm)
Carbon Disulfide	c1	50.3	335
	c2	100	665
	c3	201	1296
Benzene	c1	50.3	335
	c2	100	665
	c3	201	1342
Ammonia	c1	50.3	335
	c2	100	665
	c3	201	1342

[a]ppm*m=parts per million meters.
[b]Length of gas cell = 15.0 cm.

Table 3-2. Optical Open-Path Monitor Verification: Measurement Order for Each Target Gas

Meas. #	Gas Cell Conc.	Activity	# of Measurements	Times (min.) Integrate	Times (min.) Equilibrate	Path Length (m)	Verification Parameter Calculated
	N_2	Change gas & stabilize			10	30	
1	N_2[a]	Collect spectra	25	1		30	Accuracy, Concentration linearity, MDL
	c1	Change gas & stabilize			10	30	
2	c1	Collect spectra	5	1		30	Accuracy, Concentration linearity
3	c1	Collect spectra - ND 1[b]	5	1		30	Source strength linearity
4	c1	Collect spectra - ND 2[b]	5	1		30	Source strength linearity
5	c1	Collect spectra - ND 3[b]	5	1		30	Source strength linearity
	N_2	Change gas & stabilize			10	30	
6	N_2	Collect spectra	5	1		30	Accuracy, Concentration linearity
	c2	Change gas & stabilize			10	30	
7	c2	Collect spectra	5	1		30	Accuracy, Concentration linearity, Interference effect (Int.)
	N_2	Change gas & stabilize			10	30	
8	N_2	Collect spectra	5	1		30	Accuracy, Concentration linearity
	c3	Change gas & stabilize			10	30	
9	c3	Collect spectra	25	1		30	Accuracy, Concentration linearity
10	c3	Collect spectra - ND 1[b]	5	1		30	Source strength linearity
11	c3	Collect spectra - ND 2[b]	5	1		30	Source strength linearity
12	c3	Collect spectra - ND 3[b]	5	1		30	Source strength linearity
15	N_2	Collect spectra	25	5		30	Concentration linearity, MDL
		Change to path length 2			20	100	
16	N_2	Collect spectra	5	5		100	Int.
	c2	Change gas & stabilize			10	100	
17	c2	Collect spectra	5	5		100	Int., Accuracy, Concentration linearity
	N_2	Change gas & stabilize			10	100	
18	N_2	Collect spectra	5	5		100	Int., Accuracy, Concentration linearity
		Change to path length 3			20	90	
19	N_2	Collect spectra	5	1		90	Int., Accuracy, Concentration linearity
	c2	Change gas & stabilize			10	90	
20	c2	Collect spectra	5	1		90	Int., Accuracy, Concentration linearity
	N_2	Change gas & stabilize			10	90	
21	N_2	Collect spectra	25	1		90	Int., MDL

[a]See Table 3-1 for values of c1–c3 for the three target gases.
[b] Activity occurred only during benzene measurements.

3.2 Test Design

The verification test was performed near West Jefferson, Ohio, at an outdoor testing area belonging to Battelle, between October 23 and October 27, 2000. Testing began between 7 and 8 a.m. and ended between 5 and 7 p.m. during these five days. During each of the test days, there was consistently heavy fog (visibility was less than 100 meters) and precipitation ranging from a light drizzle to a moderate rain. This location provided sufficient length and a direct line of sight for each of the path lengths used during the test and provided an area that was away from any chemical sources that might affect the testing. The same sampling location was used during a previous period of testing of open-path optical monitors in April and May of 2000. The open space in the foreground of Figure 3-1 shows the test site at Battelle's West Jefferson facility.

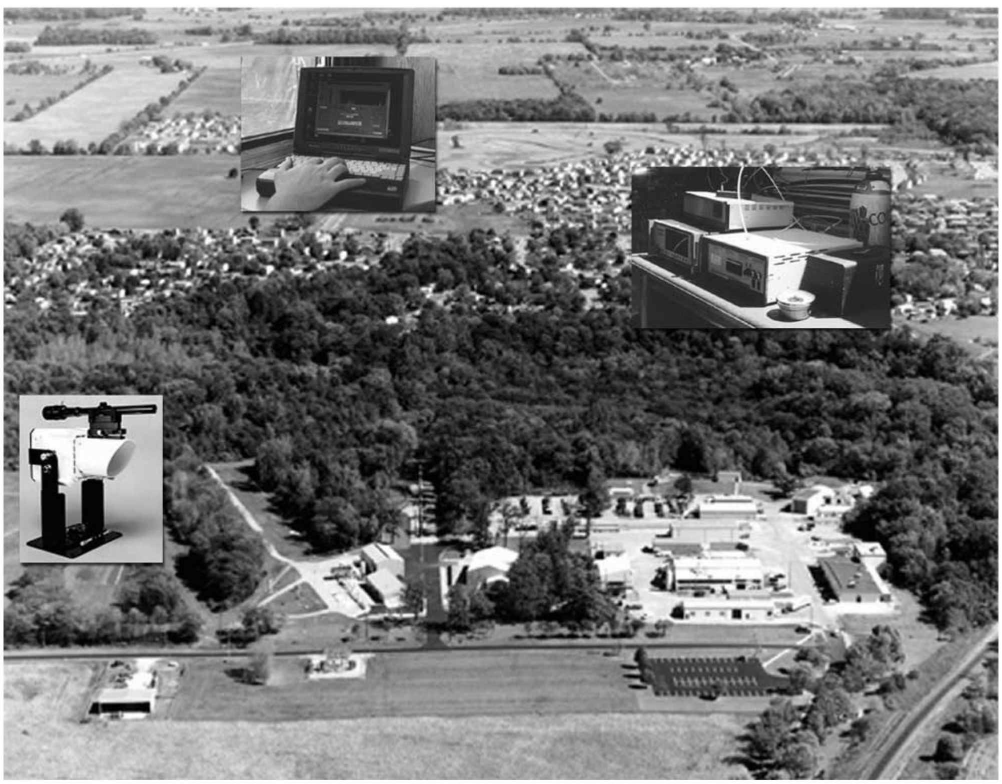

Figure 3-1. Test Site at West Jefferson Facility

The SafEye 420 was challenged with the target gases at the concentrations shown in Table 3-1, and the SafEye 420 measurement was compared to the known concentration of the target gas. For each target gas, the monitor was set up as if it were operating in the field, except that an optically transparent gas cell was placed in the light beam's path (see Figure 3-2). National Institute of Standards and Technology (NIST-)-traceable or commercially certified standard gases, a calibrated gas diluter, and a supply of certified high-purity dilution gas were used to supply the target gases to the gas cell.

