United States
Environmental Protection
Agency

EPA/600/R-07/043
April 2007

# Field Test Measurements at Five Municipal Solid Waste Landfills with Landfill Gas Control Technology

## *Final Report*

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# Field Test Measurements at Five Municipal Solid Waste Landfills with Landfill Gas Control Technology

Final Report

Prepared for:
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Office of Research and Development
Air Pollution Prevention and Control Division
National Risk Management Research Laboratory

Contract No. EP-C-04-023
Work Assignment 3-26

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# 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.

The National Risk Management Research Laboratory (NRMRL) is the Agency's center for investigation of technological and management approaches for preventing and reducing risks from pollution that threaten human health and the environment. The focus of the Laboratory's research program is on methods and their cost-effectiveness for prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites, sediments and ground water; prevention and control of indoor air pollution; and restoration of ecosystems. NRMRL collaborates with both public and private sector partners to foster technologies that reduce the cost of compliance and to anticipate emerging problems. NRMRL's research provides solutions to environmental problems by: developing and promoting technologies that protect and improve the environment; advancing scientific and engineering information to support regulatory and policy decisions; and providing the technical support and information transfer to ensure implementation of environmental regulations and strategies at the national, state, and community levels.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

Sally Gutierrez, Director
National Risk Management Research Laboratory

# Notice

The U.S. Environmental Protection Agency through its Office of Research and Development funded and managed in the research described here under Contract No. EP-C-04-023 to Arcadis G&M, Inc. It has been subjected to the Agency`s review and has been approved for publication as an EPA document.

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## 1. Introduction

The purpose of this field test program is to generate data that may be used to update EPA's factors for quantifying landfill gas emissions from municipal solid waste (MSW) landfills. Because of health and environmental concerns, EPA issued in 1996 New Source Performance Standards (NSPS) and Emission Guidelines (EGs) for new and existing MSW landfills. These regulations 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* (U.S. EPA, 1996, 1991a, 1991b, 1991c). These regulations require that large landfills collect and control landfill gas emissions.

Landfills are listed as a source for residual risk evaluation as part of EPA's Urban Air Toxic Strategy. Landfills are also subject to New Source Review under Title V of the Clean Air Act. The data being used for issuing air permits, developing estimates for emission inventories and environmental or risk assessments, are obtained from EPA's emission factors found in Chapter 2.4 of AP-42 (U.S. EPA, 1997). Factors for evaluating uncontrolled emissions and also combustion by-products are included in AP-42.

Much of the data used in developing the existing set of landfill gas emission factors in AP-42 were collected in support of the NSPS and EGs. Therefore much of this data is at least a decade old. Changes to the design and operation of MSW landfills have occurred that are suspected to influence MSW landfill air emissions. In addition, improvements in quality assurance (QA) and EPA test methods have occurred that enable better detection limits and higher quality data.

Through a Cooperative Research and Development Agreement (CRADA 01/02 CR1 26CFX81 80401F), the U.S. Environmental Protection Agency (EPA) formed a partnership with the Environmental Research and Education Foundation (EREF) to collect comprehensive and up-to-date data at U.S. MSW landfills. Field testing was conducted in two phases. The first phase helped finalize sampling and analytical methods used for the raw landfill gas and combustion by-product emissions. The second phase implemented the agreed upon methods using Category II QA project plan that included on-site auditing of field tests. The field testing began in November 2002 and was completed in June 2005. EPA's Office of Research and Development (ORD) worked in cooperation with industry partners and EPA's Office of Air Quality Planning and Standards (OAQPS) in establishing scope, field sampling and analytical protocols, and site selection. The field testing was conducted by ARCADIS G&M, Inc.

(ARCADIS), as contractor to the EPA National Risk Management Research laboratory (NRMRL) Air Pollution Prevention and Control Division (APPCD), under several work assignments as part of the Onsite Laboratory Support Contracts (68-C-99-201 and EP-C-04-023).

Testing has been conducted in parallel to this field test program and is providing data that evaluates potential fugitive emissions from landfills. Data has also been collected to help quantify the emission differences between sites with and without leachate recirculation (EPA-600/R-05/072). In addition, guidance has been developed for evaluating the air pathway from older landfills (EPA-600/R-05/123a). The data from this effort, field studies, and data collected from industry and state and local regulatory agencies will be used in updating AP-42. Once updated factors are available, EPA's Landfill Gas Emission Model (LandGEM) will be updated to reflect the newer information (EPA-600/R-05/047). The revised emission factors for estimating uncontrolled emissions and combustion by-products will be provided in a new release of AP-42 including an updated background information document.

The site selection criteria for identifying potential sites for this study included: (1) no enforcement actions associated with the site; (2) the site must be in compliance with applicable EPA regulations (Clean Air Act and Resource Conservation Recovery Act); (3) the site must have state-of-the-art combustion technology in place for landfill gas control; and (4) the combustion technology must be representative of what is typical at U.S. landfills. Because of the potential benefit from utilization of landfill methane, EPA promotes landfill gas-to-energy projects through its Landfill Methane Outreach Program (LMOP). (www.epa.gov/lmop) Updated statistics from LMOP indicate that there are more than 400 landfill gas-to-energy projects in the U.S. (U.S. EPA, 2007). There is also information providing distribution of energy recovery projects in the U.S. (Thorneloe et al., 2000) This information was used in selecting the type and number of combustion technologies to include in this study. Ideally it would be nice to include a wider range of technologies but available funding limited the number to five facilities. The technologies that were included in this evaluation were two enclosed flares, two internal combustion (IC) engines, and one direct gas-fed boiler.

Sites that use leachate recirculation to accelerate waste decomposition were excluded as potential candidate sites. It may be important in future studies to explore how leachate recirculation may affect landfill gas emissions. However, this study did not include sites that use leachate recirculation or other liquid additions to accelerate waste decomposition.

### 1.1 Objective/Purpose and Intended Use of Project Results

The objective of this project was to collect and provide current data from U.S. MSW landfills with state-of-the-art control technology used for reducing landfill gas (LFG) emissions. Comprehensive testing was conducted of the raw landfill gas and the combustion outlet exhaust. The data will be used to help develop emission factors for use in updating EPA's AP-42 for estimating uncontrolled emissions from MSW landfills and combustion by-product emissions. Pollutants of concern include methane ($CH_4$), volatile organic compounds (VOCs), persistent bioaccumulative toxics (PBTs) such as mercury (Hg), and hazardous air pollutants (HAPs) such as benzene, vinyl chloride, and methyl ethyl ketone. The data will also be used to supplement AP-42 and to provide QA to data previously supplied by industry and others as part of the AP-42 update.

### 1.2 Scope of Project

The first phase of the project included two sites in the Northeast (Landfills A and B). Input for Phase I was obtained from EREF and EPA's Office of Air Quality Planning and Standards to identify appropriate sampling and analytical protocols and QA. Input was also obtained to identify pollutants of concern for the raw landfill gas (collected from the header pipe but upstream of gas pretreatment or condensate knockout) and combustion by-product emissions. Prior to initiating Phase 2, a review was conducted to determine changes needed to sampling and analytical protocol and QA. These changes in sampling, analytical protocol and QA are listed in section 3.5. The second phase included three sites located in the mid-west (Landfills C, D and E). Phase 1 testing took place from November 1 through November 5, 2002. Phase 2 testing took place from May 12 to May 16, 2004 for Landfills C and D, and from June 22 to June 23, 2005 at Landfill E.

The pollutants of interest for the raw (untreated) landfill gas included VOCs, non-methane organic compounds (NMOCs), polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), hydrogen sulfide ($H_2S$), carbonyls (acetaldehyde, formaldehyde), and Hg (total, elemental, and organo).

The pollutants of interest for combustion outlet exhaust included carbon monoxide (CO), nitrogen oxides ($NO_X$), sulfur dioxide ($SO_2$), NMOCs as total hydrocarbons (THCs), hydrogen chloride (HCl), total Hg, polychlorinated dibenzodioxins (PCDDs), polychlorinated dibenzofurans (PCDFs), polycyclic aromatics hydrocarbons (PAHs), and toxic heavy metals.

