March 2001

Environmental Technology Verification Report

SPECTREX INC. SAFEYE 227 INFRARED OPEN-PATH MONITOR

Prepared by

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ETV ETV ETV

March 2001

Environmental Technology Verification Report

ETV Advanced Monitoring Systems Center

Spectrex Inc. SafEye 227 Infrared Open-Path Monitor

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Notice

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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.htm.

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

The authors wish to acknowledge the support of all those who helped plan and conduct the verification test, analyze the data, and prepare this report. In particular we would like to thank Paul Webb and Andy Montgomery of Battelle. We also acknowledge the participation of Jay Cooley and Eric Zinn of Spectrex Inc. in this verification test.

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List of Abbreviations

AMS	Advanced Monitoring Systems
CEM	continuous emission monitor
CO_2	carbon dioxide
EPA	U.S. Environmental Protection Agency
ETV	Environmental Technology Verification
GC	gas chromatograph
GC/FID	gas chromatography/flame ionization detection/mass spectrometry
Hg	mercury
H_2O	water
IR	infrared
LEL*m	lower explosive limit meters
MDL	minimum detection limit
ND	neutral density
NIST	National Institute of Standards and Technology
N_2	nitrogen
ppmC	parts per million of carbon
QA/QC	quality assurance/quality control
QMP	Quality Management Plan
RH	relative humidity
RSD	relative standard deviation
TSA	technical systems audit

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 regulators, 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 227 infrared (IR) 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 227. The following description of the SafEye 227 is based on information provided by the vendor.

The SafEye 227 is an alarm system that detects hydrocarbons with a high-frequency IR flash source and two absorbed band sensors centered at the 3.4-µ wavelength. This design also employs a dual-band reference that minimizes environmental factors such as moisture and other background gases to maintain a high signal-to-noise ratio. Other performance features include three levels of logic, four levels of automatic gain control, four built-in calibrations, two span settings, and four flash rates. Operational integrity can be maintained with up to three degrees of misalignment or up to 90% signal obscuration.

The SafEye 227 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.

Figure 2-1. Spectrex SafEye 227 IR Open-Path Monitor

The detector's microprocessor software interprets the data and provides output signals in terms of lower explosive limit *meters (LEL*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).

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 227 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 227 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 227

Gas	Concentration Level	Target Gas Concentration (LEL*m)[a]	Equivalent Gas Cell Concentration[b]
Methane	c1	1.0	33.3%
	c2	2.0	66.6%
	c3	3.0	100.0%
Propane	c1	1.0	14.8%
	c2	2.5	35.0%
	c3	5.0	70.0%
Mixture[c]	c1	0.96	30.7% methane 0.56% propane 80.0 ppm ethane
	c2	1.9	61.3% methane 1.12% propane 160 ppm ethane
	c3	2.9	92.0% methane 1.70% propane 240 ppm ethane

[a]LEL*m=lower explosive limit meters.
[b]Length of gas cell = 15.0 cm.
[c]Balance of gas mixtures was N_2.

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

Meas. #	Gas Cell Conc.	Activity	# of Spectra	Times (min) Integrate	Times (min) Equilibrate	Path Length (m)	Verification Parameter Calculated
	N_2	Change gas & stabilize			10	40	
1	N_2	Collect spectra	25	1		40	Accuracy, Concentration linearity, MDL
	c1[a]	Change gas & stabilize			10	40	
2	c1	Collect spectra	5	1		40	Accuracy, Concentration linearity
3	c1	Collect spectra - ND 1[b]	5	1		40	Source strength linearity
4	c1	Collect spectra - ND 2[b]	5	1		40	Source strength linearity
5	c1	Collect spectra - ND 3[b]	5	1		40	Source strength linearity
	N_2	Change gas & stabilize			10	40	
6	N_2	Collect spectra	5	1		40	Accuracy, Concentration linearity
	c2	Change gas & stabilize			10	40	
7	c2	Collect spectra	5	1		40	Accuracy, Concentration linearity, Interference Effect (Int.)
	N_2	Change gas & stabilize			10	40	
8	N_2	Collect spectra	5	1		40	Accuracy, Concentration linearity
	c3	Change gas & stabilize			10	40	
9	c3	Collect spectra	25	1		40	Accuracy, Concentration linearity, precision
10	c3	Collect spectra - ND 1[b]	5	1		40	Source strength linearity
11	c3	Collect spectra - ND 2[b]	5	1		40	Source strength linearity
12	c3	Collect spectra - ND 3[b]	5	1		40	Source strength linearity
15	N_2	Collect spectra	25	5		40	Concentration linearity, MDL
		Change to Path length 2			20	130	
16	N_2	Collect spectra	5	5		130	Int.
	c2	Change gas & stabilize			10	130	
17	c2	Collect spectra	5	5		130	Int., Accuracy, Concentration linearity
	N_2	Change gas & stabilize			10	130	
18	N_2	Collect spectra	5	5		130	Int., Accuracy, Concentration linearity
		Change to Path length 3			20	65	
19	N_2	Collect spectra	5	1		65	Int., Accuracy, Concentration linearity
	c2	Change gas & stabilize			10	65	
20	c2	Collect spectra	5	1		65	Int., Accuracy, Concentration linearity
	N_2	Change gas & stabilize			10	65	
21	N_2	Collect spectra	25	1		65	Int., MDL

[a]See Table 3-1 for values of c1-c3 for three target gases.
[b]Activities completed for methane only.

The target gas concentrations are presented in LEL*m. This refers to the lower flammability limit of each target gas in air. The LELs for methane, propane, and ethane are 5.0%, 2.1%, and 3.0% by volume, respectively.[3]

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 m) 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 2000. The open space in the foreground of Figure 3-1 shows the test site at Battelle's West Jefferson facility.

