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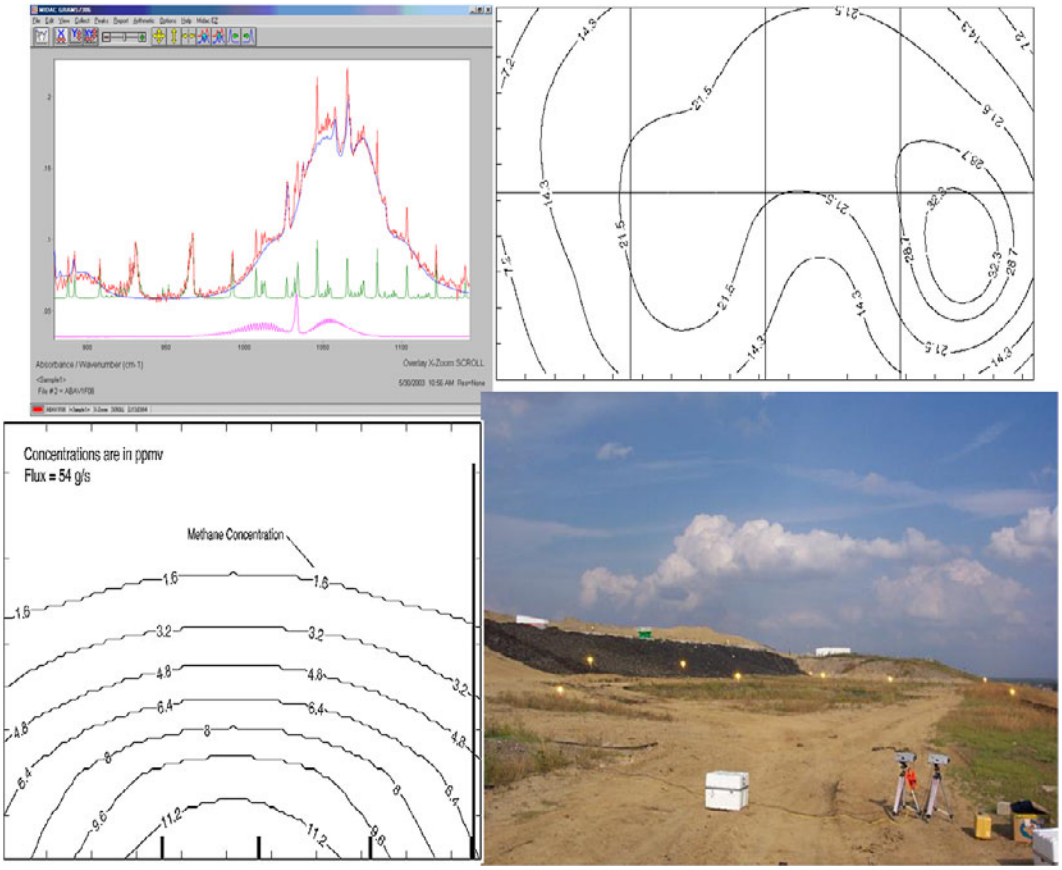
MEASUREMENT OF FUGITIVE EMISSIONS AT A BIOREACTOR LANDFILL



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Measurement of Fugitive Emissions at a Bioreactor Landfill

by

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Abstract

The data presented in this report are from three field campaigns performed during September 2002, May 2003, and September 2003 by ARCADIS and the United States Environmental Protection Agency (U.S. EPA) to measure fugitive emissions at a bioreactor landfill in Louisville, Kentucky, using an open-path Fourier transform infrared (OP-FTIR) spectrometer. The study involved a technique developed through research funded by U.S. EPA's National Risk Management Research Laboratory (NRMRL) that uses optical remote sensing-radial plume mapping (ORS-RPM). The horizontal radial plume mapping (HRPM) method was used to map surface concentrations, and the vertical radial plume mapping (VRPM) method was used to measure emissions fluxes downwind of the site.

Surveys were conducted in five areas at the Louisville facility: As-Built (an area designed as a bioreactor landfill), Retrofit (an area converted to a bioreactor landfill), Control, Biocover, and Compost.

In general, the As-Built area was found to have the highest methane fluxes. In addition to VRPM surveys, HRPM surveys were performed in the As-Built and Retrofit areas. Two definitive methane hot spots, having concentrations over 80 ppmv were found at the Retrofit area during the September 2002 campaign. During the May 2003 campaign, four hot spots were found in the As-Built area (the most intense having concentrations over 210 ppmv), and two hot spots were found in the Retrofit area (the most intense having concentrations over 78 ppmv). During the September 2003 campaign, three hot spots were found in the As-Built area (the most intense having concentrations over 89 ppmv), and two hot spots were found in the Retrofit area (the most intense having concentrations over 34 ppmv).

Further evaluation is needed to establish trends in fugitive emissions as the bioreactor areas continue to operate over time. Additional field testing is being considered to evaluate changes in fugitive emissions in response to design and operational changes. These data are also needed to help establish emission trends for the bioreactor portions of the landfill.

Foreword

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's land, air, and water 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, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

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Sally Gutierrez, Director
National Risk Management Research Laboratory

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Executive Summary

Background/Site Information

This research was conducted in support of a multi-year Cooperative Research and Development Agreement (CRADA) between the United States Environmental Protection Agency (U.S. EPA) and Waste Management, Inc. (WMI) which was signed on October 27, 2000. The purpose of this agreement is to evaluate two techniques for landfill bioreactor construction and operation. In concept, bioreactor landfills are designed to accelerate the biological stabilization of landfilled waste through increased moisture addition and other management techniques or procedures so as to enhance the microbial decomposition of organic matter (Reinhart and Townsend, 1998). Data presented in this report follow a quality assurance project plan (QAPP) established by researchers prior to commencement of the project. The focus of the research is to evaluate fugitive gas emissions for both landfill bioreactor types at the Outer Loop Landfill in Louisville, Kentucky. In addition, measurements were conducted by ARCADIS and U.S. EPA personnel to evaluate mercury emissions in the header pipe gas, the performance of a compost "biocover" used as interim cover, and emissions from a compost operation at this site.

The data presented in this report are from three field campaigns performed during September 2002, May 2003, and September 2003 by ARCADIS and U.S. EPA to measure fugitive emissions using an open-path Fourier transform infrared (OP-FTIR) spectrometer. The study involved a technique developed through research funded by U.S. EPA's National Risk Management Research Laboratory (NRMRL), which uses optical remote sensing-radial plume mapping (ORS-RPM).

The scanning OP-FTIR instrument collected path-integrated concentration (PIC) data to generate a long-term average concentration along each beam path in a configuration. The information is then directly translated using an iterative algorithm into time-averaged concentration maps along a horizontal or vertical plane (Hashmonay et al., 1999; Wu et al., 1999; Hashmonay et al., 1998; Hashmonay and Yost, 1999). By scanning in a vertical plane downwind from an area source, one can obtain plume concentration profiles and calculate the plane-integrated concentrations. The flux is calculated by multiplying the plane-integrated concentration by the wind speed component perpendicular to the vertical plane.

Figure E-1 is a map of the Outer Loop Site showing the general location of each survey area used in the study.

Surveys were conducted in five areas at the Louisville facility: As-Built (an area designed as a bioreactor landfill), Retrofit (an area converted to a bioreactor landfill), Control, Biocover, and Compost.

As-Built Area

The As-Built Area is an active landfill site where liquid is added to accelerate waste decomposition. The initial operation is to moisten the waste and inject air to encourage aerobic decomposition. WMI believes this will reduce the ammonia concentration in the leachate and accelerate the decomposition of proteins and fatty acids. According to WMI, the length of this initial phase can vary from 30 to 100 days depending upon the temperature of ambient air and the waste mass. At the end of the aerobic phase, the waste mass is moistened with landfill leachate and other liquids to establish anaerobic conditions. This is done to further accelerate waste degradation.

During these field sampling campaigns, the As-Built Area consisted of two cells with a combined area of twelve acres. Horizontal radial plume mapping (HRPM) was carried out in this area during each field campaign. Additionally, vertical radial plume mapping (VRPM) was carried out during each field campaign to measure the emission flux of methane downwind of the area. Background methane concentrations were measured using a bistatic, non-scanning OP-FTIR. Mercury measurements of the header pipe gas were conducted in the As-Built Area.

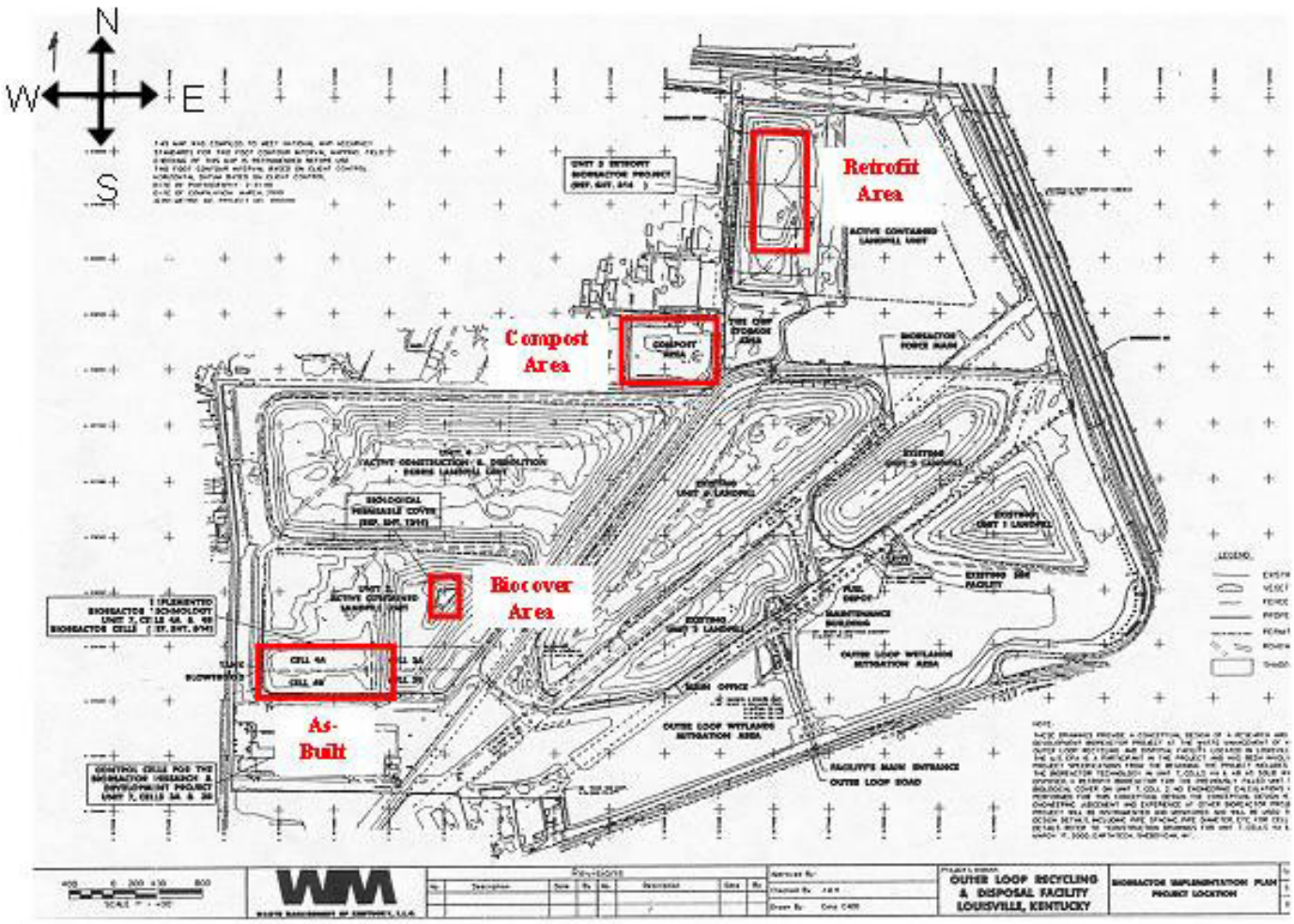

Figure E-1. Waste Management, Inc., Outer Loop Facility, Louisfille KY

Retrofit Area

The Retrofit Area is a 26-acre existing landfill that has not accepted waste since March 2001. Nitrate-containing leachate has been added to the landfill cell to accelerate waste stabilization. Testing was performed on the 8-acre flat area on top of this cell. HRPM was carried out in this area during each field campaign to identify emission hot spots, and VRPM was performed during each field campaign to calculate average methane fluxes. Background methane concentrations were measured using a bistatic, non-scanning OP-FTIR. Mercury measurements of the header pipe gas were conducted in the Retrofit Area.

Control Area

The Control Area at the site was not selected specifically for this effort, but for the overall CRADA project, but Control Area measurements were used for this study to aid in isolating emissions from each separate survey area at the site. The control study area is east of the As-Built Area. During the September 2002 field campaign, a vertical configuration was set up on the east side of the Control Area, and data were collected during periods that the observed wind direction consisted of a westerly component. During the May 2003 campaign, an upwind and downwind vertical configuration was set up in this area to measure the incoming and outgoing flux of methane. No measurements were made in this area during the September 2003 field campaign. Changes in geometry and access to the control cell limited the usefulness of data collected in this area from the initial field campaigns to the September 2003 campaign, and it was difficult to isolate emissions from the Control Area because of the size and proximity of this area to the As-Built section. Further explanation on selection of the Control Area is provided in U.S. EPA, 2003.

Biocover Area

The Biocover Area is not operated as a bioreactor (with leachate and other liquid additions); rather, a compost layer

is used as an interim cover. The survey area is approximately 1 acre. During the September 2002 field campaign, a VRPM configuration was placed to the west of the survey area to determine the emission flux of methane. Data for the Biocover Area study were collected during periods that the observed wind direction consisted of an easterly component. During the May 2003 campaign, vertical configurations were used to measure methane flux. Surveying was not performed in this area during the September 2003 field campaign because the area was inaccessible for data collection. Background methane concentrations were measured using a bistatic, non-scanning OP-FTIR

Compost Area

Measurements of the Compost Area were conducted during the first field campaign. The compost area consisted of several piles of shredded vegetative waste, approximately 50 ft long and 20 ft high, which are being decomposed under controlled conditions. Two piles were surveyed in the Compost Area using a monostatic OP-FTIR. The primary concern in the Compost Area was to evaluate emissions of volatile organic compounds (VOCs) and ammonia from the compost piles. An optical configuration was set up adjacent to each pile, and vertical configurations were set up downwind of the sources to capture any plumes originating from the piles and measure emission fluxes for each pile. Additionally, a bistatic, non-scanning OP-FTIR was operated for the determination of background measurements.

Results and Discussions

Emissions of methane, VOCs, and mercury were measured during field campaigns in September 2002, May 2003, and September 2003. Methane flux in grams per second was measured with a VRPM system and converted to units of grams per square meter per day by multiplying by 86,400 s/day and dividing by the area (in meters squared) of the upwind survey area. The size of the upwind survey area was calculated based on survey measurements taken during the field campaign. In addition, methane hot spots were located using a HRPM configuration.

As-Built Area

September 2002 Field Campaign

VRPM surveys were done using one vertical configuration on the downwind side of each cell. The average calculated methane flux from all vertical runs at the As-Built Area was 140 g/s, or 1400 g/m^2/day. The background survey from the As-Built Area found an average background methane concentration of 8.6 ppmv.

May 2003 Field Campaign

HRPM detected the presence of three methane hot spots in the As-Built Area. The most intense hot spot (estimated as greater than 210 ppmv) was in the lower cell. Each of the three hot spots were adjacent to a slope separating the two cells. This suggests that the slope area may be a significant methane source.

VRPM surveys were done using one vertical configuration on the downwind side of each cell. The average flux for the downwind side of the upper cell was 32 g/s, which is equivalent to approximately 250 g/m^2/day. The average methane flux for the downwind side of the lower cell was 99 g/s, which is equivalent to approximately 660 g/m^2/day. This is not surprising, since the most intense methane hot spot was found in the lower cell of the As-Built Area.

September 2003 Field Campaign

HRPM detected the presence of four methane hot spots in the As-Built Area. The most intense hot spot (estimated as greater than 89 ppmv) was in the upper cell. Three of the hot spots were adjacent to a slope separating the two cells. This suggests that the slope area may be a significant methane source.

VRPM was carried out on both the upwind and downwind side of each cell. The average methane flux for the upwind and downwind sides of the upper cell was 200g/s (equivalent to approximately 1300 g/m^2/day) and 210 g/s (equivalent to approximately 1400 g/m^2/day), respectively. The average methane flux for the upwind and downwind side of the lower cell was 140 g/s (equivalent to approximately 1200 g/m^2/day) and 200 g/s (equivalent to approximately 1400 g/m^2/day), respectively.

Retrofit Area

September 2002 Field Campaign

HRPM at the Retrofit Area detected the presence of two methane hot spots, or areas where methane concentrations were shown to be close to 80 ppmv by the reconstructed surface methane concentration map.

VRPM was done in the northern and southern halves of the Retrofit Area. The average calculated methane flux from the Retrofit Area was found to be 19 g/s for the northern half (equivalent to approximately 310 g/m^2/day), and 18 g/s for the southern half (equivalent to approximately 330 g/m^2/day). This is consistent with the fact that the methane concentrations found in the hot spots for each area (which would be the major contributor to methane flux values)

are similar in magnitude. Additionally, the spatial resolution of the plumes in the horizontal direction is consistent with the location of the hot spots found in the HRPM survey.

The bistatic OP-FTIR instrument was operated to collect background methane data in the Retrofit Area. However, due to instrumentation problems, the data were unavailable for this area. Looking at the boundaries of the HRPM results, the background concentrations can be estimated to be about 10 ppmv.

May 2003 Field Campaign

HRPM at the Retrofit Area detected the presence of two methane hot spots. The most intense hot spot (estimated to be greater than 78 ppmv) was in the northeastern corner of the northern half of the Retrofit Area.

VRPM was done on the upwind and downwind sides of the Retrofit Area. The average methane flux for the upwind side and downwind sides was 11g/s (equivalent to approximately 100 g/m^2/day) and 27g/s (equivalent to approximately 250 g/m^2/day), respectively.

September 2003 Field Campaign

HRPM at the Retrofit Area detected the presence of two methane hot spots. The most intense (estimated to be greater than 34 ppmv) was along the western edge Retrofit Area.

Due to limited access to the area, it was not possible to set up an upwind vertical configuration, and VRPM was only carried out on the downwind side of the Retrofit Area. As an alternative to an upwind VRPM, the path-averaged methane concentration data from the bistatic OP-FTIR were used to provide information on upwind methane concentrations. The average methane flux for the downwind side of the area was 54 g/s (equivalent to approximately 440 g/m^2/day). The data from the bistatic OP-FTIR found an average upwind methane concentration of 2.3 ppmv.

Control Area

September 2002 Field Campaign

The average calculated methane flux for the Control Area study was 6.0 g/s (equivalent to approximately 100 g/m^2/day). However, this value may be a low estimate of the total methane flux because the winds were highly variable during the period of data collection (Hashmonay et al., 2001).

May 2003 Field Campaign

VRPM was done on both the upwind and downwind sides of the Control Area. The average methane flux for the upwind side and downwind sides was 4.3 g/s (equivalent to approximately 160 g/m^2/day) and 14 g/s (equivalent to approximately 350 g/m^2/day), respectively.

Biocover Area

September 2002 Field Campaign

Several VRPM surveys were done at the Biocover Area. The average calculated methane flux was 24 g/s (equivalent to approximately 410 g/m^2/day).

The bistatic OP-FTIR instrument was operated to collect background methane data in the Biocover Area, but the data were unavailable for this area because of instrumentation problems.

May 2003 Field Campaign

VRPM was done on the upwind and downwind sides of the Biocover Area. The average methane flux for the upwind side and downwind sides was 91g/s (equivalent to approximately 1300 g/m^2/day) and 80 g/s (equivalent to approximately 890 g/m^2/day), respectively. The fact that the average calculated upwind flux was higher than the average calculated downwind flux indicates that the measured methane flux was not located in the Biocover Area. Because of the close proximity of the Biocover to the As-Built Area and the fact that the prevailing winds were from the southwest during the survey, it is likely that a methane plume from the As-Built Area caused the elevated methane levels measured in this area.

Compost Area

During the September 2002 Field Campaign, the study did not detect any VOCs or ammonia in the Compost Area. Additionally, the survey did not detect any methane plumes originating from the compost piles, which one would expect since it is an aerobic operation.

VOC and Ammonia Measurements

Additional analysis of the complete dataset was done to search for the presence of VOCs and ammonia in the landfill gas. Prior to the field campaign, it was anticipated that the VOCs and ammonia concentrations at the site would often be below the minimum detection limit of the instrumentation. This was the case. However, ammonia and VOCs were found in the As-Built, Control, and Biocover

areas at the site. Emission fluxes for these trace compounds were calculated by proportioning to the methane flux data.

Mercury Measurements

The landfill gas at the site was sampled and analyzed during the September 2002 campaign for total mercury, dimethyl mercury, and monomethyl mercury by Frontier Geosciences with sampling support from ARCADIS. During this campaign, total mercury concentrations in the landfill gas ranged from 224 to 671 ng/m^3 with an average of 522 ng/m^3 for all of the samples, excluding the As-Built data. The data from the As-Built area were not included in calculating the average because it was not attached to the rest of the landfill gas system during this campaign. Dimethyl mercury concentrations in the landfill gas ranged from not detected to 18 ng/m^3 and averaged 5.9 ng/m^3. There was no dimethyl mercury detected in the flare gas.

Spike recoveries in the dimethyl mercury traps were significantly lower than the 50% to 150% acceptance criteria listed. This was possibly due to the presence of an unknown interfering compound either destroying or masking the detection of the dimethyl mercury. For this reason, all of the dimethyl mercury results from this campaign must be labeled as suspect. Monomethyl mercury concentrations in the landfill gas ranged from 0.4 to 4.4 ng/m^3 and averaged 2.4 ng/m^3.

During the September 2003 campaign, the landfill gas at the site was sampled and analyzed by Frontier Geosciences, with sampling support from ARCADIS, for total mercury, dimethyl mercury, and monomethyl mercury. Total mercury concentrations in the landfill gas ranged from 123 to 4670 ng/m^3 with an average of 1171 ng/m^3 for all of the samples. It should be noted that the average of the Control Area is biased high because of the data from unit 73A. The vertical gas collection well sampled during this campaign was under positive pressure; therefore, the data are suspect. Dimethyl mercury concentrations in the landfill gas ranged from 22.1 to 128.3 ng/m^3 and averaged 53.3 ng/m^3 as measured by the Carbotrap method. One data point from the Retrofit Area was not included because it was improperly sampled. Dimethyl mercury concentrations in the landfill gas ranged from 49.3 to 363 ng/m^3 and averaged 116.5 ng/m^3 as measured by the methanol impinger method. Monomethyl mercury concentrations in the landfill gas ranged from 0.55 to 2.10 ng/m^3 and averaged 1.37 ng/m^3. Recoveries for the spiked/sampled monomethyl impingers were significantly lower than the acceptance criteria of 50% to 150%. For this reason, all of the monomethyl mercury results from this campaign must be labeled as suspect. Spike recoveries for the total mercury samples were 93%. Spike recoveries for the dimethyl mercury traps ranged from 60.3% to 101.1%. These recoveries are considerably better than the recoveries during the September 2002 campaign probably due to decreasing the sample volume from 9.0 liters to 0.5 liters. However, more method development is needed to further improve spike recoveries.

Conclusions

Fugitive emissions at the Outer Loop Landfill operated by Waste Management Inc. in Louisville, Kentucky, were evaluated using an OP-FTIR spectrometer and the ORS-RPM technique. Methane fluxes were calculated at four areas in the landfill. Table E-1 lists the average calculated methane fluxes found during each field campaign.

Table E-1. Average Calculated Methane Flux and Range at Each Survey Area.

Survey Area	September 2002		May 2003		September 2003	
	Average Flux (g/s)	Range (g/s)	Average Flux (g/s)	Range (g/s)	Average Flux (g/s)	Range (g/s)
As-Built Upper cell	Restricted access and equipment malfunction		32	9.4 to 88	210[a]	84 to 330
As-Built Lower Cell	140[b]	120 to 180[b]	99	76 to 180	200[a]	25 to 380
Retrofit	37	31 to 44	27	18 to 39	54[c]	35 to 75
Control	6.0	6.0	14	5.2 to 24	No control available	

[a] Gas collection system not operating because of leachate build-up in the extraction wells.
[b] Gas collection system was not operational in the As-Built cells during the September 2002 field campaign.
[c] The week prior to the field test, the interim cap was replaced with a fresh topsoil/clay cover, and the gas collection system was upgraded.

In general, the As-Built Area was found to have the highest methane fluxes. In addition to VRPM, HRPM was done in the As-Built and Retrofit Areas. Two definitive methane hot spots having concentrations over 80 ppmv were found at the Retrofit Area during the September 2002 campaign. During the May 2003 campaign, four hot spots were found in the As-Built Area (the most intense having concentrations over 210 ppmv), and two hot spots were found in the Retrofit Area (the most intense having concentrations over 78 ppmv). During the September 2003 campaign, three hot spots were found in the As-Built Area (the most intense having concentrations over 89 ppmv), and two hot spots were found in the Retrofit Area (the most intense having concentrations over 34 ppmv).

Further evaluation is needed to establish trends in fugitive emissions as the two bioreactor types continue to operate over time. Additional field testing is being considered to evaluate changes in fugitive emissions in response to design and operational changes. These data are also needed to help establish emission trends for the retrofit and as-built bioreactor portions of the Outer Loop landfill.

1. Introduction

1.1 Background

Recently, there has been a dramatic amount of interest in operating landfills as "bioreactors." In concept, bioreactor landfills are designed to accelerate the biological stabilization of landfilled waste through increased moisture (i.e., leachate, sludge, and other liquids) and other management techniques or procedures to enhance the microbial decomposition of organic matter (Reinhart and Townsend, 1998). Generally, bioreactors are designed with gas collection and control. However, there are sites without gas collection and control.

Landfill gas emissions have been found to be a concern to human health and the environment due to the explosive potential of the gas, emissions of hazardous air pollutants and volatile organic compounds (VOCs), emissions of methane that contribute to climate change, and odor nuisance associated with landfill gas. The United States Environmental Protection Agency (U.S. EPA) has promulgated regulations under the Clean Air Act to address the public health and welfare concerns of landfill gas emissions. The final rule and guidelines are contained in 40 CFR Parts 51, 52, and 60, Standards of Performance for New Stationary Sources and Guidelines for Control of Existing Sources: Municipal Solid Waste Landfills. The U.S. EPA has also considered bioreactor landfill emissions by promulgating regulations (contained in 40 CFR Part 63, Subpart AAA) that require certain bioreactor landfills to install and operate a gas collection and control system on an accelerated schedule.

A Cooperative Research and Development Agreement (CRADA) between the U.S. EPA and Waste Management, Inc. (WMI) was signed on October 27, 2000, to develop data that will enable U.S. EPA and the industry to compare conventional Subtitle D design and operation versus landfill bioreactors. The first of these studies is being conducted at the Outer Loop Landfill in Louisville, Kentucky. For further background information, refer to the existing Quality Assurance Project Plans (QAPP) for each field campaign. An interim report of the findings to date from this CRADA was released in September 2003 (U.S. EPA, 2003).

The focus of this effort was to evaluate fugitive emissions associated with the operation of bioreactors either as a retrofit (an existing landfill that is converted to a bioreactor landfill), or as-built (a landfill that was designed as a bioreactor landfill). Fugitive emissions at the Outer Loop Landfill site were evaluated over a one-year period. The study consisted of three field campaigns conducted during September 2002, May 2003, and September 2003. The primary purpose of this study was to evaluate if there is an increase in both short-term and long-term fugitive emissions associated with the operation of bioreactor landfills.

Additionally, samples were collected during the September 2002 and September 2003 campaigns to evaluate concentrations of total, dimethyl, and monomethyl mercury at the site. Emissions of methyl and dimethyl mercury have been detected at four municipal solid waste landfills in Florida (Lindberg and Price, 1999; Lindberg et al., 2001). Questions have been raised about the fate of mercury and other metals that are introduced as a result of adding septic sewage, leachate, and other liquids to the waste mass (U.S. EPA, 2002).

Five sites within the Outer Loop Facility were included in the initial field campaign. These were the As-Built Area, the Retrofit Area, the Control Area, the Biocover Area and the Compost Area. During the May 2003 campaign, the As-Built, Retrofit, Biocover, and Control areas were surveyed. During the September 2003 field campaign, only the As-Built, and Retrofit Areas were surveyed because it had been difficult to establishing a true "Control" area during the two previous field campaigns and because the Biocover Area was no longer in operation. Refer to Figure 1 for an overview of the Outer Loop Facility and the general locations of each survey area.

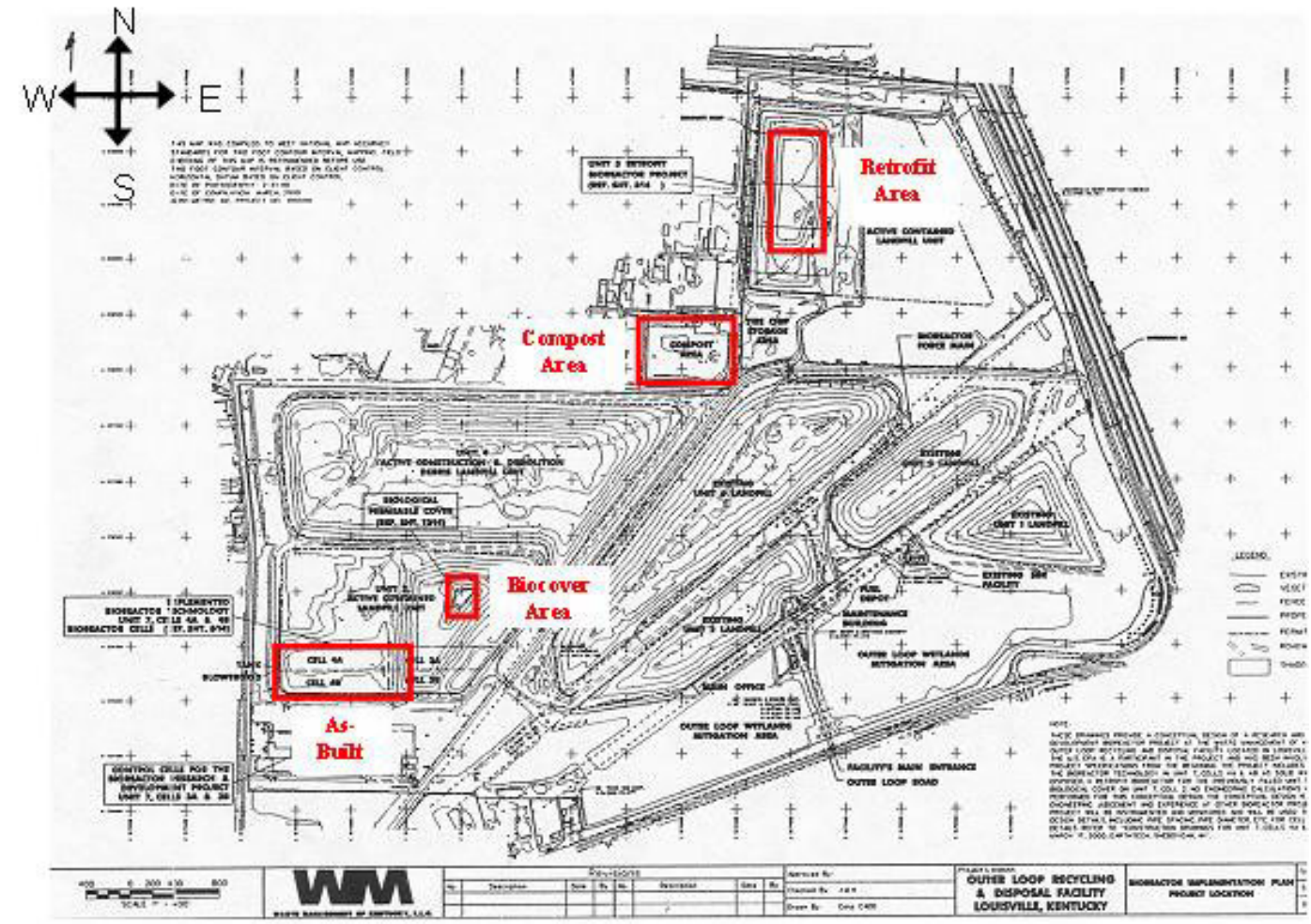

Figure 1. Waste Management, Inc., Outer Loop Facility, Louisfille KY

1.2 Project Description/Purpose

The optical remote sensing (ORS) techniques used in the Outer Loop study were designed to characterize the fugitive emissions from area sources. These techniques were developed in research and development programs funded by U.S. EPA's National Risk Management Research Laboratory (NRMRL). Detailed spatial information is obtained from path-integrated ORS measurements by the use of iterative algorithms. The method involves the use of a configuration of non-overlapping radial beam geometry to map the concentration distributions in a horizontal plane. This method, optical remotes sensing–radial plume mapping (ORS–RPM), can also be applied to a vertical plane downwind from an area emission source to map the crosswind and vertical profiles of a plume. By incorporating wind information, the flux through the plane can be calculated, which leads to an emission rate of the upwind area source. An OP-FTIR sensor was chosen as the primary instrument for the study because of its capability of accurately measuring a large number of chemical species that might occur in a plume.

The OP-FTIR Spectrometer combined with the ORS-RPM method is designed for both fence-line monitoring applications, and real-time, on-site, remediation monitoring and source characterization. An infrared light beam, modulated by a Michelson interferometer is transmitted from a single telescope to a retroreflector (mirror) target, which is usually set up at a range of 100 to 500 m. The returned light signal is received by the single telescope and directed to a detector. The light is absorbed by the molecules in the beam path as the light propagates to the retroreflector and again as the light is reflected back to the analyzer. Thus, the round-trip path of the light doubles the chemical absorption signal. In the case of a bistatic OP-FTIR (which was used to collect upwind information on methane concentrations along a single, fixed path), the instrument contains the receiving telescope and detector, and the infrared source is

located separately from the instrument. One advantage of OP-FTIR monitoring is that the concentrations of a multitude of infrared absorbing gaseous chemicals can be detected and measured simultaneously and with high temporal resolution.

Meteorological and survey measurements were also made during the field campaigns. A theodolite was used to make the survey measurement of the azimuth and elevation angles and the radial distances to the retroreflectors relative to the OP-FTIR sensor.

The objectives of the study were to

- Collect OP-FTIR data in order to identify major emissions hot spots by generating surface concentration maps in the horizontal plane,
- Measure emission fluxes of detectable compounds downwind from major hot spots,
- Collect meteorological and survey data, and
- Collect samples to evaluate total, monomethyl, and dimethyl mercury concentrations at the site.

1.2.1 Horizontal RPM (HRPM)

The horizontal RPM (HRPM) approach provides spatial information to path-integrated measurements by ORS. This technique yields information on the two-dimensional distribution of the concentrations in the form of chemical-concentration contour maps (Hashmonay et al., 1999; Wu et al., 1999; Hashmonay et al., 2002, Shores et al., 2005, Modrak et al., 2005b). This form of output readily identifies chemical hot spots (the location of high emissions). This method can be of great benefit for performing site surveys prior to site remediation activities.

HRPM is usually performed with the ORS beams located as close to the ground as is practical. This enhances the ability to detect minor constituents emitted from the ground, since the emitted plumes dilute significantly at higher elevations. The survey area is divided into a Cartesian grid of n times m rectangular cells. A retroreflector is located in each of these cells, and the ORS sensor scans to each of these retroreflectors, dwelling on each for a set measurement time (30 s in the present study). The system scans to the retroreflectors in the order of either increasing or decreasing azimuth angle. The path-integrated concentrations measured at each retroreflector are averaged over several scanning cycles.

The reconstruction algorithm for obtaining concentration contour maps consists of two stages. First, an iterative inversion algorithm is used to retrieve average concentration in each of the cells. Then, an interpolation procedure is applied to these concentration values to calculate concentration in higher spatial resolution. HRPM is performed using *Matlab* (MathWorks) software. For the first stage of reconstructing the average cell concentrations, an iterative algebraic deconvolution algorithm is applied. The path-integrated concentration (PIC), as a function of the field of concentration, is given by

$$PIC_k = \sum_m K_{k,m} c_m \qquad (1)$$

where K is a kernel matrix that incorporates the specific beam geometry with the cell dimensions; k is the number index for the beam paths; m is the number index for the cells; and c is the average concentration in the m^{th} cell. Each value in the kernel matrix K is the length of the k^{th} beam in the m^{th} cell; therefore, the matrix is specific to the beam geometry. To solve for the average concentrations (one for each cell), the non negative least squares (NNLS) was applied. The NNLS is similar to a classical least square optimization algorithm but is constrained to provide the best fit of non-negative values. This iterative procedure proceeds until the difference of the criteria parameter between sequential steps drops below a very small threshold value (tolerance). The tolerance value depends on many factors, such as the area dimensions, and number of beams used in the survey. A typical value for the tolerance is around 10^{-11}. Multiplying the resulted vertical vector of averaged concentration by the matrix K yields the end vector of predicted PIC data.

The second stage of the plume reconstruction is interpolation among the nine points, providing a peak concentration not limited to only the center of the cells. This stage is done using the triangle-based cubic interpolation procedure. To extrapolate data values beyond the peripheral cell centers and within the rectangle measurement domain, the concentration of each corner cell is assigned to the corresponding corner of the domain.

Figure 2 represents a typical HRPM configuration. In this particular case, $n = m = 3$. The black dot shows the location of the scanning OP-FTIR. The solid lines represent the nine optical paths, each terminating at a retroreflector (Hashmonay et al., 2002).

One OP-FTIR instrument (manufactured by Midac, Inc.) was used to collect HRPM data during the September 2002 field campaign, one OP-FTIR instrument (manufactured by Unisearch Associates) was used to collect HRPM data during the May 2003 campaign, and two OP-FTIR instru-

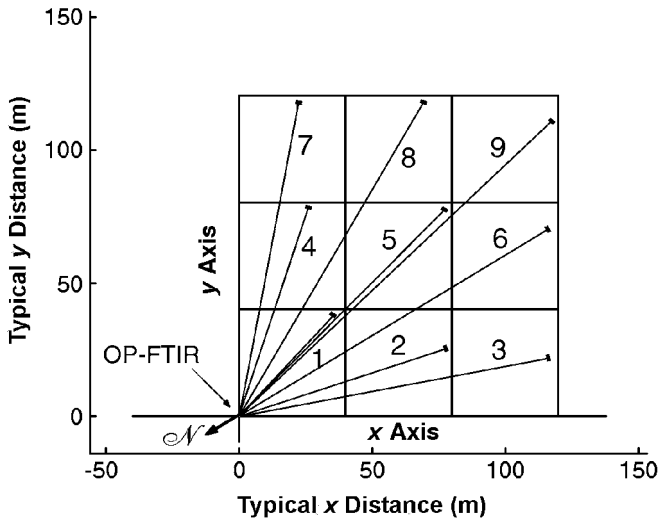

Figure 2. Example of a Typical Horizontal Radial Plume Mapping (HRPM) Configuration.

ments (one manufactured by Unisearch Associates and the other by IMACC, Inc.) were used to collect HRPM data during the September 2003 field campaign.

1.2.2 Vertical RPM (VRPM)

The vertical RPM (VRPM) method maps the concentrations in the plane of the measurement. By scanning in a vertical plane downwind from an area source, plume concentration profiles can be obtained and the plane-integrated concentrations calculated. The smooth basis function minimization (SBFM) reconstruction approach is used, with a two-dimensional smooth basis function (bivariate Gaussian) in order to reconstruct the smoothed mass equivalent concentration map. The smoothed mass equivalent concentration map is reconstructed using *Matlab* (MathWorks) software. In the SBFM approach, a smooth basis function is assumed to describe the distribution of concentrations, and the search is for the unknown parameters of the basis function. Since the interest is in the plane integrated concentration and not the exact map of concentrations in the plane, only one smoothed basis function (one bivariate Gaussian) is fit to reconstruct the smoothed map.

In each iterative step of the SBFM search procedure, the measured PIC values are compared with assumed PIC values, calculated from the new set of parameters. In order to compute the assumed PIC values, the basis function is integrated along the beam path's direction and path-length.

In the RPM beam geometry, it is convenient to express the smooth basis function G in polar coordinates r and θ.

$$G(r,\theta) = \frac{A}{2\pi\sigma_y\sigma_z\sqrt{F_1}}\exp\left\{-\frac{1}{2F_1}\left[\frac{F_2^2}{\sigma_y^2} - \frac{2\rho_{12}F_2F_3}{\sigma_y\sigma_z} + \frac{F_3^2}{\sigma_z^2}\right]\right\} \quad (2)$$

where $F_1 = 1 - \rho_{12}^2$

$F_2 = r \cdot \cos\theta - m_y$

$F_3 = r \cdot \sin\theta - m_z$

The bivariate Gaussian has six unknown independent parameters:

- A – normalizing coefficient that adjusts for the peak value of the bivariate surface
- ρ_{12} – correlation coefficient that defines the direction of the distribution-independent variations in relation to the Cartesian directions y and z (ρ_{12}=0 means that the distribution variations overlap the Cartesian coordinates)
- m_y and m_z – peak locations in Cartesian coordinates
- and σ_y and σ_z – standard deviations in Cartesian coordinates. To fit the unknown parameters of the smooth basis function to the PIC data, an error function for minimization must be defined.

The sum of squared errors (SSE) function is defined in the current study as

$$SSE = \sum_i \left(PIC_i - \int_0^{r_i} G(r,\theta)dr\right)^2 \quad (3)$$

where PIC represents the measured PIC values, and the index i is for the different beams. The SSE function is minimized using an iterative minimization procedure, such as the Simplex method, to solve for the unknown parameters. These calculations are performed using *MatLab* (MathWorks) software.

As mentioned earlier, the interest is in the plane-integrated concentration; therefore, one bivariate Gaussian surface is fit to match the volume under the underlying true concentration distribution surface. This volume is highly conserved in the fitting procedure, which emphasizes agreement over the five path integrals. Six independent beam paths are sufficient to determine one bivariate Gaussian that has six independent unknown parameters.

Some reasonable assumptions also may be made when applying the SBFM method to this problem in order to reduce the number of unknown parameters to four (e.g., setting the correlation parameter ρ_{12} equal to zero). This assumes that the reconstructed bivariate Gaussian is limited only to changes in the vertical and crosswind directions. In this case Equation 2 reduces to

$$G(r,\theta) = \frac{A}{2\pi\sigma_y\sigma_z}\exp\left\{-\frac{1}{2}\left[\frac{\left(r\cdot\cos\theta - m_y\right)^2}{\sigma_y^2} + \frac{\left(r\cdot\sin\theta - m_z\right)^2}{\sigma_z^2}\right]\right\} \quad (4)$$

Also, the peak location in the vertical direction can be fixed to the ground level when ground level emissions are known to exist, as in the current study. However, in this methodology, there is no requirement to apply a priori information on the source location and configuration.

Once the parameters of the function were found for a specific run, the concentration values are calculated for every square elementary unit in a vertical domain. Then, these values are integrated, incorporating wind speed data at each height, level to compute the flux. In this stage, the concentration values are converted from parts per million by volume to grams per cubic meter, considering the molecular weight of the target gas and ambient temperature. This enables the flux to be calculated in grams per second (g/s), using wind speed data in meters per second.