### 1.3 QA Considerations

This test program was conducted to meet Category II QA requirements. A generic QA program plan (QAPP) was prepared for the field test project. In addition, a site-specific QAPP was prepared for each field test.

This project set out to produce data that qualified to receive the "A" rating with respect to the rating system described in Section 4.4.2 of the *Procedures for Preparing Emission Factor Documents* (EPA-454/R-95-015). The cited EPA document provides a clear description of the requirements for an "A" data quality rating:

> "Tests are performed by using an EPA reference test method, or when not applicable, a sound methodology. Tests are reported in enough detail for adequate validation and raw data are provided that can be used to duplicate the emission results presented in the report."

The Data Quality Objectives (DQOs) were specified in the Generic and Site-Specific QAPPs. The extent to which this program achieved the DQOs was reported in detail in each of the landfill test reports. Overall the DQOs were met except for a few limited cases such as dimethyl mercury for landfills A and B. In addition there were issues with PAH analysis which is discussed in more detail in this report. The issues that were identified in Phase 1 were addressed in Phase 2 so that the DQOs were met as explained in the individual reports. The list of changes made between Phases 1 and 2 is provided in Section 3.5 of this report.

As part of the QA process, an EPA QA representative conducted a Technical Systems Audit (TSA) of the sampling operations during the Landfill C tests. The Audit Report indicated that the sampling operations were in compliance with standard operating procedures (SOPs) and methods.

The following two sections discuss the two groups of measurements that did not produce the results as planned. All other measurements were conducted and produced results as originally planned.

#### 1.3.1 PCDD/PCDF/PCB/PAH Measurements

Method 23 was used to evaluate the concentrations of PAHs and PCBs in the raw LFG for the two sites included in Phase 1 (Landfills A and B).

In order to achieve the desired low detection limits typically required of these target analytes, the samples had to be greatly concentrated. The process of concentrating the sample extracts produced recovery extracts that were extremely concentrated in some other (not PAHs or PCBs) organic constituents. Those concentrations were sufficiently high to cause instrumental interferences and prevented the extracts from being analyzed to give the required low detection limits of the PAHs and PCBs target analytes. Injection of these organic-rich extracts would have over-ranged and corrupted the analytical instruments, necessitating major instrument repair and cleaning.

In fact, commercial laboratories even declined to attempt to analyze these extracts. The alternative of not concentrating the samples to avoid instrument over-ranging is possible but would produce PAHs and PCBs method detection limits so high as to render the measurements not meaningful. Therefore, during subsequent tests for Landfills C, D and E, these samples were not included in the target list. However, PAHs were analyzed in the combustion outlet exhaust.

#### 1.3.2 Mercury Measurements

Landfills have been found to contain organo-mercury (Lindberg et al, 2005). Because the available organo-mercury measurement and analysis methods are not established EPA standard test methods, questions were raised about their application to landfill gas given the range of constituents of potential interferences. Phase 1 conducted a review of the protocol of these organo-mercury analysis methods and included QA checks to help in the evaluation of the methods. For both Phase 1 sites (Landfills A and B), unsatisfactory spike recoveries were obtained. ARCADIS in working with Frontier Geosciences, the subcontractor laboratory, determined that reducing the sample volume could result in more satisfactory spike recoveries. To help in improving information on the precision of the protocol for organo-mercury, a second analytical laboratory was contracted to compare results for one of the five landfills (i.e., Landfill E). These results were reported in the Landfill E report.

During the course of the test program, after Phase 1 (Landfills A and B) was completed, a review of mercury sampling and analysis was conducted including an audit of Frontier Geosciences laboratory's mercury analysis operations. This resulted in improving the procedures that were used in Phase 2. The conclusion is that organo-mercury sampling and analysis can provide useful results and that refinements in the protocols will improve the methods' applicability, accuracy, and precision.

Lindberg et al, 2005 reported mercury measurement results from a total of nine landfills. The methodology for sampling and analysis of total, di-methyl, and mono-methyl used in these tests were very similar to the methodologies used at the five landfills included in this report, although sample volumes were slightly different. The range of total mercury in the Lindbergh report is from 10 to 11,500 $ng/m^3$ while the range of total mercury in this report is from 158 to 1330 $ng/m^3$. Overall the concentration of total Hg in the Lindbergh paper is much higher (as much as an order of magnitude in some cases) than the total mercury concentrations included in this report. The range of dimethyl mercury in the Lindbergh paper is from 4.5 to 99.8 $ng/m^3$ while the range of dimethyl mercury in this report is from 6.5 to 77 $ng/m^3$. Overall the concentrations of dimethyl mercury reported in this report and the Lindberg paper are similar. The range of monomethyl mercury in the Lindbergh paper is from ND to 39 $ng/m^3$ while the range of monomethyl mercury in this report is from ND to 8.2 $ng/m^3$ . Overall the concentration of monomethyl mercury in the Lindbergh paper is higher than the monomethyl mercury concentrations included in this report.

Prestbo et al. (2003) determined total and dimethyl mercury concentrations in raw LFG and found that dimethyl mercury comprised from 1 to 60 percent of the total mercury in the LFG. Vasuki et al. (2003) measured total and dimethyl mercury concentrations in Delaware LFGD and found that dimethyl mercury comprised about 8 percent of the total LFG mercury. The percent mercury of the Vasuki et al (2003) paper is very comparable with the data reported here for the five landfills tested, however, the percent dimethyl mercury reported by Prestbo et al. (2003) appears to be very high by as much as an order of magnitude. The discrepancy in the percent of dimethyl mercury in LFG will be addressed in a follow-on study.

During the course of the test program, after Phase 1 (Landfills A and B) was completed, ARCADIS' QA staff conducted an in-depth review of the mercury measurement methodologies by conducting an audit of Frontier Geosciences laboratory's mercury analysis operations. The results of that audit were included as a part of the Phase 2 (Landfills C and D) test reports. The findings were that the mercury measurement methods were capable of producing useable results, while the methods were undergoing continuing refinements. Progress has been made steadily to improve the methods' applicability, accuracy, and precision.

## 2. Landfill Descriptions

The five landfills included in this evaluation were MSW landfills with gas collection and control technology. Two are located in the northeast and three were located in the mid-west. All five are still operational (i.e., accepting waste). Characteristics of these landfills are listed in Table 2-1.

**Table 2-1. General Description of Tested Landfills**

| | Landfill A | Landfill B | Landfill C | Landfill D | Landfill E |
|---|---|---|---|---|---|
| Year that Waste Acceptance Began | 1972 | 1967 | 1992 | 1991 | 1971 |
| Area/Waste Footprint (acres) | 56 | 40 | 63 | 31 | 240 |
| Amount of waste (tons) | 2,700,000 in 2003 | 4,000,000 in 2003 | 6,400,000 in 2004 | 2,350,000 in 2004 | 14,500,000 in 2005 |
| Amount of waste (cubic yards) | --- | --- | 1,580,000 in 2003 | 421,639 | --- |
| Facility estimated LFG extraction rate (standard cubic fee per minute) [a] | 1700 | 1500 | 600 | 400 | 4800 |
| Combustion Control Technology | Internal Combustion Engine | Flare | Internal Combustion Engine | Flare | Boiler |
| Field Test Dates | 11/1/2002 to 11/2/2002 | 11/4/2002 to 11/5/2002 | 5/12/2004 to 5/13/2004 | 5/15/2004 to 5/16/2004 | 6/22/2005 to 6/23/2005 |

[a] Extraction rate is what was collected, NOT production rate, and it is estimated

### 2.1 Characteristics of Landfills Selected for Field Tests

#### 2.1.1 Landfill A

Landfill A is located in the Northeast and it began operation in 1972. Available information provided by the landfill site operator indicated that the site had 2,700,000 tons of waste in place in 2003, over an area of 56 acres. The landfill used 3,375 feet of horizontal collectors to collect the LFG. As of 2002, 29 vertical wells were in place to extract landfill gas. The collected gas was piped to two reciprocating internal combustion (RIC) engines. Any excess gas was flared. At this site, one of the two RIC engines was selected for field testing. The engine tested was selected arbitrarily.