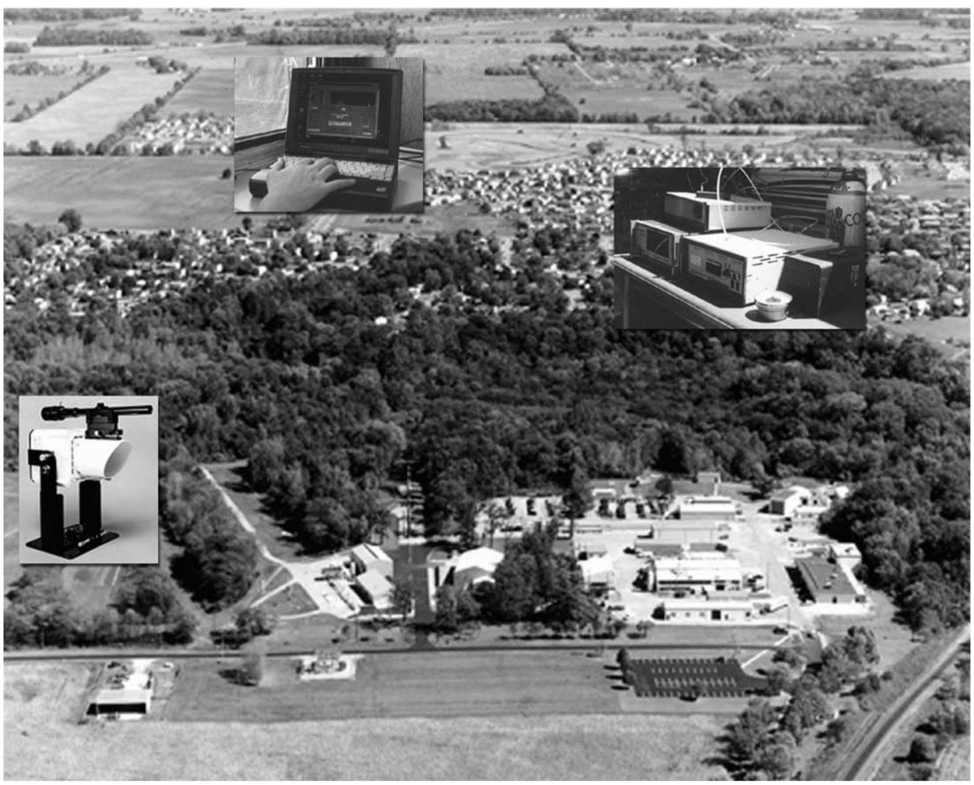

Figure 3-1. Test Site at West Jefferson Facility

The SafEye 227 was challenged with the target gases at the concentrations shown in Table 3-1, and the SafEye 227 measurement of light absorption by the monitor 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

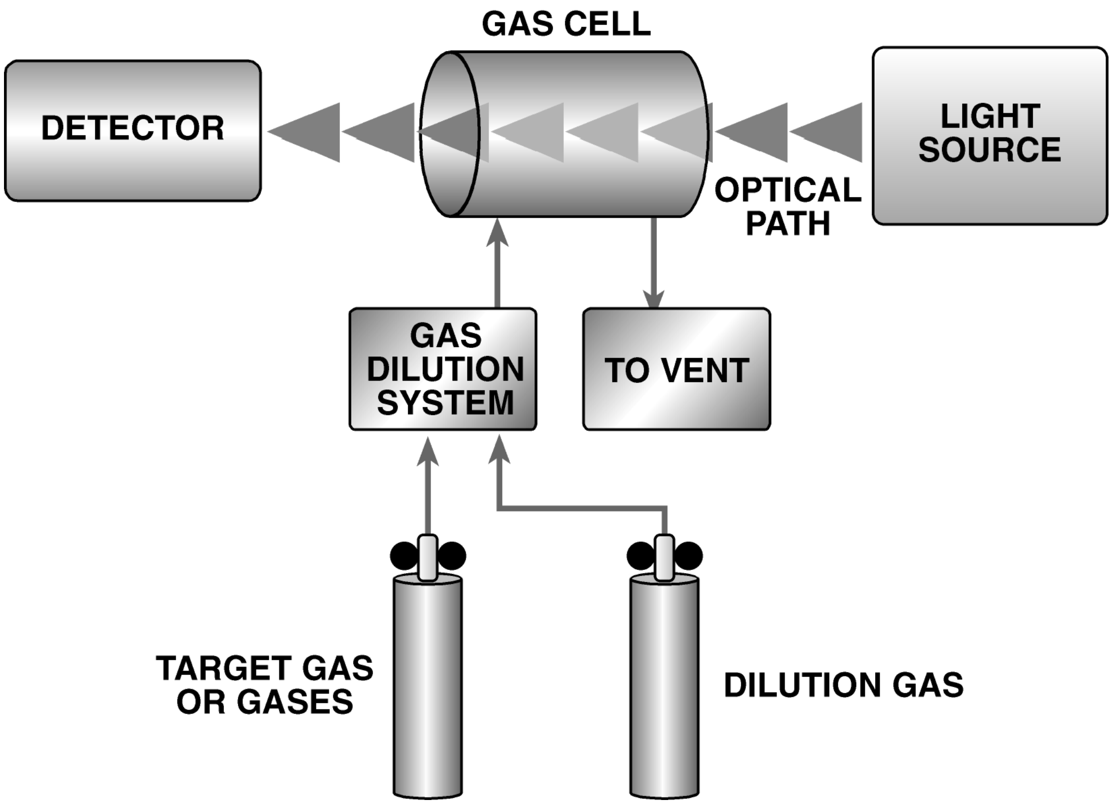

Figure 3-2. Optical Open-Path Monitor Setup

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.

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 test were NIST-traceable gases provided by Matheson Tri-Gas Inc. Gravimetrically blended cylinders of methane; propane; and a mixture of methane, propane, and ethane were used and specified to have an accuracy of 2%.