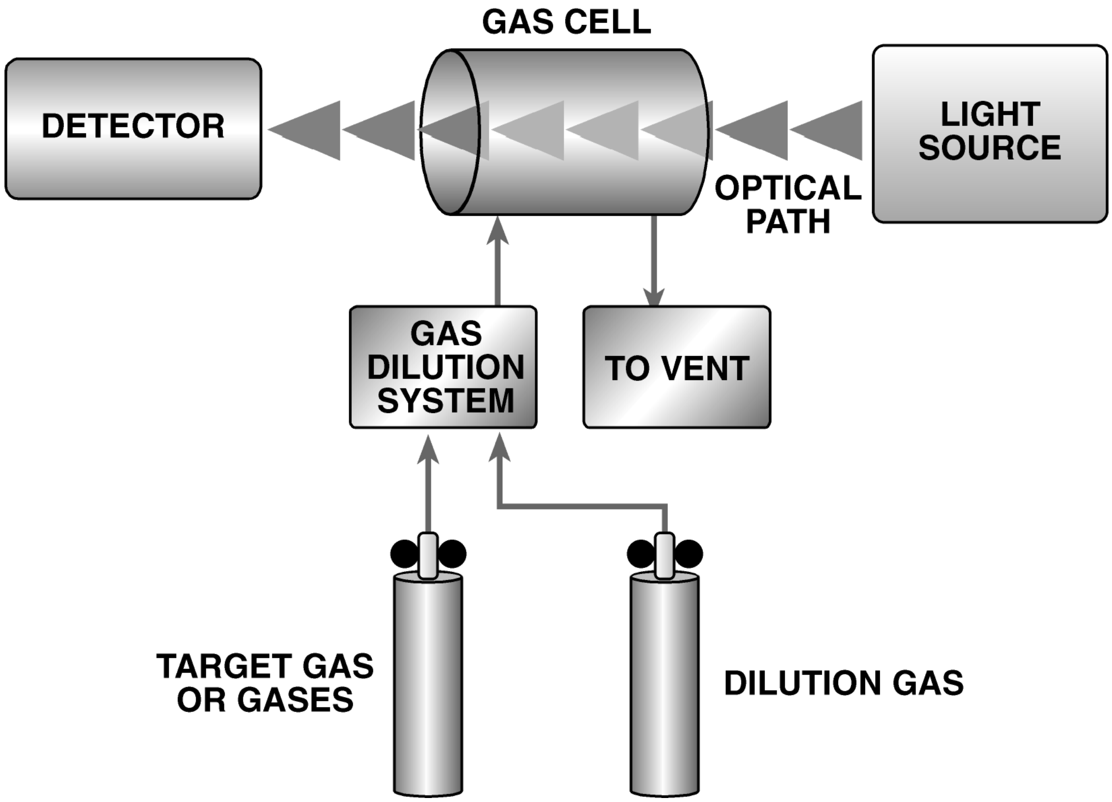

Figure 3-2. Optical Open-Path Monitor Setup

Target gases were measured at different path lengths, integration times, source intensities, and numbers of replicate measurements to assess

- Minimum detection limit (MDL)
- Source strength linearity
- Concentration linearity
- Accuracy
- Precision
- Sensitivity to atmospheric interferences.

The test procedures shown in Table 3-2 were nested, in that each measurement was used to evaluate more than one of the above parameters. In Table 3-2, N_2 in the gas cell concentration column denotes a period of cell flushing with high-purity nitrogen. The denotations c1, c2, and c3 refer to the concentrations shown in Table 3-1. The last column shows the parameters to be calculated with the data from that measurement.

3.3 Experimental Apparatus and Materials

3.3.1 Standard Gases

The standard gases used to produce target gas levels for the verification testing were NIST-traceable gases provided by Scott Specialty Gases Inc. Gravimetrically blended cylinders of carbon disulfide, benzene, and ammonia were used and were specified to have an accuracy of 2% of the certified concentration.

3.3.2 Dilution Gas

The dilution gas was acid rain continuous emission monitor (CEM) zero grade nitrogen obtained from Scott Specialty Gas.

3.3.3 Gas Dilution System

The dilution system used to generate known concentrations of the target gases was an Environics 2020 (Serial No. 2428). This system had mass flow capabilities with an accuracy of approximately ± 1%. The dilution system accepted a flow of compressed gas standard for dilution with high-purity nitrogen. It was capable of performing dilution ratios from 1:1 to at least 100:1.

3.3.4 Gas Cell

A vendor-provided gas cell 15 centimeters in length was integrated into the end of the receiver. This cell had two 1/4-inch tube fittings that allowed the target gas to flow through.

3.3.5 Temperature Sensor

An Omega CT485B temperature monitor (Serial No. 704012206W1) with a thermocouple and a digital temperature readout was used to monitor ambient air and gas cell temperatures. This sensor was operated in accordance with the manufacturer's instructions and was calibrated against a certified temperature measurement standard within the 12 months preceding the verification test.

3.3.6 Ozone Sensor

The sensor used to determine ozone in ambient air was a commercial UV absorption monitor (ThermoEnvironmental Model 49) designated by EPA as an equivalent method for this measurement. The UV absorption method is preferred for this application over the reference method (which is based on ethylene chemiluminescence) because the UV method is inherently calibrated and requires no reagent gases or calibration standards. The sensor was operated in accordance with the manufacturer's instructions.

3.3.7 Nitrogen Oxides/Ammonia Monitor

A chemiluminescent nitrogen oxides monitor [Advanced Pollution Instrumentation (API) Model 200, Serial No. 142] was used with a high-temperature ammonia converter (API Model 1000, Serial No. 100-233-120F-120H) to monitor the nitrogen oxide and ammonia concentrations supplied to the gas cell for verification testing. This monitor sampled gas immediately downstream of the gas cell to confirm the nitrogen oxide or ammonia concentrations prepared by dilution of high-concentration nitrogen oxide or ammonia standards. The API monitor was calibrated with a NIST-traceable commercial standard cylinder of nitrogen oxide in nitrogen. The conversion efficiency for ammonia was checked by comparing the calibration slope for nitrogen oxide with that found in calibrations with ammonia. All ammonia measurements were corrected for the ammonia conversion efficiency, which was generally greater than 95%.

3.3.8 Benzene/Carbon Disulfide Measurement

Benzene and carbon disulfide concentrations provided to the gas cell were checked by collecting a sample at the exit of the cell using pre-cleaned Summa® stainless steel air sampling canisters. A Hewlett Packard 5880 gas chromatograph (GC) was used to analyze the canister samples for benzene and carbon disulfide at the ppm concentration levels. A flame ionization detector (FID) was used to measure the signal response. The compounds were resolved using a fused silica capillary column (HP-1, 30 m by 0.3 mm with 1.05-μm film thickness). After an initial hold of 2 minutes, the column was temperature programmed from -50 to 220°C at a rate of 8°C/minute. Helium was the carrier gas (~3 cc/minute). A syringe filled with a 1-cc sample was used for benzene analyses. A syringe filled with a 10-cc sample was used for carbon disulfide analyses. The syringe samples were directed through a heated sampling line and onto a cold trap (-150) for preconcentration. The trap was then heated to 150°C, and a six-port valve was used to inject the contents of the trap onto the column. Data acquisition and peak integration were accomplished with a PC equipped with Chrom Perfect software.

3.4 Test Parameters

3.4.1 Minimum Detection Limit

The MDL was calculated for each target gas by supplying pure nitrogen to the gas cell in the optical path of the monitor and taking a series of 25 measurements using integration times of 1 and 5 minutes. The MDL was defined as two times the standard deviation of the calculated concentrations from the 25 absorption spectra. The sequence of measurements was conducted at both integration times: twice at a 30-meter path length and once at a 90-meter path length for carbon disulfide and once at a 30-meter path length and once at a 90-meter path length for benzene and ammonia.

3.4.2 Linearity

Two types of linearity were investigated during this verification: source strength and concentration. Source strength linearity was investigated by measuring the effects on the monitor's performance by changing the source intensity. In the field, light signal levels can be attenuated by mist, rain, snow, or dirty optical components. As a constant concentration of target gas was introduced into the gas cell, the light intensity of the source was reduced by placing a series of aluminum wire mesh screens in the path of the light to determine how the monitor's measurements were affected by an attenuated light source. Three aluminum wire screens of various meshes were placed in the beam path. These screens were approximately 1 foot square and had a mesh spacing of approximately ¼, ½, and 1 inch. At each of these attenuation levels, a measurement was made and the monitor analyzed for the target gas. The test was performed at two concentrations (50 ppm*m and 200 ppm*m) using benzene.