#### 2.1.2 Landfill B

Landfill B was located in the Northeast and began operation in 1967. Based on information provided by the facility operator, the site had 4,000,000 tons of waste in place, over an area of 40 acres in 2003. Approximately 2,500 feet of horizontal collectors were used to collect landfill gas. Operators stated that 49 vertical wells were used to extract landfill gas which is piped to an enclosed flare system.

#### 2.1.3 Landfill C

Landfill C is located in the Midwest and began operation in 1992. Based on information provided by the site operator, Landfill C has approximately 6,400,000 tons of waste in place as of August 2004. Landfill gas is extracted using 54 vertical wells at a rate of 600 standard cubic feet per minute (scfm). The gas was piped to two Caterpillar 3560 engines. Excess gas was combusted in an enclosed flare.

#### 2.1.4 Landfill D

Landfill D is located in the Midwest and began operation in 1991. Based on information provided by the site operator, Landfill D has approximately 2,350,000 tons of waste in place as of August 2004. The waste footprint covers an area of 31 acres. Landfill gas is extracted using 21 vertical wells at a rate of 400 cubic feet per minute. Extracted gas is piped to an enclosed flare.

#### 2.1.5 Landfill E

Landfill E is located in the Midwest and began operation in 1971. As of June 2005, the landfill has 14,500,000 tons of waste in place covering an area of 240 acres. The LFG was extracted with 320 vertical wells and filtered, de-watered, compressed, and piped to the end users. The flow rate of the landfill gas was 4,800 scfm. This site had a number of innovative uses of landfill gas including producing steam for greenhouses, providing fuel for a large industrial boiler (replacing fuel oil), providing fuel for an asphalt plant, and the residual gas was flared. Demand and seasonal factors largely determined the use pattern and the maximum and minimum usage rates.

## 2.2 Description and Characteristics of Combustion Technology

### 2.2.1 Enclosed-Ground Flare (Landfills B and D)

#### *2.2.1.1 Landfill B*

A Perennial Energy Enclosed Ground Flare Station, rated at a maximum LFG input rate of 1500 scfm, was used to combust landfill gas at landfill B. A burner array and an automatic louver system were designed to control gas and combustion air distribution. Manufacturer information indicated that the flare was designed to obtain a minimum residence time of 0.6 seconds at 1400 $^{o}$F. The station included a condensate removal device to prevent liquids from contacting the flare burners. The system also included a flame arrestor to prevent flame propagation into the LFG header pipe and collection system. The unit was reported to be able to operate within a 5-to-1 turndown ratio [54.0 to 10.8 million British Thermal Units per hr (MMBtu/hr)]. The manufacturer also reported minimal production of $NO_x$ and effective destruction of hydrocarbons.

#### *2.2.1.2 Landfill D*

The enclosed ground flare evaluated at Landfill D was a John Zink Model 72 rated at a maximum LFG input rate of 695 scfm. A condensate removal system prevented liquids from contacting the flare burners. A flame arrestor prevented flame from propagating from the burner array back into the LFG header pipe and collection system. A burner array and an automatic louver system controlled gas and air distribution to achieve effective combustion. The manufacturer claimed that the unit could be operated satisfactorily within a 5-to-1 turndown ratio (from 20.9 to 4.0 MMBtu/hr). The system was designed for a minimum residence time of 0.7 seconds at 1800 °F to combust hydrocarbons with minimal production of $NO_X$.

### 2.2.2 IC Engine (Landfills A and C)

#### *2.2.2.1 Landfill A*

Landfill A utilized a bank of four Caterpillar (CAT) generator sets for destruction of LFG and generation of electricity. The engines were CAT 3412 four-stoke IC engines, adapted for landfill gas. The CAT 3412 was a spark-ignited (SI) V-12 engine with displacement of 1649 cubic inches. The engine was turbocharged and after-cooled, and had a cylinder bore diameter of 5.4 inches and a stroke of 6.0 inches. Engine #2 was randomly selected and was tested. The engine was connected to a Caterpillar SR4 Generator that was rated at 470 KW.

##### *2.2.2.2 Landfill C*

Landfill C utilized a bank of two Caterpillar generator-sets for destruction of LFG and generation of electricity. The engines were CAT 3516 four-stoke engines, adapted for LFG fuel. The CAT 3516 was a spark-ignition (SI) V-16 engine with 4210 cubic inches displacement. The engine was turbocharged and after-cooled, and had a 6.7-inch diameter cylinder bore and a 7.5-inch stroke. The engine drove a Caterpillar SR4 Generator that was rated at 800KW (at a 0.8 power factor). Engine #1 was randomly selected and tested. The engine did not have pollution control equipment installed.

### 2.2.3 Boiler (Landfill E)

##### *2.2.3.1 Landfill E*

The tested boiler was a Combustion Engineering Model 33-7KT-10, A-Type Package Boiler, rated at 80,000 pounds-per-hour of 250 psi steam. The boiler was fueled by the collected LFG and produced base-load steam for an industrial facility. The boiler was located on the industrial facility’s property, located approximately three miles from Landfill E.

# 3. Test Operations

The testing operations were conducted during spring through late fall (May through early November), when ambient air temperatures were above freezing.

Sample collection and other testing operations typically required seven- to eight-person sampling teams working for two full days. Prior to the sampling crew arriving at the landfills, the host facility operator was asked to install the necessary sampling ports, if these were not already present. In the case of Landfills C and D, excavation of soil was needed to expose the underground raw LFG pipes.

Other than these modifications to allow sampling equipment access, facility modification was not required or observed to have happened immediately prior to these tests.

## 3.1 Sample Locations

Two kinds of samples were collected - the raw LFG and the exhaust gas from the combustion-based emission control systems.

The raw LFG samples were collected from the LFG header pipe that connects the landfill's network of collection pipes and wells. The sample ports were upstream of the condensate removal unit, blower/compressor, and flow control or distribution equipment. Hence, the collected samples are representative of the raw LFG in its "natural" state.

During Phase 1 testing at Landfill A, a sample of condensate was collected from the LFG pipe leading to the engines. That location was downstream of the condensate removal unit and the condensate sample was not specified in the QAPPs. The sample was judged to be extraneous to the test program and had unclear value. Analysis of that sample was not useful without corresponding analysis of a vapor phase sample collected at the same location. Therefore, that condensate sample was not analyzed and similar samples were not collected during subsequent landfill tests.

For the tested engines and boiler, the exhaust gas samples were collected at their stack as these control devices had distinct stack pipes. The tested enclosed flares did not have distinct stacks as the whole flare unit served as the combustion unit and the stack. For all tests, the sample locations were selected to allow for isokinetic sampling.

### 3.2 Target Analytes

Through consultation between the CRADA partners and EPA's Office of Air Quality Planning and Standards (OAQPS) and Landfill Methane Outreach Program (LMOP) in the planning phase of the project, target analytes were selected. The list of analytes in the raw landfill gas and combustion outlet was much more comprehensive than that typical for performance tests of LFG control technology.

For organo-mercury compounds, standard EPA test methods were not available. Methods that were developed through Frontier Associates were used. Using these non-promulgated procedures required more effort in terms of quality assurance. Measuring the range of constituents in LFG gas can be quite challenging when compared to measuring other emission sources where there are fewer constituents to analyze.

#### 3.2.1 Raw Landfill Gas

Table 3-1 lists the target analytes for the raw LFG samples that were collected at the gas header pipe. The list of target analytes for the raw LFG matched closely with the constituents listed in AP-42 emission factors for landfills. In addition to these analytes, the test included the "non-AP-42" compounds: carbonyls (formaldehyde and acetaldehyde), polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), speciated mercury (monomethyl, dimethyl, elemental, and total). These constituents were of interest because of their status of being on the EPA list of HAPs.