3.3.2 Dilution Gas

The dilution gas was acid rain continuous emission monitor (CEM) zero grade nitrogen 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 detector. 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.

3.3.6 Relative Humidity (RH) Sensor

The RH sensor used to determine the ambient air humidity was an Omega CT485B RH monitor (Serial No. 704012206W1) that used the chilled mirror principle. This sensor was operated in accordance with the manufacturer's instructions. The manufacturer's accuracy specification of this monitor was ± 3% RH.

3.3.7 Carbon Dioxide Monitor

An electrochemical monitor (TSI Model 8551 carbon dioxide monitor, Serial No. 30357) was used to monitor the level of carbon dioxide in ambient air during interference measurements. This monitor was operated in accordance with the manufacturer's instructions.

3.3.8 Target Gas Measurement

The concentrations of the target gases provided to the gas cell were determined by collecting a sample at the exit of the gas cell using a pre-cleaned Summa® stainless steel air sampling canister. The collected sample was then analyzed using gas chromatography with flame ionization (GC/FID) or thermal conductivity detection.

A Varian 3700 gas chromatograph was used to analyze for methane at the percent concentration levels. A thermal conductivity detector was used to measure the signal response. The compounds were resolved using a 3-foot by 1/4-inch outside diameter molecular sieve 5A column and a 5-foot by 1/4-inch outside diameter Porapak Q column connected in series. The columns were operated isothermally at 100°C. Argon was the carrier gas (40 cc/minute). A 1-cc sample loop and six-port valve were used to manually inject samples and gas standard mixtures. Data acquisition and peak integration were accomplished with a PC equipped with Chrom Perfect software.

A Varian 3700 gas chromatograph was used to analyze for propane at the percent concentration levels. A thermal conductivity detector was used to measure the signal response. The compounds were resolved using an Altech CTR-I column. A 6-foot by 1/8-inch outside diameter inner column was used for methane and was composed of a propriety porous polymer mixture. The column was operated isothermally at 180°C. Helium was the carrier gas (25 cc/minute). A 1-cc sample loop and six-port valve were used to manually inject samples and gas standard mixtures. Data acquisition and peak integration were accomplished with a PC equipped with Chrom Perfect software.

A Varian 3600 gas chromatograph was used to analyze for ethane at the ppm level and propane at the low percent concentration level. An FID was used to measure the signal response. The compounds were resolved using a stainless steel 15-foot by 1/8-inch outside diameter column with phenyl isocyanate/Porasil C packing. The column was operated isothermally at 40°C. Helium was the carrier gas (25 cc/minute). A 1-cc sample loop and six-port valve were used to manually inject samples and gas standard mixtures. 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 single-beam spectra using integration times of 1 and 5 minutes. The single-beam spectra were then used to create absorption spectra, using each single-beam spectrum as the background for the next spectrum. The absorption spectra were created by using the first and second single-beam spectra, the second and third, the third and fourth, etc. The resulting 25 absorption spectra were then analyzed for the target gas. This sequence of measurements was conducted at both integration times; twice at a 40-meter path length and once at a 65-meter path length. The MDL was defined as two times the standard deviation of the calculated concentrations from the 25 absorption spectra.

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.

Concentration linearity was investigated by challenging the SafEye 227 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 a single-beam spectrum was recorded. The target gas was then introduced into the cell and, after flushing with at least five cell volumes, a second single-beam spectrum of the target gas was obtained. The cell was again flushed with at least five cell volumes of nitrogen, and a third spectrum was recorded. The three spectra were analyzed for the target gas, using the background selected by the vendor. The concentration of the target gas was the result of analyzing the second spectrum minus the average of the first and third (flushed cell) spectra.

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 5-minute 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 absorption spectra of the target gas were obtained. These spectra were analyzed for the target gas. 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 each of the target gases (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. The purpose of the interference measurements was to determine the effects of the ambient atmospheric gases on accuracy and MDL of the SafEye 227. 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 40 meters. The gas cell was supplied with nitrogen; and, after flushing with at least five cell volumes, five single-beam spectra were recorded. Next, the target gas was introduced into the cell and, after similarly flushing the cell, five single-beam spectra were recorded. Finally, nitrogen was again introduced into the cell, and five spectra were recorded.

The path length was then set to 130 and to 65 meters, and the entire measurement procedure was repeated. Atmospheric concentrations of water and carbon dioxide were recorded at the beginning and end of these measurements. The extent of interference was assessed in terms of the monitor's sensitivity to these interferant gases in the optical path.

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(4) and the test/QA plan(1) for this verification test.

4.1 Data Review and Validation

Test data were reviewed and approved 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 Summa® canister 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 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 was, therefore, conducted only for a single gas.

- 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 short and 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 227. In this verification test, path lengths of 40, 65, and 130 meters were used. The test/QA plan did not specify gases for this IR technology.

- Gases 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.

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.

- The independent performance evaluation conducted for relative humidity on September 23, 2000, gave results outside the acceptance criterion for this measurement set forth in the test/QA plan.

- Measurement #15 was performed for a 1-minute integration time instead of a 5-minute integration time.

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 227.

4.3 Calibration

4.3.1 Gas Dilution System

Mass flow controllers in the Environics 2020 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 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 RH Sensor

The RH sensor was calibrated by Battelle's instrument calibration facility on September 21, 2000.

4.3.4 Carbon Dioxide Monitor

The carbon dioxide monitor was calibrated by the supplier before testing using a commercially prepared, certified standard of carbon dioxide in air. That standard was a certified gas of 0.20% carbon dioxide in N_2, NIST-traceable, with ± 2% analytical accuracy (Cylinder No. 55924, Air Liquide America).