Concentration linearity was investigated by challenging the SafEye 420 with each target gas at the concentrations shown in Table 3-1, while the path length and integration time were kept constant. At each concentration, the monitor response was recorded and its linearity evaluated by comparing the recorded response with the input target gas concentration.

3.4.3 Accuracy

Accuracy of the monitor relative to the gas standards was verified by introducing known concentrations of the target gas into the cell. The gas cell was first flushed with at least five cell volumes of nitrogen, and five zero measurements were recorded. The target gas was then introduced into the cell and, after flushing with at least five cell volumes, five measurements of the target gas were obtained. The cell was again flushed with at least five cell volumes of nitrogen, and five more zero measurements were recorded. The concentration of the target gas was the average value with the target gas in the cell, minus the average of the zero measurements.

The accuracy was evaluated at concentrations denoted as c1 through c3, using an integration time of 1 minute. The accuracy was then evaluated at concentration c2 using a longer integration time, and then again at concentration c2 using a 1-minute integration time during the interference measurements (Table 3-2). The percent relative accuracy for an experimental condition is the absolute value of the difference between the average monitor response and the reference monitor response, divided by the reference monitor response, times 100 (see Section 5.3).

3.4.4 Precision

The procedure for determining precision was very similar to the procedure for determining accuracy. The gas cell was flushed with at least five cell volumes of nitrogen. The target gas was then introduced into the cell and, after flushing with at least five cell volumes, 25 measurements of the target gas were obtained. The relative standard deviation (RSD) of this set of measurements was the precision at the target gas concentration. Precision was evaluated by this procedure at one concentration of the target gas (see Table 3-2).

3.4.5 Interferences

The effects of interfering gases were established by supplying the gas cell with a target gas and varying the distance (i.e., the path length) between the source and detector of the monitor. For the UV measurement of the target gases, the main interferences in ambient air are oxygen and ozone, and changing the path length effectively changed the amount of interferants in the light path for the measurement. The purpose of the interference measurements was to determine the effects that the ambient atmospheric gases have on the accuracy and MDL of the SafEye 420. Using two different integration times, these tests were conducted to determine the effect of integration time on the monitor's ability to perform measurements with interfering gases in the light path.

To determine the effect of the interferences, the path length was first set to 30 meters. The gas cell was supplied with nitrogen and, after flushing with at least five cell volumes, five measurements were recorded. Next, the target gas was introduced into the cell; and, after similarly flushing the cell, five measurements were recorded. Finally, the cell was flushed again, and five more measurements were recorded. Atmospheric concentrations of oxygen and ozone were recorded at the beginning and the end of these measurements.

The path length was then set to 100 and 90 meters, and the entire measurement procedure was repeated. The sensitivity of the monitor to the interferant was calculated by comparing the results at different path lengths (i.e., different ppm*m levels of oxygen and ozone).

Chapter 4
Quality Assurance/Quality Control

Quality assurance/quality control (QA/QC) procedures were performed in accordance with the quality management plan (QMP) for the AMS Center[(3)] and the test/QA plan[(1)] for this verification test.

4.1 Data Review and Validation

Test data were reviewed by the Verification Testing Coordinator and disclosed to the Verification Testing Leader. The Verification Testing Coordinator reviewed the raw data and the data sheets that were generated each day. Laboratory record notebook entries also were signed and dated.

4.2 Changes from the Test/QA Plan

Two types of changes from the test/QA plan could occur: planned changes to improve the test procedures for a specific vendor (amendments) and changes that occurred unexpectedly (deviations).

Before the verification test began, several planned amendments were made to the original test/QA plan to improve the quality or efficiency of the test. These procedural changes were implemented and, in each case, either increased the quality of the collected data set or removed inefficiencies in the test, ultimately resulting in a reduced test duration. A brief summary of these amendments is provided below:

- MDL was determined using twice the standard deviation, as described in section 3.4.1 of the test/QA plan. The test/QA plan inadvertently called for the MDL to be determined by two different methods. The correct method was chosen and used during the verification test.

- The benzene analysis procedure was changed from that specified in the test/QA plan. The test/QA plan specified using Method 18 to determine the hydrocarbon emissions from combustion or other source facilities. This method broadly describes an analysis procedure, but does not specify how the analysis is to be done, and calls for the use of Tedlar® bags rather than Summa® canisters. Instead of as described in the test/QA plan, the analysis was done according to Battelle's GC/FID analysis procedure for canister samples.

- The short and the long path lengths in the test/QA plan, which were specified as 100 and 400 meters, were changed to meet the specific technology requirements of the SafEye 420. In this verification test, path lengths of 30, 90, and 100 meters were used.

- Gases for this UV technology were selected based upon the monitor's capability. In addition, the operating range only permitted using three concentrations. Because of this change in the specific concentration, measurement #9 rather than measurement #14 was used to calculate precision.

- The order of testing in the test/QA plan was changed. The test order was originally developed to maximize the efficiency of the test procedure. Several improvements were made to the test matrix to further improve its efficiency. For example, instead of conducting all of the measurements for one gas and then changing to the next gas, all of the short path measurements were conducted before moving to the long path. This was done because changing the path length was more time consuming than changing the target gas.

- The test/QA plan specified that source strength linearity would be tested for each of the gases. The original intent was to conduct this test for one gas only. The source strength linearity test, therefore, was conducted only for a single gas.

- The original test/QA plan specified that the ambient oxygen concentration be monitored by an oxygen analyzer. Instead, the ambient oxygen concentrations were assumed to be 20.9%.

- Although monitoring ambient carbon monoxide was part of the test/QA plan, it was decided that carbon monoxide measurements would not add any useful information to the verification. Therefore, no carbon monoxide monitoring was performed.

- The test/QA plan called for determining ammonia converter efficiency by placing two converters in series with the nitrogen oxide monitor. Instead, conversion efficiency was calculated by comparing nitrogen oxide and ammonia calibration curves.

Amendments required the approval of Battelle's Verification Testing Leader and Center Manager. An amendment form was used for documentation and approval of all amendments.

Deviations from the test/QA plan were as follows:

- No independent performance evaluation was conducted for temperature during the verification test.

- Measurement #15 was not conducted for benzene and ammonia.

Deviation reports have been filed for each deviation.

Neither the amendments nor the deviations had a significant impact on the test results used to verify the performance of the SafEye 420.

4.3 Calibration

4.3.1 Gas Dilution System

Mass flow controllers in the Environics gas dilution system were calibrated by the manufacturer prior to the start of the verification test by means of a soap bubble flow meter. Corrections were applied to the bubble meter data for pressure, temperature, and water vapor content.

4.3.2 Temperature Sensor

The thermocouple was calibrated by Battelle's instrument calibration facility on September 21, 2000. This instrument has a one-year calibration period, and so was still within its calibration interval.

4.3.3 Ozone Sensor

The UV absorption method of ozone measurement is inherently calibrated, relying as it does on the accurately determined absorption coefficient of ozone. As a result, routine calibration of the ozone monitor is not needed. However, the monitor was operated according to the manufacturer's directions, with careful attention to the diagnostic indicators that assure proper operation.

4.3.4 Nitrogen Oxides/Ammonia Monitor

The nitrogen oxides/ammonia monitor was calibrated with both nitrogen oxide and ammonia standards. The nitrogen oxide standard was a Certified Master Class Calibration Standard of 6,960 ppm nitrogen oxide in nitrogen, of ± 1% analytical uncertainty (Scott Specialty Gases, Cylinder No. K026227). The ammonia standard was also a Certified Master Class Calibration Standard, of 494 ppm ammonia in air, of ± 2% analytical uncertainty (Scott, Cylinder No. ALM 005256). The ratio of the slopes of the ammonia and nitrogen oxide calibration curves established the ammonia conversion efficiency.