Experience gained during Phase 1 testing revealed that the extracts of the PAH/PCB samples contained excessive amounts of non-PAH organics. In order to make the extracts safe to be injected into the gas chromatograph/mass spectrometer (GC/MS), samples had to be diluted excessively. The high dilution made the method detection levels for the target PAHs too high, resulting in "non-detects" at the high detection limits. The planned analysis method could not produce the desired results at the needed detection levels. Therefore, these measurements were not included in Phase 2 testing.

**Table 3-1. Target Analytes for the Raw Landfill Gas Samples collected at the Gas Header**

| **Target Analytes in AP-42 List of Landfill Gas Constituents** | | |
|---|---|---|
| Methane | Acrylonitrile | t-1,2-Dichloroethene |
| Ethane | Benzene | Tetrachloroethene |
| Propane | Bromodichloromethane | Toluene |
| Butane | Carbon disulfide | Trichloroethylene |
| Pentane | Carbon tetrachloride | Vinyl chloride |
| Hexane | Chlorobenzene | Vinylidene chloride |
| Carbonyl sulfide | Chloroform | Ethanol |
| Chlorodifluoromethane | Dimethyl sulfide | Methyl ethyl ketone |
| Chloromethane | Ethyl mercaptan | 2-Propanol |
| Dichlorodifluoromethane | Ethylene dibromide | 1,4-Dichlorobenzene |
| Dichlorofluoromethane | Ethylene dichloride | Ethylbenzene |
| Ethyl chloride | Methyl chloroform | Xylenes |
| Fluorotrichloromethane | Methyl isobutyl ketone | |
| 1,3-Butadiene | Methyl mercaptan | Non-methane organic compounds |
| Acetone | Methylene chloride | Hydrogen sulfide |
| Acetone | Propylene dichloride | |
| | | |

| **Target Analytes Not Previously Included in AP-42** | | |
|---|---|---|
| Acetaldehyde | **Mercury** | **Gases** |
| Formaldehyde | Organo-mercury compounds | Carbon dioxide |
| Polycyclic aromatic hydrocarbon [a] | Elemental | Oxygen |
| Polychlorinated biphenyls [a] | Total | Moisture |

[a] These target analytes were part of Phase 1 testing. They were not included in Phase 2 testing because of difficulties experienced by the analytical laboratory to analyze the overly organic-rich sample extracts.

The other analytes, oxygen ($O_2$), carbon dioxide ($CO_2$), and moisture, are not pollutants but are of interest as they are useful indicators of the "quality" of the raw LFG. The concentrations of nitrogen ($N_2$) and $O_2$ are also indicators of the extent of ambient air infiltration into the LFG collection. Method 25C [for non-methane organic compound (NMOC) determination] specifically recommends that these measurements be made to determine the extent of potential air infiltration. Therefore, while measurements for methane ($CH_4$), $CO_2$, $O_2$, and $N_2$ by Method 3C were not included in the original QAPPs, these measurements were included and performed for all five landfill tests.

There was original interest in determining the concentration of the toxic heavy metals lead (Pb), arsenic (As), cadmium (Cd), chromium (Cr), manganese (Mn), and nickel (Ni) in the raw LFG. However, a method suitable for sampling the organics-rich raw LFG and capable of detecting the suspected low concentrations of the toxic metals, does not exist. Therefore measurement of the toxic heavy metals was not planned for the raw LFG.

#### 3.2.2 Control Technology Exit

Table 3-2 lists the target analytes for the control technology exit gas samples. The focus of these analyses was to produce data that allowed for the assessment of the efficacies of the three tested control technologies to destroy the constituents in the raw LFG. They included $O_2$, $CO_2$, carbon monoxide (CO), nitrogen oxides ($NO_X$), sulfur dioxide ($SO_2$), total hydrocarbons (THCs), hydrogen chloride (HCl), dioxins/furans, PAHs, and the metals Pb, As, Cd, Cr, Mn, Ni and Hg.

Among the specified analytes, NMOC is the only one specified on the AP-42 list. The VOCs analyzed individually for the raw LFG were not individually targeted for the control technology exhaust gases because of the expected very low concentrations there. This assumption turned out to be not true for IC engines.

The gases $O_2$ and $CO_2$ were common combustion performance control parameters. CO, $NO_X$ and $SO_2$ are criteria pollutants, the formation of which is generally associated with combustion processes.

**Table 3-2. Target Analytes for the Control Technology Exit Gas**

| **Target Analytes in AP-42 List of Landfill Gas Constituents** | | |
|---|---|---|
| NMOCs | | |
| | | |
| **Target Analytes Not Previously Included in AP-42** | | |
| **Gases**: | | **Metals**: |
| $O_2$ | HCl | Pb, As, Cd, Cr, Mn, Ni |
| $CO_2$ | | Hg (total) |
| CO | PCDD/PCDF | |
| $NO_X$ | | |
| $SO_2$ | PAHs | |
| | | |

The emission reduction performance of hydrocarbons is determined using either Method 25C or 25A. If the NMOC concentration is less than 50 ppm, then Method 25A is recommended for use.

The remaining target analytes include HCl, PCDDs/PCDFs, PAHs, total Hg, and toxic heavy metals (Pb, As, Cd, Cr, Mn, Ni). These analytes are also identified is EPA's list of HAPs.

## 3.3 Sampling and Analysis Methods

### 3.3.1 Raw Landfill Gas Sampling Analysis Methods

Table 3-3 lists the sampling, analysis and measurement methods that were followed at the raw LFG header pipe location. The table also included the name of the organizations that performed the procedures. With the exception of the organic mercury methods for mercury analysis, ARCADIS staff performed the field collection of samples and associated data collection. Where multiple organizations are listed, the

**Table 3-3. Testing Methods for Raw LFG**

| Procedure | Description | Organization Performing Analysis |
|---|---|---|
| EPA Method 1 | Selection of traverse points | ARCADIS G&M |
| EPA Method 2 | Determination of gas velocity and volumetric flow rate | ARCADIS G&M |
| EPA Method 3C | Determination of $CO_2$, $CH_4$, nitrogen ($N_2$), and $O_2$ in raw LFG | Triangle Environmental Services |
| EPA Method 11 | Determination of $H_2S$ | Oxford Laboratories (Landfills A, B, C, D)<br>Enthalpy Analytical (Landfill E) |
| EPA Method 23 | Determination of:<br>PCDDs/PCDFs by Method 8290,<br>PAHs by Method 8270<br>PCBs by Method 1668 | ALTA Analytical Perspectives |
| EPA Method 25C | Determination of raw LFG NMOCs | Triangle Environmental Services |
| EPA Method 40/TO-15 | Determination of VOCs | Research Triangle Park Laboratories |
| SW-846 Method 0100/TO-11 | Determination of carbonyls (formaldehyde, acetaldehyde) | Resolution Analytics |
| LUMEX instrument | Determination of elemental mercury ($Hg^0$) | ARCADIS G&M |
| Organic mercury methods | Determination of:<br>monomethylmercury,<br>dimethylmercury, and<br>total mercury. | Frontier Geosciences (Landfills A, B, C, D, E)<br>Studio Geochimica (Landfill E) |

letters A, B, C, D, and E in parenthesis following the organization denote the landfill site for which the organization was the performing organization.

Where multiple organizations are listed, the letters A, B, C, D, and E in parenthesis following the organization denotes the landfill site for which the organization was the performing organization.

### 3.3.2 Control Technology Exit Sampling Analysis Methods

Table 3-4 lists the sampling, analysis and measurement methods that were followed at the control technology exit stack. As before, the table also included the name of the organizations that performed the procedures. ARCADIS staff performed the field collection of samples and associated data at this sampling location.