4.3.5 Target Gas Measurement

The GC instrumentation was calibrated for the target gases using certified standards for each gas, with a multipoint calibration. A Scott II methane standard of 40% methane (Project #9286 Lot #92681C7) from Scott Specialty Gas was used to calibrate the Varian 3700 GC for methane. A cylinder of propane (Matheson Instrument Purity -99.5%) was used to calibrate the Varian 3700 gas chromatograph (GC) for the measurements conducted at percent levels. Finally, a Scott Specialty Gas calibration cylinder of 1020 ppmC propane (Scott cylinder # ALM025084) was used to calibrate the Varian 3600 for measurements of propane and ethane conducted at low percent levels.

4.4 Data Collection

Data acquisition was performed by both Battelle and the vendor during the test. 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. Data recorded by the vendor were turned over to Battelle staff immediately upon completion of the test procedure. Test records were then converted to Excel spreadsheet files.

Table 4-1. Summary of Data Recording Process for the SafEye 227 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., RH, 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	Vendor	Vendor Printout	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 technical systems audit was performed on another open-path verification test during the initial testing of this type of technology. The TSA of the test procedures was conducted on April 13 and 14, during the period of 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 Center QMP. Specifically, the calibration sources and methods used were reviewed and compared with test procedures specified 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 227.

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 Battelle 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 deviations concerning the temperature and RH performance evaluations listed in Section 4.2 of this report. The results from the performance evaluations are shown in Table 4-2. The temperature measurement agreed to within -0.4°C. The relative humidity agreed to only within 16% (i.e., within 8% RH at 50% RH).

The data quality of the study was not seriously impacted by the large percent difference between the expected and actual readings of the RH monitor. The RH measurement is used to calculate the absolute concentration of water vapor in the atmosphere in a test of the relative impact that changes in atmospheric water concentration have on the open-path monitor's ability to correctly measure the target gas of interest. That test is done by changing the optical path length by a large amount, in a short period of time. Thus, the absolute accuracy of the RH measurement is not of critical importance because the change in path length achieves the desired difference in water in the path. When the carbon dioxide gas standard was compared, the monitor reading agreed to within 1.4% of the expected value.

The target gas concentrations were audited by independent analysis of the test gas mixture supplied to the gas cell during verification testing. This procedure involved collecting a sample of the test gas mixture exiting the cell using a pre-cleaned and evacuated Summa®-polished sampling canister. This gas sample was analyzed for methane, propane, and the gas mixture described in Table 3-1. Calibration of the GC was based on the standards cited in Section 4.3.5. The results of the performance audit for the target gas concentrations were mostly within 10% of the expected concentrations, which met the test/QA plan criterion. Three of the four propane measurements had 14%, 14%, and 11% differences, which were outside the criterion. The mixture gas of methane, ethane, and propane was analyzed for methane and resulted in differences of -6.7%, -2.1%, and -2.5%, which met the test/QA plan criterion.

Table 4-2. Summary of Performance Evaluation Audit Procedures

Measurement Audited	Audit Procedure	Reference Reading	Monitor Reading	Difference	Acceptance Criteria
Temperature	Compare to independent temperature measurement (Hg thermometer)	19°C	18.6°C	-0.4°C	< 3°C
RH	Compare to independent RH measurement (wet/dry bulb device)	42% RH	50% RH	8% RH	± 5% RH
Carbon dioxide concentration	Compare measurement using another CO^2 standard from the same supplier	800 ppm	811 ppm	1.4%	± 10%
Methane	Compare to results of GC analysis of canister sample	100%	100.1%	0.1%	< 10%
Methane		66%	62.2%	-5.8%	< 10%
Methane		33%	32.3%	-2.1%	< 10%
Propane		14%	15.9%	14%	< 10%
Propane		35%	39.8%	14%	< 10%
Propane		70%	77.6%	11%	< 10%
Propane		0.56%	0.55%	-1.5%	< 10%
Mixture 1 - 31% Methane		31%	28.9%	-6.7%	< 10%
Mixture 2 - 61% Methane		61%	59.7%	-2.1%	< 10%
Mixture 3 - 92% Methane		92%	89.7%	-2.5%	< 10%

Field blank and background samples were also taken with Summa® canisters, with resulting analyses showing non-detects for the target gas concentrations.

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

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

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 of cyclohexane in air with an interference concentration of 100 ppm of carbon dioxide indicates 30 ppm of cyclohexane when the carbon dioxide concentration is changed to 200 ppm. This would result in an interference effect of $(30 \text{ ppm} - 26 \text{ ppm})_{cyclohexane}/(200 \text{ ppm} - 100 \text{ ppm})_{CO_2} = 0.04$ or 4% relative sensitivity.

Chapter 6
Test Results

The results of the verification test of the SafEye 227 are presented in this section, based upon the statistical methods shown in Chapter 5. The monitor was challenged with methane; with propane; and with a mixture of methane, propane, and ethane over path lengths of 40 to 130 meters, which are typical path lengths for this monitor. 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.

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 227 has an MDL of between 0.003 and 0.012 LEL*m for methane, 0.001 and 0.008 LEL*m for propane, and 0.001 and 0.008 LEL*m for the mixture of methane, propane, and ethane at the path lengths and integration times tested. Changing the integration times from 1 to 5 minutes reduced the MDL, but changing the path lengths between 40 and 65 meters had little consistent effect on the MDL.