A performance evaluation audit was also conducted once during the test, in which the API monitor's response was tested with a different nitrogen oxide standard. For that audit, the comparison standard used was a NIST-traceable EPA Protocol Gas of 3,925 ppm nitrogen oxide in nitrogen, with ± 1% analytical uncertainty (Scott Specialty Gases, Cylinder No. ALM 057210).

4.3.5 Benzene/Carbon Disulfide Measurement

The GC/FID instrumentation was calibrated using a cylinder of benzene in nitrogen, with an analytical uncertainty of ± 2% (Cylinder No. AAL 18549). Calibration for carbon disulfide was conducted using a cylinder of carbon disulfide in nitrogen, with ± 2% analytical uncertainty (Cylinder No. ALM 003452, Scott Specialty Gases).

4.4 Data Collection

Data acquisition was performed primarily by Battelle and the vendor. Table 4-1 summarizes the type of data recorded (see also the example data recording form in Appendix A); where, how often, and by whom the recording was made; and the disposition or subsequent processing of the data. Test records were then converted to Excel spreadsheet files.

Table 4-1. Summary of Data Recording Process for the SafEye 420 Verification Test

Data Recorded	Recorded By	Where Recorded	When Recorded	Disposition of Data
Dates, Times, Test Events	Battelle	Data Sheet	Start of each test, whenever testing conditions changed	Used to compile results, manually entered into spreadsheet as necessary
Test Parameters (temp., etc.)	Battelle	Data Sheet	Every hour during testing	Transferred to spreadsheet
Interference Gas Concentrations	Battelle	Data Sheet	Before and after each measurement of target gas	Transferred to spreadsheet
Target Gas Concentrations	Battelle	Data Sheet	At specified time during each test	Transferred to spreadsheet
GC Concentrations	Battelle	PC Stored Chromatograms	After GC analysis	Stored on PC and on printouts
Optical Open-Path Monitor Readings	Battelle	Data Sheet	At specified time during each test	Transferred to spreadsheet

4.5 Audits

4.5.1 Technical Systems Audit

No technical systems audit (TSA) was performed during this verification test. A TSA was performed on another open-path verification test during the initial testing of this type of technology. The TSA of similar test procedures was conducted on April 13 and 14 during the period of open-path monitor verification testing in early 2000. The TSA was performed by Battelle's Quality Manager as specified in the AMS Center QMP. The TSA ensures that the verification test is conducted according to the test/QA plan and that all activities associated with the test are in compliance with the AMS QMP. Specifically, the calibration sources and methods used were reviewed and compared with test procedures in the test/QA plan. Equipment calibration records and gas certificates of analysis were reviewed. The conduct of the testing was observed, and the results were assessed.

All findings noted during the TSA on the above dates were documented and submitted to the Verification Testing Coordinator for correction. The corrections were documented by the

Verification Testing Coordinator and reviewed by Battelle's Quality Manager, Verification Testing Leader, and Center Manager. None of the findings adversely affected the quality or outcome of this verification test, and all were resolved to the satisfaction of the Battelle Quality Manager. The records concerning the TSA are permanently stored with the Battelle Quality Manager.

In addition to the internal TSA performed by Battelle's Quality Manager, an external TSA was conducted by EPA on April 14, 2000, during a previous set of open-path monitor verifications. The TSA conducted by EPA included all the components listed in the first paragraph of this section. A single finding was noted in that external TSA, which was documented in a report to the Battelle Center Manager for review. A response and corrective action were prepared and returned to EPA. The finding did not adversely affect the quality or outcome of this verification test. The results of both the Battelle and EPA TSAs were accounted for in preparing for testing the SafEye 420.

4.5.2 Performance Evaluation Audit

A performance evaluation audit was conducted during the testing period to assess the quality of the measurements made in the verification test. This audit addressed only those measurements made by Battelle in conducting the verification test. The performance audit procedures (Table 4-2) were performed by the technical staff responsible for the measurements. Battelle's Quality Manager assessed the results. The performance evaluation audit was conducted by comparing test measurements to independent measurements or standards.

Each of the required procedures for the performance evaluation audit was conducted during the testing period in accordance with the direction specified in the test/QA plan, except for the deviation concerning the temperature performance evaluations listed in Section 4.2 of this report. The results from the performance evaluation are shown in Table 4-2. The temperature measurement agreed to within 0.4°C and the ozone to within 0.4 ppm. The monitor used for nitrogen oxides/ammonia determination agreed with the performance evaluation standard within 2% at a concentration of 75 ppm*m.

The benzene and carbon disulfide concentrations were audited by independent analysis of the test gas mixture supplied to the gas cell during verification testing.

The GC/FID analysis of both the benzene and carbon disulfide measurements showed that the performance evaluation failed, resulting in an investigation into the reason for failure. It was determined that a leaky orifice caused an additional amount of ambient air to flow into the Summa® canister during sample collection.

The GC/FID results for both benzene and carbon disulfide were lower than the expected value, based upon the controlled concentration being delivered by the Environics 2020 diluter (SN 2428) gas dilution system. The Environics, which was calibrated and passed the

Table 4-2. Summary of Performance Evaluation Audit Procedures

Measurement Audited	Audit Procedure	Reference Reading	Monitor Reading	Difference	Acceptance Criteria
Temperature[a]	Compare to independent temperature measurement (Hg thermometer)	19°C	18.6°C	-0.4°C	< 3°C
Ozone	Compare to independent ozone measurement	16 ppm	16.4 ppm	2.5%	< 10%
NO/NH_3	Compare using another NO standard from the same supplier	100 ppm	98 ppm	-2.0%	< 5%
Benzene	Compare to results of GC analysis of canister sample	335 ppm 665 ppm 1342 ppm	214 ppm 352 ppm 910 ppm	-36.1% -47.1% -39.6%	< 10% < 10% < 10%
Carbon disulfide	Compare to results of GC analysis of canister sample	335 ppm 665 ppm 1296 ppm	280 ppm 392 ppm 1010 ppm	-16.4% -41.1% -22.1%	< 10% < 10% < 10%

[a]Performed on January 27, 2001.

performance evaluation, delivered ammonia, benzene, and carbon disulfide to the target gas cell at a controlled concentration. The benzene and carbon disulfide performance evaluations were performed using Summa® canisters. The ammonia performance evaluation used an ammonia converter and an nitrogen oxide monitor. Ammonia was converted to nitrogen oxide and then monitored using the API (SN 142). The ammonia performance evaluation passed, as did the dilution system performance evaluation, confirming that the Environics was functioning properly. Next, the GC/FID analysis was checked by analyzing an independent cylinder of both benzene and carbon disulfide. The results from these two analyses agreed with the expected concentration; and, therefore, it was concluded that the GC analysis procedure was correct.

At the same time that the carbon disulfide and benzene samples were being collected, methane, propane, and a mixed hydrocarbon were being sampled for verification of a different SafEye monitor. The same operator conducted both sampling efforts. The only difference in the Summa® canister collection technique was that two different flow orifices were used on the inlets of the canisters to control the flow rate into the canister. It was desired that, over a 5-minute period, approximately 3 liters of sample be collected. This was, in fact, what occurred. The performance evaluation results from the methane, propane, and mixed gas were satisfactory. Since the only difference between the two sampling efforts (benzene/carbon disulfide vs. methane/propane/mixed gas) was the use of different critical flow orifices, it was concluded that the orifice used during the benzene and carbon disulfide sampling effort allowed ambient air to flow into the Summa® canister, effectively diluting the canister samples and causing the audit to show lower than expected results. Therefore, the concentration delivered to the target gas cell is reported as the nominal value displayed by the Environics 2020 dilution system.