**Table 3-4. Testing Methods for Control Technology Exit Gas**

| Procedure | Description | Organization Performing Analysis |
|---|---|---|
| EPA Method 1 | Selection of traverse points | ARCADIS G&M |
| EPA Method 2 | Determination of stack gas velocity and volumetric flow rate | ARCADIS G&M |
| EPA Method 3A | Determination of $O_2$ and $CO_2$ for flare stack gas molecular weight calculations | ARCADIS G&M |
| EPA Method 4 | Determination of stack gas moisture | ARCADIS G&M |
| EPA Method 6C | Determination of $SO_2$ | ARCADIS G&M |
| EPA Method 7E | Determination of $NO_X$ | ARCADIS G&M |
| EPA Method 10 | Determination of CO | ARCADIS G&M |
| EPA Method 23 | Determination of:<br>PCDDs/PCDFs by Method 8290,<br>PAHs by Method 8270<br>PCBs by Method 1668 | ALTA Analytical Perspectives |
| EPA Method 25A | Determination of flare stack gas NMOCs, as THCs when total organic concentration was less than the 50 ppm Method 25C applicability threshold | ARCADIS G&M |
| EPA Method 26A | Determination of HCl | Resolution Analytics |
| EPA Method 29 | Determination of toxic heavy metals | First Analytical Laboratories |
| LUMEX instrument | Determination of elemental mercury ($Hg^0$) | ARCADIS G&M |

## 3.4 Field Test Sampling Operations Narrative

As stated earlier, sampling typically required a sample team with seven or more experienced samplers. Prior to the tests, site visits to each landfill were conducted to gather necessary information for developing the quality assurance project plans and making arrangements for the field tests. The ARCADIS field chief noted the availability of sample ports and made arrangements with the host facility to have them installed if suitable ports were absent. He confirmed that the necessary staging area was available and that needed electrical utilities were accessible.

Two or more days before the scheduled tests, ARCADIS staff transported its field sampling trailer to the site. The trailer carried the needed sampling instruments, supplies, and emission monitors. Typically, one day of on-site preparation was needed before the scheduled test began.

The actual sample collection required two full days. All measurements and samples were collected in triplicate. The test samples and the required QA samples (field blanks and spike samples) were prepared, recovered, and recorded on sample chain-of-custody forms on site. The samples were transported back to ARCADIS' offices in Durham, North Carolina, by ARCADIS' sampling truck-trailer. The sample custodian, together with the sampling crew chief, made the arrangements to deliver the samples to the subcontracted laboratories for analysis.

### 3.5 Variation from Test Methods or Planned Activities

The test program for the five landfills spanned over three and a half years. Results from the earlier tests were used to guide the later tests. Some of the originally planned test methods were substituted by other methods and are described in the following sections.

#### 3.5.1 Method Exceptions

Laboratory analytical procedures followed those prescribed by the specified methods, with the following exceptions.

#### *3.5.1.1 Raw Landfill Gas*

Alternative method for the raw landfill gas samples included the following:

- Carbonyls were analyzed by EPA TO-11, instead of the originally selected Method 8315. Methods TO-11 and 8315 closely resemble each other.

- PAHs in the raw LFG were to be analyzed by SW-846 Method 8270 - The sample extracts resulting from the raw LFG were found to contain excessive amounts of non-PAH organics. In retrospect, this should have been expected as the LFG is organic-rich (~40%). In order to make the extracts safe for injection into the gas chromatograph mass spectrometer (GC/MS) (i.e., not cause instrument damage), they have to be diluted significantly. The high dilution makes the method detection levels for the target PAHs too high, resulting in “non-detects” at high detection limits. The planned analysis method could not produce PAH concentrations at the needed detection levels. The sample extracts are in storage and may be submitted for analysis if a suitable method is available. These analyses were deleted from the Landfills C, D, and E tests.

- PCBs in the raw LFG were analyzed by EPA Method 1668 (EPA 812/R-97-001) as specified in the QAPP. However, similar to the difficulties experienced for the PAH analysis, in order to make the extracts safe to be injected inject into the GC, they have to be diluted excessively. The planned analysis method could not produce the desired results at the needed detection levels. These analyses were deleted from the Landfills C, D and E tests.

- NMOCs were analyzed by the GC/MS Method as described in EPA Publication EPA/600-R-98/16.

- VOCs and $CH_4$ were analyzed by EPA Method TO-15, with GC/MS and with GC/flame ionization detector (FID).

- Method 3C for the analysis of $CH_4$, $CO_2$, $O_2$, and $N_2$ was added to support the Method 25C analysis, as recommend by Method 25C.

- For Landfills C, D, and E, the sampling procedure for dimethylmercury was altered by reducing the sample size volume on the Carbotrap from 10 L to 0.5 L.

*3.5.1.2 Control Device Exit*

Alternative method for the control device exit samples included the following:

- Method 25A was to evaluate organic compound concentrations in the combustion outlet because of the low concentrations detected in Phase 1 sites. Method 25C is applicable at concentrations of 50 ppmv or more. However, test results showed that the IC engines exhaust gases contained several hundred ppm of THCs. Therefore, for any future field tests for IC engines, Method 25C should be used to quantify NMOCs rather than Method 25A.

- For Method 23 samples collected at Landfill C, analyses for PAHs were performed by CARB Method 429 as opposed to Method 8270. However, these methods are comparable. CARB Method 429 contains procedures for sampling, sample recovery, clean-up, and analysis. Method 8270 is strictly an analytical method. CARB Method 429 is specific to 19 PAHs, the target analytes of this portion of the specified tests. The 19 PAHs are a subset of the 200+ target analytes listed for Method 8270 for semivolatile organic compounds (SVOCs). Though specific compounds called out for use in instrument performance verifications, internal standard preparation, surrogate standards and continuing calibration verifications/calibration checks are slightly different, both methods require them. CARB Method 429 adds another level of QC with a required recovery standard. Method performance and acceptance criteria for recoveries are better defined in CARB Method 429 and meet or exceed those stated in Method 8270C. As long as any additional compounds reported by the laboratory using CARB Method 429 are included in the calibration standards and acceptable response factors are demonstrated, using CARB Method 429 is essentially equivalent to using SW-846 Method 8270.

- As a result of examining the test results from Landfill A, which showed very low concentrations of PCDDs/PCDFs/PAHs at the exit of an enclosed flare, no Method 23 sampling was conducted at Landfill D, also a site with an enclosed flare. A decision was made to not sample for PCDDs/PCDFs at the exit of the enclosed flare systems because the combustion gas temperature conditions found in the exit of an enclosed flare system were not likely to allow the formation of PCDDs/PCDFs. This also eliminated analysis of PAHs which uses the same sample.

# 4. Test Results

The following sections present data summaries of the measurements that were planned and conducted. Section 4.1 and its subsections present data related to the raw LFG. Section 4.2 and its subsections present data for the combustion exhaust gases at the exit of the flares, engines, and boiler.

## 4.1 Raw Landfill Gas

### 4.1.1 Landfill Gas Flow Rate and Temperature

Table 4-1 presents information regarding the LFG flow rate for each landfill. The LFG flowrate ranged from a low of 400 scfm for Landfill D to over 4000 scfm for Landfill E. Landfill E was a much larger landfill as it was reported to have over 14 million tons of waste in place, while Landfill D had about 2.4 million tons of waste.

The LFG header pipes at all the landfills did not have sufficiently long straight pipe sections to allow ideal EPA Method 2 gas velocity measurements. Velocity measurements were made under non-ideal conditions and were able to provide crude estimates of the LFG flowrates. For the purpose of this study, the estimated LFG flowrates were judged to be sufficiently accurate. For their intended use to estimate pollutant emission rates, the added cost of needed improvement of the landfill gas header piping system, and associated potential schedule delay, were not warranted.

Temperature of the LFG ranged from 54 to 71°F. Landfill E, with the largest volume of LFG, also had the highest measured LFG temperature.

### 4.1.2 Landfill Gas Constituent Concentrations

The principal focus of this test program was to determine the constituents that were present in the raw LFG. The major constituents consist of $CH_4$, $CO_2$, $N_2$, $O_2$ and moisture. These constituents were present in percent levels. Other constituents were the various organic compounds which were present in ppm or lower concentrations. Landfill gas also contained mercury including methyl- and dimethylmercury.