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. 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 methane concentration is the concentration of gas being delivered to the gas cell during the measurement, and the monitor

Table 6-1. Minimum Detection Limits Data for the SafEye 227

Measure-ment Number	Methane Path Length (m) 40	40	65	Propane Path Length (m) 40	40	65	Mixture #1 Path Length (m) 40	40	65
	Integration Time (min) 1	1	1	Integration Time (min) 1	5	1	Integration Time (min) 1	5	1
	Concentration (LEL*m)								
1	-0.001	0.010	0.000	0.005	-0.002	0.000	0.007	-0.002	0.020
2	0.000	0.008	0.000	0.000	-0.002	0.004	0.007	-0.001	0.004
3	-0.001	0.025	0.002	-0.001	-0.002	0.003	0.004	-0.001	0.002
4	0.008	0.007	-0.001	-0.001	-0.002	0.002	0.003	-0.002	0.004
5	0.012	0.005	0.003	-0.002	-0.004	0.008	0.005	-0.002	0.004
6	0.002	0.000	0.000	-0.002	-0.002	0.007	0.008	-0.002	0.003
7	0.007	-0.001	-0.001	-0.004	-0.002	0.008	0.007	-0.002	0.009
8	-0.001	-0.001	0.000	-0.004	-0.004	0.008	0.007	-0.002	0.014
9	0.007	-0.002	-0.002	-0.002	-0.002	0.008	0.005	-0.002	0.008
10	0.014	-0.001	0.000	-0.001	-0.002	0.005	0.007	-0.002	0.007
11	0.009	0.000	0.000	-0.001	-0.002	0.003	0.007	-0.004	0.009
12	-0.002	-0.001	0.002	-0.004	-0.002	0.000	0.007	-0.002	0.009
13	0.003	0.000	-0.001	-0.002	-0.004	0.002	0.003	-0.002	0.004
14	-0.004	-0.002	0.000	-0.002	-0.002	0.009	0.003	-0.002	0.013
15	-0.001	-0.002	-0.001	-0.001	-0.002	0.007	0.002	-0.004	0.007
16	-0.001	-0.002	-0.001	-0.005	-0.004	0.004	0.002	-0.002	0.010
17	0.008	-0.002	0.002	-0.002	-0.002	0.004	0.002	-0.002	0.010
18	0.004	-0.002	0.002	-0.002	-0.004	0.007	-0.002	-0.004	0.005
19	0.007	-0.001	-0.001	0.003	-0.002	0.010	-0.001	-0.002	0.020
20	0.003	-0.001	-0.001	0.000	-0.002	0.009	-0.004	-0.004	0.014
21	-0.001	-0.002	0.008	0.007	-0.002	0.007	-0.001	-0.002	0.019
22	0.007	-0.002	0.004	0.004	-0.002	0.003	-0.001	-0.002	0.012
23	0.008	-0.002	0.005	0.005	-0.004	0.012	-0.004	-0.002	0.004
24	0.009	-0.002	0.012	0.003	-0.002	0.017	-0.004	-0.002	0.008
25	NA	-0.001	0.007	-0.002	-0.002	0.014	-0.002	-0.004	0.010

response is the resulting reading from the SafEye 227. The source strength results show that there is little degradation in monitor performance during conditions of declining source strength. The maximum differences between SafEye 227 response and the methane concentration were 0.13 LEL*m at 1.00 LEL*m methane and 0.1 LEL*m at 3.0 LEL*m methane. The data indicate only a slight effect of source strength on methane measurement, with source reductions of up to 62%. The slopes of the linear regression lines of zero and 0.05, shown in Figure 6-1, indicate that reducing the source strength had a slightly negative effect on the monitor's response over the range tested.

Table 6-2. Minimum Detection Limits of the SafEye 227

Target Gas	Path Length (m)	Integration Time (min)	MDL (LEL*m)
Methane	40	1	0.010
Methane	40	1	0.012
Methane	65	1	0.003
Propane	40	1	0.006
Propane	40	5	0.001
Propane	65	1	0.008
Mixture	40	1	0.008
Mixture	40	5	0.001
Mixture	65	1	0.005

Table 6-3. Source Strength Linearity of the SafEye 227

Relative Signal Power	Methane Concentration (LEL*m)	Monitor Response (LEL*m)
1.00	1.0	0.91
0.79	1.0	0.87
0.57	1.0	0.88
0.38	1.0	0.87
1.00	3.0	2.9
0.79	3.0	2.9
0.57	3.0	2.9
0.38	3.0	2.9

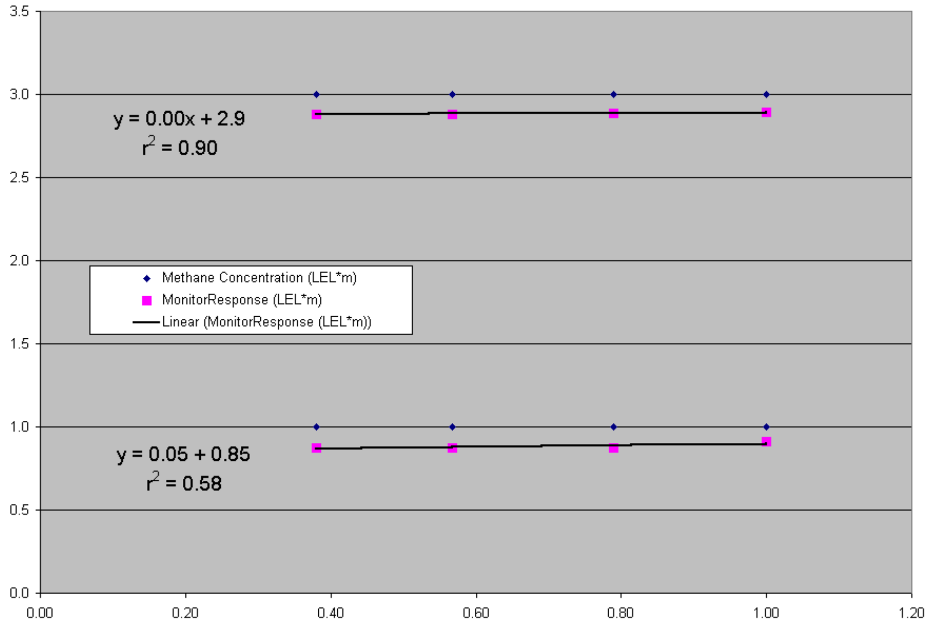

Figure 6-1. Source Strength Linearity Plot of the SafEye 227

6.2.2 Concentration Linearity

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

Table 6-4. Concentration Linearity Data for the SafEye 227

Target Gas	Target Gas Concentration (LEL*m)	Monitor Response (LEL*m)
Methane	1.0	0.91
Methane	2.0	1.7
Methane	3.0	2.9
Methane	2.0	1.8
Methane	2.0	1.8
Propane	1.0	1.0
Propane	2.5	2.6
Propane	5.0	3.8
Propane	2.5	3.0
Propane	2.5	3.2
Mixture	0.96	0.9
Mixture	1.9	1.7
Mixture	2.9	2.6
Mixture	1.9	1.7
Mixture	1.9	1.7