The flux leads directly to a determination of the emission rate (Hashmonay et al., 1998; Hashmonay and Yost, 1999, Hashmonay et al., 2001, Modrak et al., 2004, Modrak et al., 2005a, Thoma et al., 2005). Thus, VRPM leads to a direct measurement-based determination of the upwind source emission rate.

Figure 3 shows a schematic of the experimental setup used for VRPM. Several retroreflectors are placed in various locations on a vertical plane in-line with the scanning OP-FTIR. A vertical platform (scissors jack) is used to place two of the retroreflectors at a predetermined height above the surface. The location of the vertical plane is selected so that it intersects the mean wind direction as close to perpendicular as practical.

One OP-FTIR instrument (manufactured by Midac, Inc.) was used to collect Vertical RPM data during the September 2002 field campaign to form one vertical plane downwind from the source area. During the May 2003 and September 2003 field campaigns, two OP-FTIR instruments (one manufactured by Unisearch Associates and the other by IMACC, Inc.) were used to create two vertical planes, one upwind and one downwind of the source area. This configuration made it possible to calculate an upwind emission flux from the upwind vertical plane measurements and a downwind emission flux from the downwind vertical plane measurements. The difference between the two fluxes yields the actual emission flux from the survey area. More

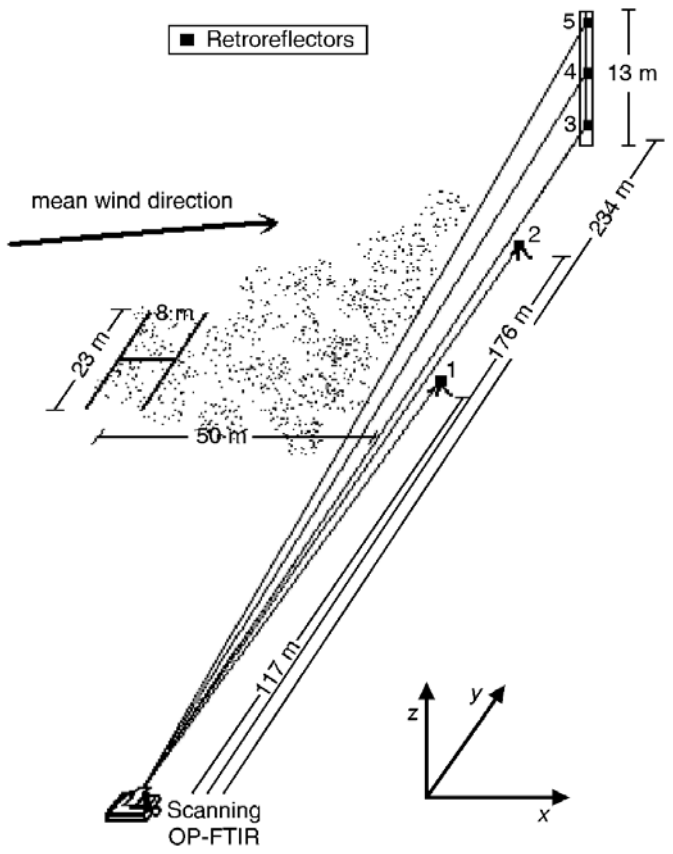

Figure 3. Example of a Typical Vertical Radial Plume Mapping (VRPM) Configuration.

information on the configurations used in each survey area can be found in Section 2 of this report.

1.2.3 Mercury Speciation

During the September 2002 campaign, Frontier Geosciences, with sampling support from ARCADIS, sampled and analyzed the Outer Loop Landfill gas for concentrations of total mercury, dimethyl mercury, and monomethyl mercury. ARCADIS personnel did the sampling during the September 2003 campaign. Samples were collected from the extracted gas pipelines at the Retrofit and the As-Built Areas.

To collect the total mercury samples, an iodated charcoal trap was used as a sorbent, and a backup tube was present to assess any breakthrough. The sorbent tube was heated to a temperature above the dew point of the gas stream to prevent condensation on the sorbent. Water vapor from the stream was collected and quantified using a silica gel impinger. A diaphragm air pump was used to pull sample through the train and collect the sample. The volume of gas sampled was monitored and quantified using a volatile

organic sampling train (VOST) box. The sample flow rate was nominally 0.8 L/min for 37.5 min, which equates to a total volume of approximately 30 L. The traps were returned to the lab where the iodated carbon was leached of collected Hg using hot-refluxing HNO_3/H_2SO_4 and then further oxidized by a 0.01 N BrCl solution. The digested and oxidized leachate sample was analyzed using the FGS-069 cold vapor atomic fluorescence spectrometry (CVAFS) total Hg analysis method (which served as the basis for U.S. EPA Method 1631 that was developed, authored, and validated by Frontier Geosciences).

Dimethyl mercury (DMHg) was sampled using a slightly different technique. A Carbotrap was used as a sorbent, with a backup tube to assess any breakthrough. A third iodated carbon trap was also present to collect any elemental mercury present. The sorbent tube was heated to a temperature above the dew point of the gas stream to prevent condensation on the sorbent. Water vapor from the stream was collected and quantified using a silica gel impinger. A diaphragm air pump was used to pull sample through the train and collect the sample. The volume of gas sampled was monitored and quantified using a VOST box. The sample flow rate was nominally 0.35 L/min for a total volume of approximately 0.5 L.

The DMHg content of the Carbotraps was determined by thermal-desorption (TD), gas chromatography (GC), and CVAFS. The analytical system was calibrated by purging precise quantities of DMHg in methanol (1 –500 pg) from deionized water onto Carbotraps and then thermally desorbing (45 s at a 25 to 450 °C ramp) them directly into the isothermal GC (1 m × 4 mm ID column of 15% OV-3 on Chromasorb WAW-DMCS 80/100 mesh) held at 80 °C. The output of the GC was passed through a pyrolytic cracking column held at 700 °C, converting the organomercury compounds to elemental form. DMHg was identified by retention time and quantified by peak height.

In addition to collecting DMHg using the Carbotrap method, an alternative was performed using a methanol impinger. The primary purpose of using an alternative method was to further evaluate the accuracy of the Carbotrap method. In general, samples were collected using the same equipment and techniques as those outlined below for the collection of monomethyl mercury. The only difference was that methanol was used as an impinger solution rather than 0.001 M HCl. A diaphragm air pump was used to pull sample through the train and collect the sample. The volume of gas sampled was monitored and quantified using a VOST box. The sample flow rate was nominally 0.8 L/min for 37.5 min, which equates to a total volume of approximately 30 L.

Samples were analyzed at the laboratory using procedure listed in FGS-070 using a direct aqueous purge of small aliquots of the MeOH solutions. The DMHg evolved from the analytical sparging vessels was collected onto the Carbotrap and introduced into the TD-GC-CVAFS instrument as described above.

To collect the monomethyl mercury sample, a set of three impingers filled with 0.001 M HCl was used. An empty fourth impinger was used to knock out any impinger solution carryover to the pump and meter system. A diaphragm air pump was used to pull sample through the train and collect the sample. The volume of gas sampled was monitored and quantified using a VOST box. The sample flow rate was nominally 0.8 L/min for 37.5 min, which equates to a total volume of approximately 30 L.

The analysis method uses distillation, ethylation, Carbotrap preconcentration, thermal desorption, gas-chromatography separation, thermal conversion, and CVAFS detection. See the Appendix A SOPs FGS-070 and FGS-013 for introductory pages to the respective methods. This analytical method for monomethyl mercury in a water matrix was the basis for U.S. EPA Draft Method 1631.

1.2.4 As-Built Area

The As-Built Area is an active landfill site where liquid is added to accelerate waste decomposition. The initial operation is to moisten the waste and inject air to encourage aerobic decomposition. This is believed by WMI to result in reducing the concentration of ammonia in the leachate in addition to accelerating the decomposition of proteins and fatty acids. According to WMI, the length of this initial phase can vary from 30 to 100 days depending upon the temperature of ambient air and the waste mass. At the end of the aerobic phase, the waste mass is moistened with landfill leachate and other liquids to establish anaerobic conditions. This is done to further accelerate waste degradation.

A horizontal piping system was installed to facilitate control of the condition in the waste body as waste is added to the cell. This piping system serves three functions: injection of air, injection of liquids, and extraction of gas.

The As-Built study consisted of cells 4A and 4B of Unit 7. Testing was done on the face of each of these cells. Over the course of the long-term study, some gas collection and

control measures were in place in some areas of cells 4A and 4B.

Surveying was conducted in this area during the September 2002, May 2003, and September 2003 field campaigns.

1.2.5 Retrofit Area

The Retrofit Area study was conducted in Unit 5, a 26-acre landfill that has not accepted waste since March 2001. Perforated pipes were installed in cells in Unit 5 North and Unit 5 South, and six vertical gas extraction wells were installed in each of these cells. Testing was performed on the eight-acre flat area on top of this multi-cell unit.

The study in this area is being conducted to test the efficiency of accelerating waste stabilization by injecting nitrate-containing leachate into an existing landfill cell. The expectation is that microorganisms present in the waste will use the nitrate to promote and accelerate degradation of the waste.

Surveying was conducted in this area during the September 2002, May 2003, and September 2003 field campaigns.

1.2.6 Control Area

A Control Area was chosen to determine a typical background methane concentration for the entire site. The Control Area at the site was not selected specifically for this effort, but for the overall CRADA project. The purpose of the Control Area study was to aid in isolating emissions from each separate survey area at the site. The Control Area was located adjacent to the Biocover Area and to the east of the As-Built Area. Further explanation on selection of the Control Area is provided in U.S. EPA, 2003.

Surveying was conducted in the Control Area during the September 2002 and May 2003 field campaigns, but this area was not surveyed during the September 2003 field campaign due to the difficulty of establishing a control area representative of an operating landfill. Changes occurred with regard to geometry of the control cell, which limited the usefulness of data collected in this area from the initial field campaigns to the September 2003 campaign. Also, it was difficult to isolate emissions from the Control Area because of its central location within the landfill.

1.2.7 Biocover Area

Another focus of this study was to determine if emissions reduction is enhanced through use of a WMI-proposed biocover, which is one in which the clay cap is replaced by a layer of compost material. The compost layer is used to reduce any fugitive emissions. Characterization of the gas emissions from a landfill with a compost cover was performed at a site located in the northeast quadrant of Unit 7. This unit consists of a fifty-acre conventional landfill capped with clay. The clay-cover of a one-acre area was scraped and replaced with a compost layer.

Surveying was conducted in this area during the September 2002 and May 2003 field campaigns. Surveying was not conducted in this area during the September 2003 campaign because the Biocover was no longer operational.

1.2.8 Compost Area

The Outer Loop Facility also includes a Compost Area. This area consists of shredded vegetative waste in several piles approximately 50 feet long by 20 feet tall, which are being decomposed under controlled conditions. At the request of WMI, and with the concurrence of the project officer, sampling of fugitive emissions was also performed at this location as a one-time survey. The primary concern in the Compost Area was to evaluate emissions of volatile organic compounds (VOCs) from the compost piles. This area was surveyed during the September 2002 field campaign.

1.3 Quality Objectives and Criteria

Data quality objectives (DQOs) are qualitative and quantitative statements developed using U.S. EPA's DQO Process (U.S. EPA, 1996) that clarify study objectives, define the appropriate type of data, and specify tolerable levels of potential decision errors that will be used as the basis for establishing the quality and quantity of data needed to support decisions. DQOs define the performance criteria that limit the probabilities of making decision errors by considering the purpose of collecting the data, defining the appropriate type of data needed, and specifying tolerable probabilities of making decision errors.

Quantitative objectives are established for critical measurements using the data quality indicators of accuracy, precision, and completeness. The acceptance criteria for these data quality indicators (DQI) are summarized in Table 1. Accuracy of measurement parameters is determined by comparing a measured value to a known standard, assessed in terms of percent bias. Values must be within the listed tolerance to be considered acceptable.

Precision is evaluated by making replicate measurements of the same parameter and by assessing the variations of the results. Precision is assessed in terms of relative percent difference (RPD), or relative standard deviation (RSD).

Replicate measurements are expected to fall within the tolerances shown in Table 1. Completeness is expressed as a percentage of the number of valid measurements compared to the total number of measurements taken.

Estimated minimum detection limits, by compound, are given in Table 2. It is important to note that the values listed in Table 2 should be considered first step approximations because the minimum detection limit is highly variable and depends on many factors including atmospheric conditions. Actual minimum detection levels are calculated in the quantification software for all measurements taken. Minimum detection levels for each absorbance spectrum are determined by calculating the root mean square (RMS) absorbance noise in the spectral region of the target absorption feature. The minimum detection level is the absorbance signal (of the target compound) that is five times the RMS noise level, using a reference spectrum acquired for a known concentration of the target compound.

Table 1. DQI Goals for Critical Measurements

Measurement Parameter	Analysis Method	Accuracy	Precision	Detection Limit	Completeness
Analyte PIC	OP-FTIR	±5%	±10%	see Table 2	90%
Ambient Wind Speed	Climatronics Met heads side-by-side comparison in the field	±1 m/s	±1 m/s		90%
Ambient Wind Direction	Climatronics Met heads side-by-side comparison in the field	±10°	±10°		90%
Distance Measurement	Theodolite- Topcon	±1 m	±1 m	0.1 m	100%
Elemental Mercury	Lumex (direct method)	±20%	±20%	2 – 500 ng/m^3 [e]	90%
Total Mercury[a]	TD-GC-AFS[c]	50–150% recovery	±20%	33 ng/m^3 [f]	90%
Dimethyl Mercury (Carbotrap)[a]	TD-GC-pyrolysis-CVAFS[d]	50–150%	±20%	1.1 ng/m^3 [g]	90%
Monomethyl Mercury[a]	TD-GC-CVAFS	50–150%	±20%	0.63 ng/m^3 [h]	90%
Total Mercury[b]	TD-GC-AFS	50–150%	±20%	33 ng/m^3 [f]	90%
Dimethyl Mercury (Carbotrap)[b]	TD-GC-pyrolysis-CVAFS	50–150%	±20%	19.8 ng/m^3 [i]	90%
Dimethyl Mercury (methanol)[b]	TD-GC-CVAFS	50–150%	±20%	0.34 ng/m^3 [f]	90%
Monomethyl Mercury[b]	TD-GC-CVAFS	50–150%	±20%	0.34 ng/m^3 [f]	90%

[a] September 2002 campaign.
[b] September 2003 campaign.
[c] TD = thermal desorption; GC = gas chromatography; AFS = atomic fluorescence spectrometry.
[d] CVAFS = cold vapor atomic fluorescence spectrometry.
[e] Estimated detection limit for natural and industrial gases. The landfill gas would have to be assayed to determine the actual detection limit of the instrument.
[f] Estimated detection limit for a 30 L sample.
[g] Estimated detection limit for a 9.0 L sample.
[h] Estimated detection limit for a 16.0 L sample.
[i] Estimated detection limit for a 0.5 L sample.
All of the detection limits listed for the Frontier methods are method limits, which are essentially 10× the detection limit.

Table 2. Detection Limits for Target Compounds.

Compound	Sampling/Analytical Method	Est. Detect. Limit for Path Length = 100 m, 1 min Ave. (ppmv)	AP-42 Value[a] (ppmv)
Acetaldehyde	FTIR	0.010	N/A[b]
Acetone	FTIR	0.024	7.01
Acrylonitrile	FTIR	0.010	6.33
Benzene	FTIR	0.040	N/A
Bromodichloromethane	FTIR	N/A	3.13
Butane	FTIR	0.006	5.03
1,3-Butadiene	FTIR	0.012	N/A
Carbon disulfide	FTIR	0.028	0.58
Carbon tetrachloride	FTIR	0.008	0.004
Carbonyl sulfide	FTIR	0.006	0.49
Chlorobenzene	FTIR	0.040	0.25
Chloroform	FTIR	0.012	0.03
Chloromethane	FTIR	0.012	1.21
1,4-Dichlorobenzene	FTIR	0.012	0.21
Dichlorodifluoromethane	FTIR	0.004	15.7
t-1,2-Dichloroethene	FTIR	N/A	2.84
Dichlorofluoromethane	FTIR	N/A	2.62
Dimethyl sulfide	FTIR	0.018	7.82
Ethane	FTIR	0.010	889.
Ethanol	FTIR	0.006	27.2
Ethyl benzene	FTIR	0.060	4.61
Ethyl chloride	FTIR	0.004	1.25
Ethyl mercaptan	FTIR	N/A	2.28
Ethylene dibromide	FTIR	0.006	0.001
Ethylene dichloride	FTIR	0.030	0.41
Fluorotrichloromethane	FTIR	0.004	0.76
Formaldehyde	FTIR	0.006	N/A
Hexane	FTIR	0.006	6.57
Hydrogen sulfide	FTIR	6.0	35.5
Methane	FTIR	0.024	N/A
Methyl chloroform	FTIR	0.006	N/A
Methyl ethyl ketone	FTIR	0.030	7.09
Methyl isobutyl ketone	FTIR	0.040	1.87
Methyl mercaptan	FTIR	0.060	2.49
Methylene chloride	FTIR	0.014	14.3
Pentane	FTIR	0.008	3.29
Propane	FTIR	0.008	11.1
2-Propanol	FTIR	0.006	50.1
Propylene dichloride	FTIR	0.014	0.18
Tetrachloroethene	FTIR	0.004	3.73
Toluene	FTIR	0.040	N/A

continued

Table 2 (concluded). Detection Limits for Target Compounds.

Compound	Sampling/Analytical Method	Est. Detect. Limit for Path Length = 100 m, 1 min Ave. (ppmv)	AP-42 Value[a] (ppmv)
Trichloroethylene	FTIR	0.004	2.82
Vinyl chloride	FTIR	0.010	7.34
Vinylidene chloride	FTIR	0.014	0.20
Xylenes	FTIR	0.030	12.1
Elemental mercury	Lumex (direct method)	2–500 ng/m^3 [g]	
Total mercury[c]	TD-GC-AFS[e]	33 ng/m^3 [h]	
Dimethyl mercury (carbotrap)[c]	TD-GC-pyrolysis--CVAFS[f]	1.1 ng/m^3 [i]	
Monomethyl mercury[c]	TD-GC-CVAFS	0.63 ng/m^3 [j]	
Total mercury[d]	TD-GC-AFS	33 ng/m^3 [h]	
Dimethyl mercury (carbotrap)[d]	TD-GC-pyrolysis--CVAFS	19.8 ng/m^3 [k]	
Demethy mercury (methanol)[d]	TD-GC-CVAFS[f]	0.34 ng/m^3 [h]	
Monomethyl mercury	TD-GC-CVAFS[f]	0.34 ng/m^3 [h]	

[a] The AP-42 values represent an average concentration of different pollutants in the raw landfill gas. This is not comparable to the detection limits for the OP-FTIR, which is an average value for a path length of 100 m across the surface of the area source being evaluated. However, it does provide an indication of the types of pollutants and range of concentrations associated with landfill gas emissions in comparison to the detection limits of the OP-FTIR.
[b] N/A = not applicable.
[c] September 2002 campaign.
[d] September 2003 campaign.
[e] TD = thermal desorption; GC = gas chromatography; AFS = atomic fluorescence spectrometry.
[f] CVAFS = cold vapor atomic fluorescence. spectrometry
[g] Estimated detection limit for natural and industrial gases. The landfill gas would have to be assayed to determine the actual detection limit of the instrument.
[h] Estimated detection limit for a 30 L sample.
[i] Estimated detection limit for a 9.0 L sample.
[j] Estimated detection limit for a 16.0 L sample.
[k] Estimated detection limit for a 0.5 L sample.
All of the detection limits listed for the Frontier methods are method limits, which are essentially 10X the detection limit.

1.4 Schedule of Work Performed for the Project

Three field measurement campaigns were completed for this study. Surveying was done at the site during September 2002, May 2003, and September 2003. Table 3 provides the schedule of ORS work that was performed during each field campaign.

Table 3. Schedule of ORS Work Performed at the Outer Loop Facility.

Field Campaign	Date	Day of Week	Detail of Work Performed
September 2002	6 September	Friday	AM – Arrive at site PM – Begin survey/set-up work
September 2002	7 September	Saturday	VRPM of Compost Area
September 2002	8 September	Sunday	HRPM and VRPM of As-Built Area
September 2002	9 September	Monday	VRPM of Biocover Area
September 2002	10 September	Tuesday	VRPM of Control Area
September 2002	11 September	Wednesday	HRPM of Retrofit Area
September 2002	12 September	Thursday	VRPM of Retrofit Area
May 2003	27 May	Tuesday	AM – Arrive at site PM – HRPM of As-Built Area
May 2003	28 May	Wednesday	HRPM of As-Built Area
May 2003	29 May	Thursday	VRPM of As-Built Area
May 2003	30 May	Friday	VRPM of As-Built and Biocover Areas
May 2003	31 May	Saturday	VRPM of Biocover and Control Areas
May 2003	2 June	Monday	HRPM of Retrofit Area
May 2003	3 June	Tuesday	VRPM of Retrofit Area
September 2003	24 September	Wednesday	AM – Arrive at site PM – HRPM of As-Built Area
September 2003	25 September	Thursday	HRPM and VRPM of As-Built Area
September 2003	26 September	Friday	HRPM and VRPM of As-Built Area
September 2003	27 September	Saturday	VRPM of Retrofit Area
September 2003	28 September	Sunday	HRPM of Retrofit Area

2. Testing Procedures, Results, and Discussion from the Field Campaigns

The following subsections describe the testing procedures, results, and a discussion of the results from the three field campaigns completed at the Outer Loop Facility.

The discussion of the testing procedures includes a figure detailing the orientation of the instruments in each survey area. The figures represent magnifications of the pertinent areas from Figure 1. These figures depict the locations of the scanner/OP-FTIR instruments (indicated by the cylindrical figure), as well as the optical paths of the OP-FTIR instruments. The location of the scissors jack is indicated by a square. It should be noted that the orientation of the instruments in each survey area changed slightly for each subsequent field campaign.

The distance and horizontal and vertical position of each retroreflector (mirror) were taken during each field campaign and are presented in Appendix A of this report. Additionally, a Global Positioning System (GPS) was used in the May 2003, and September 2003 field campaign to measure the coordinates of the boundaries of each survey area. The GPS measurements are presented in Appendix D of this report.

OP-FTIR data were collected as interferograms. All data were archived to CD-ROMs. After archiving, interferograms were transformed to absorbance spectra and then calculated concentrations using a combination of *AutoQuant* (Midac) and *Non-Lin* (Spectrosoft) quantification software. This analysis was done after completion of the field campaign. Concentration data were matched with the appropriate mirror locations, wind speed, and wind direction. *MatLab* (Math-works) software was used to process the data into horizontal plane concentration maps or vertical plane plume visualizations, as appropriate. The fluxes are then determined as the sum across the matrix of the point-wise multiplication of the concentrations times the wind speed.

Meteorological data including wind direction, wind speed, temperature, relative humidity, and barometric pressure were continuously collected during the sampling/measurement campaign with a Climatronics model 101990-G1instrument, which is automated. It collects real-time data from its sensors and records time-stamped data as one-minute averages to a data logger. Wind direction and speed-sensing heads were used to collect data at two heights, nominally at two and ten meters (the ten meter sensor was placed on top of the scissors jack). The sensing heads for wind direction incorporate an auto-northing function (automatically adjusts to magnetic north) that eliminates the errors associated with subjective field alignment to a compass heading. The sensing heads incorporate standard cup-type wind speed sensors. Post-collection, a linear interpolation between the two sets of data is done to estimate wind velocity as a function of height.

The results from the ORS-RPM data collected at the Outer Loop Facility are also presented in the following subsections. Statistical analysis was performed on several of the data sets to assess data quality and consistency. At this time, it is necessary to provide some background information on some of the statistical parameters presented in this section.

The concordance correlation factor (CCF) is used to represent the level of fit for the reconstruction in the path-integrated domain (predicted vs observed PIC). The CCF is similar to the Pearson correlation coefficient (r), but is adjusted to account for shifts in location and scale. Like the Pearson correlation coefficient, CCF values are bounded between -1 and 1, yet the CCF can never exceed the absolute value of the Pearson correlation factor. For example, the CCF will be equal to the Pearson correlation when the linear regression line intercepts the ordinate at 0 and its slope equals 1. Its absolute value will be lower than the Pearson correlation when the above conditions are not met.

For the purposes of this report, the closer the CCF value is to 1, the better the fit for the reconstruction in the path-integrated domain.

In reporting the average calculated fluxes, a moving average is used in several of the tables to show temporal variability in the flux values. A moving average involves averaging flux values calculated from several consecutive loops (a loop is defined as data collected when scanning one time through all the mirrors in the configuration). For example, a data set taken from 5 loops may be reported using a moving average of 4, where values from loops 1 to 4, and 2 to 5 are averaged together to show any variability in the flux values.

During each of the three field campaigns, U.S. EPA personnel set up a bistatic OP-FTIR in an upwind location at each survey area and operated it in a classical non-scanning configuration. Refer to the maps of configurations used in each area that are included in the subsections below for the location of the bistatic instrument. Path-averaged methane concentration data collected by this instrument were used to establish background concentrations from ambient, or upwind, sources. This was especially important during the September 2002 field campaign, since only one monostatic OP-FTIR was used during this campaign.

During the May 2003 field campaign, upwind data were collected in each survey area with a second monostatic OP-FTIR. The use of an upwind vertical configuration using multiple mirrors allowed for the calculation of an upwind flux value. Refer to the maps of configurations used in each area for the location of the upwind configuration.

During the September 2003 field campaign, upwind data were collected with a second monostatic OP-FTIR in the As-Built Area. However, it was not possible to set up an upwind vertical configuration in the Retrofit Area because access to this area was limited. The bistatic OP-FTIR was operating during the Retrofit VRPM survey (see Figure 33 for the location of the bistatic OP-FTIR configuration). The path-averaged methane concentration data from this instrument are presented below as an alternative to upwind flux measurements.

The following sections contain figures depicting the reconstructed methane plume map and calculated methane flux generated from the collected data using the VRPM method. It should be noted that the shape of the plume maps generated by this method are used to give information on the homogeneity of the plume and do not affect the calculated flux values. The shape of the maps generated represents the best fit of the limited data to a symmetric Gaussian function, and this fit may drive the plume shape outside of the configuration. The plume shapes depicted should not be used to assess whether or not the plume was captured by the VRPM configuration.

The calculated methane flux values are presented in grams per second (g/s). However, the majority of the existing literature relating to methane emissions from landfills present methane flux values in units of mass per unit area per time. In order to normalize the calculated flux values to unit area, the values are also presented in units of grams per square meter per day ($g/m^2/day$). The area of each emissions area was estimated by multiplying the length of the VRPM configuration by 50 m (the estimated upwind or downwind distance that would be the largest contributor to measured methane emissions).

2.1 As-Built Area

This section describes procedures and summarizes results for the As-Built Area for the September 2002, May 2003, and September 2003 field campaigns. It should be noted that the dimensions of the As-Built area surveyed during the May 2003, and September 2003 campaigns were not consistent with the dimensions of the area provided during the September 2002 campaign.

2.1.1 Testing Procedures used during the September 2002 Field Campaign

Figure 4 shows the optical configurations used at the As-Built Area during the September 2002 field campaign. Although a full HRPM survey of the area was planned, this was not possible due to the operations schedule in the As-Built Area, and the limitations of the scanner equipment.

As an alternative, four surface non-scanning experiments were performed prior to the VRPM survey. Although these four surface scans do not permit construction of a contour map of surface concentrations, they do provide the best data available on concentrations of methane and volatile organic compounds.

The VRPM configuration was set up along the southern boundary of the As-Built Area (see Figure 4). The configuration used one monostatic OP-FTIR, and five retroreflectors. Although it was desired to set up the configuration along the entire southern boundary of the As-Built Area, this was not possible due to limitations in the monostatic OP-FTIR instrumentation.

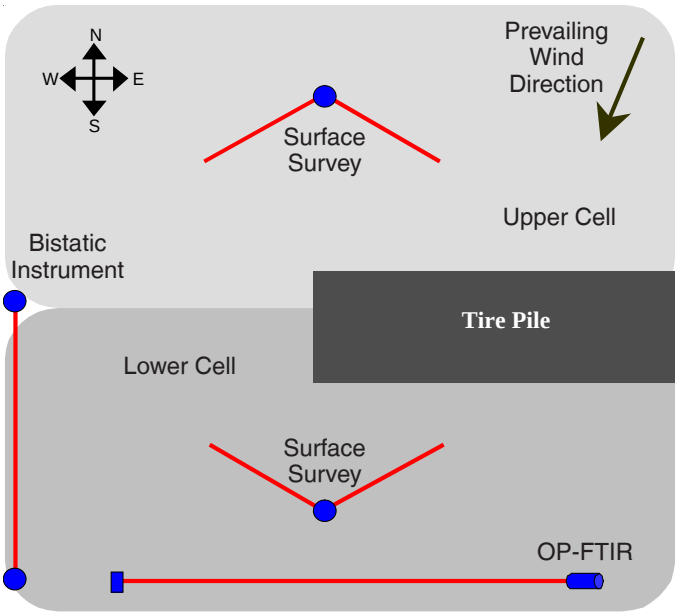

Figure 4. Map of As-Built Area Showing Instrumentation during the September 2002 Field Campaign.

Concurrent meteorological data were collected during these tests. The bistatic OP-FTIR instrument was operated by U.S. EPA personnel along the western boundary of the As-Built Area to collect background concentration data.

2.1.2 Results and Discussion from the September 2002 Field Campaign

Table 4 presents the methane emission flux from the VRPM survey of the As-Built Area (refer to Figure 4 for a map of this site and the optical configurations there). The first column of this table refers to a running average calculation from the several loops of data collected. The second column shows the calculated CCF. The third, fourth, and fifth columns show the calculated methane flux (in g/s) as well as the average wind speed and wind direction, respectively, during the time the measurements were taken. The average wind speed and wind direction values were obtained from the ORS-RPM software. The methane concentrations used to create this table can be found in Appendix B.

Figure 5 presents a map of the reconstructed methane plume from the As-Built VRPM survey. Contour lines give methane concentrations in ppmv. The average calculated methane flux from the As-Built Area was 140 g/s (this average is the average of all of the loops used in the flux calculation, while the average reported in Table 4 is an average of the fluxes calculated using a moving average of four loops). This value is converted to units of grams per square meter, per day (g/m^2/day) by multiplying by 86,400 s/day, and dividing by the area (in meters squared) of the upwind survey area. The area of the upwind survey area was calculated based on survey measurements taken during the field campaign. The methane flux value of the As-Built Area was 1400 g/m^2/day.

Table 4. Moving Average of the Calculated Methane Flux, CCF, Wind Speed, and Wind Direction for the As-Built Area During the September 2002 Field Campaign.

Loops	CCF	Flux (g/s)	Wind Speed (m/s)	Wind Direction[a] (deg)
1 to 4	0.980	170	1.9	51
2 to 5	0.977	180	2.4	33
3 to 6	0.962	170	2.5	36
4 to 7	0.958	120	2.2	43
Average	0.969			
Std. Dev. of Mean	0.0108			

[a] Measured from a vector normal to the configuration plane.

Concentrations of various compounds were calculated from the four surface non-scanning experiments as well as the from VRPM experiments. The measured concentrations are presented in the Appendix B of this report.

Background data collected with the bistatic OP-FTIR found an average methane concentration of 8.6 ppmv. Figure 4 shows that the bistatic OP-FTIR configuration was located along the western boundary of the As-Built Area. Although the prevailing wind direction was from the northeast during the VRPM surveys (see Figure 4), the prevailing winds were generally from the west-northwest during the time that background data was collected. However, closer inspection of the wind data collected at the time of the background measurements found that the wind directions were variable, and some of the background data probably included some methane emissions from the landfill. Consequently, the background measurements were probably not indicative of a true background methane measurement for the As-Built Area.

Due to time constraints and instrument limitations discussed previously, a complete HRPM survey of the As-Built Area was not performed to identify the exact location of hot spots, which may have contributed to the calculated methane flux. However, a non-scanning surface survey was performed in the As-Built using four beams. This survey was conducted over the western and central areas of the As-Built Area (see Figure 4). Analysis of the wind data revealed that the prevailing wind direction during the VRPM survey was from the northeast. Using this wind data, and the

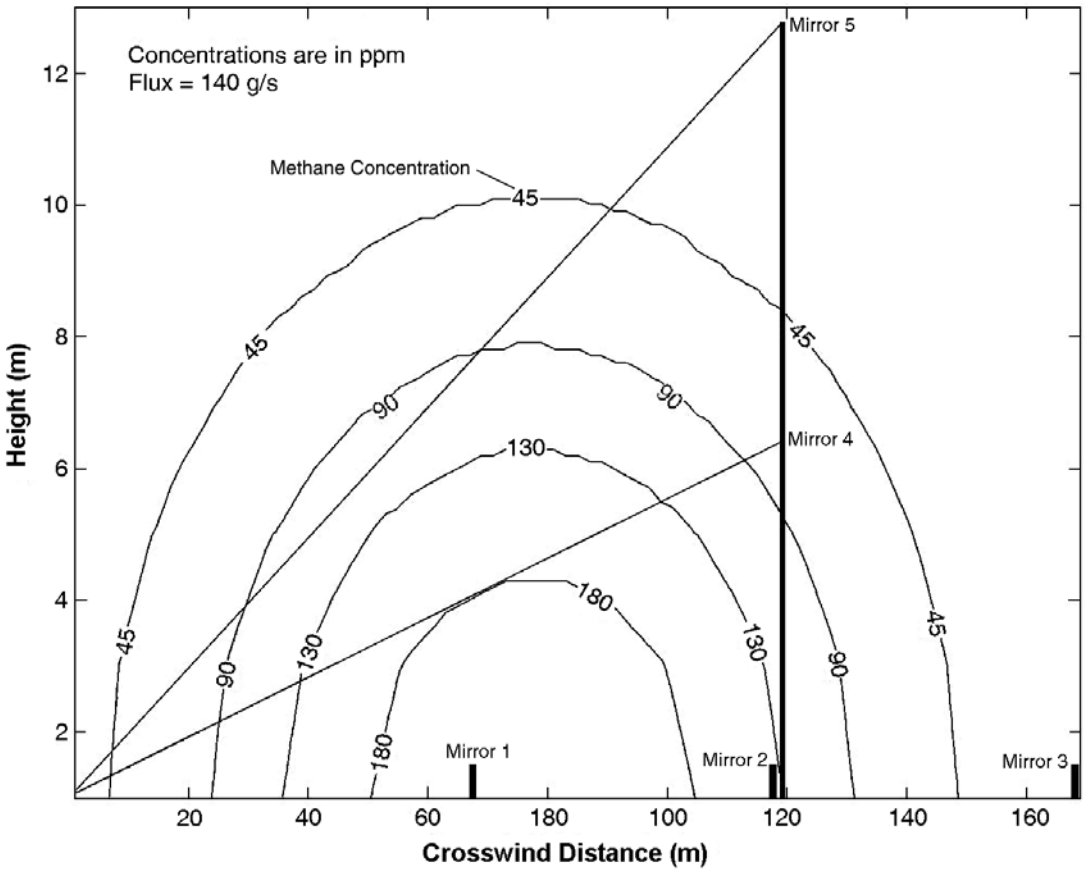

Figure 5. Average Reconstructed Methane Plume from the September 2002 As-Built VRPM Survey.

fact that much lower methane concentrations were found during the surface survey of the western and central portions of the As-Built Area, the conclusion can be drawn based on the method described by Hashmonay and Yost [1999] that any hot spots contributing to the methane fluxes calculated were probably located in the eastern portion of the As-Built Area (consisting of cells 4A and 4B).

The average calculated methane flux from the As-Built Area was 140 g/s. However, this value may be a low estimate of the total methane flux from the As-Built Area. The observed wind direction during the VRPM survey was variable, and environments having variable wind directions are classified as unstable. Other studies have found that calculated fluxes could underestimate actual fluxes by as much as 35% in unstable environments [Hashmonay et al., 2001]. Additionally, the axis of the VRPM configuration was oriented along the southern boundary of the As-Built Area (see Figure 4). However, due to limitations in the optical range of the OP-FTIR instrument (see Section 4.7.1 for further discussion), it was not possible for the VRPM configuration to include the entire southern boundary of the survey area. Thus, it is possible that the entire methane plume from the As-Built was not captured by the vertical configuration. Consequently, the calculated methane flux from the As-Built Area may be underestimating the actual flux, but the major identified hot spot was fully quantified. This is supported by the results shown in Figure 5, which shows that the plume concentrations are not homogenous along the crosswind axis. This indicates that the source of the methane plume (hot spot) is located in close proximity to the vertical configuration, which greatly increases the chances that all emissions from this hot spot were captured by the vertical configuration.

2.1.3 Testing Procedures Used During the May 2003 Field Campaign

During the May 2003 field campaign, HRPM and VRPM were conducted in the As-Built Area, which consisted of an upper cell (4A) and a lower cell (4B). Due to the size of the As-Built Area and the large slope that existed between the two cells, the cells were surveyed separately during this field campaign. The GPS coordinates of the boundaries of the cells are presented in Appendix D.

HRPM of both cells was completed separately using one monostatic OP-FTIR. For the horizontal survey of the lower cell, the OP-FTIR/scanner was placed in the southwest corner of the cell, and eight retroreflectors were placed along the surface of the area. The HRPM survey of the upper cell was conducted using eight retroreflectors as well, with the OP-FTIR/scanner placed in the southeastern corner of the cell. Figure 6 shows the HRPM configuration used for the survey of the lower cell.

VRPM surveys of both cells were completed using two monostatic OP-FTIR instruments and two scissors jacks. The configuration formed two vertical planes (one upwind and one downwind). Two retroreflectors were used in the upwind vertical plane, and six retroreflectors were used in

Figure 6. HRPM Configuration Used to Survey the As-Built Lower Cell During the May 2003 Field Campaign.

the downwind vertical plane. Figures 7 and 8 show the vertical configurations used for the upper and lower cells, respectively, of the As-Built Area. Figure 9 is a photograph of the VRPM configuration used in the survey of the upper cell.

In addition to the HRPM and VRPM surveys, a more detailed HRPM survey was done on a large slope that separated the lower and upper cells of the As-Built Area. During the field campaign, a large number of shredded tires were observed along the surface of the slope. Five retroreflectors were set up across the surface of the slope to collect data. The monostatic OP-FTIR was located on the upper cell, and scanned downward across the surface of the slope to the five retroreflectors.

Concurrent meteorological data were collected during these tests. Additionally, the bistatic OP-FTIR instrument was

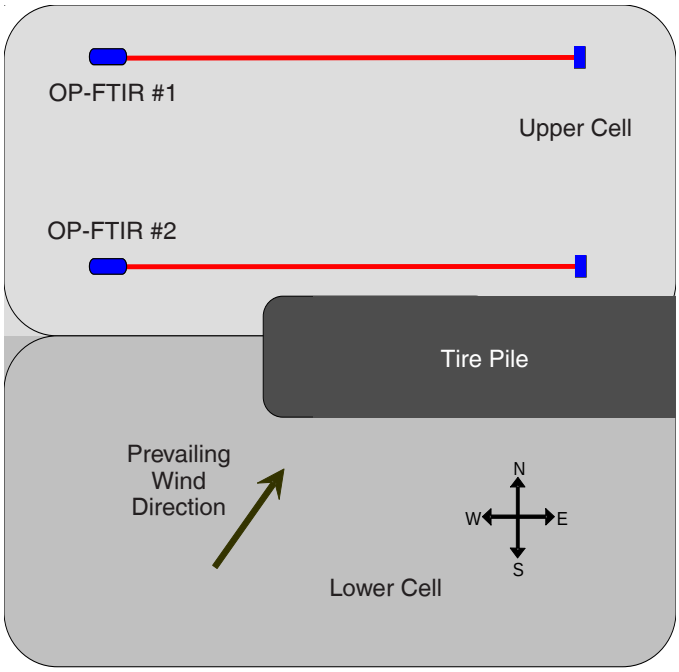

Figure 7. Map of As-Built Area Upper Cell Showing the Location of Vertical Planes Used During the May 2003 Field Campaign.

operated by U.S. EPA personnel in a location south of the As-Built Area.

2.1.4 Results and Discussion from the May 2003 Field Campaign

As mentioned above, HRPM and VRPM were performed in both cells of the As-Built Area. The HRPM surveys were performed to identify methane hot spots. Figures 10 and 11 present a contour map of reconstructed methane concentrations (in parts per million by volume) for the upper and lower cells, respectively. The figures show the presence of two methane hot spots in the upper cell and two hot spots in the lower cell. The most intense hot spot (over 210 ppmv) was located in the lower cell.

Table 5 presents the methane emission flux from the downwind VRPM survey of the As-Built upper area. Due to differences in the temporal resolution of the upwind and downwind collected data, the upwind data from this area were not included in this report. The upwind vertical configuration was scanned manually, with the OP-FTIR dwelling on each retroreflector for 30 min, while the downwind configuration was scanned automatically with the OP-FTIR dwelling on each retroreflector for 30 s. The resulting differences in resolution between the two configurations made it extremely difficult to produce a valid comparison of the

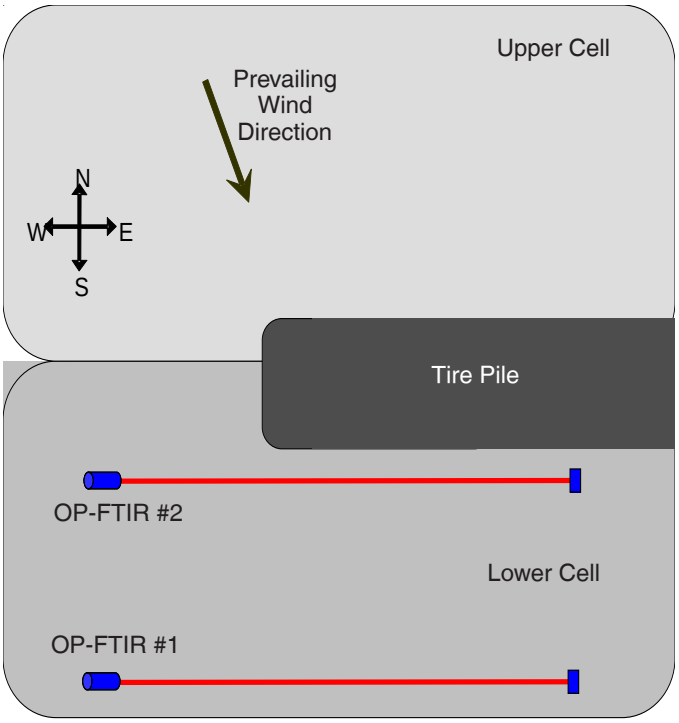

Figure 8. Map of As-Built Area Lower Cell Showing the Location of Vertical Planes Used During the May 2003 Field Campaign.

Figure 9. VRPM Configuration Used for the Survey of the Upper Cell During the May 2003 Field Campaign.

upwind and downwind fluxes. Refer to Figure 5 for a map of the cell and the optical configurations used there. The methane concentrations used to create this table can be found in Appendix B.

Figure 12 is a map of the reconstructed methane plume from the downwind As-Built upper cell VRPM survey.