4.5.3 Data Quality Audit

Battelle's Quality Manager audited at least 10% of the verification data acquired in the verification test. The Quality Manager traced the data from initial acquisition, through reduction and statistical comparisons, to final reporting. All calculations performed on the data undergoing audit were checked.

Chapter 5
Statistical Methods

The following statistical methods were used to reduce and generate results for the performance factors.

5.1 Minimum Detection Limit

The MDL is defined as the smallest concentration at which the monitor's expected response exceeds the calibration curve at the background reading by two times the standard deviation (σ_o) of the monitor's background reading, i.e.,

$$MDL = 2\sigma_o$$

5.2 Linearity

Both concentration and source strength linearity were assessed by linear regression with the certified gas concentration as independent variable and the monitor's response as dependent variable. Linearity was assessed in terms of the slope, intercept, and correlation coefficient of the linear regression.

$$y = mx + b$$

where y is the response of the monitor to a target gas, x is the concentration of the target gas in the gas cell, m is the slope of the linear regression curve, and b is the zero offset.

5.3 Accuracy

The relative accuracy (A) of the monitor with respect to the target gas was assessed by

$$A = \frac{\left|\overline{T} - \overline{R}\right|}{\overline{R}} \times 100$$

where the bars indicate the mean of the reference (R) values and monitor (T) results.

5.4 Precision

Precision was reported in terms of the percent RSD of a group of similar measurements. For a set of measurements given by T_1, T_2, ..., T_n, the standard deviation (σ) of these measurements is

$$\sigma = \left[\frac{1}{n-1} \sum_{k=1}^{n} (T_k - \overline{T})^2 \right]^{1/2}$$

where $\overline{T}$ is the average of the monitor's readings. The RSD is calculated from

$$RSD = \left| \frac{\sigma}{\overline{T}} \right| \times 100$$

and is a measure of the measurement uncertainty relative to the absolute value of the measurement. This parameter was determined at one concentration per gas.

5.5 Interferences

The extent to which interferences affected MDL and accuracy was calculated in terms of sensitivity of the monitor to the interferant species, relative to its sensitivity to the target gas, at a fixed path length and integration time. The relative sensitivity is calculated as the ratio of the observed response of the monitor to the actual concentration of the interferant. For example, a monitor that indicates 26 ppm*m of cyclohexane in air with an interference concentration of 100 ppm*m of carbon dioxide indicates 30 ppm*m of cyclohexane when the carbon dioxide concentration is changed to 200 ppm*m. This would result in an interference effect of $(30\ \text{ppm*m} - 26\ \text{ppm*m})_{\text{cyclohexane}}/(200\ \text{ppm*m} - 100\ \text{ppm*m})_{CO_2} = 0.04$, or 4% relative sensitivity.

Chapter 6
Test Results

The results of the verification test of the SafEye 420 are presented in this section, based upon the statistical methods described in Chapter 5. The monitor was challenged with carbon disulfide, benzene, and ammonia over path lengths of 30 to 100 meters. These gases were chosen because they are representative of gases monitored by this monitor. Test parameters included MDL, linearity, accuracy, precision, and the effects of atmospheric interferants on concentration measurements. The SafEye 420 was programmed to respond using theoretical and limited empirical calibration data. The vendor indicated that the performance results from this verification test will be used to make calibration adjustments that improve performance as part of the SafEye 420's development program.

6.1 Minimum Detection Limit

The MDL was calculated from measurements in which there were no target gases in the gas cell, but the monitor analyzed the absorption spectra for the presence of a target gas. The data used to determine the MDL were obtained under several experimental conditions, including different path lengths and integration times, as shown in Table 6-1. Table 6-2 shows the results of the MDL calculations.

The results in Table 6-2 show that the SafEye 420 has an MDL of between 0.096 and 0.515 ppm*m for carbon disulfide, 0.111 and 0.340 ppm*m for benzene, and 0.081 and 3.53 ppm*m for ammonia, at the path lengths and integration times tested. Changing the integration times from 1 to 5 minutes increased the MDL for carbon disulfide. Changing the path lengths between 30 and 90 meters substantially reduced the MDLs for carbon disulfide and benzene. The opposite path length effect was seen for ammonia.

6.2 Linearity

6.2.1 Source Strength Linearity

Table 6-3 shows the results from this evaluation of source strength linearity, and Figure 6-1 shows a plot of the effect that the light signal level has on the monitor's measurements. In Table 6-3, the relative signal power is the measure of light attenuation during that measurement.

Table 6-1. Minimum Detection Limits Data for the SafEye 420

Measure-ment Number	Carbon Disulfide Path Length (m) 30, Integration Time (min) 1	Carbon Disulfide Path Length (m) 30, Integration Time (min) 5	Carbon Disulfide Path Length (m) 65, Integration Time (min) 1	Benzene Path Length (m) 30, Integration Time (min) 1	Benzene Path Length (m) 90, Integration Time (min) 1	Ammonia Path Length (m) 30, Integration Time (min) 1	Ammonia Path Length (m) 90, Integration Time (min) 1
	Concentration (ppm*m)						
1	-0.542	0.613	-0.241	0.362	-0.241	-0.542	4.28
2	0.060	-0.492	-0.241	-0.291	-0.241	-0.492	3.73
3	-0.492	-0.542	-0.241	-0.291	-0.291	-0.542	3.73
4	-0.492	-0.593	-0.241	-0.241	-0.342	-0.492	5.63
5	-0.492	-0.593	-0.291	-0.191	-0.342	-0.492	3.63
6	-0.492	-0.593	-0.291	-0.191	-0.291	-0.492	4.33
7	-0.442	-0.593	-0.291	-0.191	-0.291	-0.492	2.97
8	-0.492	-0.593	-0.291	-0.141	-0.342	-0.492	3.83
9	-0.442	-0.643	-0.291	-0.090	-0.342	-0.492	2.92
10	-0.492	-0.593	-0.291	-0.040	-0.342	-0.492	5.13
11	-0.492	-0.643	-0.342	0.060	-0.392	-0.492	3.68
12	-0.442	-0.643	-0.342	0.161	-0.342	-0.492	3.07
13	-0.442	-0.643	-0.342	0.060	-0.342	-0.492	2.07
14	-0.442	-0.643	-0.342	0.110	-0.392	-0.492	2.82
15	-0.492	-0.643	-0.342	0.161	-0.342	-0.492	2.32
16	-0.492	-0.643	-0.342	0.161	-0.392	-0.492	2.62
17	-0.442	-0.693	-0.342	0.060	-0.392	-0.492	2.67
18	-0.492	-0.643	-0.342	0.010	-0.392	-0.442	4.38
19	-0.492	-0.693	-0.342	0.161	-0.442	-0.442	3.12
20	-0.492	-0.693	-0.342	0.010	-0.442	-0.442	3.22
21	-0.442	-0.693	-0.392	-0.141	-0.392	-0.492	2.37
22	-0.442	-0.693	-0.392	-0.090	-0.392	-0.442	3.32
23	-0.492	-0.693	-0.392	-0.090	-0.392	-0.392	3.48
24	-0.492	-0.743	-0.392	-0.241	-0.392	-0.392	5.03
25	-0.492	-0.743	-0.342	-0.141	-0.442	-0.392	11.1