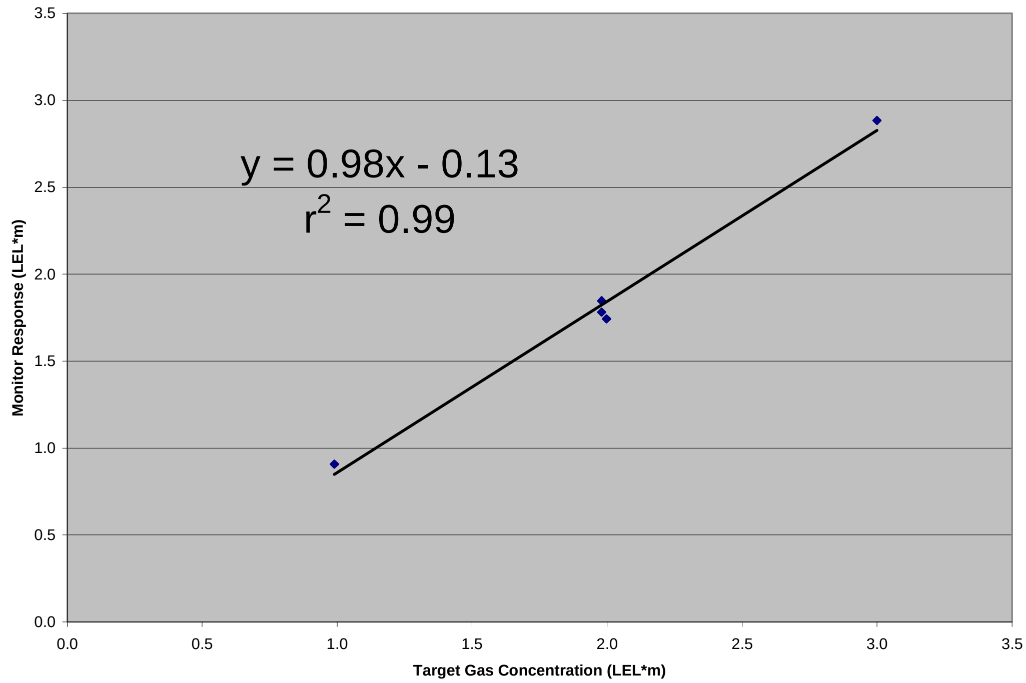

Figure 6-2. Concentration Linearity Plot of the SafEye 227 Challenged with Methane

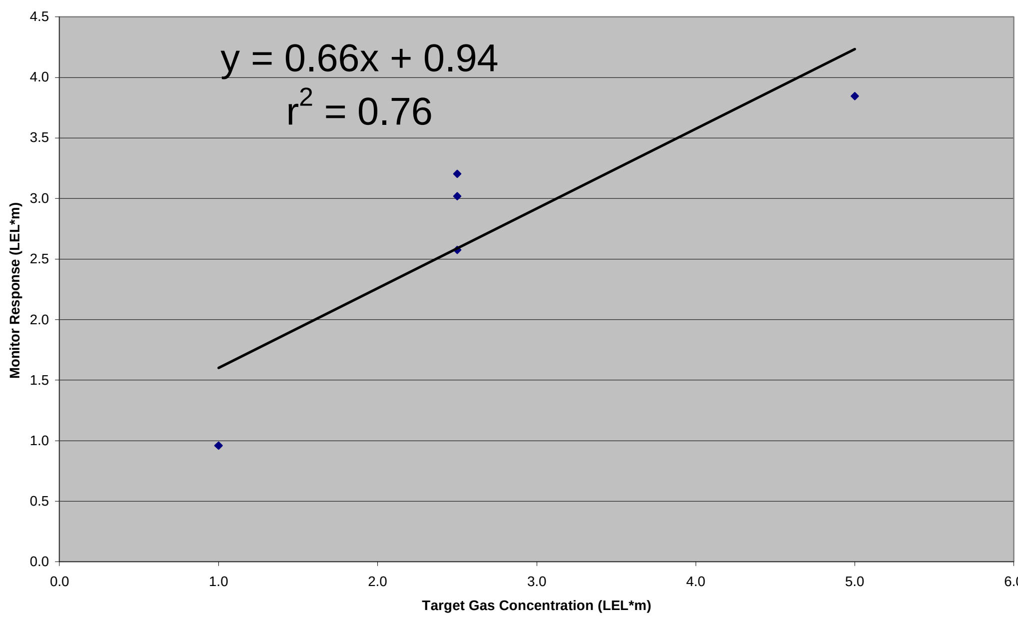

Figure 6-3. Concentration Linearity Plot of the SafEye 227 Challenged with Propane