**Table 4-1. Raw LFG Flow Rates**

| Parameter | Landfill A | Landfill B | Landfill C | Landfill D | Landfill E |
|---|---|---|---|---|---|
| Facility flowrate readings (scfm) | 1650 – 1700 J | 1500 J | 550 – 600 J | 400 J | 4340 J |
| ARCADIS measured flow rate by pitot probe (scfm) | 1580 J | 1745 J | 700 J | 380 -850 J | 3860 J |
| LFG gas temperature (°F) | 57 | 62 | 56 | 54 | 71 |
| Reported amount of waste (ton) | 2,700,000 in 2003 | 4,000,000 in 2003 | 6,400,000 in 2004 | 2,350,000 in 2004 | 14,500,000 in 2005 |
| Header pipe inner diameter (in) | 12 | 11 | 14 | 11 | 16 |
| Straight pipe upstream (No. of pipe diameters) | ~8 | < 2 | > 8 | > 8 | < 2 |
| Straight Pipe Downstream (No. of pipe diameters) | ~4 | < 2 | > 8 | > 8 | < 2 |
| Vacuum in header pipe, Inches water column (WC.) | 34 - 35 | -- | 21 | --- | -- |

J –Estimated value per EPA/G-8 guidance

*4.1.2.1 Major Constituents ($CH_4$, $CO_2$, $O_2$) by Method 3C and NMOCs by Method 25*

Table 4-2 presents the concentrations of the major LFG constituent components and NMOCs. The tabled provides the range and average for each of the constituent concentrations.

The concentrations $CH_4$, $CO_2$, $O_2$, $N_2$, moisture and NMOCs varied over quite a wide range between the landfills. In particular, Landfill D showed unusually high $CH_4$ content of more than 55 percent. Landfill B showed the lowest methane concentration, at just below 40 percent.

**Table 4-2. Raw LFG Major Constituents**

| | Constituent | | Landfill A | Landfill B | Landfill C | Landfill D | Landfill E |
|---|---|---|---|---|---|---|---|
| Method 25C | Methane (% v/v) | Range | 48.0 – 49.8 | 37.7 – 40.6 | 54.6 – 57.7 | 57.4 – 59.5 | 46.7 – 50.9 |
| | | Average | 48.8 | 39.2 | 56.0 | 58.6 | 49.5 |
| | Carbon Dioxide (% v/v) | Range | 38.1 – 39.4 | 29.5 – 31.9 | 45.2 – 47.2 | 40.2 – 41.7 | 33.3 – 36.3 |
| | | Average | 38.7 | 30.7 | 46.2 | 41.0 | 35.3 |
| | NMOC (ppm as hexane) | Range | 297 – 491 | 314 – 377 | 3650 – 9330 | 971 -1024 | 194 – 288 |
| | | Average | 374 | 355 | 5870 | 1006 | 233 |
| Method 3C | Methane (% v/v) | Range | 43.5 – 45.4 | 35.2 – 37.3 | 47.4 – 49.1 | 54.3 – 55.6 | 46.8 – 51.7 |
| | | Average | 44.5 | 36.1 | 48.0 | 55.1 | 49.5 |
| | Carbon Dioxide (% v/v) | Range | 35.2 – 36.9 | 28.2 – 29.9 | 35.4 – 36.9 | 37.6 – 38.5 | 30.2 – 31.9 |
| | | Average | 36.1 | 29.0 | 35.9 | 38.1 | 31.3 |
| | Oxygen (% v/v) | Range | 1.6 - 1.8 | 6.0 - 6.6 | 1.4 – 1.9 | 0.01 - 0.02 | 2.1 - 3.4 |
| | | Average | 1.7 | 6.4 | 1.6 | 0.02 | 2.6 |
| | Nitrogen (% v/v) | Range | 12.7 – 13.4 | 24.4 – 26.2 | 13.5 – 18.9 | 9.5 – 12.8 | 11.9 - 16.4 |
| | | Average | 13.1 | 25.6 | 15.9 | 11.2 | 13.6 |
| Method 23 | Moisture (% v/v) | Range | 11.6 – 12.3 | 1.8 – 2.1 | NM | NM | NM |
| | | Average | 12.0 | 2.0 | | | |

NM – Not measured because moisture data were obtained by Method 23, which were not conducted during these tests.

All values are reported on an as-is basis, without correction for nitrogen-indicated potential air infiltration.

Data on the moisture in the LFG were only available for Landfills A and B because the data is a computed output of the Method 23 sampling procedure. Method 23 samples were collected for PAH and PCB analysis. This procedure was deleted from the test program after experiences with Landfills A and B samples revealed that the analysis could not be done. More explanation of this finding will be presented later in this report. Without Method 23 sampling for Landfills C, D, E, no moisture data were collected.

#### *4.1.2.2 Other Constituents*

In addition to the major constituents, the other lower concentration constituents were of interest because of their potential to cause adverse health effects. The following sections summarize the results related to these compounds.

#### 4.1.2.2.1 VOCs by Method 0040 with TO-15

Table 4-3 presents the average concentrations of the target volatile organic compounds. The concentration data were obtained by summa canister samples collected using Method 40 procedures. Analysis was performed by Method TO-15, with gas chromatography and mass spectrometry (GC/MS). The alkanes (C2 through C6), being present in much higher concentrations, were analyzed by GC flame ionization detection (FID).

**Table 4-3. Raw LFG Volatile Organic Compounds**

| Compound | Unit | Method Detection Limit (NDL) Range [a] | | Average Concentration [b] | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | Landfill A | Landfill B | Landfill C | Landfill D | Landfill E |
| **By gas chromatography flame ionization detector (GC/FID)** | | | | | | | | |
| Ethane | Part per million by vol (ppmv) | 1 | 1 | 6.2 | 4.6 | 14.3 | 5.6 | 14 |
| Propane | ppmv | 1 | 1 | 8.9 | 5.9 | 40.0 | 30.5 | 13.0 |
| Butane | ppmv | 1 | 1 | 4.9 | 3.3 | 37.9 | ND | 3.6 |
| Pentane | ppmv | 1 | 1 | 3.2 | 2.6 | 26.6 | 2.4 | 1 |
| Hexane | ppmv | 1 | 1 | Not Detected (ND) | ND | 28.4 | 2.5 | ND |
| | | | | | | | | |
| **By TO-15 gas chromatography and mass spectrometer (GC/MS)** | | | | | | | | |
| Dichlorodifluoromethane (Freon 12) | Part per billion by vol (ppbv) | 0.2 | 0.3 | 118 | 468 | 1600 | 1240 | 232 |
| 1,2-Chloro-,1,2,2-Tetrafluoroethane (CFC114) | ppbv | 0.2 | 0.2 | 8 | 44 | 127 | 110 | 15.3 |
| Chloromethane | ppbv | 0.1 | 0.2 | 12 | 72 | 1263 | 232 | ND |
| Vinyl chloride | ppbv | 0.2 | 0.2 | 97 | 410 | 768 | 1200 | 63 |
| 1,3-Butadiene ((Vinylethylene) | ppbv | 0.2 | 0.3 | 22 | 89 | 642 | 326 | ND |
| Bromomethane (Methyl Bromide) | ppbv | 0.2 | 0.2 | 16 | 46 | 23 | 2.8 | ND |
| Chloroethane (Ethyl Chloride) | ppbv | 0.2 | 0.2 | 770 | 1880 | 30400 | 634 | ND |
| Trichloromonofluoromethane (CFC11) | ppbv | 0.2 | 0.2 | 51 | 327 | 504 | 116 | 8.1 |