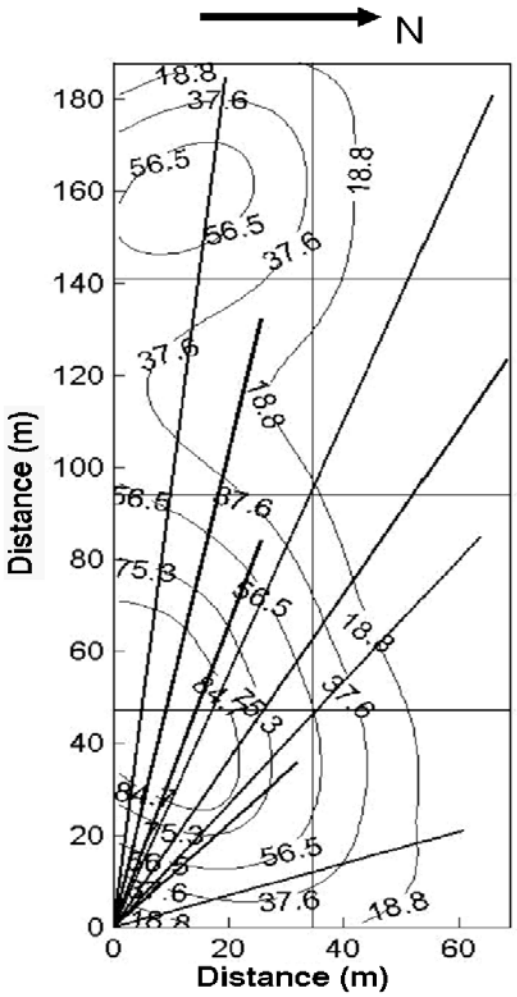

Figure 10. Reconstructed Methane Surface Concentrations (in ppm) for the As-Built Upper Cell During the May 2003 Field Campaign.

Contour lines give methane concentrations in parts per million by volume. The average calculated methane flux from this survey was 32 g/s, which is equivalent to approximately 250 g/m^2/day.

Table 6 presents the methane emission flux from the downwind VRPM survey of the As-Built lower area. Due to problems with data processing, the results of the upwind survey from this area are not available. Refer to Figure 8 for a map of the cell and the optical configurations used there. The methane concentrations used to create this table can be found in Appendix B.

Figure 13 is a map of the reconstructed methane plume from the downwind As-Built lower cell VRPM survey. Contour lines give methane concentrations in parts per

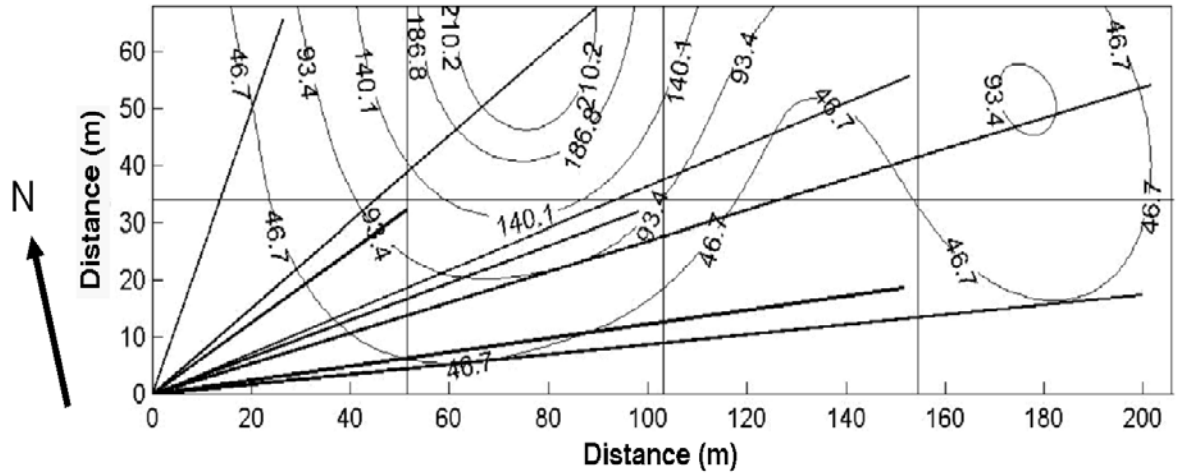

Figure 11. Reconstructed Methane Surface Concentrations (in ppmv) for the As-Built Lower Cell During the May 2003 Field Campaign.

Table 5. Moving Average of Calculated Methane Flux, CCF, Wind Speed, and Wind Direction for the Downwind As-Built Area Upper Cell During the May 2003 Field Campaign.

Loops	CCF	Flux (g/s)	Wind Speed (m/s)	Wind Dir.[a] (deg)
1 to 4	0.881	55	4.2	61
2 to 5	0.889	69	3.7	51
3 to 6	0.961	88	3.6	49
4 to 7	0.941	75	3.5	53
5 to 8	0.945	62	3.3	55
6 to 9	0.984	65	3.0	59
7 to 10	0.932	59	2.8	61
8 to 11	0.919	43	2.6	65
9 to 12	0.907	41	2.6	65
10 to 13	0.976	17	2.6	65
11 to 14	0.994	12	2.6	65
12 to 15	0.963	9.5	2.6	65
13 to 16	0.990	9.4	2.8	64
14 to 17	0.893	37	2.7	57
15 to 18	0.942	37	2.6	64
16 to 19	0.916	32	2.0	65
17 to 20	0.826	28	2.8	71
18 to 21	0.899	29	2.5	65
19 to 22	0.998	32	2.7	64
20 to 23	0.880	30	3.0	64
21 to 24	0.822	43	3.5	58
22 to 25	0.898	59	3.6	55
23 to 26	0.963	53	3.4	56
24 to 27	0.974	48	3.3	60
25 to 28	0.983	37	3.3	64
26 to 29	0.867	33	3.5	70
Average	0.929			
Std. Dev.	0.0503			

[a] Wind direction shown is measured from a vector normal to the plane of the configuration.

million by volume. The average calculated methane flux from this survey was 99 g/s, which is equivalent to approximately 660 g/m^2/day.

As mentioned above, two methane hot spots were detected along the surface of the upper cell, and two hot spots were detected along the surface of the lower cell. Three of the hot spots detected were located adjacent to the slope separating the two cells, indicating that this area may be a significant source of methane emissions in the As-Built Area.

The average calculated methane flux from the upper and lower cells was 32 g/s and 99 g/s, respectively. The methane flux values measured in the lower cell were much higher than those measured in the upper cell. This is probably due to the fact that the observed winds during the vertical survey of the lower cell were closer to perpendicular to the vertical plane than during the vertical surveys of the upper cell. This allowed a greater portion of the methane emissions to be captured by the vertical plane of the lower cell survey.

2.1.5 Testing Procedures Used During the September 2003 Field Campaign

HRPM and VRPM were conducted in the As-Built Area during the September 2003 field campaign. The topography of the As-Built Area was identical to the May 2003 field campaign, so the two cells were again surveyed separately. The GPS coordinates of the boundaries of the cells are presented in Appendix D.

HRPM of both cells was completed separately using one monostatic OP-FTIR. For the horizontal survey of the lower

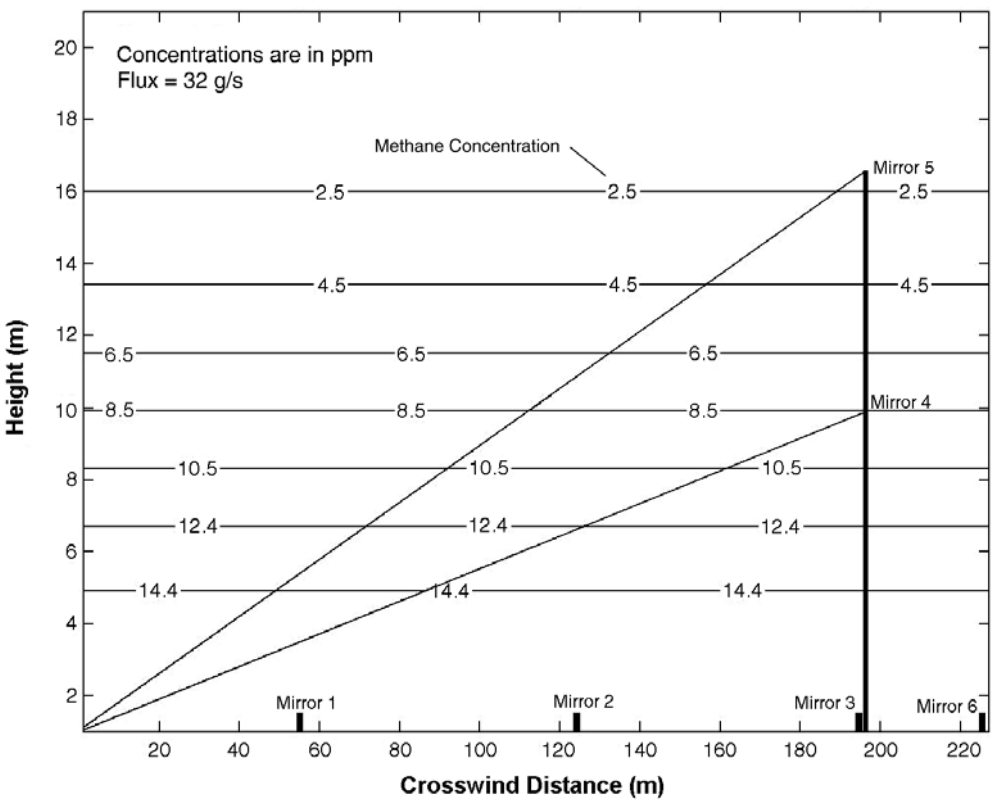

Figure 12. Average Reconstructed Methane Plume from the May 2003 Downwind As-Built Upper VRPM Survey.

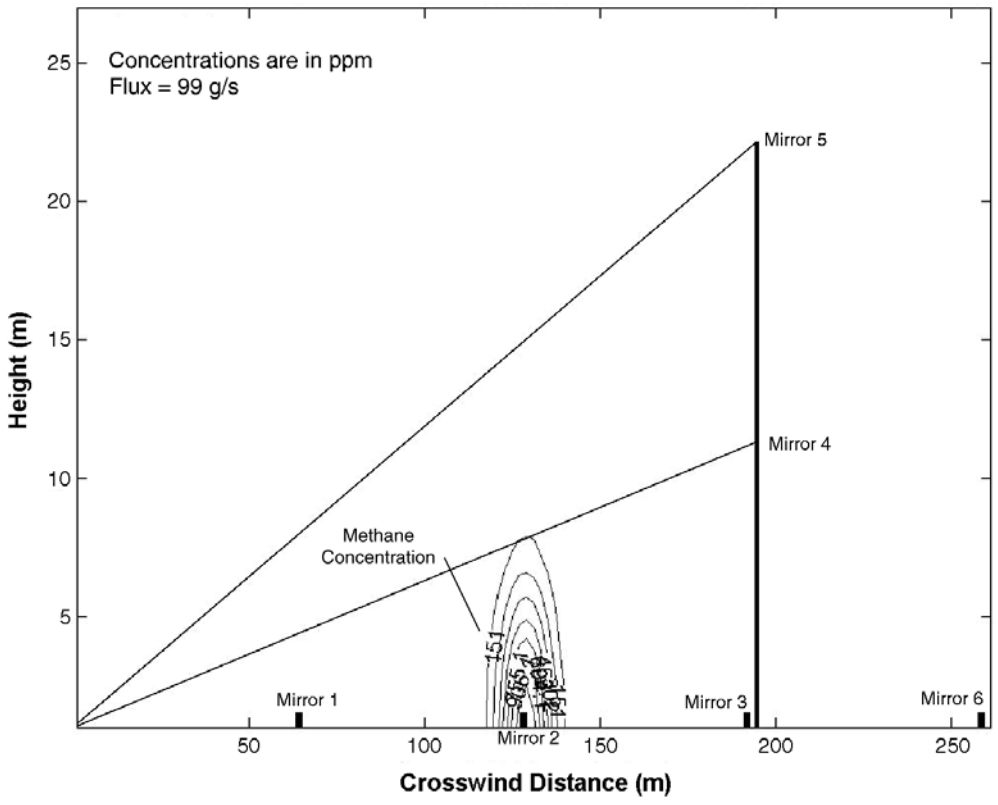

Figure 13. Average Reconstructed Methane Plume from the May 2003 As-Built Lower VRPM Survey.

Table 6. Moving Average of Calculated Methane Flux, CCF, Wind Speed, and Wind Direction for the As-Built Area Lower Cell During the May 2003 Field Campaign.

Loops	CCF	Flux (g/s)	Wind Speed (m/s)	Wind Dir.[a] (deg)
1 to 4	0.999	140	4.9	297
2 to 5	0.999	130	4.5	294
3 to 6	0.999	110	4.5	296
4 to 7	0.999	94	4.2	292
5 to 8	0.999	79	4.6	293
6 to 9	0.996	130	4.6	296
7 to 10	0.995	98	4.4	291
8 to 11	0.988	95	4.6	291
9 to 12	0.997	140	3.9	297
10 to 13	0.975	150	3.8	306
11 to 14	0.980	140	3.6	306
12 to 15	0.982	140	3.6	306
13 to 16	0.982	120	3.6	304
14 to 17	0.986	110	4.0	297
15 to 18	0.999	76	4.8	296
16 to 19	0.997	160	5.2	296
17 to 20	0.997	170	5.5	295
18 to 21	0.997	170	5.3	297
19 to 22	0.997	180	5.1	299
20 to 23	0.996	170	4.9	301
Average	0.993			
Std. Dev.	0.0076			

[a] Wind direction shown is measured from a vector normal to the plane of the configuration.

cell, the OP-FTIR was placed in the southwest corner of the cell, and eight retroreflectors were placed along the surface of the area. The HRPM survey of the upper cell was done using eight retroreflectors as well, with the OP-FTIR placed in the southwestern corner of the cell.

VRPM surveys of both cells were completed using two monostatic OP-FTIR instruments, and two scissors jacks. The configuration formed two vertical planes (one upwind plane, and one downwind plane). For the VRPM survey of the lower cell, three retroreflectors were used in the upwind vertical plane located along the southern boundary of the cell, and six retroreflectors were used in the downwind vertical plane located along the northern boundary of the cell. For the VRPM survey of the upper cell, only two retroreflectors were used in the downwind vertical plane along the northern boundary of the cell, and six retroreflectors were used in the upwind vertical plane located along the southern boundary of the cell. When the VRPM was being set up, the breeze was out of the north, and the downwind plane had six retroreflectors. But the breeze shifted to out of the south as Figure 14 shows when measurements began, putting the six retroreflectors in the upwind direction. Figures 14 and 15 show the vertical configurations used for the upper and lower cells of the As-Built Area.

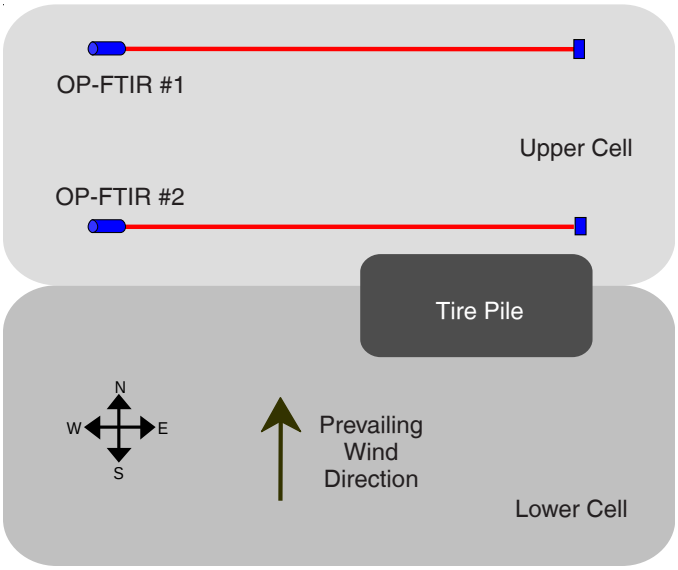

Figure 14. Map of As-Built Area Upper Cell Showing Location of Vertical Planes Used During the September 2003 Field Campaign.

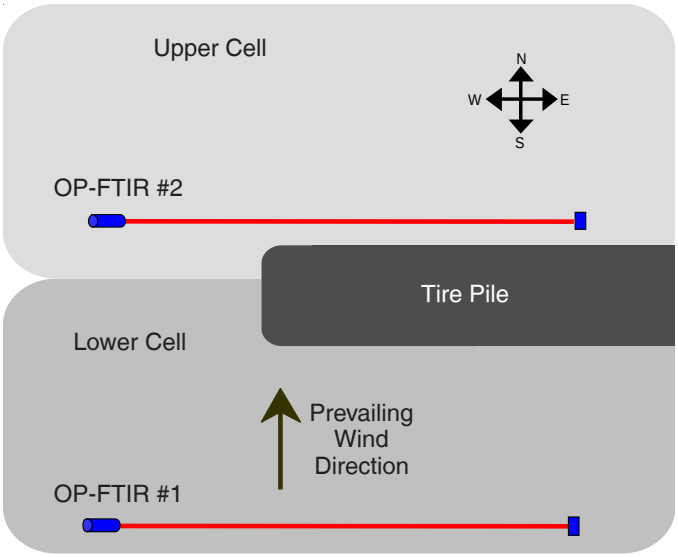

Figure 15. Map of As-Built Area Lower Cell Showing Location of Vertical Planes Used During the September 2003 Field Campaign.

Meteorological data were collected concurrently with the emissions data during these tests. Additionally, the bistatic OP-FTIR instrument was operated by U.S. EPA personnel in a location south of the As-Built Area.

2.1.6 Results and Discussion from the September 2003 Field Campaign

HRPM and VRPM were performed in the both cells of the As-Built Area. The HRPM surveys were performed to identify methane hot spots. Figures 16 and 17 are a contour map of reconstructed methane concentrations (in ppmv) for the upper and lower cells, respectively. The figures show the presence of one methane hot spot in the upper cell and two methane hot spots in the lower cell. The three hot spots detected were similar in magnitude.

Tables 7 and 8 present the methane emission flux from the upwind and downwind VRPM survey, respectively, of the As-Built upper area. It should be noted that, in general, the highest calculated methane fluxes occur during periods when the observed wind direction is close to perpendicular to the plane of the configuration. Refer to Figure 14 for

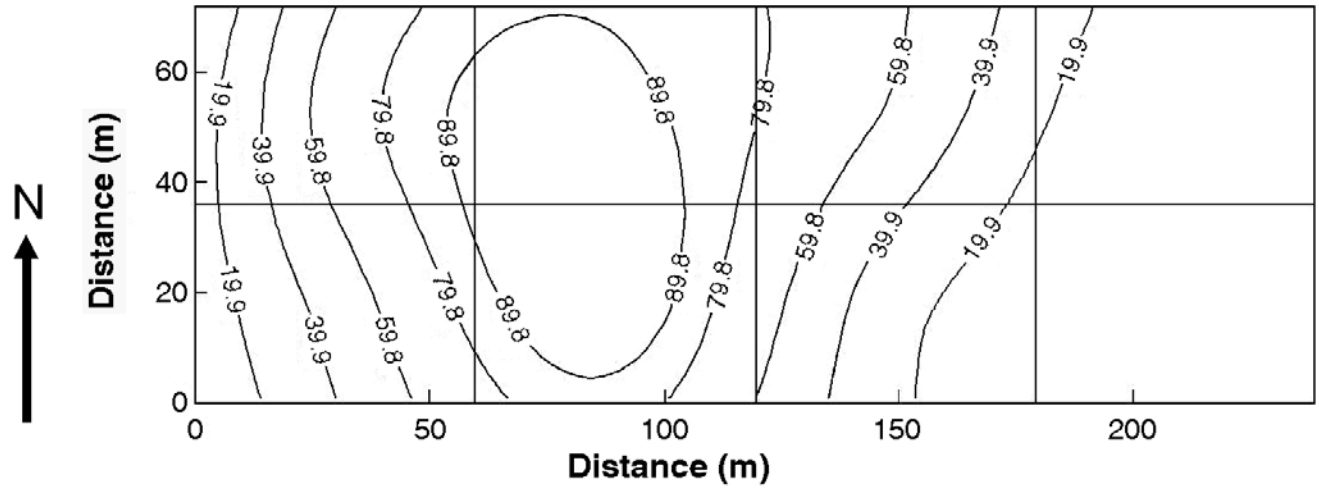

Figure 16. Reconstructed Methane Surface Concentrations (in ppmv) for the As-Built Upper Cell During the September 2003 Field Campaign.

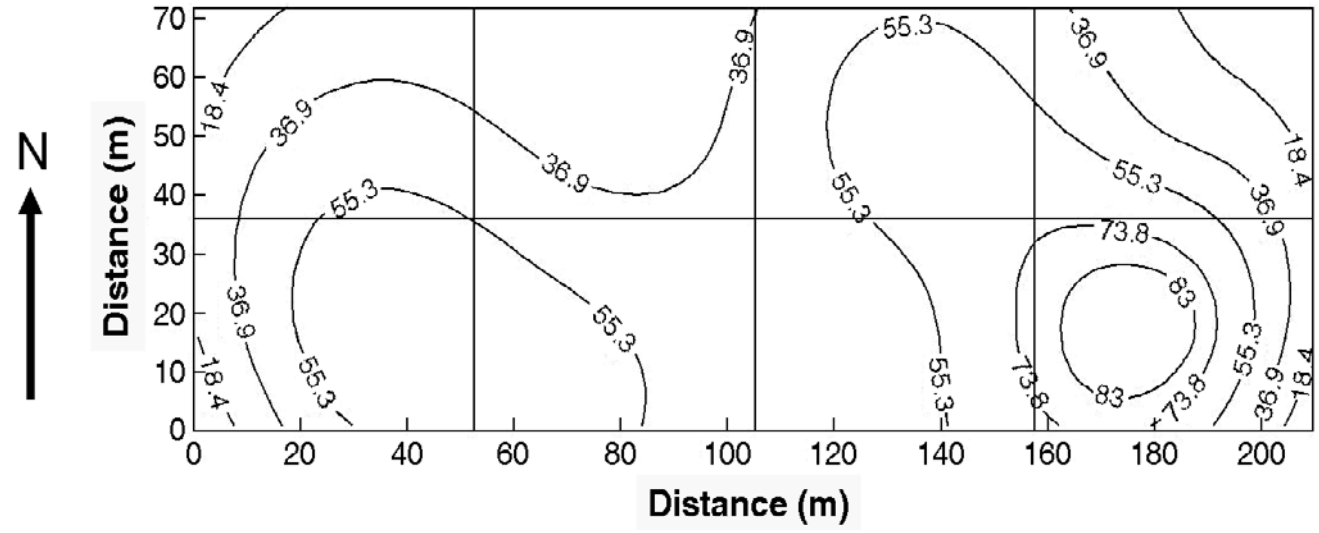

Figure 17. Reconstructed Methane Surface Concentrations (in ppmv) for the As-Built Lower Cell During the September 2003 Field Campaign.

Table 7. Moving Average of Calculated Methane Flux, CCF, Wind Speed, and Wind Direction for the Upwind As-Built Area Upper Cell During the September 2003 Field Campaign.

Loops	CCF	Flux (g/s)	Wind Speed (m/s)	Wind Dir.[a] (deg)
1 to 4	0.938	230	5.8	38
2 to 5	0.990	170	6.0	29
3 to 6	0.987	201	5.6	22
4 to 7	0.990	220	4.7	13
5 to 8	0.984	240	5.1	21
6 to 9	0.965	200	4.6	33
7 to 10	0.967	150	4.5	49
Average	0.974			
Std. Dev.	0.0192			

[a] Wind direction shown is measured from a vector normal to the plane of the configuration.

Table 8. Moving Average of Calculated Methane Flux, Wind Speed, and Wind Direction for the Downwind As-Built Area Upper Cell During the September 2003 Field Campaign.[a]

Loops	Flux (g/s)	Wind Speed (m/s)	Wind Dir.[b] (deg)
1 to 4	200	6.7	50
2 to 5	210	6.5	46
3 to 6	230	6.1	39
4 to 7	280	6.2	34
5 to 8	280	6.5	34
6 to 9	260	6.6	37
7 to 10	200	6.8	50
8 to 11	150	6.5	57
9 to 12	150	6.3	51
10 to 13	130	5.4	48
11 to 14	130	5.0	42
12 to 15	150	4.6	36
13 to 16	160	4.5	34
14 to 17	250	5.6	25
15 to 18	330	6.4	14
16 to 19	310	6.7	10
17 to 20	290	6.1	6
18 to 21	260	5.7	6
19 to 22	230	4.5	3
20 to 23	200	3.8	2
21 to 24	190	3.5	10
22 to 25	170	3.6	27
23 to 26	160	4.4	47
24 to 27	99	4.6	67
25 to 28	98	4.9	70
26 to 29	110	4.7	66
27 to 30	140	5.2	59

continued

Table 8 (concluded). Moving Average of Calculated Methane Flux, Wind Speed, and Wind Direction for the Downwind As-Built Area Upper Cell During the September 2003 Field Campaign.

Loops	Flux (g/s)	Wind Speed (m/s)	Wind Dir.[b] (deg)
28 to 31	130	5.3	57
29 to 32	84	4.8	67
30 to 33	120	5.3	64
31 to 34	190	6.1	45
32 to 35	190	6.2	39
33 to 36	270	6.3	29
34 to 37	290	6.1	26
35 to 38	290	6.3	29
36 to 39	230	6.0	37
37 to 40	180	5.3	37
38 to 41	200	5.5	33
39 to 42	230	5.3	25
40 to 43	220	4.8	20
41 to 44	220	4.8	19
42 to 45	190	4.6	21
43 to 46	160	4.0	25
44 to 47	200	4.9	21
45 to 48	210	5.4	27
46 to 49	220	5.9	34
47 to 50	240	6.7	35
48 to 51	230	7.0	42
49 to 52	230	6.9	42
50 to 53	220	6.7	42
51 to 54	170	6.5	49
52 to 55	150	6.1	50
53 to 56	130	5.8	48
54 to 57	110	5.1	44
55 to 58	140	4.8	32
56 to 59	160	4.3	23
57 to 60	210	4.3	17
58 to 61	250	4.4	15
59 to 62	230	4.5	28
60 to 63	180	4.5	41
61 to 64	120	4.5	55
62 to 65	96	4.9	64
63 ot 66	98	4.9	62
64 to 67	120	4.9	58
65 to 68	140	4.9	49
66 to 69	150	5.2	48
67 to 70	160	5.1	44

[a] CCF values were all 1.00 because only two mirrors were used in the reconstruction, so CCFs are not included.

[b] Wind direction shown is measured from a vector normal to the plane of the configuration.

a map of the cell and the optical configurations used there. The methane concentrations used to create these tables can be found in Appendix B.

Figures 18 and 19 are maps of the reconstructed methane plume from the upwind and downwind As-Built upper cell VRPM surveys, respectively. Contour lines give methane concentrations in ppmv. The average calculated methane flux from the upwind survey was 200 g/s, which is equivalent to approximately 1300 g/m^2/day. The average calculated methane flux from the downwind survey was 210 g/s, which is equivalent to approximately 1400 g/m^2/day.

Although the difference between the average calculated upwind and downwind methane fluxes is about 10 g/s, a more accurate representation of the methane fluxes from this area is obtained by looking at the peak methane values from the upwind and downwind surveys because peak fluxes typically occur when wind directions are closer to being perpendicular to the configurations. When wind directions are diagonal to the configurations, hot spots outside of the survey area could influence one vertical plane and miss the other, introducing error to the flux difference between the planes. Table 7 shows that the peak upwind methane fluxes occur during times that the winds are the most perpendicular to the upwind configuration (220 g/s when the winds are 13° from perpendicular and 240 g/s when the winds are 21° from perpendicular). Table 8 shows that the peak downwind methane fluxes also occur during times that the winds are the most perpendicular to the configuration (330 g/s when the winds are 14° from perpendicular and 310 g/s when the winds are 10° from perpendicular). Since the truest representation of net methane flux from the area occurs when the winds are perpendicular to the vertical configurations, it is likely that the actual net methane flux from the As-Built Upper cell is approximately 90 g/s.

Tables 9 and 10 present the methane emission flux from the upwind and downwind VRPM survey of the As-Built lower area, respectively. Refer to Figure 15 for a map of the cell and the optical configurations used there. The methane concentrations used to create these tables can be found in Appendix B.

Figures 20 and 21 present maps of the reconstructed methane plume from the upwind and downwind As-Built lower cell VRPM surveys, respectively. Contour lines give methane concentrations in ppmv. The average calculated methane flux from the upwind survey was approximately 140

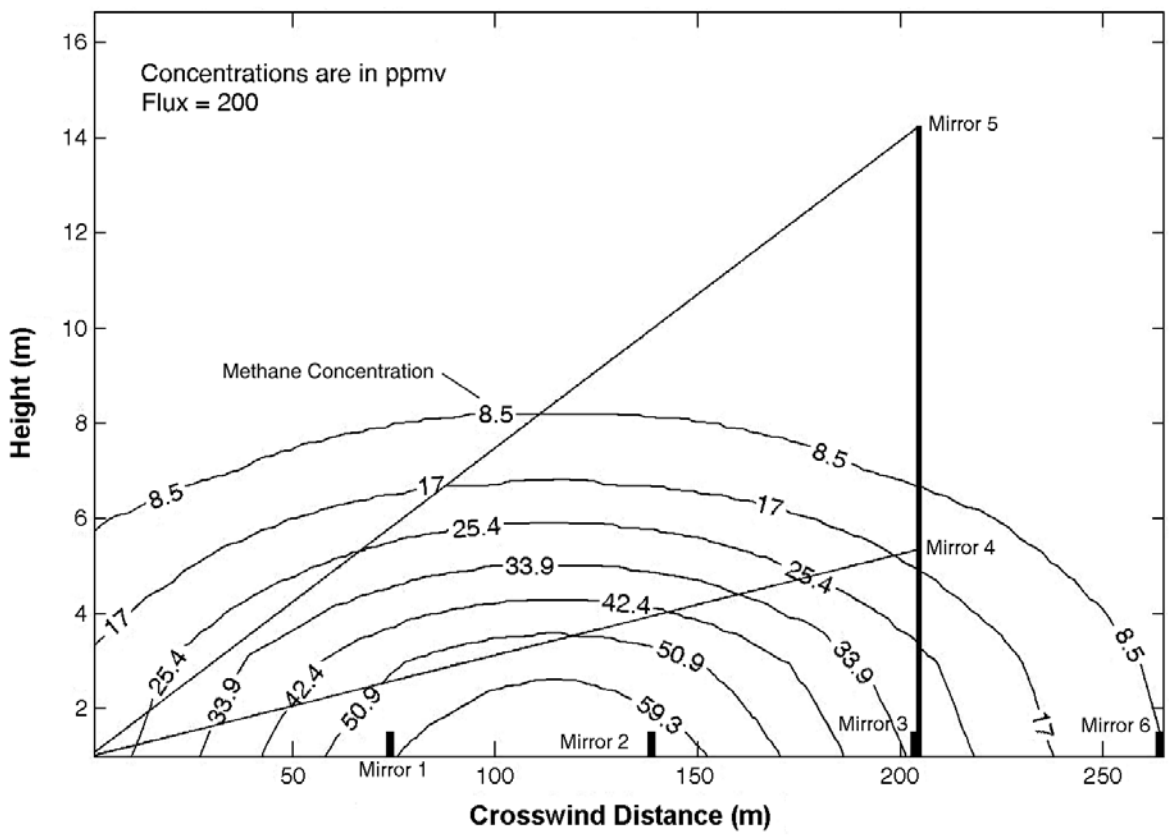

Figure 18. Average Reconstructed Methane Plume from the September 2003 Upwind As-Built Upper Cell VRPM Survey.

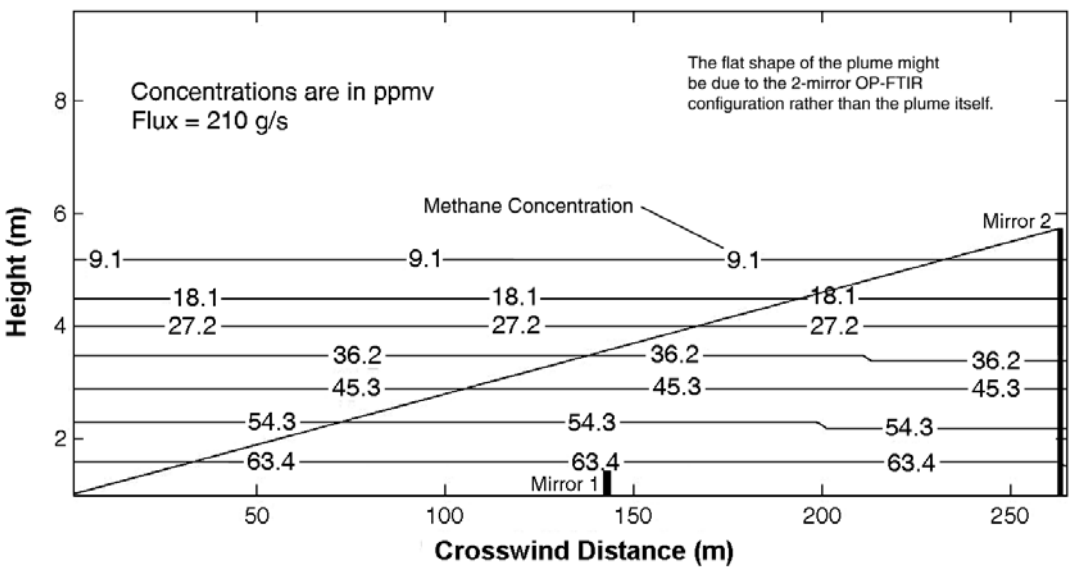

Figure 19. Average Reconstructed Methane Plume from the September 2003 Downwind As-Built Upper Cell VRPM Survey.

g/s, which is equivalent to approximately 1200 g/m^2/day. The average calculated methane flux from the downwind survey was approximately 200 g/s, which is equivalent to approximately 1400 g/m^2/day.

Table 9. Moving Average of Calculated Methane Flux, CCF, Wind Speed, and Wind Direction for the Upwind As-Built Area Lower Cell During the September 2003 Campaign.

Loops	CCF	Flux (g/s)	Wind Speed (m/s)	Wind Dir.[a] (deg)
1 to 4	0.913	430	5.1	14
2 to 5	0.922	420	5.2	12
3 to 6	0.916	390	5.1	12
4 to 7	0.881	350	4.8	14
5 to 8	0.786	280	4.6	22
6 to 9	0.736	250	4.1	21
7 to 10	0.682	220	3.7	17
8 to 11	0.813	200	3.4	17
9 to 12	0.753	190	3.6	15
10 to 13	0.782	160	3.5	23
11 to 14	0.881	130	3.4	33
12 to 15	0.859	150	3.3	27
13 to 16	0.914	160	3.3	20
14 to 17	0.880	170	3.6	25
15 to 18	0.827	140	3.4	26
16 to 19	0.759	110	3.2	27
17 to 20	0.708	85	2.6	16
18 to 21	0.827	87	2.2	3
19 to 22	0.800	110	2.8	6
20 to 23	0.864	130	3.5	23
21 to 24	0.855	130	3.9	45
22 to 25	0.865	120	4.1	52
23 to 26	0.888	130	3.8	43
24 to 27	0.837	150	3.6	30
25 to 28	0.804	150	3.6	19
26 to 29	0.788	120	3.2	6
27 to 30	0.872	130	3.2	1
28 to 31	0.926	150	3.6	3
29 to 32	0.918	160	3.5	16
30 to 33	0.864	170	3.7	29
31 to 34	0.803	170	3.7	31
32 to 35	0.832	160	3.5	29
33 to 36	0.792	150	3.7	18
34 to 37	0.835	120	3.4	5
35 to 38	0.873	100	3.2	360
36 to 39	0.809	100	3.2	358
37 to 40	0.711	82	2.9	2
38 to 41	0.664	48	2.5	38
39 to 42	0.962	47	2.0	41
40 to 43	0.935	45	1.5	354
41 to 44	0.930	56	1.7	9
42 to 45	0.884	53	1.6	10
43 to 46	0.839	57	1.6	22
44 to 47	0.825	84	2.4	23
45 to 48	0.828	110	2.7	19

continued

continued

Table 9 (concluded). Moving Average of Calculated Methane Flux, CCF, Wind Speed, and Wind Direction for the Upwind As-Built Area Lower Cell During the September 2003 Campaign.

Loops	CCF	Flux (g/s)	Wind Speed (m/s)	Wind Dir.[a] (deg)
46 to 49	0.852	160	3.5	14
47 to 50	0.856	200	4.1	8
48 to 51	0.750	220	4.5	7
49 to 52	0.803	220	4.2	5
50 to 53	0.814	210	3.9	355
51 to 54	0.846	230	4.3	350
52 to 55	0.895	230	4.3	346
53 to 56	0.855	260	4.8	347
54 to 57	0.832	210	4.6	359
55 to 58	0.689	140	3.9	358
56 to 59	0.541	84	2.8	342
57 to 60	0.777	64	2.2	336
58 to 61	0.554	66	2.7	330
59 to 62	0.713	67	2.7	325
60 to 63	0.725	120	3.6	344
61 to 64	0.475	130	4.2	352
62 to 65	0.629	170	4.5	359
63 to 66	0.703	190	5.0	14
64 to 67	0.734	140	4.9	22
65 to 68	0.848	92	4.3	15
66 to 69	0.727	46	3.6	6
67 to 70	0.817	23	2.8	339
68 to 71	0.884	15	2.1	313
69 to 72	0.940	24	2.3	308
Average	0.810			
Std. Dev.	0.0961			

[a] Wind direction shown is measured from a vector normal to the plane of the configuration.

Table 10. Moving Average of Calculated Methane Flux, CCF, Wind Speed, and Wind Direction for the Downwind As-Built Area Lower Cell During the September 2003 Field Campaign.

Loops	CCF	Flux (g/s)	Wind Speed (m/s)	Wind Dir.[a] (deg)
1 to 4	0.878	110	3.5	311
2 to 5	1.000	92	3.4	310
3 to 6	0.941	97	3.2	307
4 to 7	0.999	100	3.0	305
5 to 8	0.976	150	2.9	308
6 to 9	0.720	130	2.7	314
7 to 10	0.914	140	2.9	322
8 to 11	0.780	140	2.9	328

continued

Table 10 (concluded). Moving Average of Calculated Methane Flux, CCF, Wind Speed, and Wind Direction for the Downwind As-Built Area Lower Cell During the September 2003 Field Campaign.

Loops	CCF	Flux (g/s)	Wind Speed (m/s)	Wind Dir.[a] (deg)
9 to 12	0.994	66	2.9	326
10 to 13	0.986	75	3.0	323
11 to 14	0.977	82	2.9	318
12 to 15	0.958	130	3.6	321
13 to 16	0.967	130	4.2	325
14 to 17	0.942	150	4.5	328
15 to 18	0.947	150	4.7	330
16 to 19	0.678	130	4.3	331
17 to 20	0.624	120	3.9	333
18 to 21	0.908	130	3.6	331
19 to 22	0.638	91	3.3	337
20 to 23	0.722	84	3.2	336
21 to 24	0.921	120	3.2	335
22 to 25	0.752	73	3.2	339
23 to 26	0.948	99	3.3	337
24 to 27	0.735	160	4.0	343
25 to 28	0.966	220	5.3	348
26 to 29	0.699	310	6.6	349
27 to 30	0.709	370	8.2	355
28 to 31	0.739	380	8.4	357
29 to 32	0.627	340	7.7	359
30 to 33	0.874	380	6.9	1
31 to 34	0.864	370	5.8	3
32 to 35	0.613	320	5.5	8
33 to 36	0.610	310	5.2	8
34 to 37	0.940	270	5.1	13
35 to 38	1.000	190	4.6	17
36 to 39	0.992	150	4.2	16
37 to 40	0.995	150	3.9	23
38 to 41	0.946	90	3.6	32
39 to 42	0.921	92	3.7	32
40 to 43	0.811	95	3.7	30
41 to 44	0.940	73	3.7	22
42 to 45	0.632	74	3.5	19
43 to 46	0.680	67	3.5	18
44 to 47	0.650	61	3.4	14
45 to 48	0.699	52	3.3	14
46 to 49	0.957	40	3.1	19
47 to 50	0.976	25	2.5	55
Average	0.846			
Std. Dev.	0.1376			

[a] Wind direction shown is measured from a vector normal to the plane of the configuration.

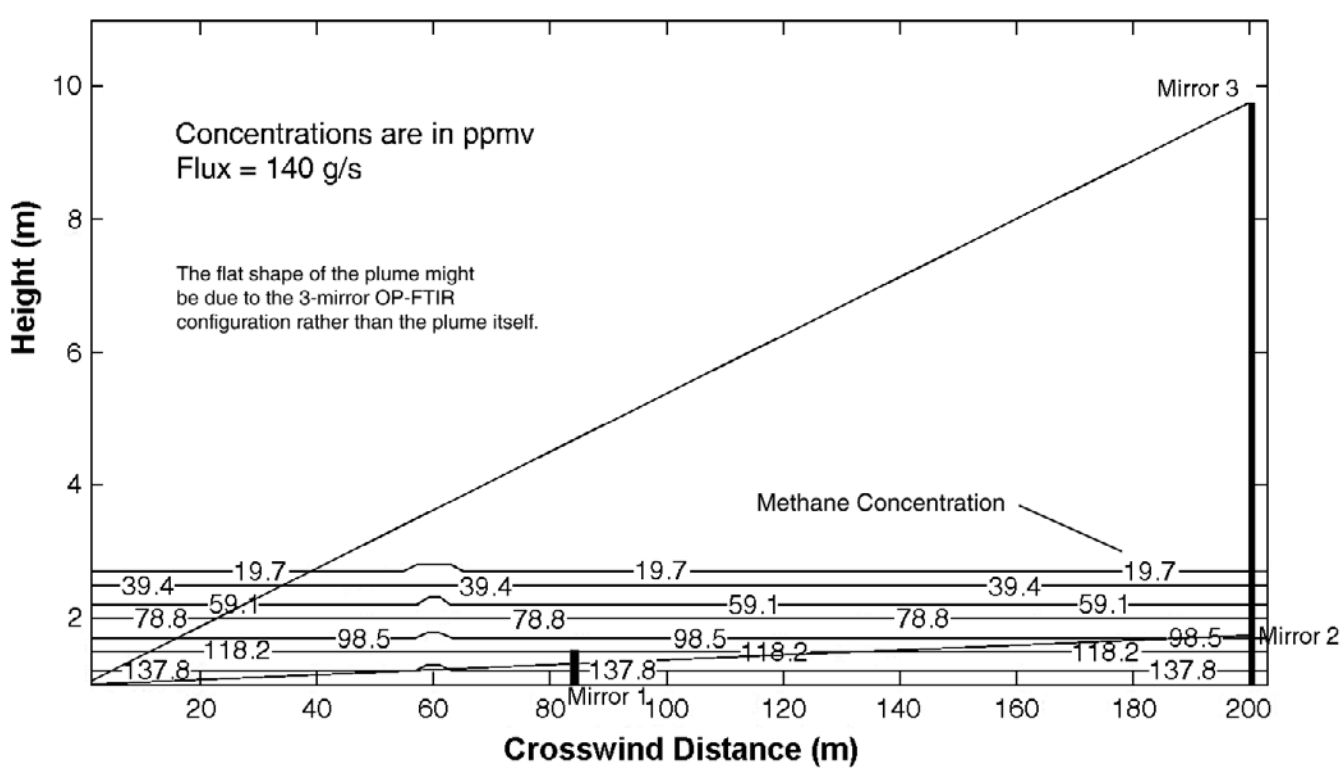

Figure 20. Average Reconstructed Methane Plume from the September 2003 Upwind As-Built Lower VRPM Survey.