Table 6-2. Minimum Detection Limits of the SafEye 420

Target Gas	Path Length (m)	Integration Time (min)	MDL (ppm*m)
Carbon disulfide	30	1	0.222
Carbon disulfide	30	5	0.515
Carbon disulfide	90	1	0.096
Benzene	30	1	0.340
Benzene	90	1	0.111
Ammonia	30	1	0.081
Ammonia	90	1	3.53

Table 6-3. Source Strength Linearity of the SafEye 420

Relative Signal Power	Benzene Concentration (ppm*m)	Monitor Response (ppm*m)
1.00	50.3	84.1
0.79	50.3	84.2
0.57	50.3	85.7
0.38	50.3	86.3
1.00	201	213
0.79	201	213
0.57	201	213
0.38	201	214

For example, a relative signal power of 0.79 means that the light level for that test is 79% of what the light level is during normal operating conditions. The benzene concentration is the concentration of gas being delivered to the gas cell during the measurement, and the monitor response is the resulting reading from the SafEye 420. The source strength results show that there is little degradation in monitor performance during conditions of declining source strength. The data indicate a slight effect of source strength on benzene measurement, with source reductions of up to 62%. The slopes of the linear regression lines of -0.49 and -4.0 , shown in Figure 6-1, indicate that reducing the source strength had a slightly positive effect on the monitor's response over the range tested.

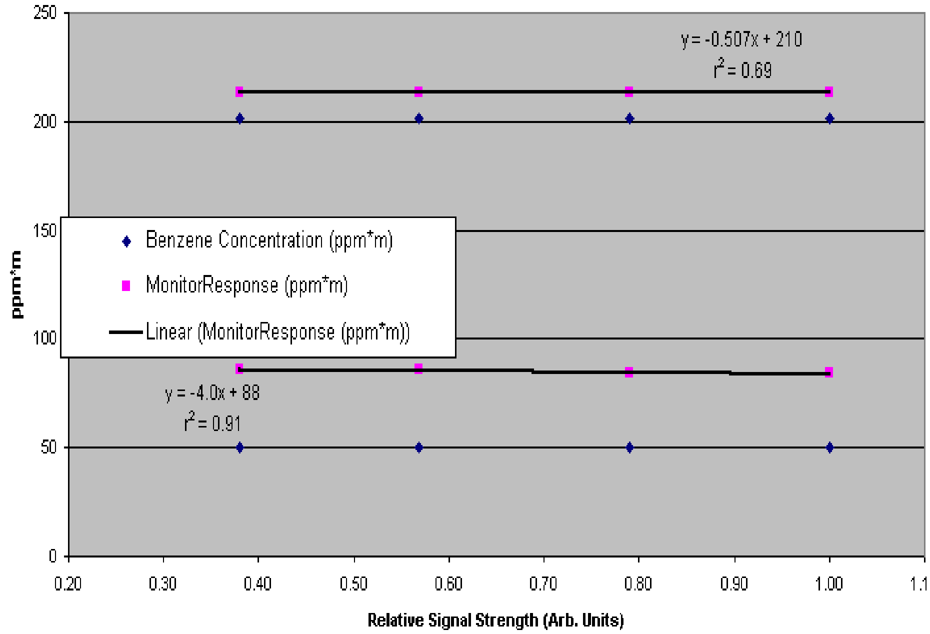

Figure 6-1. Source Strength Linearity Plot of the SafEye 420

6.2.2 Concentration Linearity

Table 6-4 and Figures 6-2 through 6-4 show the path-average results of the evaluation of concentration linearity. The regression analysis results are shown on the individual figures.

The target gas concentration values used for this calculation are based on the concentration of gas delivered by the Environics 2020 dilution system and not the concentrations as determined by GC (as explained in Section 4.5.2 of this report).

The concentration linearity results show that the SafEye 420 has a linear response over the concentration ranges tested. The monitor response as given by the slope of the linear regression line is 0.56 for carbon disulfide, with an r^2 value of 0.47; a slope of 0.73 for benzene, with an r^2 value of 0.59; and a slope of 1.2 for ammonia, with an r^2 value of 0.95.

The best results were found when the monitor was challenged with ammonia. The results from challenges of benzene and carbon disulfide show that the instrument generally responds to both compounds; however, the low r^2 values show that the instrument's response is variable and not linear over the tested range.

6.3 Accuracy

The accuracy of the SafEye 420 was evaluated at each target gas concentration introduced into the cell. These concentrations were introduced at the path lengths and integration times shown in Table 6-5. The accuracy results compare the monitor response with the target gas concentration as delivered by the Environics 2020 diluter. The SafEye 420's relative accuracy ranged from

Table 6-4. Concentration Linearity Data for the SafEye 420

Target Gas	Target Gas Concentration (ppm*m)	Monitor Response (ppm*m)
Carbon disulfide	50.3	113
Carbon disulfide	99.8	213
Carbon disulfide	194	214
Carbon disulfide	99.8	190
Carbon disulfide	99.8	208
Benzene	50.3	86.7
Benzene	99.8	200
Benzene	201	209
Benzene	99.8	118
Benzene	99.8	156
Ammonia	50.3	29.3
Ammonia	99.8	66.7
Ammonia	201	210
Ammonia	99.8	108
Ammonia	99.8	101

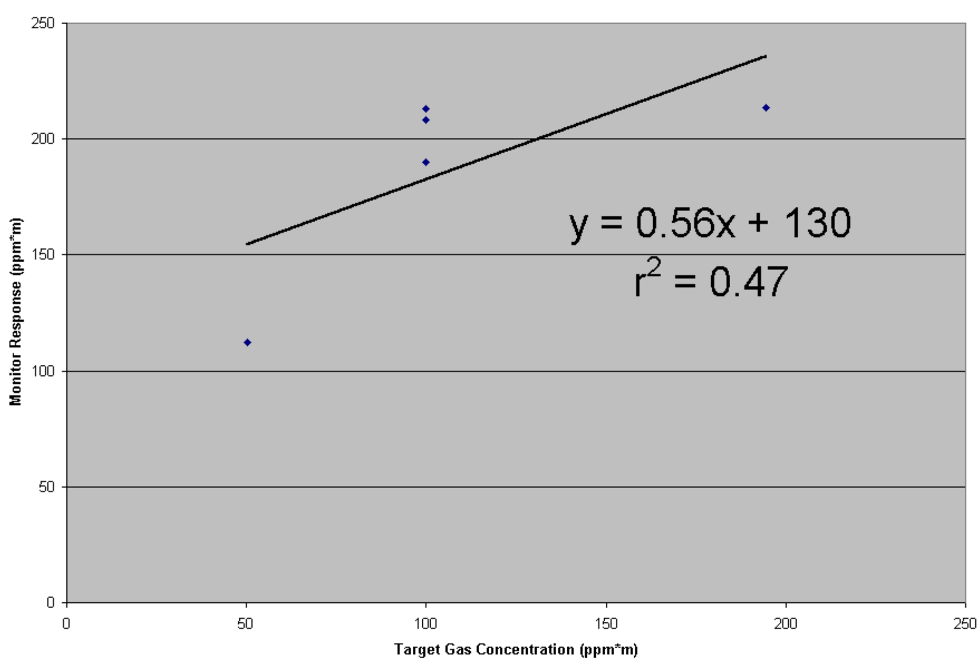

Figure 6-2. Concentration Linearity Plot of the SafEye 420 Challenged with Carbon Disulfide