| Compound | Unit | Method Detection Limit (NDL) Range [a] | | Average Concentration [b] | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | Landfill A | Landfill B | Landfill C | Landfill D | Landfill E |
| 1,1-Dichloroethene | ppbv | 0.2 | 0.2 | 1.7 | 8 | 55 | 21 | ND J |
| 1,1,2-Trichloro-1,2,2-trifluoroethane (CFC113) | ppbv | 0.2 | 0.2 | 2.0 | 11 | 39 | 19 | ND |
| Carbon Disulfide | ppbv | 0.2 | 0.3 | 14.4 | 134 | 157 | 93 | 339 |
| Ethanol | ppbv | 0.2 | 0.2 | 19.7 J | 202 | 172 | 394 | ND J |
| Isopropyl Alcohol (2-Propanol) | ppbv | 0.2 | 0.2 | 114 J | 356 | 1280 | 6630 | 2360 J |
| Methylene chloride (Dichloromethane) | ppbv | 0.1 | 0.2 | 997 | 169 | 5350 | 1110 | 3050 |
| Dimethyl sulfide | pppv | 20 | 20 | ND | ND | 68 | ND | ND |
| Acetone | ppbv | 0.2 | 0.3 | 328 | 1610 | 11700 | 12800 | 15500 |
| t-1,2-dichloroethene | ppbv | 0.2 | 0.3 | 2.7 | 9 | 42 | 53 | ND |
| Hexane | ppbv | 0.2 | 0.3 | 2470 J | 1950 | 4940 | 3980 | 597 J |
| Methyl-t-butyl ether (MTBE) | ppbv | 0.2 | 0.3 | 54.4 | 177 | 257 | 39 | ND |
| 1,1-Dichloroethane | ppbv | 0.2 | 0.4 | 33.4 | 178 | 423 | 591 | ND |
| Vinyl Acetate | ppbv | 0.2 | 0.5 | 242 | 686 | 24 | 44 | 111 |
| cis-1,2-Dichloroethene | ppbv | 0.2 | 0.3 | 74.1 | 292 | 1640 | 1780 | 163 |
| Cyclohexane | ppbv | 0.2 | 0.3 | 165 | 734 | 3300 | 2270 | ND |
| Chloroform | ppbv | 0.2 | 0.3 | 40 | 190 | 744 | 485 | ND |
| Ethyl Acetate | ppbv | 0.2 | 0.3 | 1830 | 2310 | 1420 | 4600 | ND |
| Carbon Tetrachloride | ppbv | 0.2 | 0.5 | 0.8 | 5 | ND | 38 | ND |
| Tetrahydrofuran (Diethylene Oxide) | ppbv | 0.2 | 0.4 | 1180 | 882 | 1170 | 2060 | ND |
| 1,1,1-Trichloroethane | ppbv | 0.2 | 0.5 | 4.9 | 31 | ND | ND | ND |
| 2-Butanone (Methyl Ethyl Ketone) | ppbv | 0.2 | 0.3 | 273 | 1430 | 4570 | 8070 | 2490 |
| Heptane | ppbv | 0.2 | 0.2 | 242 | 918 | 2860 | 3580 | 331 |
| Benzene | ppbv | 0.2 | 0.2 | 73 | 251 | 1630 | 1200 | 887 |
| 1,2-Dichloroethane | ppbv | 0.2 | 0.3 | 1.0 | 5 | 37 | 22 | ND |
| Trichloroethylene (Trichloroethene) | ppbv | 0.2 | 0.2 | 28.0 | 103 | 515 | 418 | 93.9 |
| 1,2-Dichloropropane | ppbv | 0.2 | 0.3 | 0.8 | 5 | ND | ND | ND |
| Bromodichloromethane | ppbv | 0.2 | 0.2 | 2.6 | 10 | ND | ND | ND |
| 1,4-Dioxane (1,4-Diethylene Dioxide) | ppbv | 0.2 | 0.2 | 1.9 | 9.4 | 7 | 12 | ND |
| cis-1,3-Dichloropropene | ppbv | 0.2 | 0.2 | 0.2 | 1.4 | ND | 4 | ND |
| Toluene (Methyl Benzene) | ppbv | 0.2 | 0.3 | 1330 | 6770 | 23300 | 30300 | 7950 |
| 4-Methyl-2-pentanone (MIBK) | ppbv | 0.2 | 0.2 | 1070 | 886 | 2170 | ND | ND |

| Compound | Unit | Method Detection Limit (NDL) Range [a] | | Average Concentration [b] | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | Landfill A | Landfill B | Landfill C | Landfill D | Landfill E |
| t-1,3-Dichloropropene | ppbv | 0.2 | 0.2 | 0.3 | 3 | 33 | 8 | ND |
| Tetrachloroethylene (Perchloroethylene) | ppbv | 0.2 | 0.3 | 42.1 | 176 | 1690 | 1020 | 125 |
| 1,1,2-Trichloroethane | ppbv | 0.2 | 0.2 | 7.6 | 39 | 445 | ND | ND |
| Dibromochloromethane | ppbv | 0.2 | 0.2 | ND | 16 | 9 | 16 | ND |
| 1,2-Dibromoethane (Ethylene dibromide) | ppbv | 0.2 | 0.2 | 1.1 | 7 | 21 | ND | ND |
| 2-Hexanone (Methyl Butyl Ketone) | ppbv | 0.2 | 0.2 | 557 | 441 | ND | ND | ND |
| Methyl Mercaptan (Methanethiol) | ppbv | 20 | 20 | ND | ND | ND | ND | ND |
| Ethylbenzene | ppbv | 0.2 | 0.3 | 575 | 2800 | 5890 | 8120 | ND |
| Chlorobenzene | ppbv | 0.2 | 0.2 | 195 | 229 J | 833 | 21 | 135 |
| m/p-Xylene (Dimethyl Benzene) | ppbv | 0.2 | 0.65 | 3730 J | 3980 | 9200 | 13600 | 9000 J |
| o-Xylene (Dimethyl Benzene) | ppbv | 0.2 | 0.3 | 300 | 1410 | 3660 | 5410 | 3100 |
| Styrene (Vinylbenzene) | ppbv | 0.1 | 0.2 | 29.5 | 222 | 1270 | 1180 | 420 |
| Tribromomethane (Bromoform) | ppbv | 0.2 | 0.3 | 0.4 | ND | 16 | 9 | ND |
| 1,1,2,2-Tetrachloroethane | ppbv | 0.2 | 0.2 | 29.9 | ND | ND | ND | ND |
| 1-Ethyl-4-methylbenzene (4-Ethyl Toluene) *see Note c* | ppbv | 0.2 | 0.2 | 79.3 J | 386 J | 894 J | 976 J | 2510 |
| 1,3,5-Trimethylbenzene *see Note c* | ppbv | 0.2 | 0.2 | 79.3 J | 386 J | 894 J | 976 J | 1040 |
| 1,2,4-Trimethylbenzene | ppbv | 0.2 | 0.3 | 193 | 949 | 1510 | 2190 | 2640 |
| 1,4-Dichlorobenzene | ppbv | 0.2 | 0.3 | 43.4 | 255 | 328 | 686 | ND |
| 1,3-Dichlorobenzene | ppbv | 0.2 | 0.3 | 0.5 | 2.03 | 394 | 650 | ND |
| Benzyl Chloride | ppbv | 0.2 | 0.2 | 6.3 | 20 | ND | ND | ND |
| 1,2-Dichlorobenzene | ppbv | 0.2 | 0.3 | 1.9 | 0.4 | ND | 31 | ND |
| 1,1,2,3,4,4-Hexachloro-1,3-butadiene | ppbv | 0.2 | 0.2 | 1.2 | 5 | ND | ND | ND |
| 1,2,4-Trichlorobenzene | ppbv | 0.2 | 0.3 | 1.0 | 5 | ND | ND | ND |
| Acrylonitrile | ppbv | 20 | 20 | ND | ND | ND | ND | ND |
| Dichlorofluoromethane (Freon 21) | ppbv | 20 | 20 | ND | ND | ND | ND | ND |
| Chlorodifluoromethane (Freon 22) | ppbv | 20 | 20 | ND | ND | ND | ND | ND |
| Ethyl Mercaptan (Ethanediol) | ppbv | 20 | 20 | ND | ND | ND | ND | ND |
| Carbonyl Sulfide (Carbon oxysulfide) | ppbv | 20 | 20 | ND | ND | ND | ND | ND |

ND - Constituent not detected at the stated method detection limits

a – Method detection limits provided by analytical laboratory

b – In computing averages, when all measurements are ND, the average is reported as ND. When one or more measurement is above detection, the ND measurement is treated as 50% of the stated MDL. Though not applicable here, the method further specifies that If MDL is not reported, a ND measurement is treated as zero.

c - 1-Ethyl-4-methylbenzene (4-Ethyl Toluene) and 1,3,5-Trimethylbenzene co-eluted from the GC and also have the same quantitation ions, thus making them indistinguishable. Therefore, the reported values represent the combined concentrations of these two compounds.