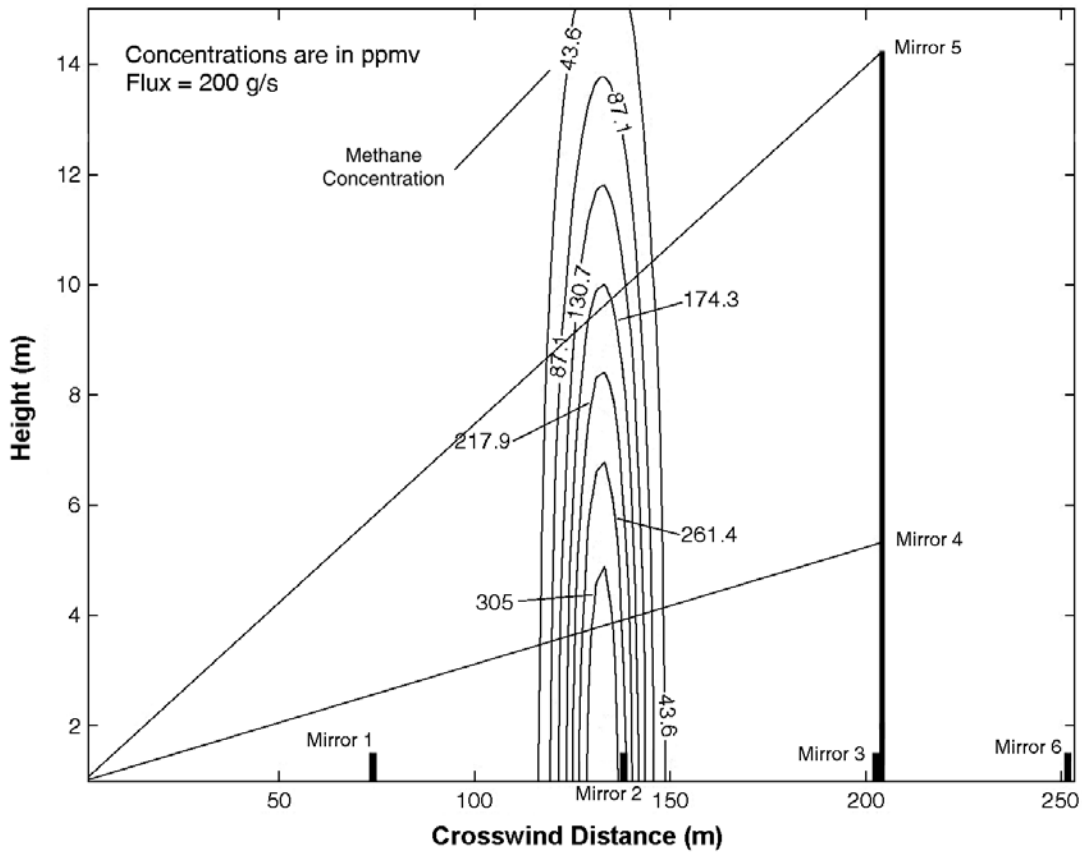

Figure 21. Average Reconstructed Methane Plume from the September 2003 Downwind As-Built Lower VRPM Survey.

2.2 Retrofit Area

The Retrofit Area is located in the northeast quadrant of the Outer Loop Facility (see Figure 1) and is directly adjacent to the Louisville International Airport. Testing for this project was performed on the eight-acre flat area on top of this multi-cell unit. Due to the site's elevation, proximity to the airport, and the height of the fully extended scissors jacks used in this project, approval from the Federal Aviation Administration (FAA) for narrowly defined scissors jack locations was required. In some cases, this limited the possible configuration locations used for the VRPM surveys in this area. This section describes procedures and summarizes results from the Retrofit Area for the September 2002, May 2003, and September 2003 field campaigns.

2.2.1 Testing Procedures Used During the September 2002 Field Campaign

HRPM and VRPM were performed at the Retrofit Area test site. Due to the size and dimensions of the site and limitations of the OP-FTIR used for this campaign, experiments of each type were performed on the northern and southern areas of this plateau.

HRPM was done at the Retrofit Area using one monostatic OP-FTIR instrument. For the survey of the northern area, eight retroreflectors were used, and the OP-FTIR was placed in the southwest corner of the area. The survey of the southern area was completed using eight retroreflectors as well, and the OP-FTIR was placed in the northwest corner of the area. Figure 22 shows a picture of the HRPM configuration used for the survey.

The vertical surveys of the two areas were completed using one monostatic OP-FTIR instrument, and one scissors jack. The configuration for each area used five retroreflectors, and the vertical plane formed was located on the western boundary (downwind side) of the survey area. Figure 23 shows the location of the vertical configurations used at the Retrofit Area test site.

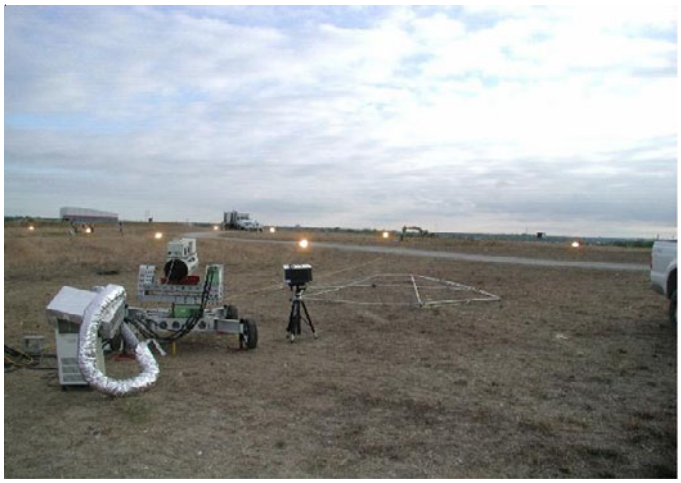

Figure 22. HRPM Configuration Used in the Retrofit Area During the September 2002 Field Campaign.

Meteorological data were collected concurrently during these tests. U.S. EPA personnel operated a non-scanning bistatic OP-FTIR in an upwind location concurrent with these tests.

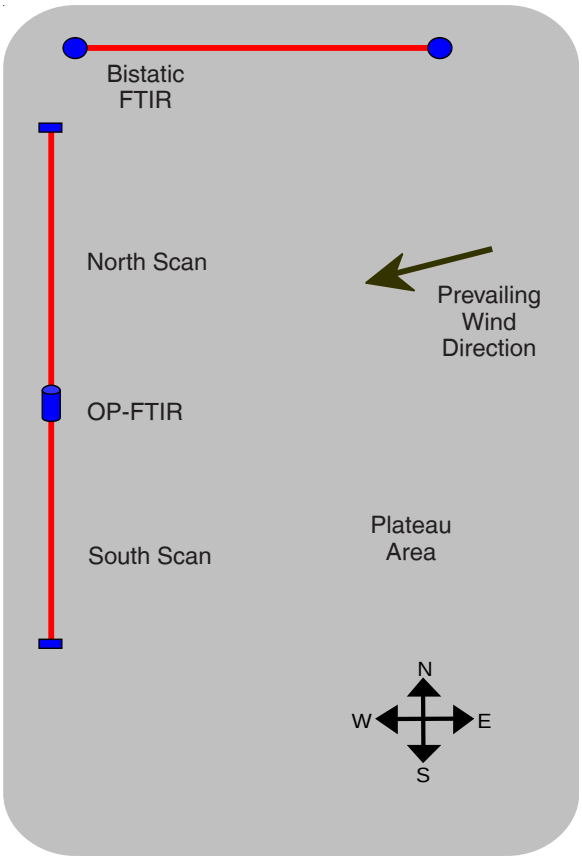

Figure 23. Map of Retrofit Area (north and south) Showing the Location of the Vertical Planes and Background Measurements During the September 2002 Field Campaign.

2.2.2 Results and Discussion from the September 2002 Field Campaign

The HRPM survey was performed to identify methane hot spots. Figure 24 is a contour map of reconstructed methane concentrations (in ppmv) from this area. The figure shows the presence of two hot spots (areas where methane concentrations were close to 80 ppmv). The circles show the locations of ten gas extraction pipes observed in the Retrofit Area.

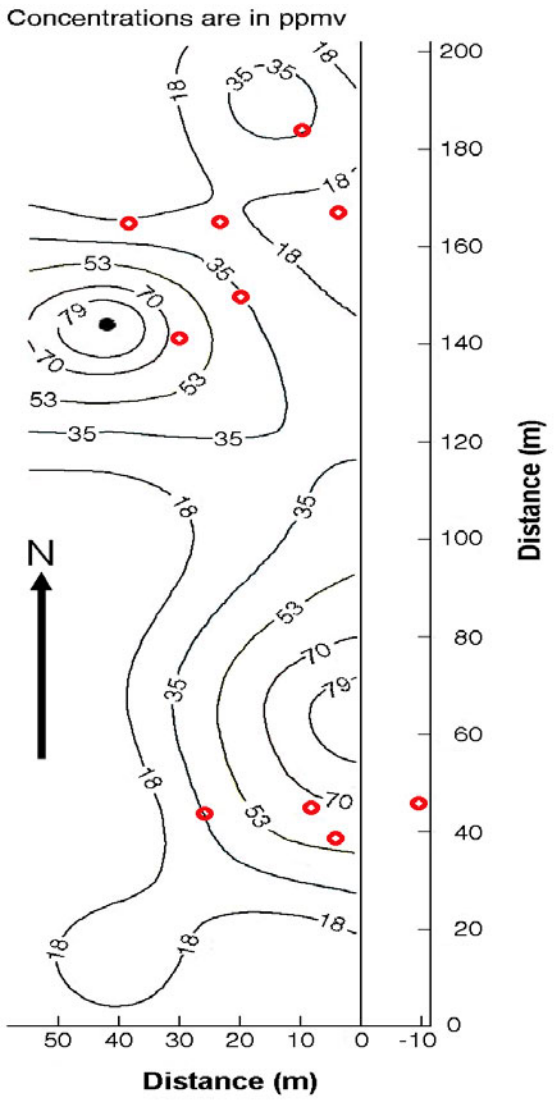

Figure 24. Reconstructed Methane Surface Concentrations for the Retrofit North and South Areas During the September 2002 Field Campaign.

Table 11. Moving Average of Calculated Methane Flux, CCF, Wind Speed, and Wind Direction for the Retrofit North Area During the September 2002 Field Campaign.

Loops	CCF	Flux (g/s)	Wind Speed (m/s)	Wind Dir.[a] (deg)
1 to 4	0.980	20	3.1	355
2 to 5	0.987	18	3.3	356
Average	0.983			
Std. Dev.	0.0049			

[a] Wind direction shown is measured from a vector normal to the plane of the configuration.

Table 12. Moving Average of Calculated Methane Flux, CCF, Wind Speed, and Wind Direction for the Retrofit South Area During the September 2002 Field Campaign.

Loops	CCF	Flux (g/s)	Wind Speed (m/s)	Wind Dir.[a] (deg)
1 to 4	0.976	13	3.3	11
2 to 5	0.937	21	3.9	3
3 to 6	0.924	24	4.1	360
4 to 7	0.939	22	4.1	328
5 to 8	0.931	19	3.9	348
6 to 9	0.941	25	3.9	1
7 to 10	0.968	22	3.8	17
8 to 11	0.954	22	3.5	17
9 to 12	0.986	21	3.6	345
10 to 13	0.992	17	3.7	338
11 to 14	0.981	15	3.4	329
12 to 15	0.991	19	3.6	344
13 to 16	0.989	19	3.7	15
Average	0.962			
Std. Dev.	0.0253			

[a] Wind direction shown is measured from a vector normal to the plane of the configuration.

Tables 11 and 12 present methane emission flux determinations for the northern and southern halves of the Retrofit Area, respectively. Refer to Figure 23 for a map of this site and the optical configurations there. The methane concentrations used to create these tables can be found in Appendix B.

Figures 25 and 26 present the reconstructed methane plume from Retrofit North and South VRPM survey, respectively. Contour lines give methane concentrations in ppmv. The average calculated methane flux for the northern half of the Retrofit Area was 19 g/s, which is equivalent to approximately 310 g/m^2/day, and the average calculated methane flux for the southern half was 18 g/s, which is equivalent to approximately 330 g/m^2/day.

As mentioned earlier, Figure 24 shows that two distinct methane hot spots were found in the Retrofit Area. The peak methane concentrations found in each hot spot were similar (greater than 80 ppmv). One hot spot was located in the Retrofit North area, and one in the Retrofit South area. The proximity of these hot spots to the location of the gas extraction pipes (indicated by red circles), and analysis of wind data at the time of the measurements, suggests the pipes may be a significant source of methane emissions.

Closer inspection of the average reconstructed methane plume from Retrofit North and South VRPM survey (Figures 25 and 26, respectively) shows that the average cal-

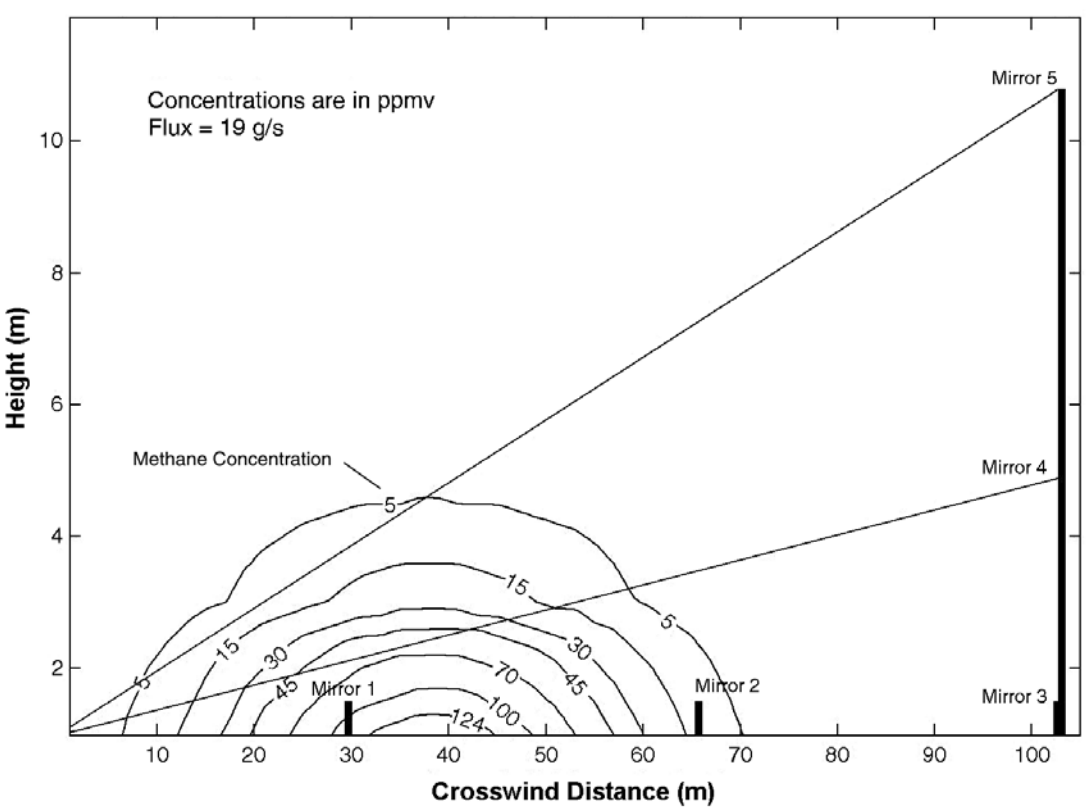

Figure 25. Average Reconstructed Methane Plume from the September 2002 Retrofit North VRPM Survey.

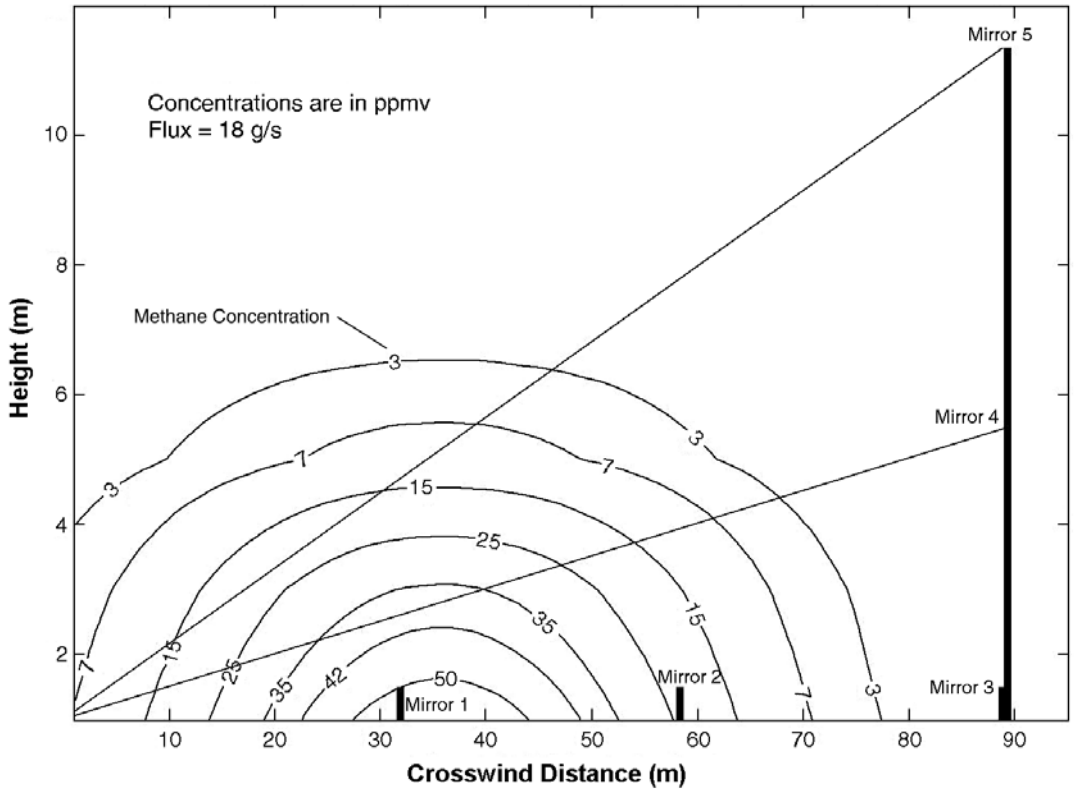

Figure 25. Average Reconstructed Methane Plume from the September 2002 Retrofit South VRPM Survey.

culated methane fluxes for each area are very similar. This is not surprising, since the methane concentrations found in the hot spots for each area (which would be the major contributor to methane flux values) are similar in magnitude. Additionally, the spatial distribution of the plumes in the horizontal direction is consistent with the location of the hot spots. The center of the Retrofit North hot spot is located about 45 meters north of the position of the OP-FTIR. Figure 25 shows that the center of the methane plume found in the Retrofit North area is located about 40 meters from the scanner position. The center of the Retrofit South hot spot is located about 30 meters south of the position of the OP-FTIR. Figure 26 shows that the center of the methane plume found in the Retrofit South area is located about 35 meters from the scanner position. It appears that there was very good agreement between the locations of hot spots found during the HRPM surveys, and the plume reconstruction from the VRPM surveys.

Observed wind directions during the Retrofit Area VRPM surveys were not variable. This would be indicative of a stable atmosphere. Hashmonay et al. (2001) found that fluxes calculated during stable environments may underestimate the actual flux by around 10%.

The background methane concentration data from the bistatic OP-FTIR were unavailable due to instrumentation problems. However, in looking at the boundaries of the HRPM results, one can estimate the background concentrations to be about 10 ppmv.

2.2.3 Testing Procedures Used During the May 2003 Field Campaign

HRPM and VRPM were performed at the Retrofit Area test site. Due to the size and dimensions of the site, the area was divided into two halves for the HRPM survey, but an improvement in the instrumentation from the previous field campaign made it possible to perform one VRPM survey for the entire Retrofit Area. The GPS coordinates of the boundaries of the area are presented in Appendix D.

HRPM was conducted using one monostatic OP-FTIR instrument. For the survey of the northern area, eight retroreflectors were used, and the OP-FTIR was placed in the southwest corner of the area. The survey of the southern area was completed using eight retroreflectors as well, and the OP-FTIR was placed in the northwest corner of the area.

The vertical survey of the Retrofit Area was completed using two monostatic OP-FTIR instruments, and two scissors jacks. The configuration formed two vertical planes (one upwind and one downwind). Two retroreflectors were used in the upwind vertical plane, and eight were used in the downwind vertical plane. Figure 27 shows the location of the vertical configurations used at the Retrofit Area test site. Figure 28 shows a picture of the configuration.

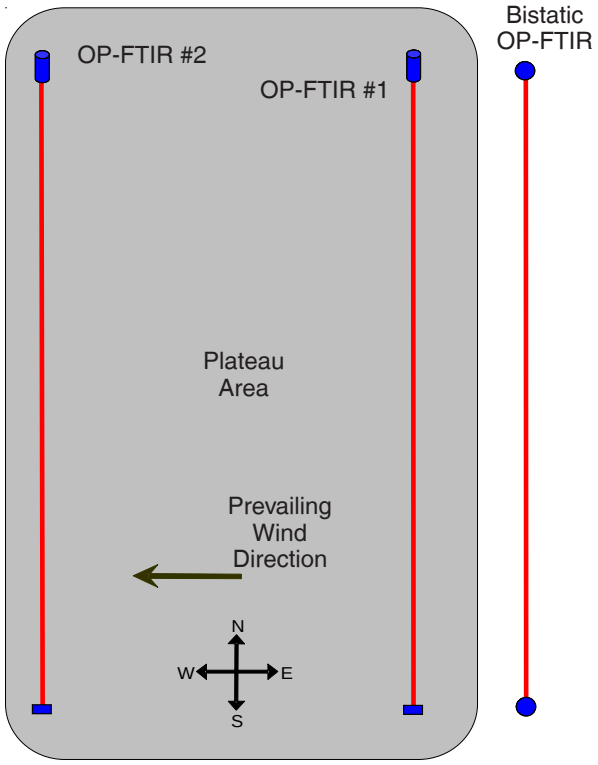

Figure 27. Map of the Retrofit Area Showing the Location of Vertical Planes and Background Measurements During the May 2003 Field Campaign.

Figure 28. VRPM Configuration Used in the Retrofit Area during the May 2003 Field Campaign.

Meteorological data were collected concurrent with these tests. U.S. EPA personnel operated a non-scanning bistatic OP-FTIR in an upwind location concurrent with these tests.

2.2.4 Results and Discussion from the May 2003 Field Campaign

The HRPM survey was performed to identify methane hot spots. Figures 29 and 30 are contour maps of reconstructed methane concentrations (in parts per million by volume) for the northern and southern halves of the Retrofit Area, respectively. The figures show the presence of one hot spot on the eastern side of the northern half and one hot spot in the southwestern corner of the southern half of the Retrofit Area.

Tables 13 and 14 present methane emission flux determinations from the upwind and downwind vertical surveys, respectively. Refer to Figure 27 for a map of this site and the optical configurations there. The methane concentrations used to create these tables can be found in Appendix B.

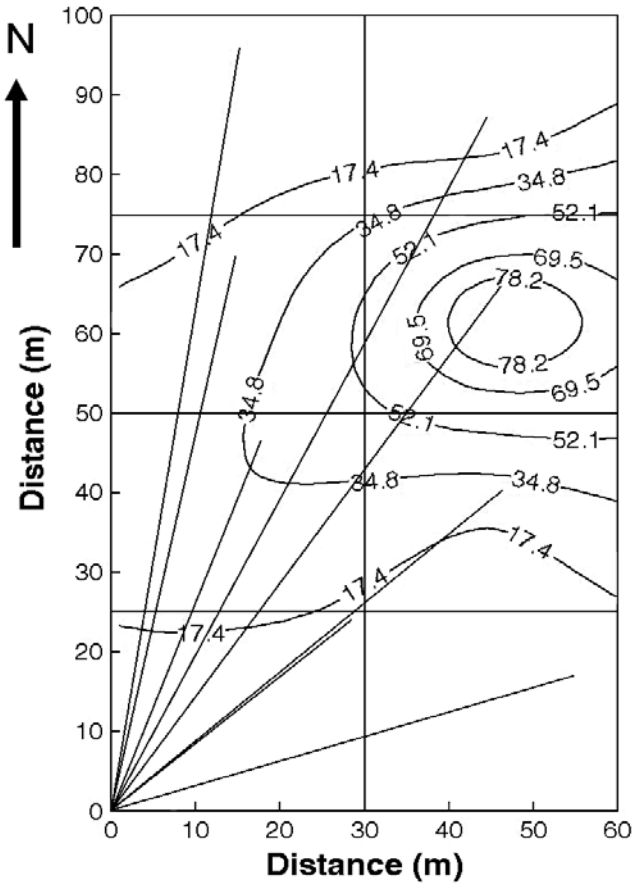

Figure 29. Reconstructed Mentane Surface Concentrations (in ppmv) for the Retrofit North Area During the May 2003 Field Campaign.

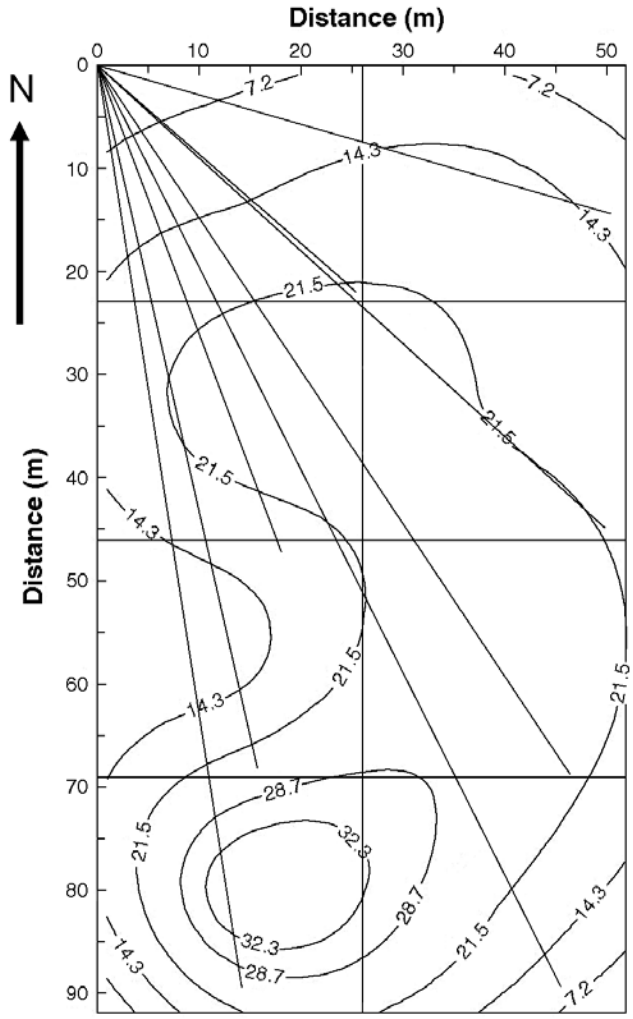

Figure 30. Reconstructed Mentane Surface Concentrations (in ppmv) for the Retrofit South Area During the May 2003 Field Campaign.

Table 13. Moving Average of Calculated Methane Flux, Wind Speed, and Wind Directions for the Upwind Vertical Survey of the Retrofit Area During the May 2003 Field Campaign.

Loops	Flux (g/s)	Wind Speed (m/s)	Wind Dir.[b] (deg)
1 to 4	11	2.9	14
2 to 5	9.9	3.1	9
3 to 6	9.6	3.0	5
4 to 7	8.9	3.0	3
5 to 8	10	2.9	6
6 to 9	11	2.6	12
7 to 10	11	2.6	13

[a] CCF values were all 1.00 because only two mirrors were used in the reconstruction, so CCFs are not included.
[b] Wind direction shown is measured from a vector normal to the plane of the configuration.

Table 14. Moving Average of Calculated Methane Flux, CCF, Wind Speed, and Wind Directions for the Downwind Vertical Survey of the Retrofit Area During the May 2003 Field Campaign.

Loops	CCF	Flux (g/s)	Wind Speed (m/s)	Wind Dir.[a] (deg)
1 to 4	0.996	29	2.9	19
2 to 5	0.996	31	2.9	16
3 to 6	0.996	35	3.0	15
4 to 7	0.997	32	3.0	15
5 to 8	0.998	31	2.8	16
6 to 9	1.000	26	2.8	14
7 to 10	1.000	24	2.9	12
8 to 11	1.000	23	3.0	10
9 to 12	1.000	21	3.0	9
10 to 13	1.000	22	3.1	8
11 to 14	1.000	23	3.0	6
12 to 15	1.000	22	3.0	5
13 to 16	0.999	22	3.2	4
14 to 17	0.999	22	3.2	3
15 to 18	0.999	21	3.2	2
16 to 19	1.000	21	3.1	1
17 to 20	0.999	19	2.9	0
18 to 21	0.999	18	2.9	358
19 to 22	0.999	18	2.8	359
20 to 23	0.999	19	2.8	1
21 to 24	0.999	20	2.9	3
22 to 25	0.989	30	2.7	13
23 to 26	0.988	3	2.6	17
24 to 27	0.990	39	2.5	23
25 to 28	0.994	36	2.2	27
26 to 29	0.999	32	2.1	22
27 to 30	1.000	33	2.1	21
28 to 31	1.000	25	2.2	13
29 to 32	1.000	24	2.6	6
30 to 33	1.000	20	3.2	360
31 to 34	1.000	18	3.4	354
Average	0.998			
Std. Dev.	0.0033			

[a] Wind direction shown is measured from a vector normal to the plane of the configuration.

Figures 31 and 32 present the reconstructed methane plume from the upwind and downwind sides of the Retrofit Area, respectively. Contour lines give methane concentrations in parts per million. The average calculated methane flux for the upwind side was 11 g/s, which is equivalent to approximately 100 g/m^2/day. The average calculated methane flux for the downwind side was 27 g/s, which is equivalent to approximately 250 g/m^2/day.

The VRPM survey of the Retrofit Area found a difference in calculated flux values between the upwind and downwind vertical planes of approximately 16 g/s. Easterly winds were observed during the time of the survey. The measured upwind flux value of 11 g/s suggests that the slope along the eastern edge of the Retrofit Area may also be a source of methane.

2.2.5 Testing Procedures Used During the September 2003 Field Campaign

Both HRPM and VRPM were performed at the Retrofit Area test site. The week prior to the September 2003 field campaign, a layer of top soil was added to this area, and the gas collection system was upgraded to minimize fugitive gas emissions. The concern is that fugitive emissions may not be representative of future emissions, given that these improvements were made just prior to the field test.

Due to continued improvements in the instrumentation and equipment used from the previous field campaign, it was possible to perform a single HRPM and VRPM survey for the entire area. The GPS coordinates of the boundaries of the area are presented in Appendix D.

HRPM was performed using one monostatic OP-FTIR instrument. The OP-FTIR was located in the southeast corner of the site, and fifteen retroreflectors were placed throughout the area.

VRPM was done using one monostatic OP-FTIR instrument and one scissors jack. The configuration used six retroreflectors and was located along the eastern boundary (downwind) of the area. Due to limited access roads in the Retrofit Area, it was not possible to maneuver some of the equipment into the desired locations. Consequently, it was not possible to set up a second (upwind) vertical configuration in this area. As an alternative, the path-averaged methane concentration data from the bistatic OP-FTIR are presented below. Figure 33 shows the location of the vertical configurations used at the Retrofit Area test site.

Both meteorological data and data from a non-scanning bistatic OP-FTIR operated in an upwind location by U.S. EPA personnel were collected concurrent with these tests.

2.2.6 Results and Discussion from the September 2003 Field Campaign

The HRPM survey was performed to identify methane hot spots. Figure 34 presents a contour map of reconstructed methane concentrations (in parts per million by volume) for this area. The figure shows that two hot spots were

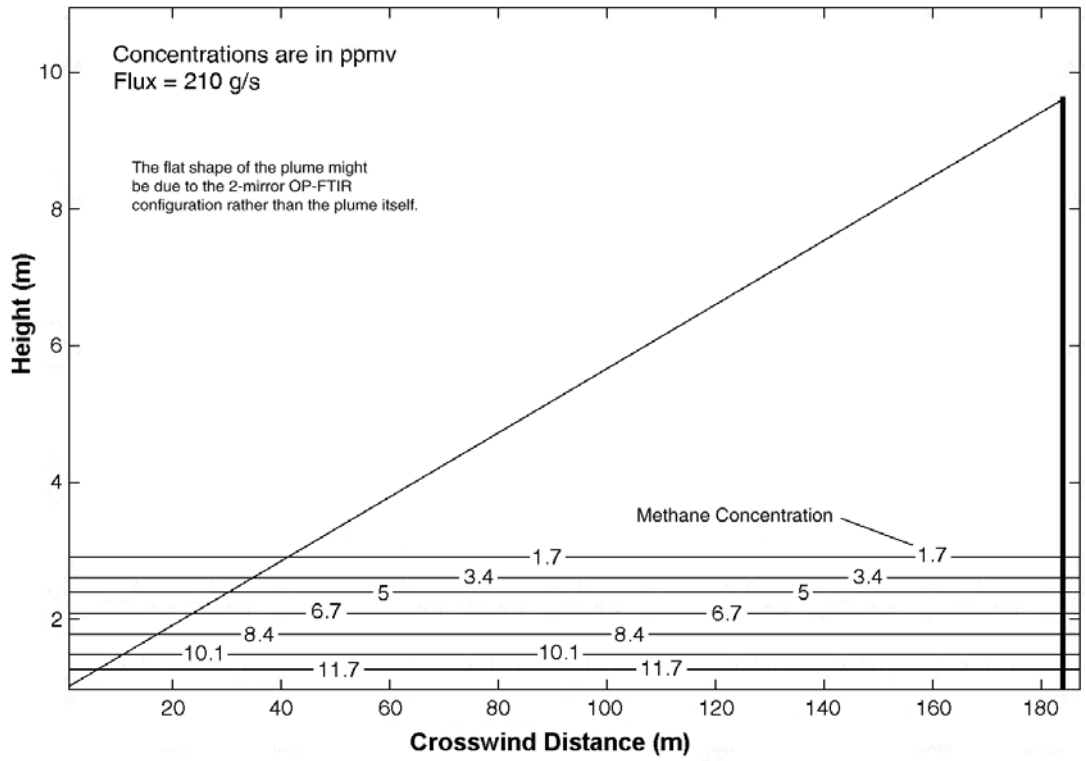

Figure 31. Average Reconstructed Methane Plume from the May 2003 Upwind Retrofit VRPM Survey.

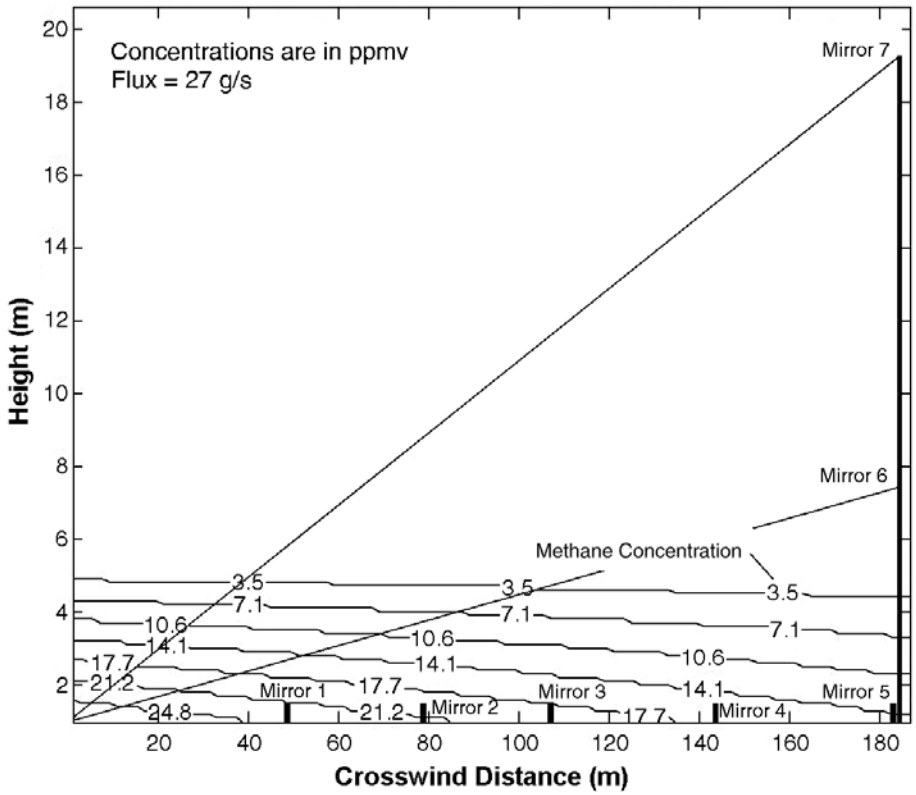

Figure 32. Average Reconstructed Methane Plume from the May 2003 Downwind Retrofit VRPM Survey.

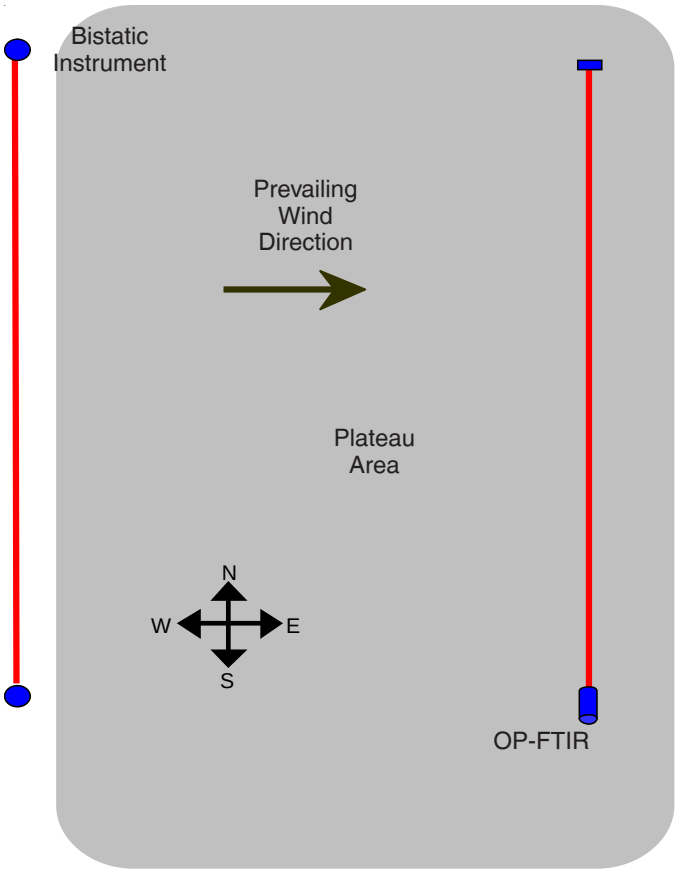

Figure 33. Map of Retrofit Area (north and south) Showing the Location of the Vertical Plane and Background Measurements During the September 2003 Field Campaign.

located along the surface of the Retrofit Area. The most intense hot spot (greater than 33 ppmv) was located along the western edge of the area. Another less intense hot spot (greater than 14 ppmv) was located in the northeastern corner of the area.

Table 15 presents methane emission flux determinations from the downwind vertical survey of the entire area. Refer to Figure 33 for a map of this site and the optical configurations there. The methane concentrations used to create these tables can be found in Appendix B.

Figure 35 presents the reconstructed methane plume from the downwind side of the Retrofit Area. Contour lines give methane concentrations in parts per million by volume. The average calculated methane flux for the Retrofit Area was 54 g/s, which is equivalent to approximately 440 g/m^2/day.

The data from the bistatic OP-FTIR found an average background methane concentration of 2.3 ppmv. Figure 33 shows that the bistatic OP-FTIR configuration was located along the western boundary of the As-Built Area, and the observed mean wind direction was from the west during the time data were collected.

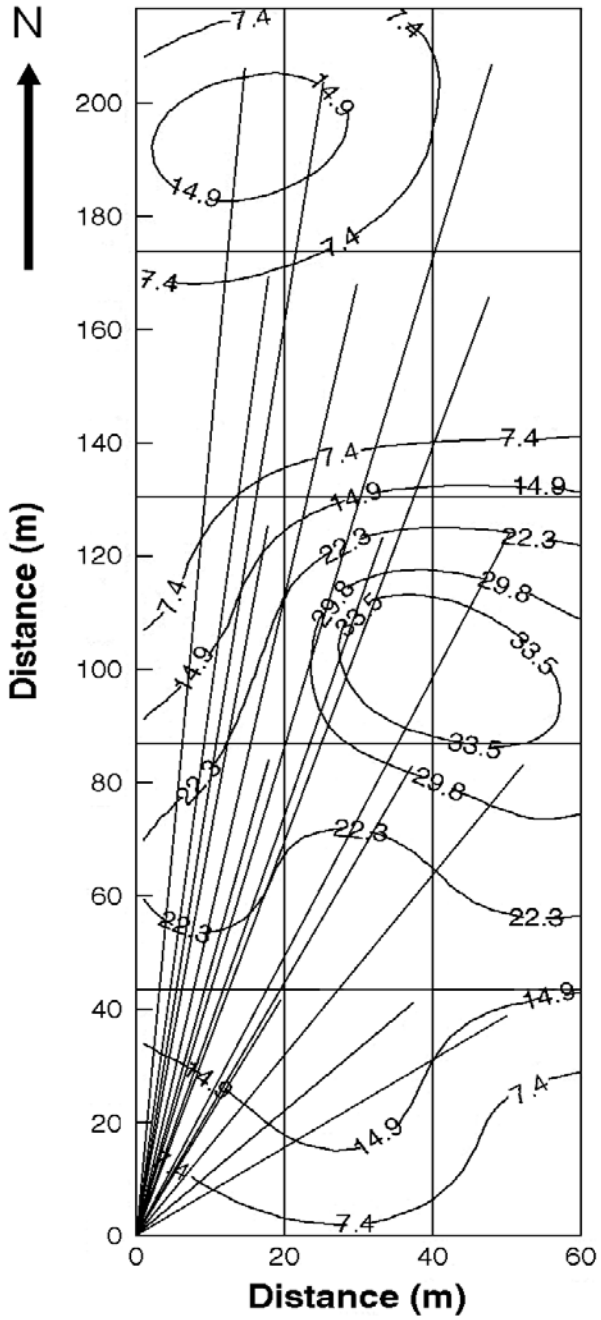

Figure 34. Reconstructed Methane Surface Concentrations (in ppmv) for the Retrofit North and South Areas During the September 2003 Field Campaign.

Table 15. Moving Average of Calculated Methane Flux, CCF, Wind Speed, and Wind Direction Downwind of the Retrofit Area During the September 2003 Field Campaign.

Loops	CCF	Flux (g/s)	Wind Speed (m/s)	Wind Dir.[a] (deg)
1 to 4	0.999	74	12	355
2 to 5	0.997	68	12	354
3 to 6	0.989	75	12	352
4 to 7	0.994	74	12	348
5 to 8	0.998	67	12	341
6 to 9	0.999	64	12	339
7 to 10	0.999	56	12	332
8 to 11	0.996	50	11	327
9 to 12	0.996	49	11	325
10 to 13	0.995	53	11	324
11 to 14	0.997	57	11	325
12 to 15	0.989	56	11	325
13 to 16	0.992	52	11	323
14 to 17	0.999	40	11	317
15 to 18	0.991	37	11	315
16 to 19	1.000	40	10	318
17 to 20	0.997	40	9.6	320
18 to 21	0.995	44	10	323
19 to 22	0.997	45	9.9	324
20 to 23	0.997	39	10	319

continued

Table 15 (concluded). Moving Average of Calculated Methane Flux, CCF, Wind Speed, and Wind Direction Downwind of the Retrofit Area During the September 2003 Field Campaign.