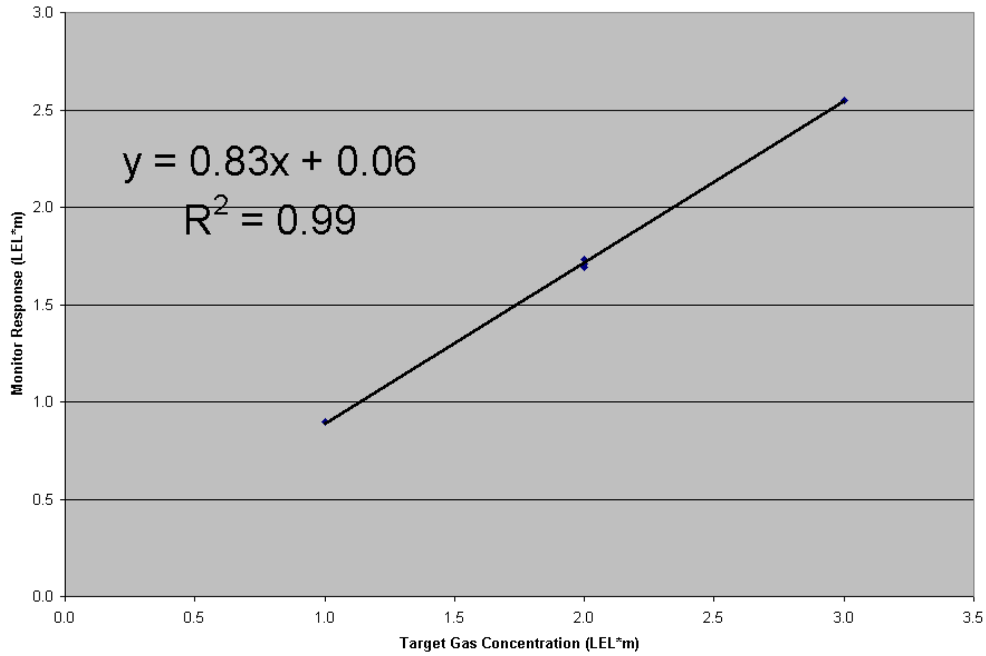

Figure 6-4. Concentration Linearity Plot of the SafEye 227 Challenged with Mixture

The results from the concentration linearity test show that the SafEye 227 exhibits linear behavior for methane and for the gas mixture, with non-linear responses for propane. When challenged with methane, the monitor had a slope of 0.98 and an r^2 value of 0.99. The monitor had a slope of 0.66 and an r^2 value of 0.76 when challenged with propane and a slope of 0.83 and an r^2 value of 0.99 when challenged with the mixture of gases. The monitor responded well to methane in all cases, considering that the mixture of gases was composed of mostly methane. The additional gases in the mixture (propane and ethane) may have caused the monitor to change sensitivity, reflected by the smaller slope of 0.83.

6.3 Accuracy

The accuracy of the SafEye 227 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, where the measurement data and relative accuracy results are shown. The accuracy results compare the monitor response with the target gas concentration as delivered by the Environics 2020 gas dilution system.

These results show that the SafEye 227 had a relative accuracy of between -3.8 and -13% for methane, -23 and 28% for propane, and -6.5 and -12% for the mixture of gases. The results also show that the monitor is most accurate when challenged with methane. The mixture of gases, composed mostly of methane, deviated the most from the expected value, but it consistently

Table 6-5. Results of Accuracy Tests for the SafEye 227

Gas	Target Gas Concentration (LEL*m)	Path Length (m)	Integration Time (min)	Monitor Response (LEL*m)	Relative Accuracy (%)
Methane	0.99	40	1	0.907	- 8.4
Methane	2.0	40	1	1.74	- 13
Methane	3.0	40	1	2.88	- 3.8
Methane	2.0	130	5	1.78	- 10
Methane	2.0	65	1	1.85	- 6.7
Propane	1.0	40	1	0.958	- 4.2
Propane	2.5	40	1	2.57	2.9
Propane	5.0	40	1	3.85	- 23
Propane	2.5	130	5	3.02	21
Propane	2.5	65	1	3.20	28
Mixture	0.96	40	1	0.898	- 6.5
Mixture	1.9	40	1	1.69	- 11
Mixture	2.9	40	1	2.55	- 12
Mixture	1.9	130	5	1.73	- 9.0
Mixture	1.9	65	1	1.71	- 10

deviated in the same direction and by the same magnitude, suggesting a possible scale factor or responsiveness error. If caused by the presence of propane and ethane in the mixtures, the effect of these gases on SafEye response must be strong, given the low proportions of these gases in the mixtures.

The SafEye 227 has four built-in calibrations, each one for a different target gas. These calibrations settings are for pure methane, pure propane, and two general hydrocarbon mixtures. The mixed gas calibrations used for the test unit were based on a gas mixture of 92% methane, 4% propane, and 4% ethane. The actual mixture used during the test differed from this calibration setting. Given the fact that the monitor's setting did not exactly match the gas being used, the accuracy results for the mixture gas were expected by the vendor.

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 40 meters. The target gas was introduced into the gas cell at a concentration of 3 LEL*m for methane, 5 LEL*m for propane, and 4.5 LEL*m for the mixture of gases. Twenty-five 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 6-6. Data from Precision Tests on the SafEye 227

	Target Gas		
Analysis #	Methane (LEL*m)	Propane (LEL*m)	Mixture (LEL*m)
1	2.90	3.83	2.56
2	2.90	3.83	2.55
3	2.88	3.86	2.55
4	2.90	3.87	2.54
5	2.87	3.85	2.55
6	2.89	3.88	2.55
7	2.89	3.88	2.54
8	2.90	3.86	2.55
9	2.90	3.87	2.55
10	2.90	3.90	2.55
11	2.90	3.87	2.54
12	2.90	3.88	2.53
13	2.87	3.87	2.54
14	2.89	3.89	2.55
15	2.88	3.89	2.54
16	2.89	3.91	2.54
17	2.90	3.89	2.54
18	2.90	3.93	2.53
19	2.89	3.91	2.53
20	2.88	3.93	2.53
21	2.89	3.90	2.54
22	2.90	3.89	2.54
23	2.90	3.90	2.54
24	2.87	3.92	2.54
25	2.89	3.92	2.54

Table 6-7. Results of Precision Tests on the SafEye 227[a]

Target Gas	Gas Cell Concentration (LEL*m)	Average Monitor Response (LEL*m)	Standard Deviation (LEL*m)	Relative Standard Deviation (%)
Methane	3.0	2.89	0.010	0.340
Propane	5.0	3.89	0.027	0.705
Mixture	4.6	2.54	0.008	0.326

[a]Integration time = 1 minute; path length = 40 meters.