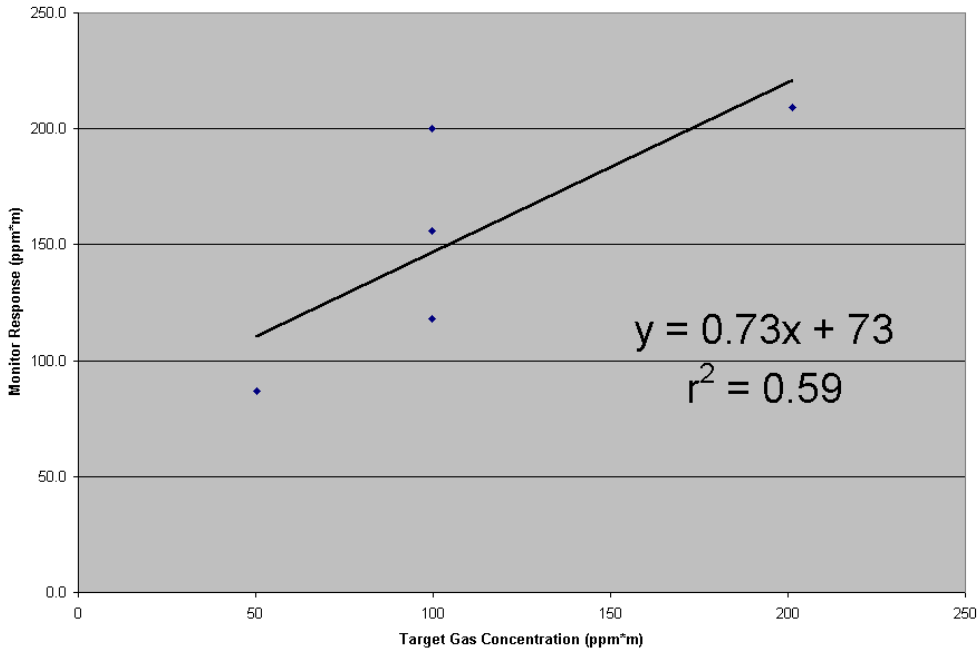

Figure 6-3. Concentration Linearity Plot of the SafEye 420 Challenged with Benzene

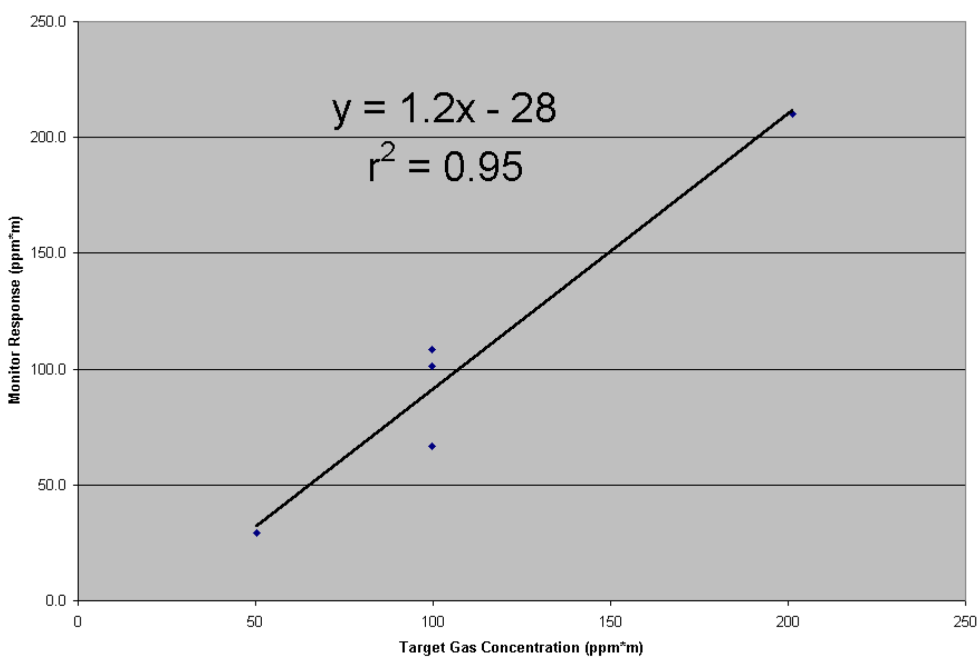

Figure 6-4. Concentration Linearity Plot of the SafEye 420 Challenged with Ammonia

Table 6-5. Results of Accuracy Tests for the SafEye 420

Target Gas	Target Gas Concentration (ppm*m)	Path Length (m)	Integration Time (min)	Monitor Response (ppm*m)	Relative Accuracy (%)
Carbon disulfide	50.3	30	1	113	126
Carbon disulfide	99.8	30	1	213	113
Carbon disulfide	194	30	1	214	10
Carbon disulfide	99.8	100	5	190	90
Carbon disulfide	99.8	90	1	208	108
Benzene	50.3	30	1	86.7	73
Benzene	99.8	30	1	200	100
Benzene	201	30	1	209	4
Benzene	99.8	100	5	118	18
Benzene	99.8	90	1	156	56
Ammonia	50.3	30	1	29.3	-41
Ammonia	99.8	30	1	66.7	-33
Ammonia	201	30	1	210	4
Ammonia	99.8	100	5	108	8
Ammonia	99.8	90	1	101	1

10 to 126% for carbon disulfide, from 4 to 100% for benzene, and from -41 to 8% for ammonia. Integration time had little effect on the accuracy of the SafEye 420.

The results from the accuracy tests show that the monitor is most accurate when challenged with ammonia. Both carbon disulfide and benzene have widely varying accuracy results, with the best relative accuracy at the shortest tested path length (30 meters) and concentrations at the high end of the instrument's operating range (200 ppm*m in the cell); however, the same 30-meter path length also resulted in the poorest accuracy when challenged at lower concentrations. Increasing the integration time from 1 to 5 minutes had no consistent effect on the relative accuracy results.

6.4 Precision

Precision data were collected during measurement #9 (see Table 3-2) using an integration time of 1 minute and a path length of 100 meters. The target gas was introduced into the gas cell at a fixed concentration, and 25 successive analyses were made for the target gas. The data from these measurements are found in Table 6-6, and the results are shown in Table 6-7. Table 6-7 shows precision of 0.00% RSD for carbon disulfide, 3.52% RSD for benzene, and 2.45% RSD for ammonia. The variability for benzene and ammonia occurs in the form of sporadic individual readings that differ sharply from the other values, which are highly consistent.

The 0.00% RSD found for the carbon disulfide is probably the result of a saturated signal. At the concentration used for this test, the monitor produced a constant, saturated signal of 213 ppm*m, resulting in a zero reading. This may also be the case with benzene, although there were several

Table 6-6. Data from Precision Tests on the SafEye 420

	Target Gas		
Analysis #	Carbon Disulfide (ppm*m)	Benzene (ppm*m)	Ammonia (ppm*m)
1	213	213	208
2	213	213	211
3	213	192	210
4	213	213	213
5	213	213	214
6	213	213	191
7	213	213	214
8	213	213	214
9	213	213	214
10	213	192	214
11	213	213	215
12	213	213	213
13	213	213	215
14	213	213	214
15	213	213	215
16	213	213	215
17	213	213	215
18	213	213	215
19	213	213	215
20	213	192	215
21	213	213	215
22	213	213	215
23	213	213	215
24	213	213	215
25	213	213	215

Table 6-7. Results of Precision Tests on the SafEye 420[a]

Target Gas	Gas Cell Concentration (ppm*m)	Average Monitor Response (ppm*m)	Standard Deviation (ppm*m)	Relative Standard Deviation (%)
Carbon disulfide	194	213	0.000	0.000
Benzene	201	211	7.09	3.52
Ammonia	201	213	4.92	2.45

[a] Integration time = 1 minute, path length = 30 meters.

occasions where lower than saturation level readings (three instances of 192 ppm*m) were recorded.