Loops	CCF	Flux (g/s)	Wind Speed (m/s)	Wind Dir.[a] (deg)
21 to 24	0.998	42	11	316
22 to 25	0.999	35	11	315
23 to 26	0.991	35	12	314
24 to 27	0.996	40	12	318
25 to 28	0.995	36	12	317
26 to 29	0.985	47	12	324
27 to 30	1.000	58	13	329
28 to 31	0.998	56	12	329
29 to 32	0.999	55	11	329
30 to 33	1.000	52	10	325
31 to 34	0.966	41	9.2	322
32 to 35	0.945	46	9.5	326
33 to 36	0.954	55	10	329
34 to 37	0.973	58	11	331
35 to 38	0.998	58	11	331
36 to 39	1.000	54	11	330
37 to 40	0.997	53	11	327
Average	0.992			
Std. Dev.	0.0125			

[a] Wind direction shown is measured from a vector normal to the plane of the configuration.

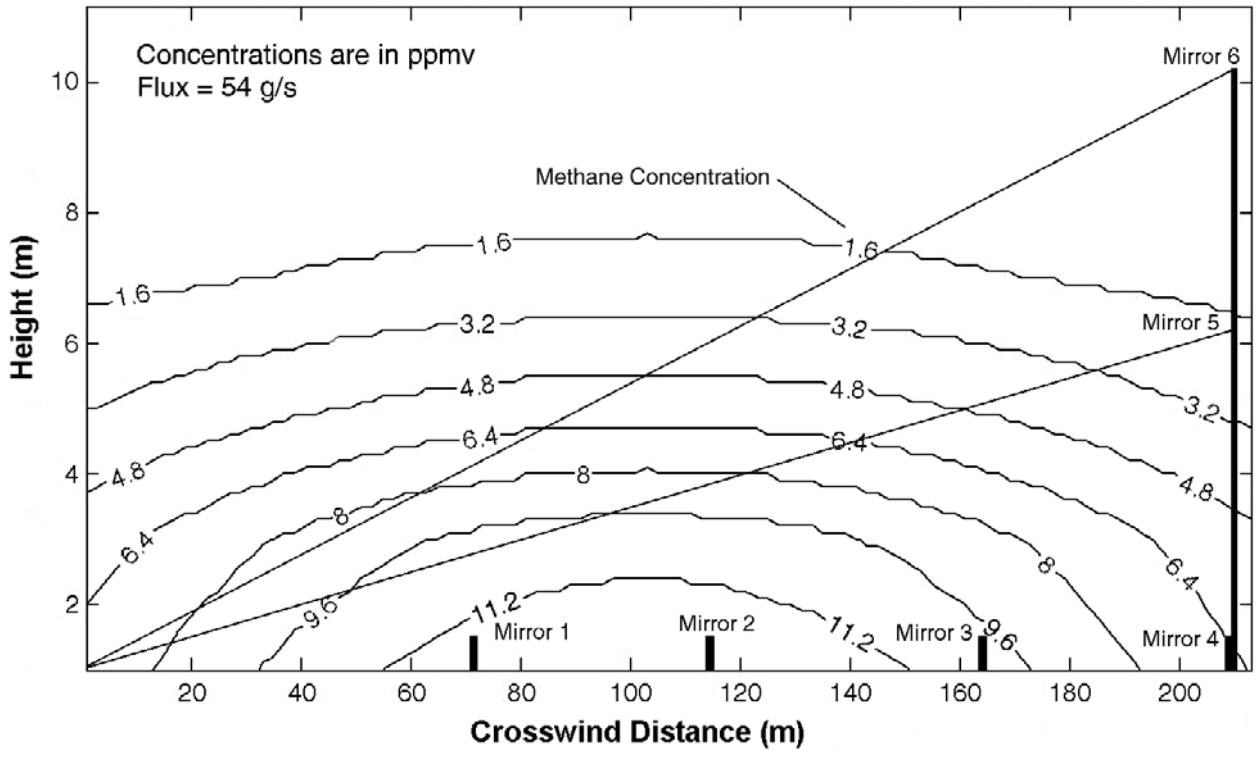

Figure 35. Average Reconstructed Methane Plume from the September 2003 Retrofit VRPM Survey.

2.3 Control Area

The Control Area survey was done to determine a typical background methane flux for the entire site. The Control Area was provided to ARCADIS and U.S. EPA by WMI. The area selected was located adjacent to the Biocover Area and to the east of the As-Built Area. This area was chosen as a favorable control site because of its relatively central location within the landfill facility. The dimensions and actual location of this area changed slightly between the September 2002 and May 2003 field campaigns due to topographical changes in the site associated with normal landfill operations. Because of the small dimensions of the Control Area, HRPM was not done in this area. As mentioned previously, surveying was not performed in this area during the September 2003 field campaign due to the difficulty of establishing a control area representative of an operating landfill. Changes occurred with regard to geometry of the control cell, which limited the usefulness of data collected in this area from the initial field campaigns to the September 2003 campaign. Additionally, it was difficult to isolate emissions from the Control Area due its central location within the landfill.

2.3.1 Testing Procedures Used During the September 2002 Field Campaign

The VRPM survey was conducted using one monostatic OP-FTIR and one scissors jack. The configuration used five retroreflectors and was set up on the eastern boundary of the Control Area. Data were collected during periods that westerly winds were observed at the test site. Figure 36 shows the vertical configuration used in the Control Area.

Both meteorological data and data from a non-scanning bistatic OP-FTIR operated in an upwind location by U.S. EPA personnel were collected concurrent with these tests.

2.3.2 Results and Discussion from the September 2002 Field Campaign

Methane fluxes were calculated in the Control Area for instances when westerly winds were observed, and these fluxes are presented in Table 16. The methane concentrations used to create these tables can be found in Appendix B.

Figure 37 presents the reconstructed methane plume from the VRPM survey of the Control Area. Contour lines give methane concentrations in parts per million. The average calculated methane flux was 6.0 g/s, which is equivalent to approximately 100 g/m^2/day.

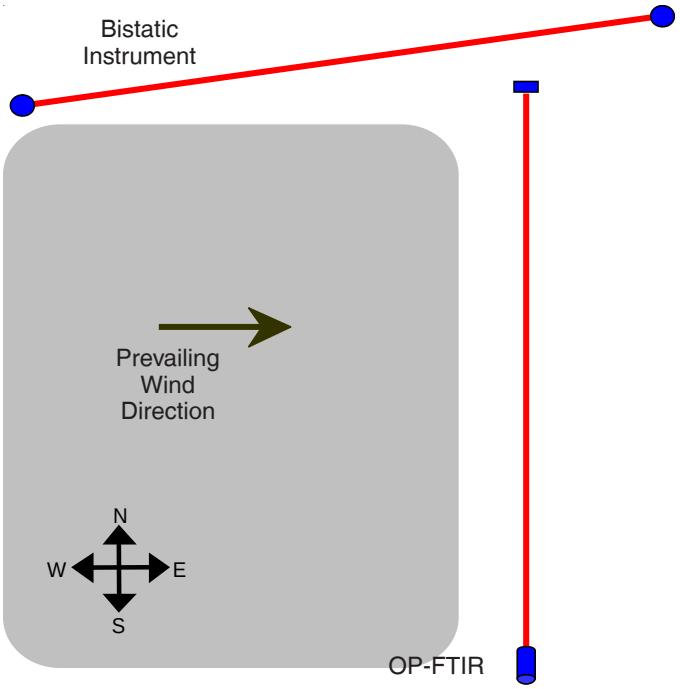

Figure 36. Map of Control Area Showing the Location of the Vertical Plane and Background Measurements During the September 2002 Field Campaign.

Table 16. Moving Average of Calculated Methane Flux, CCF, Wind Speed, and Wind Direction for the VRPM Survey of the Control Area During the September 2002 Field Campaign.

Loops	CCF	Flux (g/s)	Wind Speed (m/s)	Wind Dir.[a] (deg)
1 to 4	0.973	5.0	0.95	332

[a] Wind direction shown is measured from a vector normal to the plane of the configuration.

The background methane concentration data from the bistatic OP-FTIR were unavailable due to instrumentation problems.

2.3.3 Testing Procedures Used During the May 2003 Field Campaign

The VRPM survey was completed using two monostatic OP-FTIR instruments and two scissors jacks. The configuration formed two vertical planes (one upwind plane, and one downwind plane). Two retroreflectors were used in the upwind vertical plane, and six retroreflectors were used in the downwind vertical plane. Figure 38 shows the location of the vertical configurations used at the Control Area

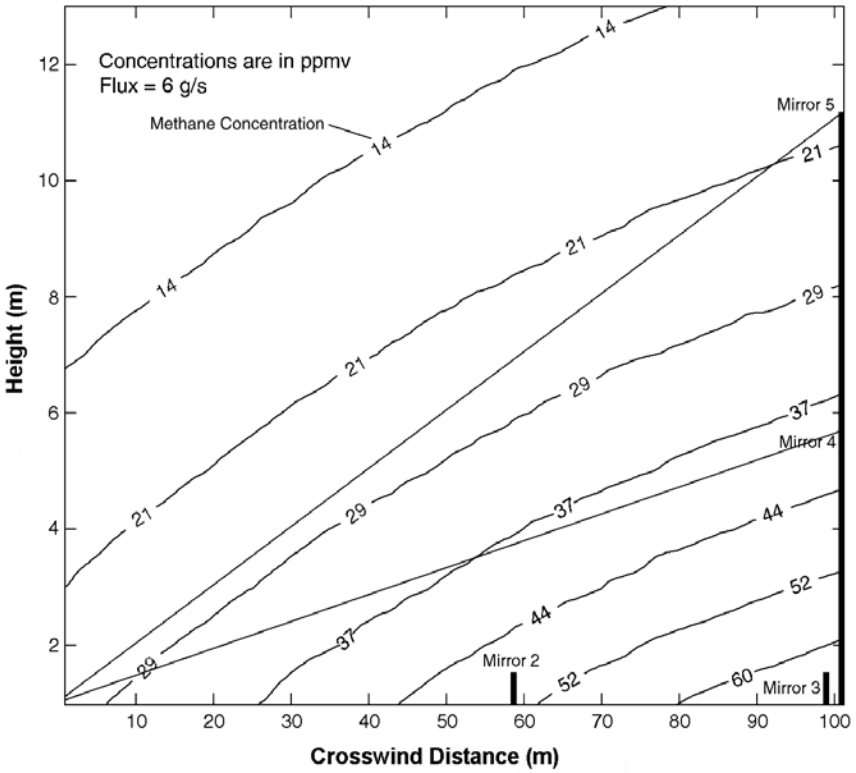

Figure 37. Average Reconstructed Methane Plume from the September 2002 Control Area VRPM Survey.

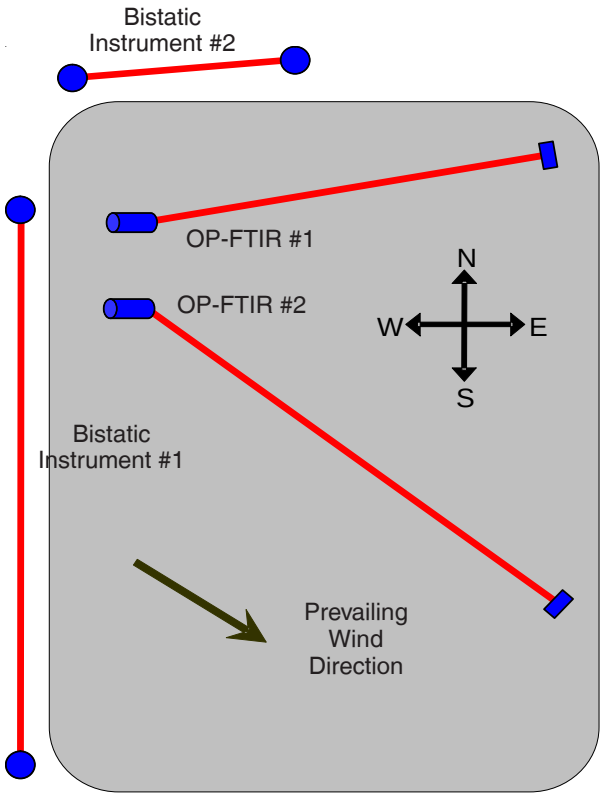

Figure 38. Map of Control Area Showing Location of Vertical Plane and Background Measurements During the May 2003 Field Campaign.

test site. The GPS coordinates of the boundaries of the area are presented in Appendix D.

2.3.4 Results and Discussion from the May 2003 Field Campaign

Methane fluxes were calculated in the Control Area from data taken along the upwind and downwind vertical planes. Tables 17 and 18 present calculated methane fluxes for the upwind and downwind sides of the Control Area, respectively. The methane concentrations used to create these tables can be found in Appendix B.

Table 17. Moving Average of Calculated Methane Flux, Wind Speed, and Wind Direction for the Upwind Control Area VRPM Survey During the May 2003 Field Campaign.

Loops	Flux (g/s)	Wind Speed (m/s)	Wind Dir.[b] (deg)
1 to 4	4.3	7.4	317

[a] CCF values were all 1.00 because only two mirrors were used in the reconstruction, so CCFs are not included.
[b] Wind direction shown is measured from a vector normal to the plane of the configuration.

Table 18. Moving Average of Calculated Methane Flux, CCF, Wind Speed, and Wind Direction for the Upwind Control Area VRPM Survey During the May 2003 Field Campaign.

Loops	CCF	Flux (g/s)	Wind Speed (m/s)	Wind Dir.[a] (deg)
1 to 4	0.980	8.1	7.9	290
2 to 5	0.937	6.9	7.8	293
3 to 6	0.974	6.9	7.7	296
4 to 7	0.963	5.5	7.4	298
5 to 8	0.985	6.3	7.2	302
6 to 9	0.998	6.5	7.7	309
7 to 10	0.996	8.6	7.6	312
8 to 11	0.998	8.4	7.7	314
9 to 12	0.996	11	7.7	313
10 to 13	0.998	7.9	7.3	310
11 to 14	0.974	7.6	7.4	313
12 to 15	0.699	11	7.5	313
13 to 16	0.792	8.6	7.5	313
14 to 17	0.792	8.3	7.6	315
15 to 18	0.737	12	7.8	314
16 to 19	0.993	7.9	7.8	313
17 to 20	0.997	7.7	7.6	314
18 to 21	0.992	8.8	7.4	311
19 to 22	0.999	5.5	7.0	307
20 to 23	0.993	5.2	6.5	308
21 to 24	0.813	11	6.9	308
22 to 25	0.886	8.1	7.3	306
23 to 26	1.000	25	7.5	308
24 to 27	0.605	21	7.8	307
25 to 28	0.594	14	7.6	308
26 to 29	0.565	14	7.6	310
27 to 30	0.601	11	7.6	312
28 to 31	0.616	11	7.6	317
29 to 32	0.587	14	7.6	320
30 to 33	0.603	14	7.1	327
31 to 34	0.571	17	7.3	330
32 to 35	0.568	22	7.3	331
33 to 36	0.579	23	7.4	333
34 to 37	0.560	20	7.3	332
Average	0.822			
Std. Dev.	0.1833			

[a] Wind direction shown is measured from a vector normal to the plane of the configuration.

Figures 39 and 40 present the reconstructed methane plume from the upwind and downwind VRPM survey of the Control Area, respectively. Contour lines give methane concentrations in parts per million by volume. The average calculated methane flux was 4.3 g/s (equivalent to approximately 160 g/m^2/day) for the upwind vertical survey, and 14 g/s (equivalent to approximately 350 g/m^2/day) for the downwind vertical survey.

2.4 Biocover Area

The Biocover Area was located northeast of the As-Built Area (see Figure 1). The dimensions of this area changed slightly between the September 2002 and May 2003 field campaigns due to topographical changes in the site associated with normal landfill operations. Because of the small dimensions of the Biocover Area, HRPM was not performed in this area. As mentioned previously, the September 2003 field campaign did not include a survey of the Biocover Area because the area was no longer operational.

2.4.1 Testing Procedures Used During the September 2002 Field Campaign

The VRPM survey was performed using one monostatic OP-FTIR and one scissors jack. The configuration was set up along the western boundary of the area using four retroreflectors, with a fifth retroreflector used to collect surface data along the diagonal of the Biocover Area. The favorable wind direction for this configuration would consist of an easterly component. During the period of the survey, westerly, as well as easterly winds were observed at the test site. Actual emission data from the Biocover Area were gathered during periods of easterly winds. Figure 41 shows the location of the vertical configurations used at the Biocover Area test site. Figure 42 shows a picture of the VRPM configuration used for the survey.

Both meteorological data and data from a non-scanning bistatic OP-FTIR operated in an upwind location by U.S. EPA personnel were collected concurrently with these tests.

2.4.2 Results and Discussion from the September 2002 Field Campaign

Methane fluxes were calculated at the Biocover Area for instances where the vertical configuration was downwind of the actual survey area. Table 19 presents calculated methane fluxes measured at the site. The methane concentrations used to create these tables can be found in Appendix B.

The background methane concentration data from the bistatic OP-FTIR were unavailable due to instrumentation problems.

Figure 43 presents the reconstructed methane plume from the VRPM survey of the Biocover Area. Contour lines give methane concentrations in parts per million by volume. The average calculated methane flux for the Biocover Area

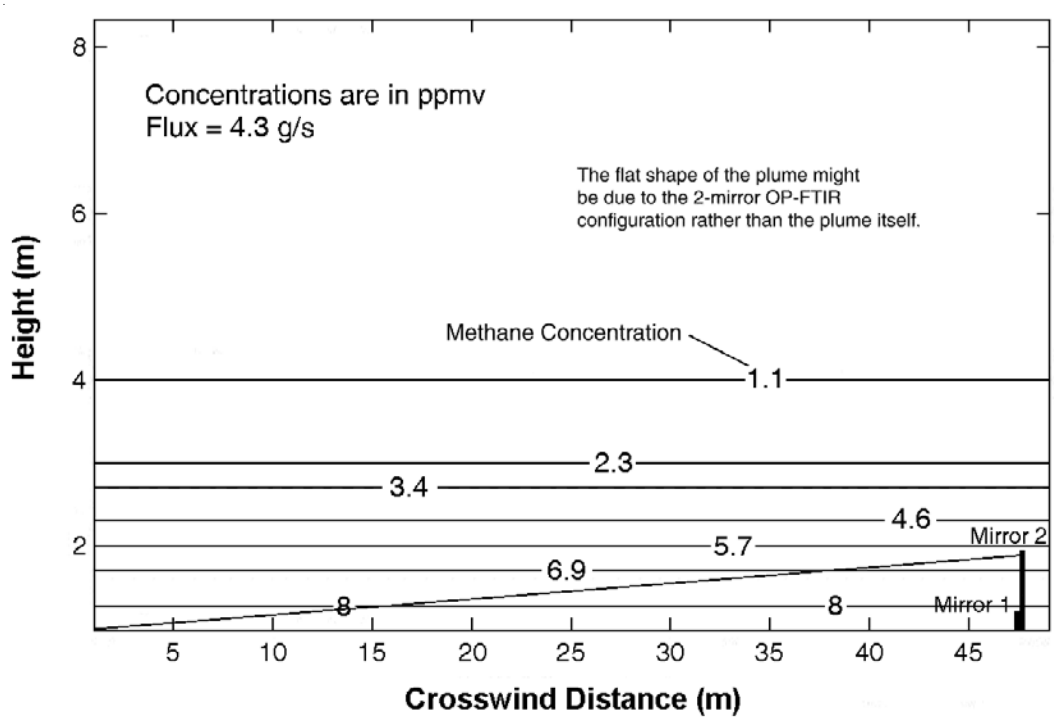

Figure 39. Average Reconstructed Methane Plume from the May 2003 Control Area Upwind Vertical Survey.

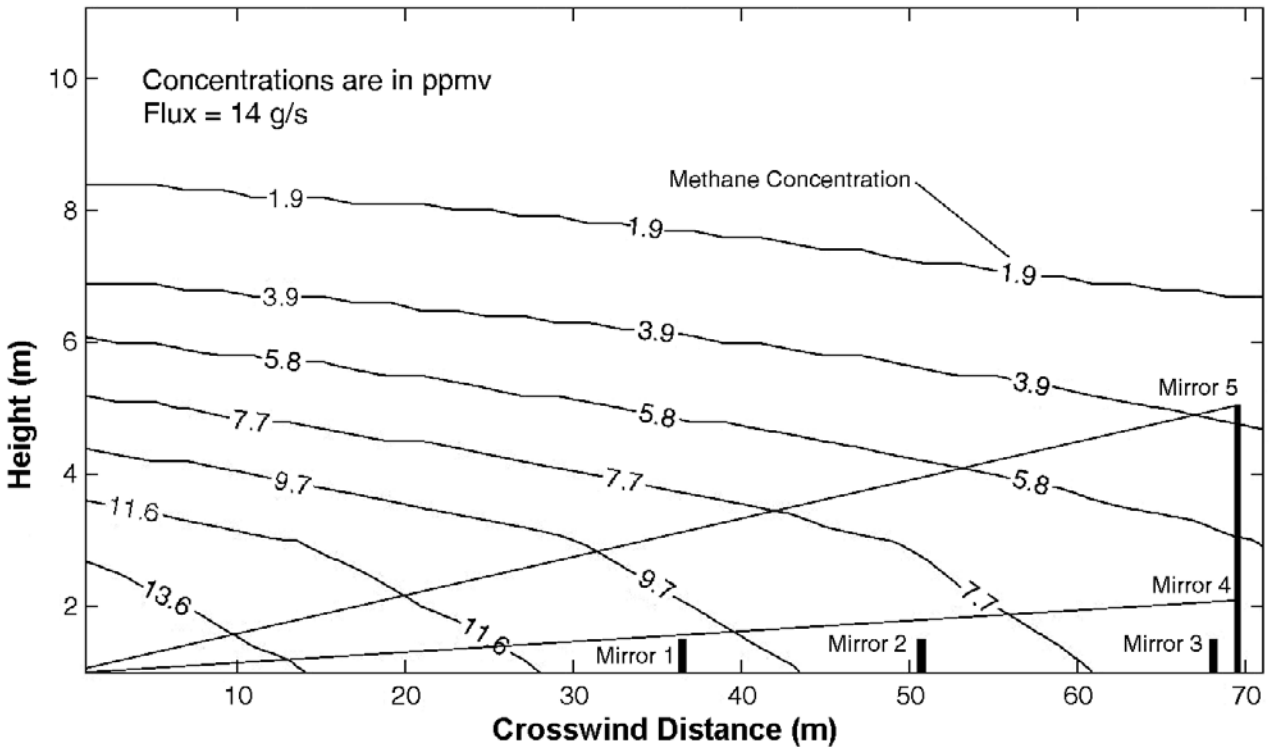

Figure 40. Average Reconstructed Methane Plume from the May 2003 Control Area Downwind Vertical Survey.

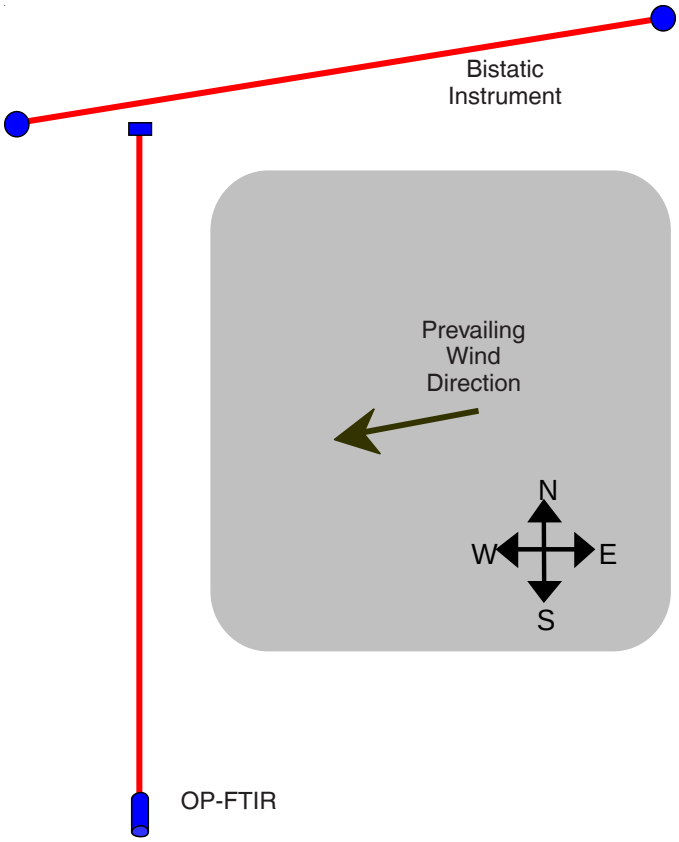

Figure 41. Map of Biocover Area Showing Location of Vertical Plane and Background Measurements During the September 2002 Field Campaign.

Figure 42. VRPM Configuration Used for the September 2002 Survey of the Biocover Area.

Table 19. Moving Average of Calculated Methane Flux, CCF, Wind Speed, and Wind Direction for the Downwind VRPM Survey of the Biocover Area During the September 2002 Field Campaign.

Loops	CCF	Flux (g/s)	Wind Speed (m/s)	Wind Dir.[a] (deg)
1 to 4	0.981	27	1.1	332
2 to 5	0.994	22	1.1	341
3 to 6	1.000	18	0.87	349
4 to 7	1.000	17	0.67	354
5 to 8	1.000	16	0.83	327
6 to 9	1.000	15	0.99	320
7 to 10	0.996	18	1.2	355
8 to 11	0.990	19	1.4	348
9 to 12	0.994	18	1.5	347
10 to 13	0.983	15	1.4	19
11 to 14	0.994	18	1.3	348
12 to 15	0.985	16	1.1	356
13 to 16	0.980	16	0.89	2
14 to 17	0.976	17	0.83	333
15 to 18	0.966	22	1.1	324
16 to 19	0.973	25	1.6	314
17 to 20	0.974	36	2.7	316
18 to 21	0.979	35	3.3	346
19 to 22	0.983	23	3.6	356
20 to 23	0.984	24	3.9	3
21 to 24	0.975	28	3.0	355
22 to 25	0.982	12	3.3	317
23 to 26	0.996	25	3.6	315
24 to 27	0.999	27	3.7	319
25 to 28	1.000	25	4.4	321
26 to 29	0.997	32	4.7	329
27 to 30	0.931	45	4.9	334
28 to 31	0.936	37	4.9	339
29 to 32	0.949	34	4.7	337
30 to 33	0.953	33	4.1	338
31 to 34	0.992	28	3.9	6
32 to 35	0.993	28	4.0	4
Average	0.932			
Std. Dev.	0.0183			

[a] Wind direction shown is measured from a vector normal to the plane of the configuration.

was 24 g/s, which is equivalent to approximately 410 g/m^2/day.

In order to analyze the results of the flux measurements, a comparison of methane flux calculations and wind data was made. Figure 44 presents a time series of methane flux and wind direction for instances when the vertical configuration was located downwind of the survey area (the

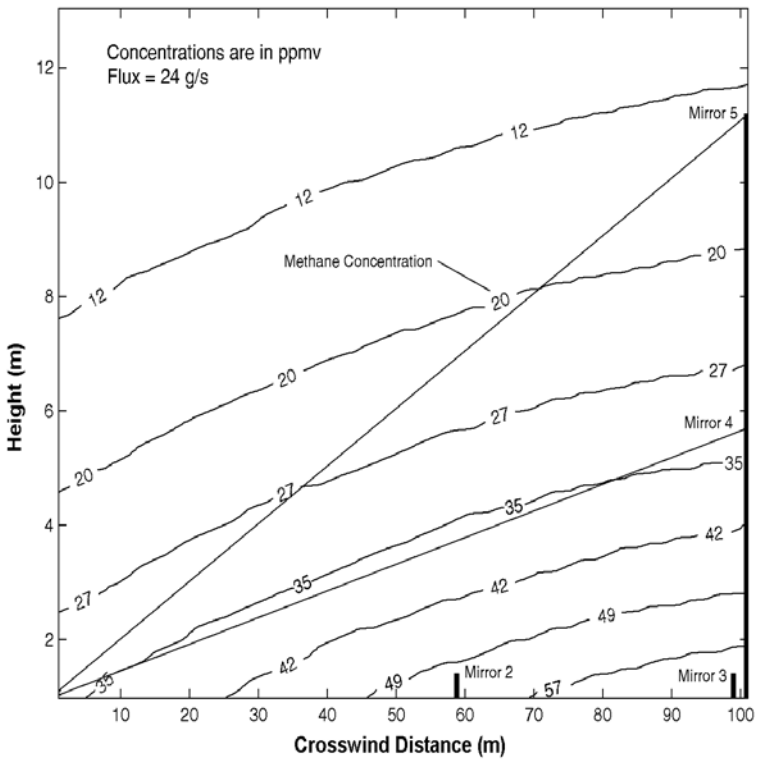

Figure 43. Average Reconstructed Methane Plume from the September 2002 Biocover Area VRPM Survey.

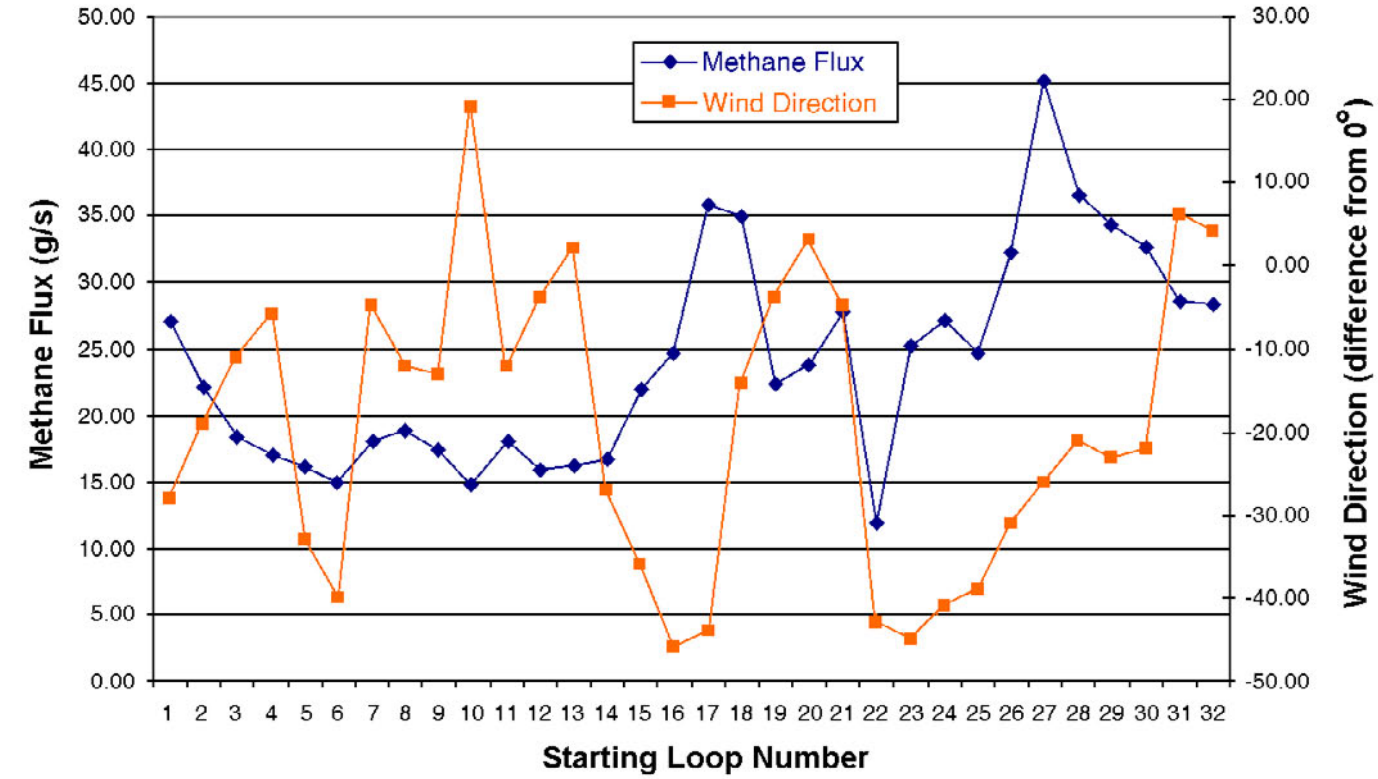

Figure 44. Time Series of Calculated Methane Flux Vs. Measured Wind Direction for the Biocover (using moving average of 4 loops) During the September 2002 Field Campaign.

data used to create this graph can be found in Appendix B). There appears to be a relationship between calculated methane flux and observed wind direction. The highest methane concentrations occur shortly after the observed wind direction has a northeasterly component (indicated as a wind direction of –30° to –40° in the figure). This suggests that methane is being transported through the vertical configuration, from a hot spot located somewhere to the northeast of the Biocover Area.

Observed wind directions during the Biocover Area VRPM survey were highly variable, which indicates an unstable environment. This suggests that the calculated methane flux values could be underestimating the actual methane flux values in this area (Hashmonay et al., 2001).

2.4.3 Testing Procedures Used During the May 2003 Field Campaign

The VRPM survey was completed using two monostatic OP-FTIR instruments and two scissors jacks. The configuration formed two vertical planes (one upwind plane, and one downwind plane). Two retroreflectors were used in the upwind vertical plane, and six retroreflectors were used in the downwind vertical plane. Figure 45 shows the location of the vertical configurations used at the Biocover Area test site. The GPS coordinates of the boundaries of the area are presented in Appendix D.

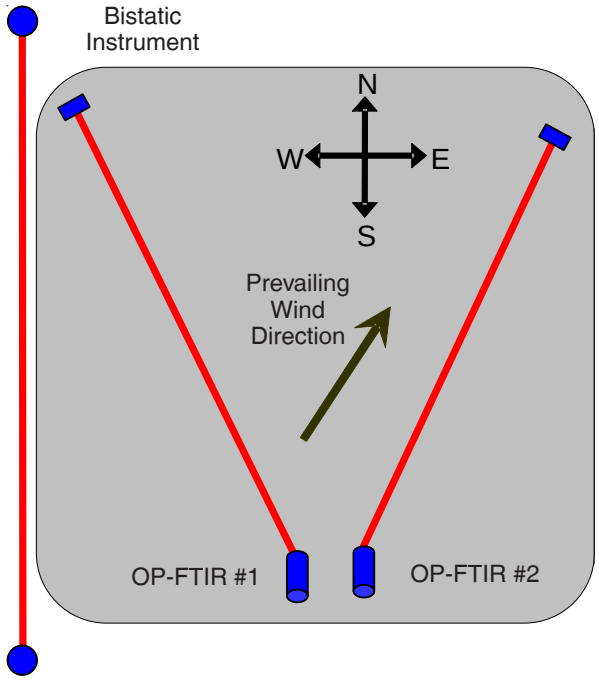

Figure 45. Map of Biocover Area Showing the Location of the Vertical Plane and Background Measurements During the May 2003 Field Campaign.

Both meteorological data and data from a non-scanning bistatic OP-FTIR operated in an upwind location by U.S. EPA personnel were collected concurrently with these tests.

2.4.4 Results and Discussion From the May 2003 Field Campaign

Methane fluxes were calculated at the Biocover Area along the upwind and downwind vertical planes. Tables 20 and 21 present the calculated methane fluxes measured along the upwind and downwind vertical planes, respectively. The methane concentrations used to create these tables can be found in Appendix B.

Figures 46 and 47 present the reconstructed methane plume from the upwind and downwind VRPM survey of the Biocover Area, respectively. Contour lines give methane concentrations in parts per million by volume. The average calculated methane flux was 91 g/s (equivalent to approximately 1300 g/m^2/day) for the upwind vertical survey, and 80 g/s (equivalent to approximately 890 g/m^2/day) for the downwind vertical survey.

The average calculated upwind methane flux was similar to the downwind flux, which indicates that the measured methane source was not located in the Biocover Area. The Biocover Area is located directly northeast of the As-Built Area (see Figure 1), and the observed winds during the time of the vertical survey were from the southwest. This suggests that a methane plume from the As-Built Area may have been carried by the prevailing winds into the vertical configurations set up in the Biocover Area. Also, the size of the Biocover Area is small relative to the size of the vertical configuration, and the source is immediately upwind of the configuration. If the methane source was located in the Biocover Area, a very narrow plume would be expected. The fact that the shape of the reconstructed methane plume (in Figure 47) is very broad horizontally supports the conclusion that the source of methane measured is not the Biocover Area.

Table 20. Moving Average of Calculated Methane Flux, Wind Speed, and Wind Direction for the Upwind Vertical Survey of the Biocover Area During the May 2003 Field Campaign.

Loops	Flux (g/s)	Wind Speed (m/s)	Wind Dir.[b] (deg)
1 to 4	91	7.1	347

[a] CCF values were all 1.00 because only two mirrors were used in the reconstruction, so CCFs are not included.
[b] Wind direction shown is measured from a vector normal to the plane of the configuration.

Table 21. Moving Average of Calculated Methane Flux, CCF, Wind Speed, and Wind Direction for the Downwind Vertical Survey of the Biocover Area During the May 2003 Field Campaign.

Loops	CCF	Flux (g/s)	Wind Speed (m/s)	Wind Dir.[a] (deg)
1 to 4	0.652	82	8.1	333
2 to 5	0.728	75	8.2	336
3 to 6	0.722	76	8.2	338
4 to 7	0.674	55	7.5	338
5 to 8	0.756	65	6.9	332
6 to 9	0.760	71	6.5	325
7 to 10	0.784	67	6.2	319
8 to 11	0.786	73	6.3	314
9 to 12	0.807	94	6.4	318
10 to 13	0.810	99	7.1	318
11 to 14	0.848	110	7.1	320
12 to 15	0.870	120	7.5	322
13 to 16	0.869	100	8.1	323
14 to 17	0.899	110	7.9	326
15 to 18	0.900	110	8.0	328
16 to 19	0.885	84	7.9	329
17 to 20	0.909	94	6.9	327
18 to 21	0.917	77	6.7	323
19 to 22	0.924	63	6.1	320
20 to 23	0.953	74	5.8	319
21 to 24	0.982	54	5.9	316
22 to 25	0.982	58	6.1	319
23 to 26	0.986	64	6.8	323
24 to 27	0.985	57	7.2	322
25 to 28	0.984	80	7.7	325
Average	0.855			
Std. Dev.	0.1020			

[a] Wind direction shown is measured from a vector normal to the plane of the configuration.

2.5 Compost Area

The Compost Area was located southwest of the Retrofit Area (see Figure 1). Surveying was conducted in this area as a one-time test during the September 2002 campaign and was not the focus of the overall effort. Since this is an aerobic operation, we did not expect to find high methane emissions in this area. HRPM was not performed in this area because it consisted of several small compost piles.

2.5.1 Testing Procedures Used During the September 2002 Field Campaign

Figure 48 shows the Compost Area and the optical configurations used during testing here. The large red ellipses denote the locations of the compost piles surveyed. At the Compost Area, two VRPM configurations were set up di-

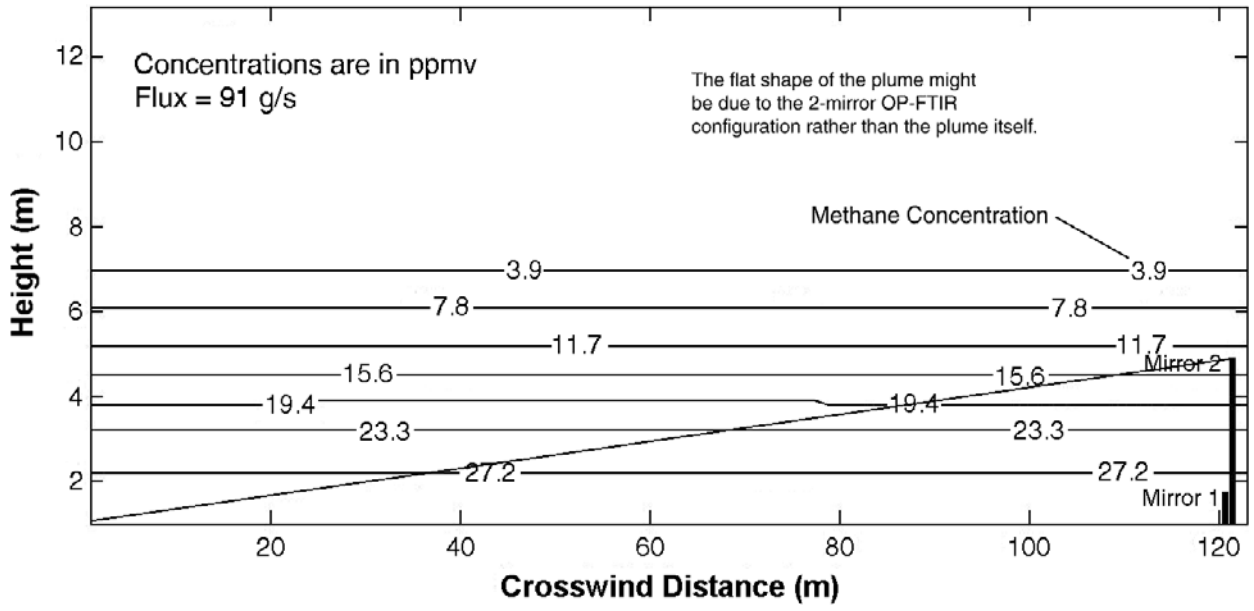

Figure 46. Average Reconstructed Methane Plume from the May 2003 Biocover Area Upwind VRPM Survey.

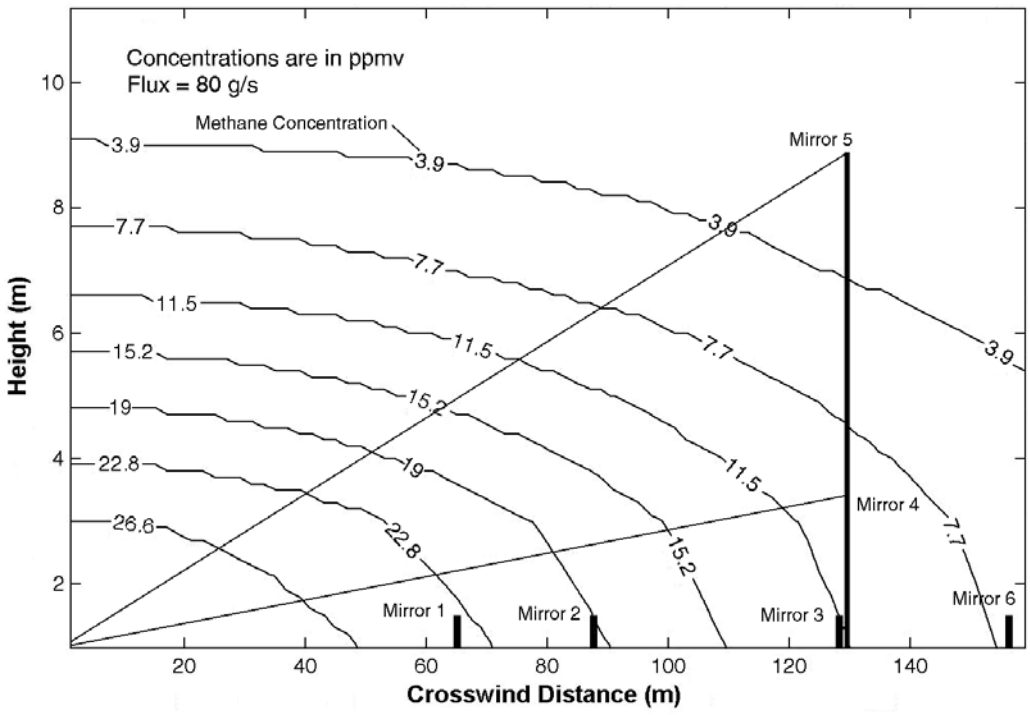

Figure 47. Average Reconstructed Methane Plume from the May 2003 Biocover Area Downwind VRPM Survey.

rectly adjacent to two compost piles. It is important to note that physical barriers such as a fence-line and the actual location of the compost piles limited the locations in which a vertical configuration could be set up to survey Pile 1.The winds during the time of the survey fluctuated but were predominately from the west-northwest. Since the VRPM configuration for pile 1 was oriented to the west of the pile, this scanning configuration was considered an upwind measurement. The scanning configuration used to survey Pile 2 was located east of the compost pile, so this was considered a downwind measurement.