These results show that the methane data had an RSD of 0.340%, propane data had an RSD of 0.705%, and the gas mixture data had an RSD of 0.326%. The magnitude of these values shows that the monitor performed very consistently over the 25 minutes required for this measurement. In addition, the similarity of the RSD values to each other shows that the monitor performs consistently while analyzing for the three target gases.

6.5 Interferences

Interference tests of the SafEye 227 evaluated the effects that the common atmospheric interferants water and carbon dioxide have on the monitor's ability to determine the concentration of the target gases and on the MDL for the target gases. Both water and carbon dioxide have absorption features in the same infrared region that the SafEye 227 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 water and carbon dioxide can make analyzing for the target compounds difficult. IR monitors use various methods to deal with these interferants, and this test evaluated the effectiveness of the SafEye 227's methods. Tables 6-8 and 6-9 show the data used to determine the interference effect of water and carbon dioxide on the concentration and MDL determination, respectively.

As shown in Table 6-8, changing the total number of water and carbon dioxide molecules in the path length had little effect on the monitor's ability to accurately calculate the concentrations of the target gas. Overall, carbon dioxide and water levels had no consistent effect on relative accuracy for the three gases.

Table 6-8. Concentration Data from Interference Tests on the SafEye 227

Target Gas	Path Length (m)	Concentration of CO_2 (ppm*m)	Concentration of H_2O (ppm*m)	Target Gas Concentration (LEL*m)	Monitor Response (LEL*m)	Relative Accuracy (%)
Methane	40	1.38E+04	5.80E+03	2.0	1.74	-13
Methane	65	2.51E+04	6.39E+03	2.0	1.85	-6.7
Methane	130	4.76E+04	1.10E+04	2.0	1.78	-10
Propane	40	1.67E+04	7.40E+03	2.5	2.57	+2.9
Propane	65	2.63E+04	7.77E+03	2.5	3.20	+28
Propane	130	5.33E+04	2.13E+04	2.5	3.02	+21
Mixture	40	1.49E+04	4.76E+03	3.1	1.69	-45
Mixture	65	2.58E+04	8.89E+03	3.1	1.71	-44
Mixture	130	4.82E+04	9.99E+03	3.1	1.73	-43

Table 6-9. MDL Data from Interference Tests on the SafEye 227

Target Gas	Path Length (m)	Concentration of CO_2 (ppm*m)	Concentration of H_2O (ppm*m)	MDL (LEL*m)
Methane	40	1.88E+04	4.44E+05	0.010
Methane	40	1.46E+04	5.27E+05	0.012
Methane	65	2.44E+04	9.06E+05	0.003
Propane	40	1.73E+04	4.81E+05	0.006
Propane	40	1.68E+04	5.00E+05	0.001
Propane	65	2.60E+04	8.59E+05	0.008
Mixture	40	1.50E+04	5.41E+05	0.008
Mixture	40	1.68E+04	5.15E+05	0.001
Mixture	65	2.58E+04	7.85E+05	0.005

Table 6-9 shows that changing the total number of water and carbon dioxide molecules in the path length also had little effect on the monitor's MDL for the target gas; no consistent impact of water and carbon dioxide levels on MDLs was found.

6.6 Other Factors

6.6.1 Costs

The cost of the SafEye 227 ranges, as tested, from $6,000 to $10,000, according to Spectrex, depending upon application.

6.6.2 Data Completeness

All portions of the verification test were completed, and all data that were to be recorded were successfully acquired. Thus, data completeness was 100%.

Chapter 7
Performance Summary

The SafEye 227 MDL for the three gases tested ranged between 0.003 and 0.012 LEL*m for methane, between 0.001 and 0.008 LEL*m for propane, and between 0.001 and 0.008 LEL*m for the mixture. While variation in detection limits can be caused by the changes in path length, no consistent trend was found when changing path length. However, increasing the integration time from 1 to 5 minutes reduced the MDL.

The tests of the effects of source strength on the ability of the monitor to measure methane showed that there was little to no degradation of monitor performance, with source strength reductions of up to 62%. Near zero slopes for both the 1 and 3 LEL*m tests showed that reducing source strength had little effect.

The concentration linearity results showed that the SafEye 227 had a regression slope of 0.98 and an r^2 value of 0.99 for methane, a regression slope of 0.66 and an r^2 value of 0.76 for propane, and a regression slope of 0.83 and an r^2 value of 0.99 for the mixture, each over a range of 1 to 5 LEL*m.

The SafEye 227 had a relative accuracy of between -3.8 and -13% for methane, -23 and 28% for propane, and -6.5 and -12% for the mixture of gases.

Precision results showed that methane data had an RSD of 0.340%, propane data had an RSD of 0.705%, and the mixture data had an RSD of 0.326%. This RSD was calculated at one experimental condition using a path length of 40 meters, an integration time of 1 minute, and a concentration of 3 LEL*m for methane, 5 LEL*m for propane, 4.5 LEL*m for the mixture of gases.

Analysis of the effects of the interferences of water and carbon dioxide on the measuring ability of the SafEye 227 showed that neither the accuracy nor the MDL were affected consistently by the changing concentrations of water and carbon dioxide in the atmosphere. Variations in MDL and relative accuracy were similar to those found during other measurements made under normal operating conditions, and no consistent interference effect could be inferred.

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. *Combustion*, Appendix E, Irvin Glassman, 1987.

4. *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