6.5 Interferences

Interference tests of the SafEye 420 evaluated the effects that the common atmospheric interferants ozone and oxygen have on the monitor's ability to determine the concentration of the target gases and on the MDL for the target gases. Because of the large relative accuracies that were seen during the accuracy tests, it is difficult to determine whether changes in the monitor's ability to perform properly when challenged with the target gas is a result of interfering compounds in the atmosphere or of other effects. The accuracy results were best for ammonia. Examining the results from the ammonia challenge, it can be seen that the longer path lengths of 90 and 100 meters are more accurate than the 30-meter path length, indicating that the increasing presence of interfering compounds did not adversely affect the monitor's ability to measure ammonia. Tables 6-8 and 6-9 show the data used to determine the interference effects of ozone and oxygen on the concentration and MDL.

Table 6-8. Concentration Data from Interference Tests on the SafEye 420

Target Gas	Path Length (m)	Concentration of Oxygen (%*m)	Concentration of Ozone (ppb*m)	Target Gas Concentration (ppm*m)	Monitor Response (ppm*m)	Relative Accuracy (%)
Carbon disulfide	30	627	1740	99.8	213	114
Carbon disulfide	90	1881	3330	99.8	208	109
Carbon disulfide	100	2090	2700	99.8	190	90.5
Benzene	30	627	480	99.8	200	101
Benzene	90	1881	4860	99.8	156	56.3
Benzene	100	2090	1300	99.8	118	18.4
Ammonia	30	627	1380	99.8	66.7	-33.2
Ammonia	90	1881	1620	99.8	101	1.71
Ammonia	100	2090	3500	99.8	108	8.55

Table 6-9. MDL Data from Interference Tests on the SafEye 420

Target Gas	Path Length (m)	Concentration of Oxygen (%*m)	Concentration of Ozone (ppb*m)	MDL (ppm*m)
Carbon disulfide	30	627	1650	0.222
Carbon disulfide	90	1881	3960	0.096
Benzene	30	627	420	0.340
Benzene	90	1881	4680	0.111
Ammonia	30	627	1170	0.081
Ammonia	90	1881	1890	3.53

Both ozone and oxygen have absorption features in the same spectral region that the SafEye 420 uses to analyze for the target compounds. Because the concentration of these two potential interferants is usually much greater than the concentration of the compounds of interest, the presence of these compounds can make analyzing for the target compounds difficult. The SafEye 420 uses various methods to deal with these interferants, and this test evaluated the effectiveness of these methods.

These results did not permit calculation of relative sensitivity, as described in Section 5.5. Instead, a comparison of the measured concentrations was made to the input concentrations.

Changing the total number of ozone and oxygen molecules in the path length had little effect on the monitor's MDL for the target gas. For both carbon disulfide and benzene, lower MDLs were found with the longer path length, despite the increased amounts of ozone and oxygen in the optical path.

6.6 Other Factors

6.6.1 Costs

The cost of the SafEye 420, as tested, ranges from $7,000 to $12,000, according to Spectrex.

6.6.2 Data Completeness

All of the expected data were collected except for measurement #15 for benzene and ammonia. Data from measurement #15 for benzene and ammonia were not collected because the vendor declined to conduct these two measurements.

Chapter 7
Performance Summary

The SafEye 420 minimum detection limits ranged between 0.096 and 0.515 ppm*m for carbon disulfide, 0.111 and 0.340 ppm*m for benzene, and 0.081 and 3.53 ppm*m for ammonia, at the path lengths and integration times tested. Changing the integration times from 1 to 5 minutes increased the MDL for carbon disulfide. Changing the path lengths between 30 and 90 meters substantially reduced the MDLs for carbon disulfide and benzene. The opposite path length effect was seen for ammonia.

The tests of the effects of source strength on the measurement capability of the monitor showed that there was little to no degradation of monitor performance, with reductions in source strength of up to 62%. The slopes at two different test concentrations were slightly negative, suggesting that reducing the source strength may have a slight positive effect on the monitor's response over the range tested.

The concentration linearity results showed that the SafEye 420 had a slope of 0.56 for carbon disulfide, with an r^2 value of 0.47 over a range of 50.3 to 194 ppm*m; a slope of 0.73 for benzene, with an r^2 value of 0.59 over a range of 50.3 to 201 ppm*m; and a slope of 1.2 for ammonia, with an r^2 value of 0.95 over a range of 50.3 to 201 ppm*m.

Percent relative accuracy was evaluated over the same ranges of concentration noted above for concentration linearity testing. Relative accuracy over these ranges was 10 to 126% for carbon disulfide, from 4 to 100% for benzene, and from -41 to 8% for ammonia. The accuracy tests show that the monitor is most accurate when challenged with ammonia. Both carbon disulfide and benzene showed the best relative accuracy at the shortest tested path length (30 meters) and a concentration at the high end of of the instrument's operating range (200 ppm*m in the cell); however, the same 30-meter path length also resulted in the poorest accuracy when challenged at lower concentrations.

Precision results showed that the SafEye 420 had an RSD of about 0.00% for carbon disulfide at a gas cell concentration of 194 ppm*m, a 3.52% RSD for benzene at a concentration of 201 ppm*m, and a 2.45% RSD for ammonia at a concentration of 201 ppm*m at a path length of 30 meters.

Analysis of the effects of interferences of oxygen and ozone on the measuring ability of the SafEye 420 showed that the MDLs were not affected. However, when examining only the accuracy results from the ammonia challenge, it can be seen that the longer path lengths of

90 meters and 100 meters are more accurate than the 30-meter path length, indicating that the increasing presence of interfering compounds did not adversely affect the monitor's ability to measure ammonia. The results from the benzene and carbon disulfide challenges showed no consistent effects, especially in light of the large relative accuracy values found for these two gases during the accuracy test.

Chapter 8
References

1. *Test/QA Plan for Verification of Optical Open-Path Monitors*, Battelle, Columbus, Ohio, October 28, 1999.

2. *Compendium Method TO-16 Long-Path Open-Path Fourier Transform Infrared Monitoring of Atmospheric Gases*, EPA-625/R-96/010b, U.S. Environmental Protection Agency, Cincinnati, Ohio, January 1999.

3. *Quality Management Plan (QMP) for the ETV Advanced Monitoring Systems Pilot*, Version 2.0, U.S. EPA Environmental Technology Verification Program, Battelle, Columbus, Ohio, October 2000.

Appendix A
Data Recording Sheet

ETV - Spectrex, Inc

Etv Advanced Monitoring Systems Pilot Verification of Optical Open Path Monitor Round Two

Meas. # (From test/QA plan Table 1):			
Vendor :	Spectrex, Inc.	Cell Temp (F):	Int. Time (min):
Instrument Model:		CO2 Conc. (ppm):	Pathlength (meters):
Location:	Battelle, West Jefferson, Ohio	Ambient RH (%):	Cell Length (cm):
Vendor Operator:	Jay Cooley	Ambient Temp (F):	Sample Gas:
Time:		Ozone Conc. (ppb):	Sample Gas Conc. in Cell (ppm):
Date:			

Data Point #	Meas. Result (volts)
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	
13	
14	
15	
16	
17	
18	
19	
20	
21	
22	
23	
24	
25	

Note: Measurement #s (3,4,5,10,11&12 only)

Neutral Density Filter #	Desired Attenuation	Monitor response (volts)
none	0	
1	20%	
2	40%	
3	60%	
none	0	

Data taken by:	Date:
Data reviewed by:	Date:

data sheet.xls