Both meteorological data and data from a non-scanning bistatic OP-FTIR operated along the eastern boundary by U.S. EPA personnel were collected concurrently with these tests.

2.5.2 Results and Discussion From the September 2002 Field Campaign

The survey of the Compost Area survey did not detect any VOCs at concentrations above the minimum detection levels of the OP-FTIR. Additionally, the survey did not detect any methane plumes originating from the compost piles, which is consistent with what was expected. The methane concentrations measured in this area are presented in Appendix B.

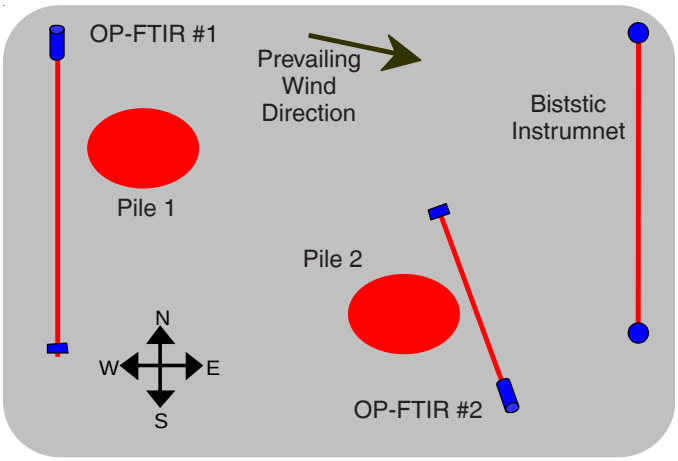

Figure 48. Map of Compost Area Showing Locations of Vertical Planes and Location of Background Measurements During the September 2002 Field Campaign.

2.6 VOC and Ammonia Measurements

ARCADIS performed additional analysis of the complete dataset to search for the presence of volatile organic compounds (VOCs) and ammonia. It is known that methane comprises approximately 50% of landfill gas. Proportioning an estimated methane concentration of 500,000 ppmv to the highest methane concentration found at the site and ratioing this to the AP-42 value for each target VOC (found

in Table 2), the expected VOC concentrations were calculated to often be below the estimated minimum detection limit of the instrumentation (for the target compound) and, consequently, were not detectable. This was anticipated prior to performance of the experiments. However, ammonia and VOCs were detected in some areas of the landfill. Consistent with the Quality Assurance Project Plan, emission fluxes for these trace compounds were calculated by proportioning to the methane flux data. These calculations are estimated emission fluxes and were only performed on data collected during VRPM surveys. This data is presented in the sections below.

2.6.1 Results and Discussion from the September 2002 Field Campaign

The presence of VOCs and ammonia was detected in the As-Built, Control, and Biocover Areas during the September 2002 field campaign. Tables 22 and 23 present concentrations and calculated fluxes (in grams per second) of VOCs and ammonia measured during runs 1 and 2, respectively, of the As-Built Area VRPM survey. Straight-chain hydrocarbons refer to the unbranched members of the alkane group (n-butane, n-pentane, n-hexane, etc.), while bent-chain hydrocarbons refer to the branched members of this group (isobutane, isopentane, isohexane, etc.). The estimated fluxes were calculated by ratioing the measured methane concentrations with the measured concentrations of VOCs and ammonia. The measurements used to create these tables can be found in Tables B-6 and B-7 of Appendix B.

Tables 24 and 25 present concentrations and calculated fluxes (in g/s) of VOCs and ammonia measured during runs 1 and 2, respectively, of the Control VRPM survey. The measurements used to create these tables can be found in Tables B-26 and B-27 of Appendix B.

Table 26 presents concentrations of VOCs and Ammonia measured on mirror 1 of the Biocover Area survey. The measurements used to create this table can be found in Table B-30 of Appendix B.

Methyl tert-butyl ether (MTBE) was also detected in the As-Built, Control, and Biocover areas during the September 2002 campaign (measured concentrations ranged from

Table 22. Average Concentration and Estimated Flux of VOCs and Ammonia During the September 2002 As-Built VRPM Run 1.

Compound	MDL[a] (ppmv)	Avg. Con. (ppmv)	Flux (g/s)	Flux (g/m²/day)
Ammonia	0.002	0.005	0.01	0.11
Straight-chain Hydrocarbons	0.490	1.97	11.3	120.
Bent-chain Hydrocarbons	0.084	0.472	2.3	24
Methane		109.	120.	

[a] MDL = minimum detection level.

Table 23. Average Concentration and Estimated Flux of VOCs During the September 2002 As-Built VRPM Run 2.

Compound	MDL[a] (ppmv)	Avg. Con. (ppmv)	Flux (g/s)	Flux (g/m²/day)
Straight-chain Hydrocarbons	0.490	2.03	12.	120.
Bent-chain Hydrocarbons	0.271	1.38	6.9	71
Methane		147.	170.	

[a] MDL = minimum detection level.

Table 24. Average Concentration and Estimated Flux of VOCs and Ammonia During the September 2002 Control Area VRPM Run 1.

Compound	MDL[a] (ppmv)	Avg. Con. (ppmv)	Flux (g/s)	Flux (g/m²/day)
TFM[b]	0.002	0.005	0.01	0.17
CFM[c]	0.010	0.034	0.02	0.34
Ethanol	0.011	0.087	0.03	0.51
Ammonia	0.004	0.020	0.01	0.17
Methane		66.5	5.0	

[a] MDL = minimum detection level.
[b] TFM = trichlorofluoromethane.
[c] CFM = chlorofluoromethane.

Table 25. Average Concentration and Estimated Flux of VOCs and Ammonia During the September 2002 Control Area VRPM Run 2.

Compound	MDL[a] (ppmv)	Avg. Con. (ppmv)	Flux (g/s)	Flux (g/m²/day)
CFM[b]	0.001	0.031	0.02	0.34
Ethanol	0.001	0.065	0.02	0.34
Ammonia	0.003	0.019	0.01	0.17
Methane		57.0	5.0	

[a] MDL = minimum detection level.
[b] CFM = chlorofluoromethane.

Table 26. Average Concentration of VOCs, Ammonia, and Methane Found on Mirror 1 of the September 2002 Biocover Area Survey.

Compound	MDL[a] (ppmv)	Avg. Con. (ppmv)
Ethylene	0.002	0.008
CFM[b]	0.002	0.031
Ethanol	0.003	0.104
TFM[c]	0.003	0.006
Ammonia	0.007	0.021
Methane		38.0

[a] MDL = minimum detection level.
[b] CFM = chlorofluoromethane.
[c] TFM = trichlorofluoromethane.

0.006 to 0.060 ppmv). MTBE is primarily used as an additive to gasoline to improve combustion and reduce emissions of carbon monoxide. Since it is possible that the source of the detected MTBE was gasoline used in the field operations, the results of the MTBE data were not included in Tables 22 through 26.

2.6.2 Results and Discussion from the May 2003 Field Campaign

Ammonia and VOCs were detected in the As-Built Area during the May 2003 field campaign. Tables 27 and 28 present concentrations of VOCs and Ammonia measured on mirror 5 of the HRPM survey, and mirror 4 of the surface survey of the slope between the two cells of the As-Built Area, respectively. The measurements used to create these tables can be found in Tables B-9 and B-10 of Appendix B.

Table 29 presents concentrations and calculated fluxes (in grams per second) of VOCs and ammonia measured during the VRPM survey of the upper cell. The VOC fluxes were calculated by forming the ratio of the measured methane concentrations to the measured concentrations of VOCs and ammonia. The measurements used to create this table can be found in Table B-13 of Appendix B.

Table 27. Average Concentration of VOCs, Ammonia, and Methane for the May 2003 As-Built Upper HRPM Survey.

Compound	MDL[a] (ppmv)	Avg. Con. (ppmv)
Ammonia	0.002	0.005
Methanol	0.003	0.023
Ethanol	0.003	0.017
Methane		34.0

[a] MDL = minimum detection level.

Table 28. Average Concentration of VOCs, Ammonia, and Methane for the May 2003 HRPM Survey of the Slope between the Upper and Lower Cells of the As-Built Area.

Compound	MDL[a] (ppmv)	Avg. Con. (ppmv)
Ammonia	0.002	0.011
Methanol	0.004	0.015
Ethanol	0.004	0.069
Methane		22.0

[a] MDL = minimum detection level.

Table 29. Average Concentration and Estimated Flux of VOCs and Ammonia for the As-Built Upper VRPM Survey During the May 2003 Field Campaign.

Compound	MDL[a] (ppmv)	Avg. Con. (ppmv)	Flux (g/s)	Flux (g/m²/day)
Ammonia	0.003	0.021	0.04	0.31
Methanol	0.005	0.032	0.12	0.92
Ethanol	0.005	0.103	0.59	4.5
Methane		16.0	32.	

[a] MDL = minimum detection level.

Due to the relatively high concentrations of ethanol detected during the VRPM survey of the As-Built Upper Cell (see Table 29), further analysis was done on the ethanol data to create a plume reconstruction and calculated ethanol flux using the VRPM algorithm. Figure 49 presents the reconstructed ethanol plume from the downwind VRPM survey of the As-Built Upper Cell (Figure 51 presents a validation of the data used to reconstruct the ethanol plume). Contour lines give ethanol concentrations in parts per million by volume. The average calculated ethanol flux was 2.2 g/s. The flux value of 2.2 g/s (equivalent to approximately 17 g/m^2/day) calculated using the VRPM method is about four times the ethanol flux value of 0.59g/s (equivalent to approximately 4.5 g/m^2/day) found using the ratio method (see Table 29). This is due to the fact that data from 29 loops were used to report the average ethanol concentration and flux reported in Table 29, although the actual ethanol event was much shorter. In fact, only 9 loops of data were used to create Figure 49. These 9 loops represent the actual period of peak ethanol concentrations, resulting in higher flux values.

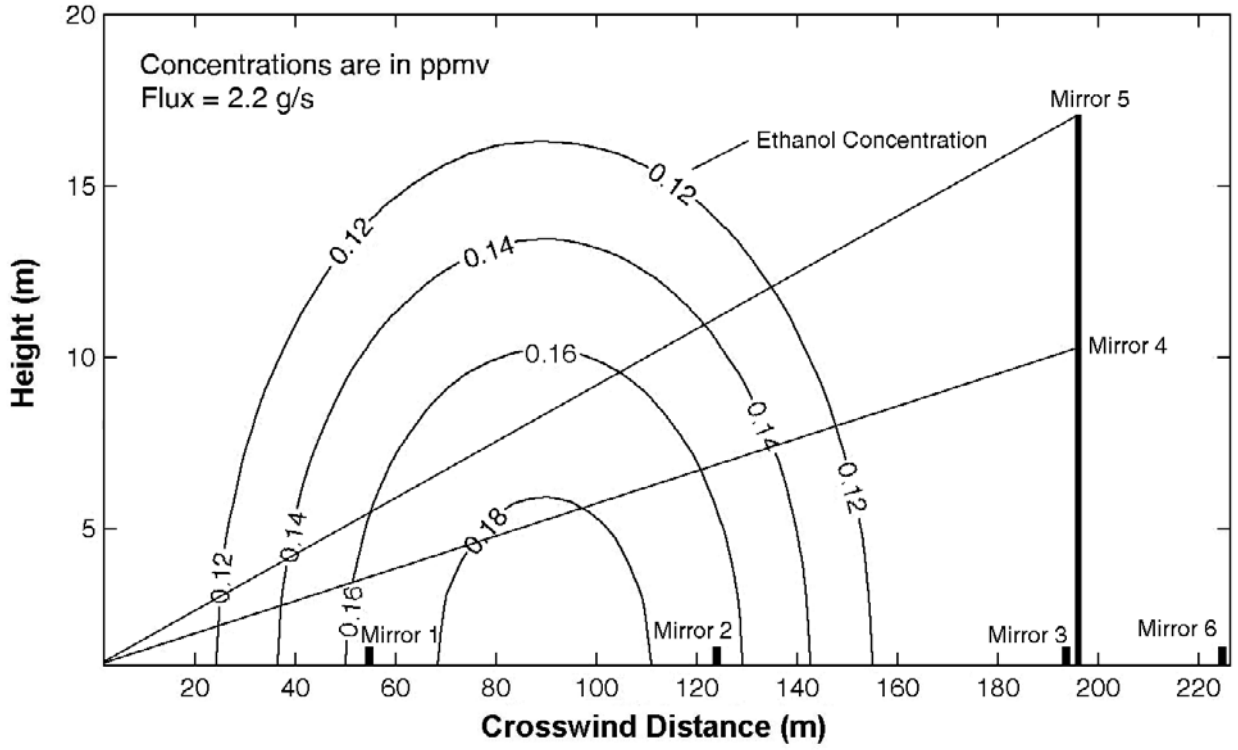

Figure 49. Average Reconstructed Ethanol Plume from the May 2003 As-Built Upper VRPM Survey.

2.6.3 Results and Discussion from the September 2003 Field Campaign

The entire data set from the September 2003 campaign was analyzed for VOCs and ammonia. However, the analysis failed to detect the presence of these compounds at levels higher than the minimum detection level of the instrumentation.

2.7 Mercury Sampling

Mercury sampling was done at the site during the September 2002 and September 2003 field campaigns. Sampling was performed for total, monomethyl, and dimethyl mercury. During the September 2002 campaign, mercury sampling was done in the As-Built Area (only one total mercury sample was taken), Retrofit Areas (unit 5), and the control areas (units 73A and 73B). It should be noted that the As-Built Area was not connected to the rest of the landfill gas system during this campaign. Additional sampling was performed at the two flares located within the site. Figure 50 shows mercury sampling being conducted at a landfill gas header access point located upstream of the main flare station. During the September 2003 campaign, mercury sampling was performed in the As-Built Area, Retrofit Areas (unit 5), and the control areas (units 73A and 73B). Additional sampling was performed at the two flares located within the site. A summary of the data collected is contained in the following sections. The entire data set is included in Appendix C of the report.

Figure 50. Mercury Sampling Conducted at a Landfill Gas Header Access Point Located Upstream of the Main Flare Station.

2.7.1 Testing Procedures Used for Mercury Sampling

2.7.1.1 September 2002 Campaign

To collect the total mercury samples, an iodated charcoal trap was used as a sorbent, and a backup tube was present

to assess any breakthrough. The sorbent tube was heated to above the dew point of the gas stream to prevent condensation on the sorbent. Water vapor from the stream was collected and quantified using a silica gel impinger. A diaphragm air pump was used to pull the gas stream through the train and collect the sample. The volume of gas sampled was monitored and quantified by a mass flow meter (MFM). The gas stream flow rate was nominally 0.8 L/min for 37.5 min, which equates to a total volume of about 30 L.

The traps were returned to the lab where the iodated carbon was leached of collected Hg using hot-refluxing HNO_3/H_2SO_4 and then further oxidized by a 0.01 N BrCl solution. The digested and oxidized leachate sample was analyzed using the FGS-069 cold vapor atomic fluorescence spectrometer (CVAFS) total Hg analysis method (which served as the basis for U.S. EPA Method 1631, developed, authored, and validated by Frontier Geosciences).

Dimethyl mercury (DMHg) was sampled using a slightly different technique. A Carbotrap was used as a sorbent, with a backup tube to assess any breakthrough, and a third iodated carbon trap was used to collect any elemental mercury present. The sorbent tube was heated to above the dew point of the gas stream to prevent condensation on the sorbent. Water vapor from the stream was collected and quantified using a silica gel impinger. A diaphragm air pump was used to pull the gas stream through the train and collect the sample. The volume of gas sampled was monitored and quantified by a MFM. The sample flow rate was nominally 0.35 L/min for a total volume of about 9.0 L.

The DMHg content of the Carbotraps was determined by thermal desorption (TD) and gas chromatography (GC), and CVAFS. The analytical system was calibrated by purging precise quantities of DMHg in methanol (1 – 500 pg) from deionized water onto Carbotraps and then thermally desorbing (45 s at a 25 to 450 °C ramp) them directly into the isothermal GC (1 m × 4 mm ID column of 15% OV-3 on Chromasorb WAW-DMCS 80/100 mesh) held at 80 °C. The output of the GC was passed through a pyrolytic cracking column held at 700 °C, converting the organic mercury compounds to elemental form. DMHg was identified by retention time and quantified by peak height.

To collect the monomethyl mercury sample, a set of three impingers filled with 0.001 M HCl was used. An empty fourth impinger was used to knockout any impinger solution carryover to the pump and meter system. A diaphragm air pump was used to pull the gas stream through the train and collect the sample. The volume of gas sampled was monitored and quantified by a MFM. The sample flow rate was nominally 0.8 L/min for 20.0 min, which equates to a total volume of approximately 16 L.

The analysis method uses distillation, ethylation, Carbotrap preconcentration, thermal desorption, gas-chromatography separation, thermal conversion, and CVAFS detection. See the Appendix A standard operating procedures (SOPs), FGS-070, and FGS-013 for introductory pages to the respective methods. This analytical method for monomethyl mercury in a water matrix is the basis for U.S. EPA Draft Method 1631.

2.7.1.2 September 2003 Campaign

To collect the total mercury samples, an iodated charcoal trap was used as a sorbent, and a backup tube was present to assess any breakthrough. The sorbent tube was heated to above the dew point of the gas stream to prevent condensation on the sorbent. Water vapor from the stream was collected and quantified using a silica gel impinger. A diaphragm air pump was used to pull the gas stream through the train and collect the sample. The volume of gas sampled was monitored and quantified using a volatile organic sampling train (VOST) box. The sample flow rate was nominally 0.8 L/min for 37.5 min, which equates to a total volume of approximately 30 L.

The traps are returned to the lab where the iodated carbon was leached of collected Hg using hot-refluxing HNO_3/H_2SO_4 and then further oxidized by a 0.01 N BrCl solution. The digested and oxidized leachate sample is analyzed using the FGS-069 CVAFS total Hg analysis method.

Dimethyl mercury was sampled using a slightly different technique. A Carbotrap was used as a sorbent, with a backup tube to assess any breakthrough and a third iodated carbon trap to collect any elemental mercury present. The sorbent tube was heated to above the dew point of the gas stream to prevent condensation on the sorbent. Water vapor from the stream was collected and quantified using a silica gel impinger. A diaphragm air pump was used to pull the gas stream through the train and collect the sample. The volume of gas sampled was monitored and quantified using a VOST box. The sample flow rate was nominally 0.35 L/min for a total volume of approximately 0.5 L.

The DMHg content of the Carbotraps was determined by TD-GC/CVAFS. The analytical system was calibrated by purging precise quantities of DMHg in methanol (1 – 500 pg) from deionized water onto Carbotraps and then thermally desorbing (45 s at a 25 to 450 °C ramp) them di-

rectly into the isothermal GC (1 m × 4 mm ID column of 15% OV-3 on Chromasorb WAW-DMCS 80/100 mesh) held at 80 °C. The output of the GC was passed through a pyrolytic cracking column held at 700 °C, converting the organic mercury compounds to elemental form. DMHg was identified by retention time and quantified by peak height.

In addition to collecting dimethyl mercury using the Carbotrap method, an alternative was performed using a methanol impinger. The primary purpose of using an alternative method was to further evaluate the accuracy of the Carbotrap method. In general, samples were collected using the same equipment and techniques as those outlined below for the collection of monomethyl mercury. The only difference was that methanol was used as an impinger solution rather than 0.001 M HCL. A diaphragm air pump was used to pull the gas stream through the train and collect the sample. The volume of gas sampled was monitored and quantified using a VOST box. The sample flow rate was nominally 0.8 L/min for 37.5 min, which equates to a total volume of approximately 30 L.

Samples were analyzed at the laboratory using procedure listed in FGS-070 using a direct aqueous purge of small aliquots of the MeOH solutions. The DMHg evolved from the analytical sparging vessels was collected onto Carbotrap and introduced into the TD-GC/CVAFS instrument as described above.

To collect the monomethyl mercury sample, a set of three impingers filled with 0.001 M HCl was used. An empty fourth impinger was used to knockout any impinger solution carryover to the pump and meter system. A diaphragm air pump was used to pull the gas stream through the train and collect the sample. The volume of gas sampled was monitored and quantified using a VOST box. The sample flow rate was nominally 0.8 L/min for 37.5 min, which equates to a total volume of approximately 30 L.

The analysis method used distillation, ethylation, Carbotrap preconcentration, thermal desorption, gas-chromatography separation, thermal conversion, and CVAFS detection. See the Appendix A SOPs FGS-070 and FGS-013 for introductory pages to the respective methods. This analytical method for monomethyl mercury in a water matrix is the basis for U.S. EPA Draft Method 1631.

2.7.2 Results and Discussion from the September 2002 Field Campaign

2.7.2.1 Total Mercury

Total mercury concentrations in the landfill gas ranged from 224 to 671 ng/m^3 with an average of 522 ng/m^3 for all of the samples excluding the As-Built data. The data from the As-Built Area were not included in calculating the average because it was not attached to the rest of the landfill gas system during this campaign. Spike recoveries for the total mercury samples were 100%. Table 30 presents the average concentration and range of concentrations of total mercury measured in each of the four survey areas.

Table 30. Average Concentrations, and Range of Concentrations of Total Mercury Measured in the Retrofit Area, As-Built Area, Control Area, and Flare Gas.

Area	Total Hg Concentration (ng/m^3)	
	Average	Range
Retrofit (Unit 5)	260	619 to 671
As-Built	21	21
Control (Units 73A and 73B)	615	585 to 619
Flare	645	619 to 671

2.7.2.2 Dimethyl Mercury

Dimethyl mercury concentrations in the landfill gas ranged from not detected (ND) to 18 ng/m^3 with an average of 5.9 ng/m^3. The As-built area was not sampled for DMHg during this campaign, and there was no dimethyl mercury gas detected in the flare gas. Spike recoveries for the DMHg traps were 7% for the flare and ND for the Control Area landfill gas. Unsampled spike traps had recoveries from 69% to 105% with an average of 87%. Recoveries for the spiked/sampled traps were significantly lower than the acceptance criteria of 50–150% given in Table 1. This is possibly due to the presence of an unknown interfering compound either destroying or masking the detection of the DMHg. For this reason, all of the DMHg results from this campaign must be labeled as suspect. Further development of this sampling procedure is being performed by Frontier Geosciences to minimize this interference and more accurately determine the actual concentrations. Table 31 presents the average concentration and range of concentration of DMHg measured in each of the three survey areas using the Carbotrap method.

Table 31. Average Concentrations, and Range of Concentrations of Dimethyl Mercury Measured (using the Carbotrap method) in the Retrofit Area, As-Built Area, Control Area, and Flare Gas.

Area	DMHg[a] Concentration (ng/m³)	
	Average	Range
Retrofit (Unit 5)	12.6	3.7 to 18
As-Built	not sampled	
Control (Units 73A and 73B)	1.85	1.7

[a] DMHg = dimethyl mercury

2.7.2.3 Monomethyl Mercury

Monomethyl mercury concentrations in the landfill gas ranged from 0.4 to 4.4 ng/m³ with an average of 2.4 ng/m³. Spike recoveries for the monomethyl samples were 97% for the flare and 91% for the control area landfill gas. Spike recoveries for unsampled impinger solution ranged from 51% to 79% with an average of 65%. The lower recoveries may have been due to a preservation issue with the shipping. Table 32 presents the average concentration and range of concentrations of monomethyl mercury measured in each of the three survey areas.

Table 32. Average Concentrations, and Range of Concentrations of Monomethly Mercury Measured in the Retrofit Area, As-Built Area, Control, and Flare Gas.

Area	MMHg[a] Concentration (ng/m³)	
	Average	Range
Retrofit (Unit 5)	4.15	3.9 to 4.4
As-Built	not sampled	
Control (Units 73A and 73B)	2.75	2.3 to 3.2
Flare	3.5	3.5

[a] MMHg = monomethyl mercury

2.7.3 Results and Discussion From the September 2003 Field Campaign

2.7.3.1 Total Mercury

Total mercury concentrations in the landfill gas ranged from 123 to 4670 ng/m³ with an average of 1171 ng/m³ for all of the samples. It should be noted that the average of the control area is biased high because of the data from unit 73A. The vertical gas collection well sampled during this campaign was under positive pressure; therefore the data are suspect. Spike recoveries for the total mercury samples were 93%. Table 33 presents the average concentration and range of concentrations of total mercury measured in each of the four survey areas.

Table 33. Average Concentrations, and Range of Concentrations of Total Mercury Measured in the Retrofit Area, As-Built Area, Control Area, and Flare Gas.

Area	Total Hg Concentration (ng/m³)	
	Average	Range
Retrofit (Unit 5)	237	123 to 350
As-Built	334	334
Control (Units 73A and 73B)	2803	935 to 4670
Flare	986	957 to 1040

2.7.3.2 Dimethyl Mercury (Carbotrap)

Dimethyl mercury concentrations in the landfill gas ranged from 22.1 to 128.3 ng/m³ with an average of 53.3 ng/m³. One data point from the retrofit area was not included because it was improperly sampled. Spike recoveries for the dimethyl mercury traps ranged from 60.3% to 101.1% with an average of 77.2%. Unsampled spike traps had recoveries from 85% to 94% with an average of 88.8%. Table 34 presents the average concentration and range of concentrations of dimethyl mercury measured in each of the four survey areas using the Carbotrap method.

Table 34. Average Concentrations, and Range of Concentrations of Dimethyl Mercury Measured (using the Carbotrap method) in the Retrofit Area, As-Built Area, Control Area, and Flare Gas.

Area	DMHg[a] Concentration (ng/m³)	
	Average	Range
Retrofit (Unit 5)	22.1	22.1
As-Built	128	128
Control (Units 73A and 73B)	71.5	60.2 to 82.7
Flare	26.7	23.1 to 29.9

[a] DMHg = dimethyl mercury

2.7.3.3 Dimethyl Mercury (Methanol)

Dimethyl mercury concentrations in the landfill gas ranged from 45.5 to 363 ng/m³ with an average of 116.5 ng/m³. Spike recoveries for the dimethyl mercury impingers ranged from 85.7% to 89.5%. Unsampled spike traps had recoveries of 90.4% for each of the two spiked impingers. Table 35 presents the average concentration and range of concentrations of dimethyl mercury measured in each of the four survey areas using the methanol method.

Table 35. Average Concentrations, and Range of Concentrations of Dimethyl Mercury Measured (using the Methanol method) in the Retrofit Area, As-Built Area, Control Area, and Flare Gas.

Area	DMHg[a] Concentration (ng/m^3)	
	Average	Range
Retrofit (Unit 5)	47.4	45.5 to 49.3
As-Built	363	363
Control (Units 73A and 73B)	66.8	66.8
Flare	58.0	58.0

[a] DMHg = dimethyl mercury

2.7.3.4 Monomethyl Mercury

Monomethyl mercury concentrations in the landfill gas ranged from 0.55 to 2.10 ng/m^3 with an average of 1.37 ng/m^3. Spike recoveries for the monomethyl samples were 26% for the flare, 26% for the retrofit area, and ranged from ND to 28% for the control area. Recoveries for the spiked/sampled monomethyl impingers were significantly lower than the acceptance criteria of 50–150% given in Table 1. Spike recoveries for the unsampled impinger solution were not determined by Frontier Scientific. The low spike recoveries in the sampled traps are most probably due to improper preparation of the spike solution by Frontier Scientific. Apparently this spike solution was made at a concentration of 0.25 ng/L instead of 1.0 ng/L. For this reason, all of the monomethyl mercury results from this campaign must be labeled as suspect. Table 36 presents the average concentration and range of concentrations of monomethyl mercury measured in each of the four survey areas.

Table 36. Average Concentrations, and Range of Concentrations of Monomethly Mercury Measured in the Retrofit Area, As-Built Area, Control Area, and Flare Gas.

Area	MMHg[a] Concentration (ng/m^3)	
	Average	Range
Retrofit (Unit 5)	2.03	1.95 to 2.10
As-Built	0.55	0.55
Control (Units 73A and 73B)	0.66	0.54 to 0.78
Flare	0.67	1.48 to 2.05

[a] MMHg = monomethyl mercury

2.7.3.5 Lumex Sampling

Sampling was performed at the As-Built Area using the Lumex mercury analyzer. Particular emphasis was placed on sampling from cracks/fissures which were emitting steam. Twenty-seven points were measured to be below detection indicating that none of the gas phase mercury at unit 74 is in the elemental form.

3. Concluding Statements

This report provides the results from three field campaigns performed at the Outer Loop Landfill in Louisville, Kentucky, over a one-year period. The campaigns were conducted during September 2002, May 2003, and September 2003. The long-term goal of this study was to evaluate the performance of landfill bioreactor operations over a period of time. The site has two different bioreactor operations, an As-Built Area and a Retrofit Area. The As-Built Area, where liquid additions are introduced at the work face, consists of two cells, which were surveyed separately during the May 2003 and September 2003 field campaigns. The Retrofit Area was split into north and south sections that were evaluated independently for the September 2002 and May 2003 field campaigns. In addition to evaluating the two types of bioreactors, the use of vegetative cover (biocover) to reduce fugitive emissions was evaluated during the first two field campaigns. Emissions from the facility's composting operation were evaluated during the first field campaign. Since this is an aerobic operation, methane emissions were not expected nor were they found. Table 37 presents the average calculated methane fluxes and the range of flux values measured in each area over the course of the long-term study.

The As-Built Area was found to have the highest methane flux values during each of the three field campaigns. The flux values found in the Biocover Area during the May 2003 field campaign were relatively high, but it was determined that this was probably caused by a source of methane from the As-Built Area. The lowest methane fluxes found at the site were from the Control Area. The Compost Area was not found to be significant source of methane, which one would expect since it is an aerobic operation.

Horizontal radial plume mapping was performed in the As-Built Area during the May and September 2003 field campaigns and in the Retrofit Area during each of the three campaigns. During the September 2002 field campaign, two methane hot spots, having concentrations over 80 ppmv, were found at the Retrofit Area. During the May 2003 field campaign, four methane hot spots were found in the As-Built Area; the most intense (over 210 ppmv) was in the lower cell. Three of the hot spots occurred adjacent to the slope separating the two cells of the As-Built Area, suggesting the slope may be a significant source of methane. Two methane hot spots were found in the Retrofit Area during this campaign, the most intense of which (over 78 ppmv) was in the northeastern corner of the northern half of the Retrofit Area.

During the September 2003 campaign, three methane hot spots were found in the As-Built Area; the most intense

Table 37. Average Calculated Methane Flux and Range of Values Found at Each Survey Area.

Survey Area	September 2002		May 2003		September 2003	
	Methane Flux (g/s)	Range (g/s)	Methane Flux (g/s)	Range (g/s)	Methane Flux (g/s)	Range (g/s)
As-Built Upper Cell	RAEM[a]	RAEM	32	9.4 to 88	210[b]	84 to 330
As-Built Lower Cell	140[c]	120 to 180[c]	99	76 to 80	200[b]	25 to 380
Retrofit	37	31 to 44	27	18 to 39	54[d]	35 to 75
Control	6.0	6.0	14	5.2 to 24	N/A[e]	N/A

[a] RAEM = restricted access and equipment malfunction.
[b] Gas collection system not operating due to leachate build-up in the extraction wells.
[c] The landfill gas collection system was not operational in the As-Built cells during the September 2002 field campaign.
[d] The week prior to the test, the interim cap was replaced with a fresh topsoil/clay cover, and the gas collection system was upgraded.
[e] N/A = no control available.

(over 89 ppmv) was in the upper cell. Two methane hot spots were found in the Retrofit Area during this campaign, the most intense of which (over 33 ppmv) was along the western edge of the Retrofit Area.

Sampling and analysis of concentrations of total mercury, dimethyl mercury, and mononmethyl mercury was performed at the site during the September 2002 and September 2003 campaigns by Frontier Geosciences with sampling support from ARCADIS.

During the September 2002 campaign, total mercury concentrations in the landfill gas ranged from 224 to 671 ng/m^3 with an average of 522 ng/m^3 for all of the samples excluding the As-Built data. The data from the As-Built area were not included in calculating the average because it was not attached to the rest of the landfill gas system during this campaign. Spike recoveries for the total mercury samples were 100%. Dimethyl mercury concentrations in the landfill gas ranged from ND to 18 ng/m^3 with an average of 5.9 ng/m^3. There was no dimethyl mercury gas detected in the flare gas. Spike recoveries for the dimethyl mercury traps were 7% for the flare and ND for the control area landfill gas. Unsampled spike traps had recoveries from 69% to 105% with an average of 87%. Recoveries were low in the spiked traps possibly due to the presence of an unknown interfering compound either destroying or masking the detection of the dimethyl mercury. For this reason it is believed that the dimethyl mercury concentrations are at least the levels reported or may be higher. Monomethyl mercury concentrations in the landfill gas ranged from 0.4 to 4.4 ng/m^3 with an average of 2.4 ng/m^3. Spike recoveries for unsampled impinger solution ranged from 51% to 79% with an average of 65%. The lower recoveries may have been due to a preservation issue with the shipping. Table 38 lists the average concentrations (in nanograms per cubic meter) of total mercury, dimethyl mercury, and monomethyl mercury measured at the site during the September 2002 field campaign.

Sampling and analysis of concentrations of total mercury, dimethyl mercury, and monomethyl mercury was performed at the site during the September 2003 campaign. Total mercury concentrations in the landfill gas ranged from 123 to 4670 ng/m^3 with an average of 1171 ng/m^3 for all of the samples. It should be noted that the average of the control area is biased high because of the data from unit 73A. The vertical gas collection well sampled during this campaign was under positive pressure; therefore, the data are suspect. Spike recoveries for the total mercury samples were 93%. Dimethyl mercury concentrations in the landfill gas ranged from 22.1 to 128.3 ng/m^3 with an average of 53.3 ng/m^3 as measured by the Carbotrap method. One data point from the retrofit area was not included because it was improperly sampled. Spike recoveries for the dimethyl mercury traps ranged from 60.3% to 101.1%. Unsampled spike traps had recoveries from 85% to 94% with an average of 88.8%. Dimethyl mercury concentrations in the landfill gas ranged from 49.3 to 363 ng/m^3 with an average of 116.5 ng/m^3 as measured by the methanol impinger method. Spike recoveries for the dimethyl mercury impingers ranged from 85.7% to 89.5%. Unsampled spike traps had recoveries of 90.4% for each of the two spiked impingers. Monomethyl mercury concentrations in the landfill gas ranged from 0.55 to 2.10 ng/m^3 with an average of 1.37 ng/m^3. Spike recoveries for the monomethyl samples were 26% for the flare, 26% for the retrofit area, and ranged from ND to 28% for the control area. Spike recoveries for the unsampled impinger solution was not determined by Frontier Scientific. The low spike recoveries are most probably due to improper preparation of the spike solution by Frontier Scientific. Apparently this spike solution was made at a concentration of 0.25 ng/L instead of 1.0 ng/L. Table 39 lists the average concentrations (in nanograms per cubic meter) of total mercury, dimethyl mercury, and monomethyl mercury measured at the site during the September 2003 field campaign.

Table 38. Average Concentrations of Total, Dimethyl, and Monomethyl Mercury Found in the Retrofit Area, Control Areal, and Flare Gas During the September 2002 Field Campaign.

Compound	Retrofit (ng/m^3)	Control (ng/m^3)	Flare (ng/m^3)
Total Hg	260.	614	645
DMHg[a]	12.6	2.3	0
MMHg[b]	2.9	2.8	3.5

[a] DMHg = dimethyl mercury.
[b] MMHg = monomethly mercury.

Table 39. Average Concentrations of Total, Dimethyl, and Monomethyl Mercury Found in the Bioreactor, Control Cell, and Flare Gas During the September 2003 Field Campaign.

Compound	Retrofit Area/Unit 5 (ng/m^3)	As-Built (ng/m^3)	Control Area/ Units 73A and 74a (ng/m^3)	Flare Gas (ng/m^3)
Total Hg	237	334	2803	986
DMHg[a] (carbotrap)	22.1	128	71.5	26.7
DMHg (methanol)	47.4	363	66.8	58
MMHg[b]	2.03	0.55	0.66	1.67

[a] DMHg = dimethyl mercury.
[b] MMHg = monomethly mercury.

4. Quality Assurance/Quality Control

The development of quality assurance and control measures for studies done using ORS methods has been an ongoing process over the duration of this long-term project. Many improvements to the QA process have been developed and implemented since the September 2002 campaign. As a result, different levels of QA measures were in place during the data collection and analysis phase of each field campaign. The most significant improvements to the QA process were implemented during the September 2003 field campaign. Some of the major QA improvements implemented during the September 2003 campaign include:

- A more thorough documentation of the calibration schedule for the theodolite and meteorological heads,
- The development of pre-deployment tests to check the precision and accuracy of the meteorological heads,
- The development of pre-deployment and in-field checks of the OP-FTIR instruments to detect potential problems that may effect data quality,
- A more detailed explanation of checks that should be done on the OP-FTIR during data collection to ensure signal strength and proper mirror alignment,
- The development of a procedure to check the accuracy of analyzed concentration data,
- A more detailed explanation of checks in place in the RPM algorithms to filter data that is incomplete or not useful, and
- The development of manual checks that can be done to verify the accuracy of the surface concentration contour maps, and the reconstructed plume maps.

All equipment is calibrated annually or cal-checked as part of standard operating procedures. Certificates of calibration are kept on file. Maintenance records are kept for any equipment adjustments or repairs in bound project notebooks that include the data and description of maintenance performed. Instrument calibration procedures and frequency are listed in Table 40 and further described in the text.

As part of the preparation for this project, a Category III Quality Assurance Project Plan (QAPP) was prepared and approved for each separate field campaign. In addition, standard operating procedures were in place during the survey, and the September 2002 campaign was audited in the field.

4.1 Assessment of DQI Goals

The critical measurements associated with this project and the established data quality indicator (DQI) goals in terms of accuracy, precision, and completeness are listed in Table 41.

Table 40. Instrumentation Calibration Frequency and Description.

Instrument	Measurement	Calibration Date	Calibration detail
Climatronics Model 101990-G1 meteorological heads	Wind speed in mi/hr	22 April 2003	APPCD Metrology Lab calibration records on file
Climatronics Model 101990-G1 meteorological heads	Wind direction in degrees from North	22 April 2003	APPCD Metrology Lab calibration records on file
Topcon Model GTS-211D theodolite	Distance	1 May 2003	Calibration: actual distance = 50ft; measured distance = 50.6 and 50.5 ft.
Topcon Model GTS-211D theodolite	Angle	21 May 2003	Calibration: actual angle = 360°; measured angle = 359° 41′ 18″ and 359° 59′ 55″.

Table 41. DQI Goals for Instrumentation.

Measurement Parameter	Analysis Method	Accuracy	Precision	Detection Limit	Completeness
Analyte PIC[a]	OP-FTIR	±5%	±5%	See Table 2	90%
Ambient wind speed	Climatronics Met heads side-by-side comparison in the field	±1 m/s	±1 m/s	N/A[b]	90%
Ambient wind direction	Climatronics Met heads side-by-side comparison in the field	±10°	±10°	N/A	90%
Distance Measurement	Theodolite-Topcon	±1 m	±1 m	0.1 m	100%
Elemental Mercury	Lumex (direct method)	±20%	±20%	2 – 500 ng/m^3 [c]	90%
Total Mercury[d]	TD-GC-AFS[e]	50–150% recovery	±20%	33 ng/m^3 [f]	90%
Dimethyl Mercury (Carbotrap)[d]	TD-GC-pyrolysis-CVAFS[g]	50–150%	±20%	1.1 ng/m^3 [h]	90%
Monomethyl Mercury[d]	TD-GC-CVAFS	50–150%	±20%	0.63 ng/m^3 [i]	90%
Total Mercury[j]	TD-GC-AFS	50–150%	±20%	33 ng/m^3 [f]	90%
Dimethyl Mercury (Carbotrap)[j]	TD-GC-pyrolysis-CVAFS	50–150%	±20%	19.8 ng/m^3 [k]	90%
Dimethyl Mercury (methanol)[j]	TD-GC-CVAFS	50–150%	±20%	0.34 ng/m^3 [f]	90%
Monomethyl Mercury[j]	TD-GC-CVAFS	50–150%	±20%	0.34 ng/m^3 [f]	90%

[a] PIC = path-integrated concentration.
[b] N/A = not applicable.
[c] Estimated detection limit for natural and industrial gases. The landfill gas would have to be assayed to determine the actual detection limit of the instrument.
[d] September 2002 campaign.
[e] TD = thermal desorption; GC = gas chromatography; AFS = atomic fluorescence spectrometry.
[f] Estimated detection limit for a 30 L sample.
[g] CVAFS = cold vapor atomic fluorescence spectrometry.
[h] Estimated detection limit for a 9.0 L sample.
[i] Estimated detection limit for a 16.0 L sample.
[j] September 2003 campaign.
[k] Estimated detection limit for a 0.5 L sample.
All of the detection limits listed for the Frontier methods are method limits, which are essentially 10X the detection limit.

As previously mentioned, different levels of QA measures were in place during the data collection and analysis phase of each separate field campaign. As a result of this, DQI checks had not been developed, or were not in place for each of the measurement parameters used during each field campaign.

4.1.1 DQI Check for Analyte PIC Measurement
The precision and accuracy of the analyte PIC measurements were assessed by analyzing the measured nitrous oxide concentrations in the atmosphere. A typical background atmospheric concentration for nitrous oxide is about 310 ppb. However, this value may fluctuate due to seasonal variations in nitrous oxide concentrations.

The precision of the analyte PIC measurements was evaluated by calculating the relative standard deviation of each data subset. A subset is defined as the data collected along one particular path length during one particular survey in one survey sub-area. The number of data points in a data subset depends on the number of loops used in a particular survey.

The accuracy of the analyte PIC measurements was evaluated by comparing the calculated nitrous oxide concentrations from each data subsets to the background global concentration of 310 ppb. The number of calculated nitrous oxide concentrations that failed to meet the DQI accuracy criterion in each data subset was recorded.

This particular DQI check was developed before the May 2003 field campaign. Consequently, this DQI check was only performed on data collected during the May 2003 and September 2003 field campaigns.

4.1.1.1 May 2003 Field Campaign
Overall, 160 data subsets were analyzed from this field campaign. Based on the DQI criterion set forth for precision of ±10%, each of the 160 data subsets were found to be acceptable. The range of calculated relative standard

deviations for the data subsets from this field campaign was 0.61 to 17.7 ppb, which represents 0.19% to 5.7% RSD.

Each data point (calculated nitrous oxide concentration) in the 160 data subsets was analyzed to assess whether or not it met the DQI criterion for accuracy of ±5% (310 ± 16 ppb nitrous oxide). A total of 2250 data points were analyzed. Based on the DQI criterion set forth for accuracy, 1315 data points were found to be acceptable, for a total completeness of 58.4%.

A closer inspection of the results of the accuracy check found that, in many instances, the data points failed to meet the accuracy criterion by a narrow margin. In response to this, the DQI criteria check for accuracy was performed again with the criterion of ±10% (310 ± 31 ppb nitrous oxide). Based on this criterion, 1943 data points were found to be acceptable, for a total completeness of 86.4%.

Another observation resulting from the DQI accuracy check was that there was a correlation between the distance of the data subset path length and the number of data points from that particular subset which failed to meet the accuracy criterion. This is not surprising since the standard global background nitrous oxide concentration of 310 ppb is close to the detection limits for this compound using OP-FTIR. Table 42 presents a more detailed look at the DQI check for accuracy that separates the results of the DQI accuracy check based on the subset path length. It is apparent from the results presented in Table 42 that many of the unacceptable data points occurred along path lengths less than 100 meters.

Table 42. Results of DQI Checks for Accuracy from the May 2003 Field Campaign Based on Different DQI Criteria and Different Data Subset Path Lengths.

Data Subset Path Length	Accuracy Criterion	Number of Data points	Number of Failed Data Points	Completeness
<100 m	±5%	817	645	21%
>100 m	±5%	1433	290	80%
<100 m	±10%	817	213	73.9%
>100 m	±10%	1433	94	93.4%

4.1.1.2 September 2003 Field Campaign

Overall, 86 data subsets were analyzed from this field campaign. Based on the DQI criteria set forth for precision of ±10%, each of the 86 data subsets were found to be acceptable. The range of calculated relative standard deviations for the data subsets from this field campaign was 0.47 to 27.9 ppb, which represents 0.15% to 9.0% RSD.

Each data point (calculated nitrous oxide concentration) in the 86 data subsets was analyzed to assess whether or not it met the DQI criterion for accuracy of ±5% (310 ± 16 ppb nitrous oxide). A total of 1712 data points were analyzed. Based on the DQI criterion set forth for accuracy, 1603 data points were found to be acceptable, for a total completeness of 93.6%. The same check was performed a second time with the criterion of ±10% (310 ± 31 ppb nitrous oxide). Based on this criterion, 1684 data points were found to be acceptable, for a total completeness of 98.4%.

4.1.1.3 Discussion of the Results from the DQI Check for Analyte PIC Measurement

Based on the results of the DQI checks that were performed to assess the precision and accuracy of the analyte PIC measurements, a couple of changes to the DQI criteria will be proposed for future field campaigns.

An analysis of the calculated nitrous oxide concentrations found that in most cases, the acceptable concentrations approached the upper limits of the acceptable criterion. The current standard global background nitrous oxide concentration used (310 ppb) is taken from an ASTM standard practice (ASTM, 2002). However, several studies have found global background nitrous oxide concentration values slightly higher (320 ppb) than the 310 ppb value currently used. In response to the analysis done associated with the DQI check for analyte PIC measurement, the global background value used to assess accuracy should be changed to 315 ppb for future field campaigns, which represents an average of the values cited in available references.

In addition, it is apparent from the results that the acceptance criterion goal for accuracy is too narrow and should be expanded slightly based on the findings of this DQI check. In addition to expanding the range of the criterion goal, the acceptance criterion goal should be differentiated based on the path length being analyzed. This is supported by the results presented in Table 42. In response to this, it is proposed that the acceptance criterion goal be changed to 315 ppb ± 20% for path lengths less than 100 m, and 315 ppb ± 10% for path lengths greater than 100 m.

4.1.2 DQI Checks for Ambient Wind Speed and Wind Direction Measurements

The meteorological equipment was calibrated prior to the May 2003 field campaign by the APPCD Metrology Lab

(see Table 40). Although calibration of the meteorological heads did not occur prior to the September 2002 field study, checks for agreement of the wind speed and wind direction measured from the two heads (2 m and 10 m) were done in the field during data collection. Although it is true that some variability in the parameters measured at both levels should be expected, this is a good first-step check for assessing the performance of the instruments. Another check is done in the field by comparing the measured wind direction to the forecasted wind direction for that particular day.

4.1.3 DQI Check for Precision and Accuracy of Theodolite Measurements

Although calibration of this instrument did not occur immediately prior to the September 2002 field campaign, the theodolite was originally calibrated by the manufacturer prior to being received by the U.S. EPA.

Additionally, there are several internal checks in the theodolite software that prevent data collection from occurring if the instrument is not properly aligned on the object being measured or if the instrument has not been balanced correctly. When this occurs, it is necessary to re-initialize the instrument to collect data.

The following DQI checks were performed on the theodolite at a field site near Chapel Hill, NC prior to the May 2003 field campaign. The calibration of distance measurement was done using a tape measure to compare the actual distance to the measured distance. This check was duplicated to test the precision of this measurement. The actual distance measured was 15.2 m. The measured distance during the first test was 15.4 m and was 15.4 m during the second test. The results indicate the accuracy (1.3% bias for test one and two) and precision (0% RSD) of the distance measurement fell well within the DQI goals.

The check to test the precision and accuracy of the angle measurement was done by placing two mirror targets approximately 180° apart. The theodolite was placed in the middle of the imaginary circle formed by the two mirrors. The actual angle was 360°. The angle measured during the first test was 359° 41′ 18″, and the angle measured during the second test was 359° 59′ 55″. The results indicate the accuracy and precision of the angle measurement fall well within the DQI goals.

4.2 QC Checks of OP-FTIR Instrument Performance during Data Collection

As mentioned previously, many improvements to the QA process have been developed and implemented over the course of this long-term study. One of these improvements involves the development of QC checks performed on the OP-FTIR instrumentation in the field. Several checks are performed on the OP-FTIR instrumentation on the first day of a particular field campaign, and a couple of checks are performed at the beginning of each day in the field. Table 43 provides more information on the OP-FTIR QC checks.

These QC checks were developed before the September 2003 field campaign. Consequently, they were not performed during the September 2002 and May 2003 field campaigns. However, there were QC procedures in place during the September 2002 and May 2003 field campaigns to ensure the strength of the signal being measured with the OP-FTIR. During the field campaigns, the quality of the instrument signal (interferogram) is checked constantly. This is done by ensuring that the intensity of the signal is

Table 43. QC Checks Performed on the OP-FTIR Instrument.

QC Check	Detail of Test	Frequency
Single Beam Ratio Test	Ratio of the signal strength at two points in a collected interferogram is calculated. Used to ensure that the infrared beam is properly aligned through the Michelson interferometer.	Daily
Stray Light	Used to identify and quantify any stray light present in the instrument detector. If stray light is present, the stray light spectrum will be used to correct the collected data.	Daily
Noise Equivalent Absorbance	Used to measure amount of instrument noise and is generally used as an instrument quality metric.	First day of field campaign
Saturation of Instrument	Used to test for instrument detector saturation, which can lead to nonlinear responses to changes in infrared intensity.	First day of field campaign
Random Baseline Noise	Used to assess the random baseline noise of the instrument.	First day of field campaign

at least 5 times the intensity of the stray light signal (the stray light signal is collected as background data prior to actual data collection and measures internal stray light from the instrument itself). In addition to checking the strength of the signal, checks are done constantly in the field to ensure that the data are being collected and stored to the data collection computer. During sampling, a member of the field team constantly monitors the data collection computer to make sure these checks are completed.

The Single Beam Ratio, Electronic Noise, Saturation, Linearity, and Random Baseline Noise tests were performed on the Unisearch OP-FTIR on September 25, 2003. The results of these tests found that the Unisearch OP-FTIR was operating efficiently.

The same tests were performed on the IMACC OP-FTIR on September 26, 2003. The results of these tests found that this instrument was operating favorably as well. Although this series of tests should have been performed on the IMACC OP-FTIR on the first day of the field campaign (September 25), this was not possible due to the intense schedule of the first full day of the field campaign.

In addition to the tests described above, the Single Beam Ratio Test, and collection of a stray light spectrum was performed on each day of the field campaign. The results of the Single Beam Ratio Test indicated that both instruments were operating favorably during the entire field campaign.

4.3 Validation of VOC Concentration Analysis

During the analysis of data from all of the field campaigns, a validation procedure was performed on the data to aid in identifying the presence of ammonia and VOCs in the data set. This validation procedure involves visually comparing an example of the measured spectra to a laboratory-measured reference spectrum.

Figure 51 shows an example of a validation done using a spectrum collected in the As-Built Area during the May 2003 field campaign. Ethanol, ammonia, and methanol were detected in this particular spectrum. The Classical Least Squares (CLS) analysis performed on this spectrum resulted in determinations of 761.2 ± 5.8 ppb of ethanol,

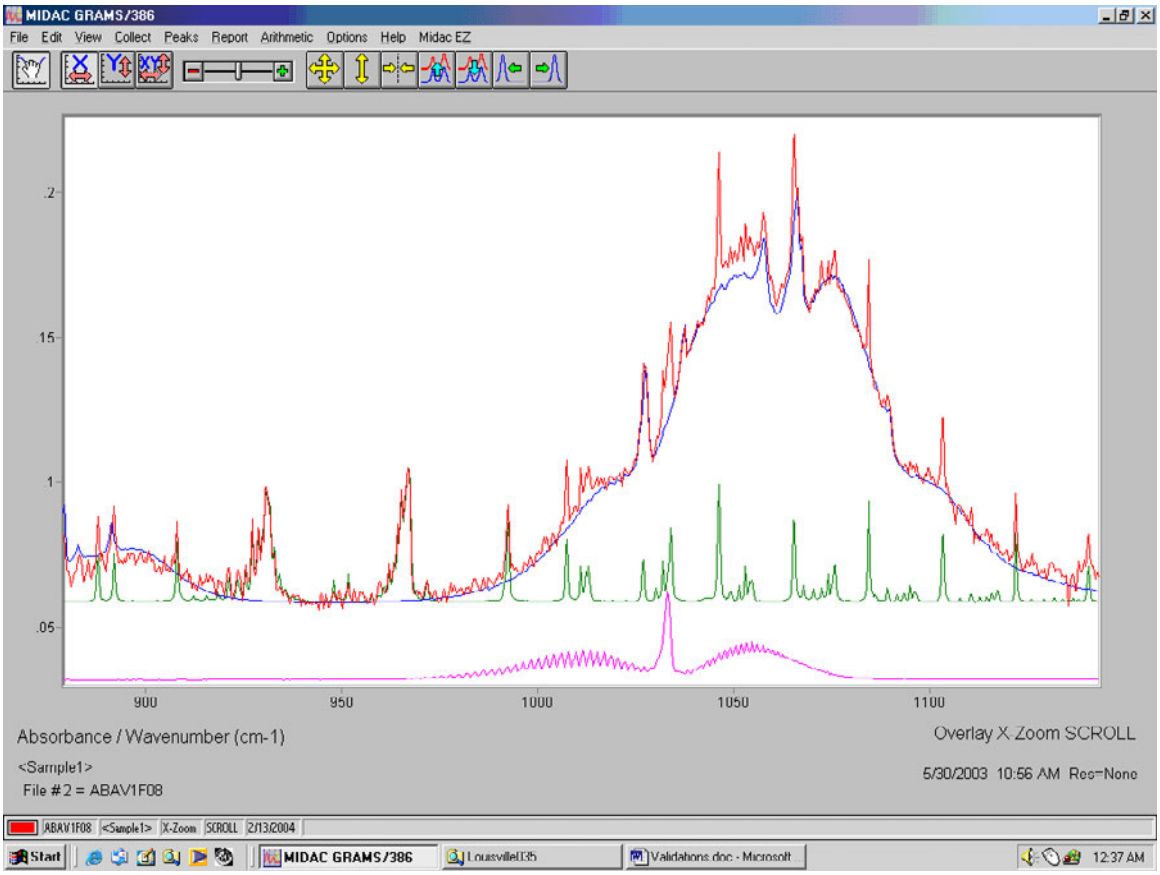

Figure 51. Comparison of a Spectrum Measured (red trace) at the As Built Area to Reference Spectra of Ethanol (blue trace), Ammonia (green trace), and Methanol (purple trace).

81.3 ± 4.2 ppb of ammonia and 49.4 ± 6.2 ppb of methanol. The plus and minus values are equal to three times the standard error in the regression fit of the measured spectrum to a calibrated reference spectrum, propagated to the concentration determination. The appearance of methanol in this spectrum is distorted by the overlapping ethanol and ammonia bands and has been further validated in another spectrum in which there was little absorption by ethanol. Nevertheless, the methane features can be seen in the spectrum shown in Figure 51, at 1033 cm^{-1}.

4.4 September 2002 Site Audit

At the request of the work assignment manager, an onsite U.S. EPA process audit was performed during the September 2002 field campaign. U.S. EPA auditors were present during a portion of the campaign and observed the data collection phase of the project. The audit continued during the data analysis process, which occurred after the field campaign.

In general, the auditors reported that ARCADIS was doing a favorable job of measuring fugitive emissions at the landfill, and that project personnel and OP-FTIR instrumentation performed well. However, the auditors offered suggestions for future field tests encompassing:

- Recommendations for improved data management,
- Clarification of the U.S. EPA's role and responsibilities in performing field measurements in collaboration with ARCADIS personnel,
- Suggestions on quantifying and reporting the quality of the emission flux measurements, and
- Recommendations for providing more explicit operational procedures for meteorological, path length, and OP-FTIR measurements.

In response to the audit, work began on developing the EPCD Optical Remote Sensing Facility Manual (U.S. EPA, 2004). The document contains the chain of custody used in the data collection and analysis process, the role of all personnel in the field, and standard operating procedures for all instrumentation used in the field.

Additionally, a statistical analysis of a few of the data sets was done to establish the minimum number of consecutive OP-FTIR measurement loops needed to permit a valid emission flux estimate. The analysis looked at trends in methane concentrations, standard deviations, and the average CCF when a different number of loops is used for the moving average.

The statistical analysis suggests that a moving average of four loops is sufficient to provide a valid emission flux. Figure 52 shows the average methane flux and average CCF calculated using many different numbers of loops for the moving average. The figure shows that the average calculated methane flux increases slightly (as the number of loops used for the moving average increases) but begins to level off after four loops. Additionally, the figure shows

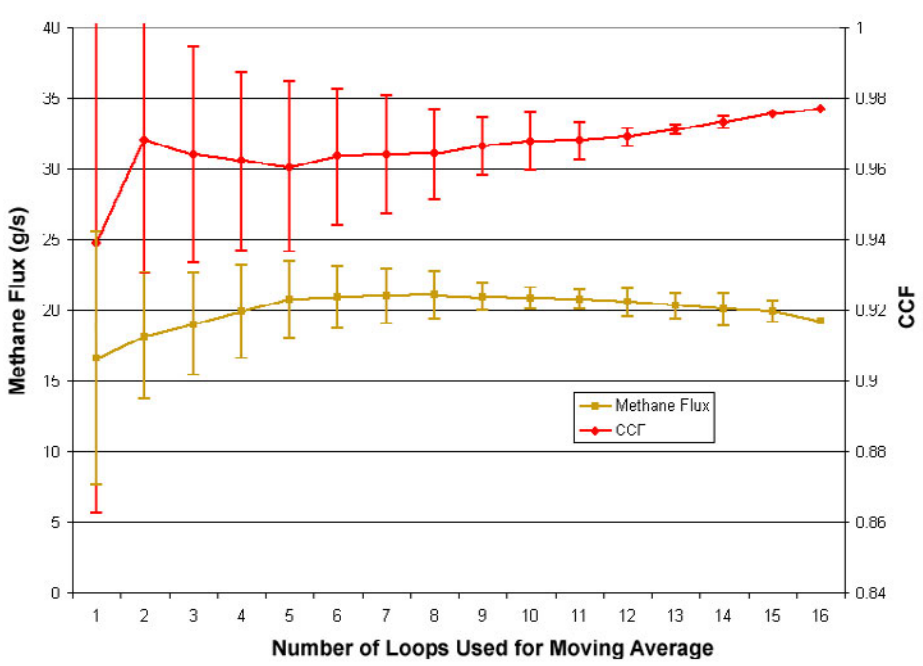

Figure 52. Distance of the Reconstructed Plume from the Average Plume, and Average CCF from the September 2002 Retrofit Area North HRPM Survey.

that the standard deviation of methane fluxes decreases rapidly after four loops. The CCF plot shows a similar trend, with values leveling off after four loops and standard deviations decreasing as well.

Figures 53 and 54 show the distance of the reconstructed methane plume from the average plume, and the average CCF for the Retrofit Area north and south HRPM surveys, respectively. Both figures show that the distance of the average plume from the reconstructed plume decreases sharply (as the number of loops used for the moving average increases) but begins to level off after four loops. Additionally, the figures show that the standard deviations decrease after four loops. The CCF plots for both figures show a similar trend, with values leveling off after four loops and standard deviations decreasing as well.

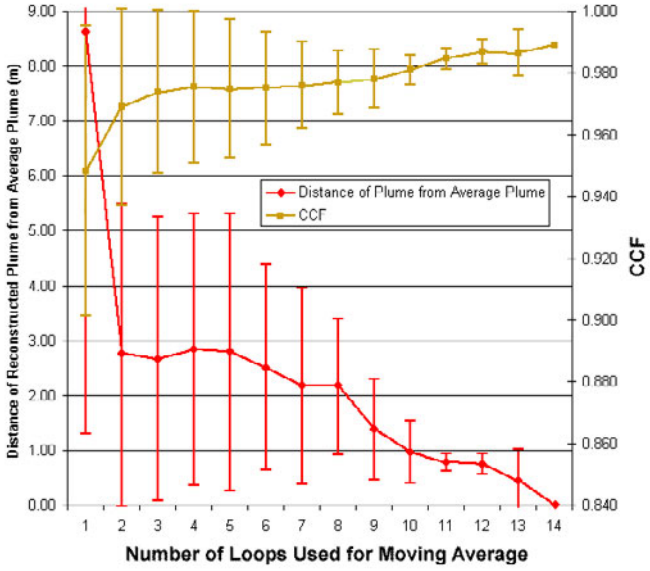

Figure 53. Distance of the Reconstructed Plume from the Average Plume, and Average CCF from the September 2002 Retrofit Area North HRPM Survey.

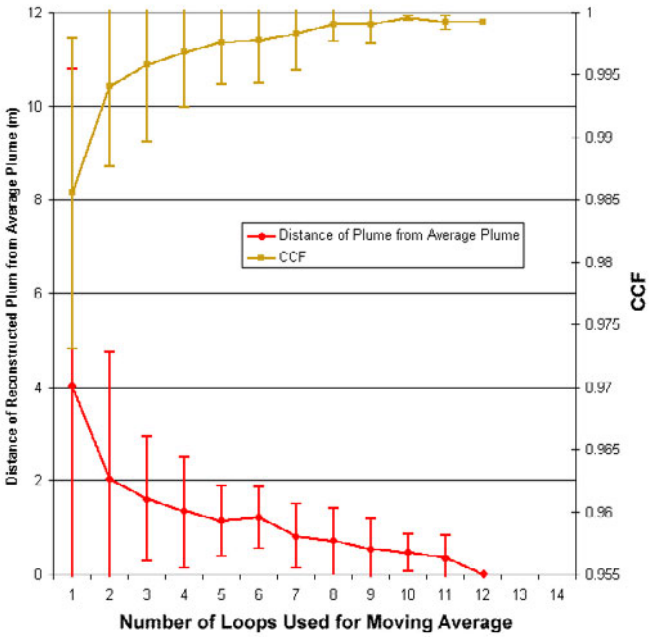

Figure 54. Distance of the Reconstructed Plume from the Average Plume, and Average CCF from the September 2002 Retrofit Area South HRPM Survey.

4.5 Internal Audit of Data Input Files

An internal audit was performed by the ARCADIS Field Team Leader on a sample of approximately 10% of the data from each field campaign. The audit investigated the accuracy of the input files used in running the RPM programs. The input files contain analyzed concentration data, mirror path lengths, and wind data. The results of this audit found no problems with the accuracy of the input files created.

4.6 Mercury Samples

Mercury samples were collected during the September 2002 and September 2003 field campaigns.

4.6.1 September 2002 Field Campaign

During the September 2002 campaign, the data from the As-Built Area were not included in calculating the average because it was not attached to the rest of the landfill gas system during this campaign. Spike recoveries for the total mercury samples were 100%. Spike recoveries for the dimethyl mercury traps were 7% for the flare and not detected for the control area landfill gas. Unsampled spike traps had recoveries from 69% to 105% and averaged 87%. Recoveries were low in the spiked traps possibly due to the presence of an unknown interfering compound either destroying or masking the detection of the dimethyl mercury. For this reason it is believed that the dimethyl mercury concentrations determined for the September 2002 field campaign are at least the levels reported herein or may be higher. Spike recoveries for the monomethyl mercury impinger solution ranged from 51% to 79% and averaged 65%. The lower recoveries may have been due to a preservation issue with the shipping.

The precision assessment was performed using data from duplicate or replicate samples and spikes (when available). Precision was expressed as %RPD for samples that were done in duplicate and as %RSD for samples performed in triplicate. Table 44 presents precision values calculated for each type of samples during the September 2002 campaign. Precision goals established in the QAPP of <20% total

mercury and <20% organic mercury were met for all samples.

Table 44. Precision Ranges for Mercury Measurements During the September 2002 Campaign.

Total mercury	0–8.1% (RPD)
Monomethylmercury	12% (RPD)
Dimethylmercury	11.8% (RPD)

Total mercury met DQI goals for accuracy and precision for all samples and was, therefore, 100% complete. Monomethyl mercury met DQI goals for accuracy and precision for all samples and was, therefore, 100% complete. Dimethyl mercury sampling met DQI goals for precision but did not meet recovery criteria due to a matrix effect. Therefore, completeness goals were not met for this method.

4.6.2 September 2003 Field Campaign

It should be noted that the average of the Control Area mercury measurements is considered to be biased high for the September 2003 campaign. The vertical gas extraction well sampled during this campaign was under positive pressure, and the data are therefore suspect. Spike recoveries for the total mercury samples were 93%. One dimethyl mercury data point from the Retrofit Area was not included because it was improperly sampled. Spike recoveries for the dimethyl mercury traps ranged from 60.3% to 101.1%. These recoveries are considerably better than the recoveries during the September 2002 campaign most probably due to decreasing the sample volume from 9.0 L to 0.5 L. However, more method development is needed to further improve spike recoveries. Unsampled spike traps had recoveries from 85% to 94% and averaged 88.8%. Spike recoveries for the dimethyl mercury impingers ranged from 85.7% to 89.5%. Unsampled spike traps had recoveries of 90.4% for each of the two spiked impingers. Spike recoveries for the monomethyl samples were 26% for the flare, 26% for the retrofit area, and ranged from ND to 28% for the control area. Spike recoveries for the unsampled impinger solution were not determined by Frontier Scientific. The low spike recoveries are most probably due to improper preparation of the spike solution by Frontier Scientific. Apparently this spike solution was made at a concentration of 0.25 ng/L instead of 1.0 ng/L.

The precision assessment was performed using data from duplicate or replicate samples and spikes (when available). Precision was expressed as %RPD for samples that were done in duplicate and as %RSD for samples performed in triplicate. Table 45 represents precision values calculated for each type of samples during the September 2003 campaign. Precision goals established in the QAPP of <20% total mercury and <20% organic mercury were met for all samples.

Table 45. Precision Ranges for Mercury Measurements During the September 2003 Campaign.

Total mercury	4.7% (RSD)
Monomethylmercury	6.5–19.8% (RSD)
Dimethylmercury	11.4% (RSD)

Total mercury met DQI goals for accuracy and precision for all samples and was, therefore, 100% complete. Monomethyl mercury met DQI goals for precision but did not meet recovery criteria due to a spiking error. Completeness goals were not met for this method. Dimethyl mercury sampling met DQI goals for accuracy and precision for all samples and was, therefore, 100% complete.

4.7 Problems and Limitations

4.7.1 September 2002 Field Campaign

During the course of the September 2002 field campaign, the project ran into some instrumentation problems and limitations that slightly hindered some aspects of the data collection process. These included geographic barriers at the site, limitations in the optical range of the OP-FTIR instrument, and scanner errors that occurred primarily in the Retrofit Area.

The optical range of the OP-FTIR instrument used in this study was approximately 200 m. The optical range is affected by many factors such as weather conditions and topography at the site. This limitation primarily affected measurements taken in the As-Built Area. As mentioned in Section 2.1.1, the VRPM survey was oriented along the southern boundary of the As-Built survey area. Because of the limitation in the optical range of the OP-FTIR instrument, it was not possible for the configuration to include the entire southern boundary of the As-Built Area. Therefore, it is possible that the calculated methane flux from the As-Built Area may be underestimating the actual flux. More advanced OP-FTIR instruments can easily have a range of 500 m in similar conditions.

Scanning errors occurred when the actual scanner (used to scan the OP-FTIR between each retroreflector in a configuration) stopped scanning. When this problem occurred,

it prevented the completion of the survey, and the scanning program had to be reprogrammed. It is unclear what caused the scanning errors, but these errors occurred most frequently in the Retrofit Area, which may receive electromagnetic energy from air traffic in the area.

4.7.2 May 2003 Field Campaign

Due to the use of improved instrumentation, the project did not encounter any instrument-related problems during the May 2003 field campaign. The only problem encountered was difficulty in establishing a true Control Area to use for this field campaign. The location of the Control Area was provided to the team by Waste Management personnel. The location and dimensions of the Control Area were not consistent with the area provided for the September 2002 field campaign.

4.7.3 September 2003 Field Campaign

Due to the continued use of improved instrumentation, the project did not encounter any instrument-related problems during the September 2003 field campaign. However, due to the continued difficulty in establishing a true Control Area for the site, U.S. EPA personnel elected not to perform data collection in the Control Area provided by Waste Management personnel.

Another difficulty encountered was access to some of the survey sub areas. The Biocover Area was inaccessible for data collection because of the presence of equipment used by WMI. This equipment blocked the access road to the Biocover Area. Due to this, and the tight schedule of the field campaign, U.S. EPA personnel elected not to perform data collection in the Biocover Area.

The Retrofit Area was only accessible by a gravel road that had been installed by Waste Management. The road was installed along the eastern edge of the area. Due to the softness of the surface in the Retrofit Area, Waste Management advised the team to only access the Retrofit Area via the gravel road. Because of this, it was not possible to set up a VRPM plane along the western boundary of the site, and only one vertical plane was used in this area.

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Appendix A
Mirror Coordinates

Table A-1. Mirror Coordinates for the VRPM Survey of the As-Built Area During the September 2002 Field Campaign.

Mirror Number	Standard Distance (m)	Horizontal Angle from North (deg)	Vertical Angle[a] (deg)
1	67.1	270	0
2	116	276	0
3	167	274	0
4	117	275	3
5	118	276	6

[a] Vertical angle is the angle from horizontal (positive values are above the horizontal, and negative values are below horizontal.)

Table A-2. Mirror Coordinates for the HRPM Survey of the As-Built Area During the September 2002 Field Campaign.

Mirror Number	Standard Distance (m)	Horizontal Angle from North (deg)
Lower Cell		
1	70.5	291
2	79.8	60
Upper Cell		
1	109	244
2	110	121

Table A-3. Mirror Coordinates for the HRPM Survey of the As-Built Area Upper Cell During the May 2003 Field Campaign.

Mirror Number	Standard Distance (m)	Horizontal Angle from North (deg)
1	64.4	332
2	47.9	303
3	106	298
4	141	290
5	192	281
6	87.9	278
7	135	272
8	181	267

Table A-4. Mirror Coordinates for the HRPM Survey of the As-Built Area Lower Cell During the May 2003 Field Campaign.

Mirror Number	Standard Distance (m)	Horizontal Angle from North (deg)
1	201	88
2	153	86
3	209	78
4	103	76
5	163	73
6	60.7	61
7	112	56
8	70.6	25

Table A-5. Mirror Coordinates for the VRPM Survey of the As-Built Area Upper Cell During the May 2003 Field Campaign.

Mirror Number	Standard Distance (m)	Horizontal Angle from North (deg)	Vertical Angle[a] (deg)
Upwind			
1	219	90	1
2	220	90	4
Downwind			
1	54.7	98	0
2	124	98	0
3	195	99	1
4	196	99	2
5	196	99	4
6	225	100	1

[a] Vertical angle is the angle from horizontal (positive values are above the horizontal, and negative values are below horizontal.)

Table A-6. Mirror Coordinates for the VRPM Survey of the As-Built Area Lower Cell During the May 2003 Field Campaign.

Mirror Number	Standard Distance (m)	Horizontal Angle from North (deg)	Vertical Angle[a] (deg)
Upwind			
1	190	86	0
2	191	86	4
Downwind			
1	64.0	86	0
2	128	89	0
3	192	90	0
4	193	89	3
5	195	89	5
6	259	87	0

[a] Vertical angle is the angle from horizontal (positive values are above the horizontal, and negative values are below horizontal.)

Table A-7. Mirror Coordinates for the HRPM Survey of the As-Built Area Upper Cell During the September 2003 Field Campaign.

Mirror Number	Standard Distance (m)	Horizontal Angle from North (deg)
1	84.6	37
2	135	58
3	190	66
4	61.8	66
5	237	72
6	121	76
7	178	78
8	238	82

Table A-8. Mirror Coordinates for the HRPM Survey of the As-Built Area Lower Cell During the September 2003 Field Campaign.

Mirror Number	Standard Distance (m)	Horizontal Angle from North (deg)
1	79.9	29
2	122	53
3	53.9	55
4	161	62
5	101	72
6	214	73
7	154	77
8	201	83

Table A-9. Mirror Coordinates for the VRPM Survey of the As-Built Area Upper Cell During the September 2003 Field Campaign.

Mirror Number	Standard Distance (m)	Horizontal Angle from North (deg)	Vertical Angle[a] (deg)
Upwind			
1	74.2	82	0
2	138	84	0
3	203	84	0
4	204	84	2
5	205	84	4
6	264	83	0
Downwind			
1	263	80	1
2	143	80	0

[a] Vertical angle is the angle from horizontal (positive values are above the horizontal, and negative values are below horizontal.)

Table A-10. Mirror Coordinates for the VRPM Survey of the As-Built Area Lower Cell During the September 2003 Field Campaign.

Mirror Number	Standard Distance (m)	Horizontal Angle from North (deg)	Vertical Angle[a] (deg)
Upwind			
1	84.4	89	0
2	200	87	0
3	201	87	3
Downwind			
1	73.9	89	0
2	138	90	0
3	203	89	0
4	204	89	2
5	204	89	4
6	252	92	0

[a] Vertical angle is the angle from horizontal (positive values are above the horizontal, and negative values are below horizontal.)

Table A-11. Mirror Coordinates for the HRPM Survey of the Retrofit Area During the September 2002 Field Campaign.

Mirror Number	Standard Distance (m)	Horizontal Angle from North (deg)
North		
1	55.5	67
2	72.2	47
3	34.3	44
4	92.7	36
5	115	30
6	56.4	25
7	84.3	18
8	108.8	13
South		
1	89.1	181
2	69.7	175
3	52.2	163
4	104	160
5	84.7	154
6	34.1	143
7	67.5	142
8	55.7	125

Table A-12. Mirror Coordinates for the VRPM Survey of the Retrofit Area During the September 2002 Field Campaign.

Mirror Number	Standard Distance (m)	Horizontal Angle from North (deg)	Vertical Angle[a] (deg)
North			
1	29.7	4	0
2	65.7	13	0
3	102	8	0
4	103	7	2
5	104	8	6
South			
1	31.8	158	0
2	58.2	172	0
3	88.7	177	0
4	91.9	176	3
5	93.1	177	7

[a] Vertical angle is the angle from horizontal (positive values are above the horizontal, and negative values are below horizontal.)

Table A-13. Mirror Coordinates for the HRPM Survey of the Retrofit Area During the May 2003 Field Campaign.

Mirror Number	Standard Distance (m)	Horizontal Angle from North (deg)
North		
1	94.4	7
2	71.8	11
3	50.1	19
4	105	25
5	87.6	34
6	37.7	48
7	74.5	48
8	60.2	72
South		
1	52.5	104
2	33.6	129
3	67.2	130
4	83.0	144
5	100.3	152
6	50.6	157
7	70.1	165
8	90.4	169

Table A-14. Mirror Coordinates for the VRPM Survey of the Retrofit Area During the May 2003 Field Campaign.

Mirror Number	Standard Distance (m)	Horizontal Angle from North (deg)	Vertical Angle[a] (deg)
Upwind			
1	183	179	0
2	184	179	3
Downwind			
1	48.6	181	0
2	78.7	185	0
3	107	182	0
4	144	183	0
5	183	181	0
6	184	181	2
7	185	181	10

[a] Vertical angle is the angle from horizontal (positive values are above the horizontal, and negative values are below horizontal.)

Table A-15. Mirror Coordinates for the HRPM Survey of the Retrofit Area During the September 2003 Field Campaign.

Mirror Number	Standard Distance (m)	Horizontal Angle from North (deg)
1	62.9	312
2	55.2	322
3	97.8	332
4	45.9	339
5	90.7	340
6	134	342
7	172	348
8	127	349
9	212	351
10	85.9	352
11	170	354
12	127	356
13	205	356
14	170	358
15	206	0

Table A-16. Mirror Coordinates for the VRPM Survey of the Retrofit Area During the September 2003 Field Campaign.

Mirror Number	Standard Distance (m)	Horizontal Angle from North (deg)	Vertical Angle[a] (deg)
1	71.6	1	0
2	114	356	0
3	164	359	0
4	209	357	0
5	210	357	1
6	210	357	3

[a] Vertical angle is the angle from horizontal (positive values are above the horizontal, and negative values are below horizontal.)

Table A-17. Mirror Coordinates for the VRPM Survey of the Biocover and Control Areas During the September 2002 Field Campaign.

Mirror Number	Standard Distance (m)	Horizontal Angle from North (deg)	Vertical Angle[a] (deg)
Upwind			
1	46.7	19	0
2	47.8	19	2
Downwind			
1	36.4	90	0
2	50.8	86	0
3	68.1	88	0
4	69.0	87	2
5	69.3	88	5

[a] Vertical angle is the angle from horizontal (positive values are above the horizontal, and negative values are below horizontal.)

Table A-18. Mirror Coordinates for the VRPM Survey of the Control Area During the May 2003 Field Campaign.

Mirror Number	Standard Distance (m)	Horizontal Angle from North (deg)	Vertical Angle[a] (deg)
Upwind			
1	46.7	19	0
2	47.8	19	2
Downwind			
1	56.6	66	0
2	36.4	90	1

[a] Vertical angle is the angle from horizontal (positive values are above the horizontal, and negative values are below horizontal.)

Table A-19. Mirror Coordinates for the VRPM Survey of the Biocover Area During the May 2003 Field Campaign.

Mirror Number	Standard Distance (m)	Horizontal Angle from North (deg)	Vertical Angle[a] (deg)
Upwind			
1	121	2	0
2	121	2	3
Downwind			
1	65.1	24	0
2	87.0	22	0
3	128	24	0
4	129	23	1
5	129	24	3
6	156	26	0

[a] Vertical angle is the angle from horizontal (positive values are above the horizontal, and negative values are below horizontal.)

Table A-20. Mirror Coordinates for the VRPM Survey of the Compost Area During the September 2002 Field Campaign.

Mirror Number	Standard Distance (m)	Horizontal Angle from North (deg)	Vertical Angle[a] (deg)
Upwind			
1	39.3	183	0
2	103	185	0
3	133	184	0
4	135	182	1
2	136	183	3
Downwind			
1	23.4	325	0
2	49.8	330	0
3	51.9	325	4
4	52.8	328	8

[a] Vertical angle is the angle from horizontal (positive values are above the horizontal, and negative values are below horizontal.)

Appendix B
Methane, Ammonia, and VOC Concentrations

Contents

Table B-1. Methane Concentrations Found During the September 2002 VRPM Survey of the As-Built Area.

Loop	Methane Concentration Detected in Path to Mirror Number (ppmv)				
	Mirror 1	Mirror 2	Mirror 3	Mirror 4	Mirror 5
1	135	123	91.9	74.9	77.3
2	194	128	90.1	65.5	71.9
3	189	159	110	50.6	60.2
4	158	128	117	35.8	65.1
5	117	134	135	56.3	58.2
6	104	102	58.7	59.2	110
7	221	148	121		73.8
8	137	211	150	62.8	35.9
9	51.3	96.7	110	132	137
10	222	186	143	94.5	71.2
11	192	168	150	96.3	71.2
12	182	162	147	104	97.1
13	203	194	164	91.1	47.9
14	101	91	143	102	91.9
15	191	188	151	100	61.4
16	219	131	161	92.8	

Table B-2. Concentrations of Methane, VOCs, and Ammonia Measured on the Mirror 1 Path During the September 2002 HRPM Survey of the As-Built Area Lower Cell.

Loop	VOC Concentration along Path to Mirror 1 (ppmv)			
	Methane	Acetylene	Ethanol	Straight-Chain HCs
1	26	0.038		
2	27			
3	21	0.031		
4	24			
5	31			
6	41			
7	32			
8	31			
9	31	0.033		
10	35			0.055
11	31			0.064
12	26	0.018		
13	21			
14	23		0.035	
15	29			
16	22		0.038	0.057
17	32			
18	23			
19	23			
20	23			
Average	28			

Table B-3. Concentrations of Methane, VOCs, and Ammonia Measured on the Mirror 2 Path During the September 2002 HRPM Survey of the As-Built Area Lower Cell.

Loop	VOC Concentration along Path to Mirror 2 (ppmv)				
	Methane	Ethanol	Ammonia	Straight-Chain HCs	Bent-Chain HCs
1	13		0.0095		
2	15		0.0086		
3	13				
4	22		0.0060		
5	22		0.0063		
6	17				
7	21		0.015		
8	21		0.012	0.022	
9	13				
10	23		0.0066		
11	19				
12	17		0.0058	0.017	
13	14	0.0075			0.014
14	11				
15	11				
16	18				
17	19	0.0074			
18	11		0.0055		
19	21		0.0063		
20	11	0.0095			
Average	17				

Table B-4. Concentrations of Methane and VOCs Measured on the Mirror 1 Path During the September 2002 HRPM Survey of the As-Built Area Upper Cell.

Loop	VOC Concentration along Path to Mirror 1 (ppmv)				
	Methane	Ethylene	Acetylene	Ethanol	MTBE[a]
1	24		0.0098		
2	18	0.0082	0.028		
3	27	0.0082	0.024		
4	25				
5	32		0.0067		
6	19				
7	29				
8	33				
9	37				
10	28			0.0055	
11	29				
12	23				
13	29				
14	19			0.012	
15	26			0.015	
16	25			0.015	
17	31			0.021	
18	27			0.020	0.0047
19	25			0.022	
20	28	0.0082	0.019	0.025	
Average	27				

[a] MTBE = methyl tert-butyl ether.

Table B-5. Concentrations of Methane, VOCs, and Ammonia Measured on the Mirror 2 Path During the September 2002 HRPM Survey of the As-Built Area Upper Cell.

Loop	Concentration of Substance along Path to Mirror 5 (ppmv)				
	Methane	Ethylene	Acetylene	Ethanol	Ammonia
1	26		0.0038		
2	21		0.00077		
3	27	0.0057	0.011		
4	24				
5	28				
6	15		0.0054	0.011	
7	39	0.0087	0.022	0.0078	
8	31		0.0036		
9	24		0.0041		
10	31				
11	16	0.0053	0.017		
12	13				
13	12				0.0038
14	22		0.0049		0.0035
15	35	0.0092	0.020	0.025	
16	24		0.011		
17	22				
18	27	0.0079	0.017		
19	33		0.012		
20	36		0.0072	0.011	0.0023
Average	25				

Table B-6. Concentrations of Ammonia and VOCs Measured During Run 1 of the September 2002 VRPM Survey of the As-Built Area.

Loop	Concentration of Substance in Mirrors 1 to 5 (ppmv)														
	Ammonia					Straight-Chain Hydrocarbons					Bent-Chain Hydrocarbons				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
1										0.13		0.39			0.41
2	0.004					0.56					0.222	1.16			0.18
3	0.004		0.005						3.69						
4	0.004		0.007				0.98		2.80						
5									2.64						
6									2.95						
7															
8									2.01						

Table B-7. Concentrations of Ammonia and VOCs Measured During Run 2 of the September 2002 VRPM Survey of the As-Built Area.

Loop	Concentration of Substance in Mirrors 1 to 5 (ppmv)									
	Straight-Chain Hydrocarbons					Bent-Chain Hydrocarbons				
	1	2	3	4	5	1	2	3	4	5
1										
2		2.03								
3										
4							0.728			
5										
6										
7							2.03			
8										

Table B-8. Methane Concentrations Found During the May 2003 HRPM Survey of the As-Built Area Upper Cell.

Loop	Methane Concentration for Path to Mirror Number (ppmv)							
	Mirror 1	Mirror 2	Mirror 3	Mirror 4	Mirror 5	Mirror 6	Mirror 7	Mirror 8
1	34	30	31	35	26	31	15	16
2	35	27	37	44	36	33	28	24
3	42	30	45	44	23	16	15	19
4	50	41	29	28	33	21	21	27
5	94	56	45	40	27	40	26	22
6	61	28	51	67	81	80	62	35
7	45	26	55	52	34	39	27	13
8	19	21	24	28	21	34	21	16
9	26	22	14	18	15	15	25	15
10	36	29	20	19	14	19	13	13
11	44	30	25	34	18	19	28	12
12	42	31	30	20	25	22	19	15
13	67	52	31	22	27	74	68	77
14	67	81	38	42	46	50	61	51
15	66	82	50	38	61	80	82	95
16	46	120	68	75	68	129	97	117
17	68	153	73	62	46	96	62	43
18	107	71	42	26	23	65	35	23
19	24	23	13	11	13	97	43	22
20	25	49	17	24	28	44	25	64
21	23	103	52	51	47	77	65	77
22	60	84	62	48	38	112	91	49

Table B-9. Concentrations of Ammonia and VOCs Measured on the Mirror 5 Path During the May 2003 HRPM Survey of the As-Built Area Upper Cell.

Loop	Concentration of Substance along Path to Mirror 5 (ppmv)		
	Ammonia	Methanol	Ethanol
1			0.007
2		0.025	0.014
3		0.020	0.011
4		0.015	
5			
6		0.034	0.022
7		0.010	
8			
9	0.009		0.021
10		0.021	0.019
11		0.029	0.022
12	0.004	0.042	0.030
13	0.006	0.029	0.024
14			0.007
15	0.005		
16	0.004		
17			0.011
18	0.005	0.017	0.015
19		0.023	0.018
20	0.004	0.024	0.021
21		0.016	0.014
22			

Table B-10. Concentrations of Ammonia and VOCs Measured on the Mirror 4 Path During the May 2003 HRPM Survey of the As-Built Area Slope.

Loop	Concentration of Substance along Path to Mirror 4 (ppmv)		
	Ammonia	Methanol	Ethanol
1		0.017	0.126
2	0.018	0.022	
3			0.199
4			
5	0.006		
6			
7	0.006		
8	0.010		
9	0.010		
10	0.014		
11	0.010	0.011	
12	0.013		
13	0.017	0.013	0.041
14	0.010	0.014	0.049
15	0.007	0.017	0.095
16			0.041
17	0.005	0.012	0.029
18	0.014	0.016	
19			
20	0.010		0.052
21	0.011	0.012	0.033
22	0.019	0.013	0.028

Table B-11. Methane Concentrations Found During the May 2003 HRPM Survey of the As-Built Area Lower Cell.

Loop	Methane Concentration for Path to Mirror Number (ppmv)							
	Mirror 1	Mirror 2	Mirror 3	Mirror 4	Mirror 5	Mirror 6	Mirror 7	Mirror 8
1	55	53	81	85	65	21	164	47
2	52	44	87	68	59	38	146	45
3	41	50	69	52	54	34	116	49
4	45	53	58	71	77	36	130	42
5	42	43	56	61	61	42	199	52
6	47	72	53	79	72	43	157	43
7	49	52	62	62	65	37	142	42
8	52	43	71	60	60	35	172	43
9	49	43	67	63	75	48	116	49
10	50	53	86	78	71	58	143	66
11	42	45	72	65	83	51	148	49
12	45	44	78	73	70	49	146	49
13	60	66	86	85	67	45	167	52
14	47	44	80	75	86	51	134	58
15	55	58	55	70	103	34	179	50
16	35	17	24	40	77	15	46	56
17	57	12	48	29	48	27	125	47
18	53	41	56	28	42	31	76	47
19	22	19	39	34	60	26	69	45
20	13	37	46	38	59	33	110	46
21	19	12	26	27	54	41	82	55
22	24	26	50	29	41	27	36	36
23	25	16	27	35	57	43	56	44
24	26	24	41	30	48	38	86	58
25	12	16	34	52	51	16	115	43
26	31	51	61	63	55	16	106	63
27	51	28	56	29	40	33	37	49

Table B-12. Methane Concentrations Found During the May 2003 VRPM Survey of the As-Built Area Upper Cell.

Loop	Methane Concentration for Path to Mirror Number (ppmv)					
	Mirror 1	Mirror 2	Mirror 3	Mirror 4	Mirror 5	Mirror 6
1	14	14	22	14	19	17
2	10	19	21	23	15	22
3	22	13	8	9	14	24
4	33	35	33	25	11	12
5	4	5	6	7	7	11
6	29	34	25	22	23	24
7	15	16	16	12	15	15
8	6	16	21	7	10	15
9	31	31	19	17	10	7
10	20	21	18	11	16	25
11	12	21	19	14	10	16
12	21	22	32	23	9	21
13	29	26	22	25	21	29
14	26	19	6	7	7	10
15	6	6	6	6	10	23
16	14	11	8	5	10	12

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Table B-12 (concluded). Methane Concentrations Found During the May 2003 VRPM Survey of the As-Built Area Upper Cell.

Loop	Methane Concentration for Path to Mirror Number (ppmv)					
	Mirror 1	Mirror 2	Mirror 3	Mirror 4	Mirror 5	Mirror 6
17	14	19	20	21	12	19
18	37	23	15	11	6	8
19	14	9	10	12	7	19
20	11	8	15	13	5	8
21	7	9	16	20	9	16
22	8	13	14	19	10	13
23	8	5	6	10	8	12
24	30	21	17	9	6	16
25	12	12	13	7	7	19
26	16	18	29	14	16	16
27	8	15	21	29	17	26
28	27	28	15	11	6	10
29	18	14	12	6	3	7
30	23	17	10	5	7	19

Table B-13. Concentrations of Ammonia and VOCs Measured During the May 2003 VRPM Survey of the As-Built Area Upper Cell.

Loop	Concentration of Substance (ppmv)		
	Ammonia	Methanol	Ethanol
1			0.038
2		0.022	0.056
3		0.010	0.030
4		0.017	0.026
5	0.006	0.020	0.050
6	0.011	0.030	0.092
7	0.018	0.017	0.067
8	0.081	0.049	0.761
9			0.048
10	0.015	0.017	0.055
11	0.026	0.036	0.206
12	0.007	0.030	0.118
13			0.010
14			
15	0.019	0.099	0.196
16	0.013	0.136	0.154
17	0.008	0.062	0.115
18		0.036	0.068
19		0.027	0.061
20	0.012	0.048	0.121
21			
22	0.018	0.013	0.058
23	0.023	0.019	0.077
24	0.015		0.072
25	0.014		

continued

Table B-13 (concluded). Concentrations of Ammonia and VOCs Measured During the May 2003 VRPM Survey of the As-Built Area Upper Cell.

Loop	Concentration of Substance (ppmv)		
	Ammonia	Methanol	Ethanol
26	0.012	0.024	0.119
27			
28			
29			
30	0.027	0.021	0.062
31	0.031	0.031	0.231
32	0.013	0.013	0.048
33	0.011	0.026	0.067
34	0.008	0.014	0.052
35			
36			
37	0.099	0.031	0.139
38	0.008		
39	0.029	0.032	0.123
40	0.010		
41	0.029	0.032	0.173
42	0.008		
43	0.017	0.016	0.081
44	0.024		0.096
45	0.017		
46	0.018		0.055
47	0.028	0.016	0.021
48	0.008		0.014
49	0.021		0.054
50	0.025	0.018	0.088

Table B-14. Methane Concentrations Found During the May 2003 VRPM Survey of the As-Built Area Lower Cell.

Loop	Methane Concentration for Path to Mirror Number (ppmv)					
	Mirror 1	Mirror 2	Mirror 3	Mirror 4	Mirror 5	Mirror 6
1	33	34	28	19	12	83
2	33	35	19	28	18	63
3	12	16	19	11	9	59
4	41	39	29	13	9	48
5	26	39	37	23	11	51
6	33	35	43	17	10	66
7	42	35	35	17	10	64
8	34	22	23	16	8	49
9	35	38	32	20	9	36
10	40	35	43	28	13	41
11	45	28	38	21	12	61
12	46	37	40	20	15	58
13	37	38	33	11	12	63
14	34	39	34	14	10	57
15	48	46	36	17	13	48
16	39	44	31	28	22	94
17	36	41	36	19	20	53
18	45	47	41	18	11	53
19	44	38	32	15	16	80
20	41	38	34	20	8	59
21	40	36	27	15	9	80
22	48	44	41	24	19	58
23	66	62	62	28	18	84
24	42	40	35	23	12	70
25	65	59	54	27	16	68
26	58	69	46	24	17	61
27	59	59	45	17	12	85
28	57	70	57	17	9	72
29	49	39	39	18	13	49
30	36	33	38	13	11	63
31	36	37	35	14	10	64
32	37	35	45	16	10	84
33	37	41	42	18	12	60
34	51	41	33	12	12	59
35	59	50	49	20	13	75
36	52	47	47	19	15	69

Table B-15. Methane Concentrations Found During the September 2003 HRPM Survey of the As-Built Area Upper Cell.

Loop	Methane Concentration for Path to Mirror Number (ppmv)							
	Mirror 1	Mirror 2	Mirror 3	Mirror 4	Mirror 5	Mirror 6	Mirror 7	Mirror 8
1	111	120	93	98	76	88	59	41
2	66	91	88	55	45	77	59	54
3	66	91	84	79	56	81	76	53
4	94	86	85	69	78	91	82	66
5	83	81	105	57	86	87	97	75
6	82	111	118	72	71	93	82	55
7	63	104	63	105	60	80	66	59
8	73	56	53	71	58	79	68	55
9	73	79	77	55	79	81	83	57
10	79	92	87	77	77	76	74	67
11	67	74	103	73	101	80	78	66
12	63	95	83	52	55	81	54	49
13	57	78	79	51	56	72	73	46
14	67	98	70	60	68	73	65	51
15	38	54	67	50	54	59	64	44
16	51	60	66	29	62	83	57	59
17	43	63	59	24	66	76	52	34
18	51	57	77	23	36	46	32	22
19	46	77	46	26	40	74	50	30
20	54	49	64	19	16	70	48	24
21	22	42	38	29	37	59	40	31
22	23	37	37	18	41	69	47	33
23	31	45	47	38	49	61	42	36
24	55	41	67	45	23	74	51	33
25	72	34	55	29	21	59	40	38
26	47	44	50	23	41	66	45	29
27	51	48	36	29	27	60	41	34
28	38	59	40	20	25	57	39	18
29	21	26	39	18	24	74	51	22
30	28	81	48	30	27	63	43	22

Table B-16. Methane Concentrations Found During the September 2003 HRPM Survey of the As-Built Area Lower Cell.

Loop	Methane Concentration for Path to Mirror Number (ppmv)							
	Mirror 1	Mirror 2	Mirror 3	Mirror 4	Mirror 5	Mirror 6	Mirror 7	Mirror 8
1	58	46	94	40	65	44	65	47
2	41	47	26	46	49	48	46	47
3	33	22	24	44	42	50	51	60
4	37	56	80	47	50	47	56	62
5	94	59	77	52	84	54	49	71
6	44	37	58	56	48	53	48	81
7	51	31	78	64	53	48	58	65
8	63	48	67	56	65	51	54	54
9	67	52	77	60	38	47	63	65
10	42	51	46	56	69	53	53	73
11	89	43	74	61	79	51	54	65
12	29	40	85	60	63	54	60	69
13	44	56	68	56	43	50	60	75
14	54	40	76	63	63	44	69	46
15	53	52	45	60	100	80	61	66

Table B-17. Methane Concentrations Found During the September 2003 VRPM Survey of the As-Built Area Upper Cell.

Loop	Methane Concentration for Path to Mirror Number (ppmv)					
	Mirror 1	Mirror 2	Mirror 3	Mirror 4	Mirror 5	Mirror 6
1	13	21	28	33	14	33
2	22	19	21	21	19	44
3	38	44	74	42	24	33
4	59	72	47	42	22	30
5	42	47	36	24	21	21
6	11	14	29	34	5	11
7	21	53	48	23	14	30
8	32	25	20	13	6	26
9	52	45	39	21	13	40
10	45	56	56	33	13	47
11	47	45	44	19	9	25
12	56	85	76	40	28	42
13	24	34	53	29	12	37
14	61	57	42	23	13	48
15	46	57	46	24	13	37
16	55	50	37	15	19	47
17	26	34	41	43	39	40
18	32	43	27	13	15	34
19	32	48	35	21	15	38
20	26	40	47	20	9	45
21	56	46	46	36	18	53
22	44	36	58	25	21	52
23	38	74	62	46	20	52
24	34	77	65	43	20	44
25	53	88	73	42	23	49
26	52	77	65	35	22	61

Table B-18. Methane Concentrations Found During the September 2003 VRPM Survey of the As-Built Area Lower Cell.

Loop	Methane Concentration for Path to Mirror Number (ppmv)					
	Mirror 1	Mirror 2	Mirror 3	Mirror 4	Mirror 5	Mirror 6
1	46	36	26	22	23	50
2	35	55	49	34	20	37
3	25	32	28	26	14	34
4	45	24	22	29	15	32
5	27	46	28	37	24	38
6	45	42	42	45	25	61
7	62	50	24	32	30	37
8	29	44	33	35	48	53
9	50	57	37	25	17	37
10	52	56	40	32	16	46
11	47	41	38	29	15	34
12	54	50	38	29	20	39
13	45	51	43	27	24	42
14	51	66	49	42	27	50
15	65	50	37	36	29	44
16	57	63	37	28	16	36

continued

Table B-18 (concluded). Methane Concentrations Found During the September 2003 VRPM Survey of the As-Built Area Lower Cell.

Loop	Methane Concentration for Path to Mirror Number (ppmv)					
	Mirror 1	Mirror 2	Mirror 3	Mirror 4	Mirror 5	Mirror 6
17	45	58	35	20	28	51
18	46	37	35	30	18	49
19	70	56	24	20	28	47
20	39	17	31	27	22	35
21	30	29	27	23	20	32
22	24	32	18	14	16	39
23	53	34	21	29	22	30
24	33	29	22	17	14	29
25	23	39	25	19	13	32
26	23	29	27	18	16	28
27	38	18	22	24	23	34
28	38	35	28	32	18	30
29	33	34	18	15	23	30
30	23	25	17	15	13	22
31	20	28	29	26	23	32
32	26	36	27	19	20	25
33	27	38	28	26	30	42
34	35	50	34	34	29	27
35	27	45	47	31	31	26
36	23	31	31	20	21	19
37	18	21	41	38	20	19
38	13	19	14	9	8	22
39	21	24	17	18	12	28
40	22	32	30	24	25	23
41	40	56	36	27	13	30
42	30	31	22	18	13	20
43	31	34	16	15	19	34
44	35	36	23	17	18	31
45	34	41	22	15	17	28
46	34	42	27	12	10	24
47	32	33	16	14	11	14
48	17	16	12	11	9	17
49	17	27	27	22	11	30
50	50	43	24	21	18	25

Table B-19a. Methane Concentrations Found During the September 2002 HRPM Survey of the Retrofit Area's Northern Part.

Loop	Methane Concentration for Path to Mirror Number (ppmv)							
	Mirror 1	Mirror 2	Mirror 3	Mirror 4	Mirror 5	Mirror 6	Mirror 7	Mirror 8
1	26	21	53	49	48	69	58	63
2	31	36	36	26	26	52	63	30
3	24	29	42	43	61	85	51	42
4	25	28	53	54	35	78	81	50
5	19	29	48	40	42	58	49	29
6	34	38	55	40	50	47	48	
7	16	34	41	39	29	39	59	26
8	18	27	41	31	43	49	43	
9	495	529	482	538	607	577	549	558
10	496	533	439	592	880	526	547	604
11	494	564	484	635	924	567	561	732
12	492	563	486	624	771	564	534	685
13	4	25	10	20	24	29	69	32
14	16	27	46	31	56	54	50	52
15	26	34	22	26	25	37	61	56
16	28	26	12	17	37	53	67	46

Table B-19b. Methane Concentrations Found During the September 2002 HRPM Survey of the Retrofit Area's Southern Part.

Loop	Methane Concentration for Path to Mirror Number (ppmv)							
	Mirror 1	Mirror 2	Mirror 3	Mirror 4	Mirror 5	Mirror 6	Mirror 7	Mirror 8
1	32	38	53	49	52	66	45	33
2	26	47	70	60	52	39	27	28
3	51	44	74	49	31	35	39	29
4	34	53	92	67	44	51	31	53
5	45	48	49	63	44	35	31	37
6	33	46	62	45	32	35	22	50
7	34	52	47	37	37	31	39	18
8	36	46	81	38	37	41	42	41
9	499	505	538	558	549	499	524	491
10	509	514	523	560	526	479	519	483
11	506	511	537	558	538	490	520	499
12	502	509	520	551	531	494	524	485
13	34	46	54	35	42	26	34	34
14	31	49	42	36	29	16	33	26
15	30	45	59	37	38	19	33	46
16	25	42	38	32	31	23	37	29

Table B-20a. Methane Concentrations Found During the September 2002 VRPM Survey of the Retrofit Area's Northern Part.

Loop	Methane Concentration for Path to Mirror Number (ppmv)				
	Mirror 1	Mirror 2	Mirror 3	Mirror 4	Mirror 5
1	45	134	78	30	24
2	98	104	60	24	14
3	69	115	58	16	9
4	54	106	60	19	19
5	77	110	66	20	9
6	98	93	67	15	N/A[a]
7	43	N/A	N/A	N/A	N/A
8	72	N/A	N/A	N/A	N/A
9	77	N/A	N/A	N/A	N/A
10	76	N/A	N/A	N/A	N/A
11	116	N/A	N/A	N/A	N/A
12	144	N/A	N/A	N/A	N/A
13	131	N/A	N/A	N/A	N/A
14	67	N/A	N/A	N/A	N/A
15	57	N/A	N/A	N/A	N/A

[a] N/A = not available.

Table B-20b. Methane Concentrations Found During the September 2002 VRPM Survey of the Retrofit Area's Southern Part.

Loop	Methane Concentration for Path to Mirror Number (ppmv)				
	Mirror 1	Mirror 2	Mirror 3	Mirror 4	Mirror 5
1	52	55	42	24	23
2	26	62	50	N/A[a]	N/A
3	56	78	48	20	N/A
4	53	69	50	20	N/A
5	22	24	17	19	N/A
6	76	68	42	N/A	N/A
7	75	65	41	27	19
8	60	60	52	28	17
9	53	71	34	31	14
10	31	73	52	24	N/A
11	81	72	49	24	12
12	48	63	27	23	30
13	91	67	53	28	20
14	46	57	49	N/A	N/A
15	37	68	33	32	33
16	27	66	52	26	23
17	51	68	53	22	12
18	35	55	43	30	31
19	37	76	66	29	28
20	78	66	51	25	15
21	31	73	53	20	16
22	27	34	29	32	13
23	33	74	49	18	14
24	29	68	55	15	16
25	52	72	60	27	13

continued

Table B-20b (concluded). Methane Concentrations Found During the September 2002 VRPM Survey of the Retrofit Area's Southern Part.

Loop	Methane Concentration for Path to Mirror Number (ppmv)				
	Mirror 1	Mirror 2	Mirror 3	Mirror 4	Mirror 5
26	103	62	57	24	24
27	N/A	N/A	36	26	20
28	41	47	27	33	18
29	56	77	N/A	N/A	N/A
30	42	70	65	25	22
31	41	61	42	23	20
32	60	55	28	22	26

[a] N/A = not available.

Table B-21a. Methane Concentrations Found During the May 2003 HRPM Survey of the Retrofit Area's Northern Part.

Loop	Methane Concentration for Path to Mirror Number (ppmv)							
	Mirror 1	Mirror 2	Mirror 3	Mirror 4	Mirror 5	Mirror 6	Mirror 7	Mirror 8
1	20	27	37	36	44	12	23	13
2	22	26	25	33	43	6	19	13
3	26	28	18	29	44	12	24	8
4	16	19	26	23	32	10	14	5
5	16	20	29	27	35	12	15	7
6	17	23	20	26	35	11	18	9
7	15	21	20	21	31	4	3	5
8	14	19	9	27	39	12	5	11
9	16	17	9	32	21	8	5	4
10	16	24	17	26	35	5	4	6
11	19	22	6	29	40	5	7	7
12	20	27	10	36	46	6	19	12
13	20	22	6	38	37	4	8	9
14	17	22	20	25	32	9	17	10
15	18	24	25	25	36	8	8	4
16	16	23	20	24	25	5	3	4

Table B-21b. Methane Concentrations Found During the May 2003 HRPM Survey of the Retrofit Area's Southern Part.

Loop	Methane Concentration for Path to Mirror Number (ppmv)							
	Mirror 1	Mirror 2	Mirror 3	Mirror 4	Mirror 5	Mirror 6	Mirror 7	Mirror 8
1	15	13	14	17	16	16	13	16
2	10	17	17	16	19	12	16	24
3	17	14	13	17	15	18	15	20
4	15	10	15	16	20	15	14	22
5	12	12	21	21	20	18	20	22
6	12	16	22	21	20	20	13	17
7	20	12	16	18	17	14	13	14
8	9	11	15	18	21	19	12	17
9	10	9	16	18	16	16	13	17
10	20	13	16	18	19	18	20	24

continued

Table B-21b (concluded). Methane Concentrations Found During the May 2003 HRPM Survey of the Retrofit Area's Southern Part.

Loop	Methane Concentration for Path to Mirror Number (ppmv)							
	Mirror 1	Mirror 2	Mirror 3	Mirror 4	Mirror 5	Mirror 6	Mirror 7	Mirror 8
11	19	8	13	17	17	17	13	18
12	18	10	14	18	23	22	17	20
13	15	10	22	28	30	22	19	24
14	7	11	16	47	28	21	18	21
15	12	13	19	15	17	14	14	25
16	20	12	19	22	29	30	19	21
17	23	16	17	20	23	18	17	18
18	12	11	14	13	20	22	15	17
19	8	11	20	20	22	19	17	19
20	15	13	10	20	21	18	17	22
21	10	10	19	23	19	20	20	23
22	14	18	20	19	22	15	18	20
23	12	14	16	28	23	24	25	21
24	17	14	12	22	16	14	9	21
25	7	23	28	24	21	16	14	19
26	13	8	18	30	27	24	19	21
27	15	12	15	14	16	15	25	21
28	12	11	16	18	24	18	15	30
29	20	7	14	20	22	18	13	15
30	19	16	19	18	19	17	15	22

Table B-22. Methane Concentrations Found During the May 2003 VRPM Survey of the Retrofit Area.

Loop	Methane Concentration for Path to Mirror Number (ppmv)						
	Mirror 1	Mirror 2	Mirror 3	Mirror 4	Mirror 5	Mirror 6	Mirror 7
1	29	30	34	28	26	11	10
2	51	38	30	27	23	11	6
3	27	16	24	21	28	9	5
4	29	24	17	21	23	8	5
5	28	20	27	22	25	10	9
6	34	26	30	26	26	10	6
7	33	32	31	27	24	11	6
8	36	31	32	21	32	10	5
9	25	20	22	19	17	8	5
10	26	32	27	20	21	7	5
11	22	19	21	21	18	8	4
12	25	25	25	14	24	9	4
13	27	23	24	20	17	8	5
14	23	19	22	20	20	8	4
15	29	13	21	20	16	7	5
16	27	18	23	18	20	8	4
17	28	22	26	18	17	7	5
18	34	23	25	23	21	7	4
19	27	16	22	16	18	7	4
20	35	17	22	21	21	7	5
21	38	14	20	18	15	7	4

continued

Table B-22 (concluded). Methane Concentrations Found During the May 2003 VRPM Survey of the Retrofit Area.

Loop	Methane Concentration for Path to Mirror Number (ppmv)						
	Mirror 1	Mirror 2	Mirror 3	Mirror 4	Mirror 5	Mirror 6	Mirror 7
22	24	15	19	18	19	7	4
23	29	27	21	20	22	8	5
24	28	35	32	26	22	10	7
25	31	26	23	23	29	17	13
26	52	36	37	37	30	12	8
27	30	34	30	31	36	19	9
28	35	36	35	31	34	13	6
29	42	47	29	37	34	16	8
30	39	24	30	29	27	10	5
31	43	25	36	25	22	8	4
32	33	15	24	20	19	6	4
33	22	10	18	16	14	6	3
34	22	13	19	16	16	7	4

Table B-23. Methane Concentrations Found During the September 2003 HRPM Survey of the Retrofit Area.

Loop	Methane Concentration for Path to Mirror Number (ppmv)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	9	16	22	17	11	28	21	29	18	16	16	20	11	14	15
2	17	13	20	8	14	25	14	22	14	23	15	18	14	13	14
3	7	8	23	6	20	20	14	26	17	14	10	15	16	15	14
4	19	13	22	15	16	17	20	21	18	18	14	20	12	12	15
5	10	8	18	8	14	19	20	28	17	20	16	15	14	16	15
6	23	7	20	6	14	20	14	21	14	16	16	16	13	14	14
7	8	7	16	6	15	22	18	27	11	16	15	12	13	11	14
8	13	16	17	6	23	24	19	24	13	17	20	20	10	10	10
9	18	15	20	11	13	16	13	19	13	18	12	14	12	11	13
10	11	22	12	14	14	20	15	27	15	16	15	15	12	13	12
11	29	12	19	13	15	22	16	27	15	18	16	17	14	17	18
12	15	25	17	20	20	24	18	28	18	20	21	18	13	11	12
13	18	10	16	11	15	19	16	28	16	17	14	15	13	14	14
14	22	27	14	27	15	20	19	23	14	21	15	16	14	15	13
15	26	21	17	19	17	22	16	25	18	17	17	16	14	11	13
16	20	18	16	16	19	25	19	25	15	15	12	17	11	13	13

Table B-24. Methane Concentrations Found During the September 2003 VRPM Survey of the Retrofit Area.

Loop	Methane Concentration for Path to Mirror Number (ppmv)					
	Mirror 1	Mirror 2	Mirror 3	Mirror 4	Mirror 5	Mirror 6
1	15	15	13	15	8	8
2	17	15	14	13	7	6
3	18	14	14	11	8	7
4	12	13	14	11	9	5
5	18	14	14	13	9	5
6	12	13	14	15	9	5
7	13	18	16	12	7	5
8	11	14	13	11	7	5
9	12	15	16	13	9	7
10	19	9	15	11	10	7
11	13	12	13	12	8	7
12	11	12	13	13	7	5
13	7	13	13	16	8	6
14	11	13	11	13	9	5
15	6	10	11	10	7	8
16	6	17	10	11	10	7
17	13	12	17	15	8	5
18	7	14	13	12	8	5
19	13	12	8	11	8	7
20	9	11	12	11	7	6
21	15	14	13	14	8	6
22	8	13	13	12	8	5
23	6	10	10	11	6	5
24	8	10	12	15	8	6
25	8	9	10	7	8	6
26	11	12	8	10	6	6
27	6	10	8	11	6	5
28	7	15	12	11	7	5
29	13	17	14	13	7	6
30	13	13	13	12	12	6
31	10	11	11	13	7	5
32	11	12	13	11	8	6
33	7	10	13	14	7	8
34	7	13	17	12	8	7
35	9	10	14	13	7	6
36	12	18	12	14	7	5
37	8	12	13	13	8	6
38	14	13	12	10	10	6
39	18	15	19	15	8	5
40	16	10	8	13	9	6

Table B-25. Methane Concentrations Found During the September 2002 VRPM Survey of the Control Area.

Loop	Methane Concentration for Path to Mirror Number (ppmv)			
	Mirror 2	Mirror 3	Mirror 4	Mirror 5
1	125	102	77.2	77.1
2	131	87.6	82.4	68.6
3	132	107	67.4	67.5
4	127	122	77.6	66.6
5	136	87.2	46.7	N/A[a]
6	83.7	100	75.3	75.0
7	77.3	92.1	87.3	78.1
8	88.2	137	37.1	27.5
9	56.5	72.5	27.9	28.1
10	54.3	54.3	39.0	24.9
11	119	82.8	60.2	24.9
12	73.5	77.0	51.0	46.6
13	66.8	67.7	45.5	36.6
14	61.5	106	52.7	61.9
15	N/A	N/A	N/A	N/A
16	83.5	90.2	53.3	53.0
17	94.9	78.6	50.9	35.5
18	80.0	73.1	N/A	N/A
19	66.8	67.3	71.2	46.8
20	76.5	63.0	56.2	37.8
21	82.3	86.6	62.3	42.5
22	66.8	91.8	45.0	41.9
23	62.5	83.2	41.8	38.2
24	67.6	79.0	46.4	42.6
25	56.0	80.6	63.3	33.2
26	77.7	68.4	51.6	28.0
27	61.5	65.9	37.0	39.9
28	50.3	60.7	42.2	41.6
29	80.7	98.6	54.1	39.7
30	56.8	75.8	35.8	26.9

[a] N/A = not available.

Table B-26. Concentrations of Ammonia and VOCs Found During the September 2002 VRPM Survey of the Control Area Run 1.

Compound	Loop	Ammonia and VOC Concentration for Path to Mirror Number (ppmv)				
		Mirror 1	Mirror 2	Mirror 3	Mirror 4	Mirror 5
TFM[a]	1	0.006				
	2					
	3			0.004		
	4					
	5					
CFM[b]	1					
	2					
	3					
	4					0.023
	5	0.035	0.043	0.038		

continued

Table B-26 (concluded). Concentrations of Ammonia and VOCs Found During the September 2002 VRPM Survey of the Control Area Run 1.

Compound	Loop	Ammonia and VOC Concentration for Path to Mirror Number (ppmv)				
		Mirror 1	Mirror 2	Mirror 3	Mirror 4	Mirror 5
Ethanol	1	0.106		0.098	0.063	0.044
	2			0.193	0.134	0.026
	3				0.097	
	4			0.105	0.034	
	5			0.054		
Ammonia	1	0.012				
	2	0.007			0.015	0.017
	3	0.023	0.021	0.027	0.034	0.029
	4	0.028	0.027	0.029	0.025	0.024
	5	0.026	0.019	0.024	0.029	

[a] TFM = trichloromethane.
[b] CFM = chlorodifluoromethane.

Table B-27. Concentrations of Ammonia and VOCs Found During the September 2002 VRPM Survey of the Control Area Run 2.

Compound	Loop	Ammonia and VOC Concentration for Path to Mirror Number (ppmv)				
		Mirror 1	Mirror 2	Mirror 3	Mirror 4	Mirror 5
CFM[a]	1	0.029		0.033	0.022	0.038
	2	0.031		0.037	0.021	
	3					
	4					
	5					
	6					
Ethanol	1				0.022	
	2				0.022	0.119
	3					0.076
	4					
	5					
	6					0.085
Ammonia	1	0.032	0.028	0.025	0.025	0.023
	2	0.021	0.018	0.018	0.022	0.019
	3	0.017	0.019	0.009		
	4					
	5					
	6					

[a] CFM = chlorodifluoromethane.

Table B-28. Methane Concentrations Found During the May 2003 VRPM Survey of the Control Area.

Loop	Methane Concentration for Path to Mirror Number (ppmv)					
	Mirror 1	Mirror 2	Mirror 3	Mirror 4	Mirror 5	Mirror 6
1	29	21	17	21	17	24
2	24	27	27	33	22	29
3	17	39	33	16	25	21
4	26	26	29	22	20	20
5	34	22	33	26	23	23
6	33	26	28	21	23	16
7	29	35	27	20	26	26
8	27	36	22	22	28	24
9	18	40	26	22	17	10
10	15	31	22	21	23	13
11	14	27	26	21	20	10
12	15	13	14	12	13	10
13	23	26	11	10	9	8
14	12	10	8	10	8	5
15	8	7	8	10	10	7
16	9	6	7	7	7	7
17	9	9	7	8	7	6
18	12	14	11	7	8	6
19	9	8	10	10	8	10
20	9	7	7	6	6	5
21	7	7	8	10	8	4
22	11	11	11	6	6	9
23	10	12	12	11	8	8
24	10	6	6	8	5	4
25	12	8	6	8	10	7
26	10	11	11	8	8	5
27	15	18	15	20	14	4
28	10	12	9	7	9	11
29	18	18	17	12	8	5
30	11	9	10	7	6	6
31	13	13	11	7	8	8
32	12	11	14	10	10	10
33	15	16	11	9	10	10
34	15	13	14	13	10	9
35	10	9	12	8	6	6
36	11	7	6	8	8	8
37	7	8	8	12	7	7
38	9	6	7	15	7	7
39	12	6	6	8	6	6
40	13	8	13	11	10	10
41	14	6	6	13	9	9
42	8	5	14	16	12	12
43	12	8	10	15	8	8
44	21	9	7	7	6	6

Table B-29. Methane Concentrations Found During the September 2002 VRPM Survey of the Biocover Area.

Loop	Methane Concentration for Path to Mirror Number (ppmv)			
	Mirror 2	Mirror 3	Mirror 4	Mirror 5
1	53.5	60.0	41.6	34.7
2	65.8	66.5	50.2	39.1
3	74.2	57.9	41.1	44.0
4	103	70.3	55.8	55.1
5	93.4	57.0	56.3	53.2
6	90.2	59.1	52.9	52.3
7	76.3	60.0	42.3	31.9
8	64.8	66.5	54.4	30.9
9	69.5	57.9	45.0	42.0
10	80.0	70.3	34.9	36.0
11	102	57.0	21.9	25.3
12	63.0	59.1	57.5	46.0
13	109	90.8	42.9	24.4
14	70.0	72.6	56.5	45.1
15	60.3	42.5	22.1	0.0
16	74.7	68.1	46.9	0.0
17	24.9	29.6	16.5	0.0
18	57.6	61.2	47.0	0.0
19	44.3	48.5	20.2	20.4
20	33.7	33.3	22.2	19.2
21	35.2	42.3	21.7	17.1
22	42.8	65.5	23.3	17.7
23	38.9	94.7	41.5	42.8
24	86.2	68.7	33.6	17.8
25	74.3	59.4	45.0	63.4
26	71.2	54.8	50.8	44.9
27	42.9	49.6	51.0	37.1
28	77.8	78.2	55.3	50.5
29	109	50.5	37.6	19.4
30	40.1	43.7	33.8	19.9
31	85.5	68.8	48.6	36.8
32	73.2	85.7	54.1	21.3
33	55.1	66.2	34.6	40.6
34	42.4	41.3	25.3	23.8
35	42.6	41.2	23.1	13.8
36	44.8	51.6	25.6	34.0
37	58.5	48.0	28.7	29.5
38	79.8	82.9	68.0	37.0
39	46.8	53.7	28.7	22.8
40	41.1	40.8	26.1	16.2
41	49.9	60.7	25.7	25.4
42	60.8	56.1	26.1	26.3

Table B-30. Methane, Ammonia, and VOC Concentrations Found Along the Path to Mirror 1 During the September 2002 VRPM Survey of the Biocover Area.

Loop	Concentration along Path to Mirror 1 of the Biocover Area (ppmv)						
	Methane	TFM[a]	CFM[b]	Ethanol	MTBE[c]	Ammonia	Ethylene
1	51	0.0057		0.104		0.012	
2	54					0.0068	
3	41					0.023	
4	38					0.028	
5	42		0.035			0.026	
6	32		0.028			0.031	
7	38		0.031			0.021	0.0077
8	28					0.016	
9	16				0.0059		
Average	38					0.021	

[a] TFM = trichlorofluoromethane.
[b] CFM = chlorofluoromethane.
[c] MTBE = methyl tert-butyl ether.

Table B-31. Methane Concentrations Found During the May 2003 VRPM Survey of the Biocover Area.

Loop	Methane Concentration for Path to Mirror Number (ppmv)					
	Mirror 1	Mirror 2	Mirror 3	Mirror 4	Mirror 5	Mirror 6
1	23	38	56	72	54	90
2	54	28	41	37	19	55
3	32	30	47	17	18	67
4	48	40	25	12	51	74
5	17	27	31	28	40	71
6	10	20	24	21	16	67
7	61	43	54	46	30	60
8	51	47	28	31	46	66
9	64	60	45	46	18	53
10	86	93	63	59	31	53
11	46	57	61	69	46	71
12	71	61	63	63	34	29
13	30	30	56	63	34	39
14	85	57	55	40	36	57
15	33	36	29	19	19	21
16	28	28	25	16	16	19
17	24	20	17	19	19	22
18	36	29	22	10	10	14
19	31	25	21	14	14	17
20	17	18	22	11	11	14
21	26	26	24	13	13	21
22	35	33	24	19	19	28
23	36	31	32	21	21	27
24	44	32	27	21	21	26
25	34	30	27	21	21	25
26	33	26	27	22	22	26
27	30	24	23	18	18	25

continued

Table B-31 (concluded). Methane Concentrations Found During the May 2003 VRPM Survey of the Biocover Area.

Loop	Methane Concentration for Path to Mirror Number (ppmv)					
	Mirror 1	Mirror 2	Mirror 3	Mirror 4	Mirror 5	Mirror 6
28	22	21	24	17	16	18
29	31	26	21	20	19	24
30	27	24	22	15	13	19
31	24	26	28	23	20	25
32	27	23	27	16	15	20
33	25	27	22	14	10	22
34	33	33	30	27	24	29
35	39	37	34	26	20	25
36	42	38	34	21	16	22
37	39	34	32	28	24	27
38	34	29	24	19	10	17
39	31	21	23	22	18	23
40	35	24	22	15	12	20
41	29	33	28	22	17	24
42	29	26	23	22		20

Table B-32. Methane Concentrations Found During the September 2002 Downwind VRPM Survey of the Compost Area.

Loop	Methane Concentration for Path to Mirror Number (ppmv)			
	Mirror 1	Mirror 2	Mirror 3	Mirror 4
1	5.8	5.1	5.8	4.2
2	5.8	5.1	5.3	5.5
3	5.3	5.3	6.0	4.3
4	5.2	5.3	6.8	5.6
5	6.4	5.4	6.2	4.6

Table B-33. Methane Concentrations Found During the September 2002 Upwind VRPM Survey of the Compost Area.

Loop	Methane Concentration for Path to Mirror Number (ppmv)				
	Mirror 1	Mirror 2	Mirror 3	Mirror 4	Mirror 5
1	10	13	13	12	11
2	7.3	11	9.5	10	10
3	10	10	9.3	10	10
4	7.7	9.1	8.4	8.6	8.8
5	8.7	10	10	10	11
6	10	11	11	13	13
7	8.5	15	15	15	16
8	19	20	19	20	22
9	13	28	27	29	28
10	28	30	27	28	26
11	22	26	23	24	24
12	12	23	21	22	21
13	5.4	6.1	5.9	4.7	6.7
14	5.4	7.2	6.4	5.5	8.3
15	5.7	6.3	6.4	4.8	6.9
16	6.1	7.5	7.4	5.7	7.1
17	6.0	7.1	6.0	5.4	5.4
18	6.0	8.0	5.7	6.1	9.0

Appendix C
Mercury Data

Table C-1. Total Mercury Measured During the September 2002 Field Campaign.

Site	Location	Mercury Conc. in Gas (ng/m³)	Spike Recovery (%)
Flare	Primary	619	N/A[a]
Flare	Duplicate	671	N/A
Flare	Spike	680	100
Flare	Spike Duplicate	680	100
Control	Well 73A	585	N/A
Control	Well 73A	642	N/A
Control	Well 73B	619	N/A
Control	Well 73B	21	N/A
Retrofit	U5 North	224	N/A
Retrofit	U5 South	296	N/A

[a] N/A = not available.

Table C-2. Dimethyl Mercury Measured During the September 2002 Field Campaign.

Site	Location	Mercury Conc. in Gas (ng/m³)	Spike Recovery (%)
Flare	Field Blank	ND[a]	N/A[b]
Flare	Primary	ND	N/A
Flare	Spike	ND	7
Control	Well 73A	1.7	N/A
Control	Well 73A Spike	3.3	0
Control	Well 73B	2.0	N/A
Retrofit	U5 North	3.7	N/A
Retrofit	U5 South	16	N/A
Retrofit	U5 South Duplicate	18	N/A
--	Trip Spike 1	N/A	105
--	Trip Spike 2	N/A	69

[a] ND = not detected
[b] N/A = not available.

Table C-3. Monomethyl Mercury Measured During the September 2002 Field Campaign.

Site	Location	Mercury Conc. in Gas (ng/m³)	Spike Recovery (%)
Flare	Primary	3.4	N/A[a]
Flare	Spike	3.6	97
Conventional	Well 73A	2.3	N/A
Conventional	Well 73B	3.2	N/A
Conventional	Well 73B Spike	2.9	91
Retrofit	U5 North Primary	4.4	N/A
Retrofit	U5 North Duplicate	3.9	N/A
Retrofit	U45 South	0.4	N/A
--	Spike Solution A	N/A	51
--	Spike Solution B	N/A	79

[a] N/A = not available.

Table C-4. Total Mercury Measured During the September 2003 Field Campaign.

Site	Location	Mercury Conc. in Gas (ng/m³)	Spike Recovery (%)
Flare	Primary	957	N/A[a]
Flare	Duplicate	1040	N/A
Flare	Triplicate	962	N/A
Flare	Spike		92
Flare	Spike Duplicate		94
Control[b]	Well 73A	4670	N/A
Control	Well 73B	935	N/A
As-Built	Well 74B	334	N/A
Retrofit	U5 North	123	N/A
Retrofit	U5 South	350	N/A

[a] N/A = not available.
[b] Under positive pressure.

Table C-5. Dimethyl Mercury Measured Using the Carbotrap Method During the September 2003 Field Campaign.

Site	Location	Mercury Conc. in Gas (ng/m³)	Spike Recovery (%)
Flare	Primary	58.0	N/A[a]
Flare	Primary Spike		
Control	Well 73A	66.8	N/A
Control	Well 73A Spike		
Control	Well 73B		N/A
As-Built	Well 74B	363	
As-Built	Primary Spike		
Retrofit	U5 North	45.5	N/A
Retrofit[b]	U5 South	49.3	N/A
Retrofit	Primary Spike		90.4
Retrofit	Secondary Spike		90.4
--	Trip Spike 1		89.5
--	Trip Spike 2		85.7

[a] N/A = not available.
[b] No sample collected.

Table C-6. Dimethyl Mercury Measured Using the Methanol Impinger Method During the September 2003 Field Campaign.

Site	Location	Mercury Conc. in Gas (ng/m^3)	Spike Recovery (%)
Flare	Primary	58.0	N/A[a]
Flare	Primary Spike		
Control	Well 73A	66.8	N/A
Control	Well 73A Spike		
Control	Well 73B		N/A
As-Built	Well 74B	363	
As-Built	Primary Spike		
Retrofit	U5 North	45.5	N/A
Retrofit[b]	U5 South	49.3	N/A
Retrofit	Primary Spike		90.4
Retrofit	Secondary Spike		90.4
--	Trip Spike 1		89.5
--	Trip Spike 2		85.7

[a] N/A = not available.
[b] No sample collected.

Table C-7. Monomethyl Mercury Measured During the September 2003 Field Campaign.

Site	Location	Mercury Conc. in Gas (ng/m^3)	Spike Recovery (%)
Flare	Primary	1.48	N/A[a]
Flare	Duplicate	1.48	N/A
Flare	Triplicate	2.05	N/A
Flare	Primary Spike		26
Control	Well 73A	0.542	N/A
Control	Well 73B	0.778	N/A
Control[b]	Well 73B Spike		BD[c]
As-Built	Well 74B	0.551	
As-Built	Primary Spike		28
Retrofit	U5 North Primary	1.95	N/A
Retrofit	U5 North Duplicate	2.10	N/A
Retrofit	Primary Spike		26
--	Spike Solution A		51
--	Spike Solution B		79

[a] N/A = not available.
[b] No spike solution.
[c] BD = below detection level.

Appendix D
GPS Coordinates of Survey Areas

Table D-1. GPS Coordinates of the As-Built Cells for the May 2003 Field Campaign.

Position	Latitude	Longitude	Altitude
NW Corner of Upper Cell	38° 08.28′	85° 44.11′	158
SW Corner of Upper Cell	38° 08.25′	85° 44.11′	158
NE Corner of Upper Cell	38° 08.27′	85° 43.98′	157
SE Corner of Upper Cell	38° 08.28′	85° 43.98′	161
NW Corner of Lower Cell	38° 08.23′	85° 44.11′	148
SW Corner of Lower Cell	38° 08.19′	85° 44.11′	148
NE Corner of Lower Cell	38° 08.23′	85° 43.98′	154
SE Corner of Lower Cell	38° 08.19′	85° 43.98′	152

Table D-2. GPS Coordinates of the As-Built Cells for the September 2003 Field Campaign.

Position	Latitude	Longitude	Altitude
NW Corner of Upper Cell	38° 08.27′	85° 44.17′	159
SW Corner of Upper Cell	38° 08.24′	85° 44.17′	156
NE Corner of Upper Cell	38° 08.27′	85° 43.96′	165
SE Corner of Upper Cell	38° 08.24′	85° 43.97′	157
NW Corner of Lower Cell	38° 08.24′	85° 44.17′	156
SW Corner of Lower Cell	38° 08.18′	85° 44.19′	147
NE Corner of Lower Cell	38° 08.24′	85° 43.97′	157
SE Corner of Lower Cell	38° 08.19′	85° 43.97′	144

Table D-3. GPS Coordinates of the Retrofit Area for the May 2003 Field Campaign.

Position	Latitude	Longitude	Altitude
NW Corner	38° 08.99′	85° 43.27′	161
SW Corner	38° 08.82′	85° 43.28′	159
NE Corner	38° 08.99′	85° 43.23′	160
SE Corner	38° 08.82′	85° 43.23′	155

Table D-4. GPS Coordinates of the Retrofit Area for the September 2003 Field Campaign.

Position	Latitude	Longitude	Altitude
NW Corner	38° 08.99′	85° 43.27′	161
SW Corner	38° 08.82′	85° 43.28′	159
NE Corner	38° 08.99′	85° 43.23′	160
SE Corner	38° 08.82′	85° 43.23′	155

Table D-5. GPS Coordinates of the Control Area for the May 2003 Field Campaign.

Position	Latitude	Longitude	Altitude
NW Corner	38° 08.34′	85° 43.92′	157
SW Corner	38° 08.31′	85° 43.91′	154
NE Corner	38° 08.34′	85° 43.87′	155
SE Corner	38° 08.31′	85° 43.87′	157

Table D-6. GPS Coordinates of the Biocover Area for the May 2003 Field Campaign.

Position	Latitude	Longitude	Altitude
NW Corner	38° 08.32′	85° 43.93′	152
SW Corner	38° 08.24′	85° 43.94′	147
NE Corner	38° 08.32′	85° 43.86′	153
SE Corner	38° 08.28′	85° 43.90′	154