J – Estimated value per EPA QA/G-8 guidance

#### 4.1.2.2.2 Hydrogen Sulfide ($H_2S$) by Method 11

Table 4-4 present the concentrations of hydrogen sulfide measured with Method 11. $H_2S$ concentrations ranged from a low average concentration of 13 ppmv in Landfill A to a high average concentration of 322 ppmv for Landfill E.

**Table 4-4. Raw LFG Hydrogen Sulfide**

| | | Landfill A | Landfill B | Landfill C | Landfill D | Landfill E |
|---|---|---|---|---|---|---|
| ($mg/m^3$) | Range | 10.7 – 26.1 | 26.4 – 36.1 | 26.8 – 110.0 | 32.1 – 185.6 | 413 – 519 |
| | Average | 18.5 | 32.3 | 78.3 | 102.6 | 458 J |
| (ppmv) | Range | 7.6 – 18.4 | 18.7 – 25.6 | 19.0 – 78.0 | 22.7 – 132 | 291 – 366 |
| | Average | 13.0 | 22.9 | 55.5 | 72.7 | 322 J |

J Estimated value per EPA QA/G-8 guidance

#### 4.1.2.2.3 Carbonyls by Method 0100 & 8315A

Table 4-5 presents the concentrations of formaldehyde and acetaldehyde. Notably, acetaldehyde was uniformly present at a higher concentration than formaldehyde. Formaldehyde was present in the single-digit to low-tens of $\mu g/m^3$. Acetaldehyde was present at concentration several times higher than formaldehyde.

**Table 4-5. Raw LFG Carbonyls**

| | | | Landfill A | Landfill B | Landfill C | Landfill D | Landfill E |
|---|---|---|---|---|---|---|---|
| **Formaldehyde** | (µg/m$^3$) | Range | 2.3 – 5.0 | 3.3 – 4.1 | 26.9 – 46.6 | 16.0 – 39.0 | 8.1 – 11.8 |
| | | Average | 4.1 | 3.6 J | 33.9 | 25.0 | 9.6 |
| | (X10$^{-3}$ ppmv) | Range | 1.8 – 4.1 | 2.65 – 3.30 | 22.7 – 37.3 | 12.9 – 31.5 | 6.5 – 9.6 |
| | | Average | 3.3 | 2.90 J | 27.2 | 20.1 | 7.8 |
| **Acetaldehyde** | (µg/m$^3$) | Range | 18.9 – 67.8 | 21.9 – 35.0 | 114 – 495 | 72 – 534 | 27.9 – 151 |
| | | Average | 45.7 | 27.0 | 242 | 348 | 92.4 |
| | (X10$^{-3}$ ppmv) | Range | 10.3 – 37.0 | 12.0 – 19.2 | 62.4 – 27.0 | 39 – 293 | 15.3 – 82.8 |
| | | Average | 24.9 | 14.8 | 132 | 191 | 50.6 |

#### 4.1.2.2.4 PAHs by Method 0010 with 8270

As discussed previously in Section 3.5.1.1, attempts to analyze the PAH concentrations in the raw LFG were unsuccessful.

#### 4.1.2.2.5 PCBs by Method 0010 with 1668

As discussed previously in Section 3.5.1.1, attempts to analyze the PCB concentrations in the raw LFG were unsuccessful.

#### 4.1.2.2.6 Mercury

Mercury comes in various forms. It can be bound to particulates or in a gaseous form. Gaseous mercury species is either organic or inorganic. Organic mercury or methyl mercury is more toxic and regarded as a priority for determining the potential release from U.S. landfills. Previous testing has identified both methyl and dimethyl mercury in landfills.

Metallic, or elemental mercury, is an inorganic form used in products such as electrical switches, fluorescent bulbs, and thermometers. It is a liquid and can evaporate into the air as a gas. Inorganic mercury compounds take the form of mercury salts. Oxidized mercury (sometimes called ionic or reactive gaseous mercury (RGM) is found predominantly in water-soluble forms and may be deposited at a range of distances from sources depending on a variety of factors including topographic and meteorological conditions downwind of a source. Once mercury is deposited into bodies of water like lakes or streams, it can be converted to methyl mercury through microbial decomposition in soils and sediments. In this form, it is taken up by tiny aquatic plants and animals. Fish that eat these organisms build up methylmercury in their bodies. As ever-bigger fish eat smaller ones, the methylmercury is concentrated further up the food chain which is referred to as "bioaccumulation".

Table 4-6 summarizes the results of the mercury measurements which include ograno-mercury (i.e., dimethyl and monomethyl), elemental mercury, and total gaseous mercury. Total mercury and organo-mercury were sampled and analyzed by the Organic mercury method. Elemental mercury was measured by the LUMEX instrument. Oxidized mercury was not analyzed directly but can be determined by subtracting elemental and organo-mercury from total mercury.

The dimethyl mercury data for Landfills A and B did not meet data quality objectives and the results were rejected due to low spike recoveries. During the Landfill A and B tests, total sample volumes collected for dimethyl mercury on the Carbotrap were approximately 10 L. The analysis of these samples resulted in poor recovery of spiked dimethyl mercury. According to the researchers of the analytical laboratory, the poor spike recoveries could be attributed to the migration of the spiked material during sampling. The extent of material migration was believed to be highly dependent on sample volume. Therefore spike recoveries in this instance could be improved by reducing the sample volume.

For Landfills C, D, and E, the sampling procedure for dimethyl mercury was altered by reducing the sample size volume on the Carbotrap from 10 L to 0.5 L. The modified procedure resulted in much improved spike recoveries. The details of the mercury measurement methods and method development experiences were included in the Landfill C, and D reports, which are provided in appendices to this document.

Most of the mercury found was in the elemental state. The concentrations of the organic forms of the mercury were about two orders of magnitude lower than the total and elemental mercury concentrations. The results are comparable to those reported by Lindberg et al. in 2005 for twelve landfills, although the total amount of mercury reported in Lindberg et. al. 2005 is as much as one order of magnitude greater than the total mercury reported here. In the Lindberg study, total gaseous Hg ranged from 10 to 12000 ng/m$^3$. Dimethyl mercury ranged from 4.5 to 77 ng/m$^3$ and monomethyl mercury ranged from non-detect to 39 ng/m$^3$.

Total mercury concentration averages ranged from 204 to 1460 ng/m$^3$. Of these amounts, elemental mercury was the highest component, with its averaged values ranging from 58 to 440 ng/m$^3$. Dimethyl mercury was the next most prevalent. After discarding the Landfills A and B data because it did not meet data quality objectives, dimethyl mercury averaged concentrations ranged from 15 to 53 ng/m$^3$ approximately.

Monomethyl mercury was present at the lowest concentration, ranging from less than 1 to 5.4 $ng/m^3$.

Using the total mercury measurements as the basis, the sum of the elemental, monomethyl and dimethyl mercury species contributed to about 28 to 49 percent of the total mercury measured. It is suspected that the majority of the remaining mercury is in the oxidized form.

**Table 4-6. Raw LFG Mercury Compounds**

| | | | Landfill A | Landfill B | Landfill C | Landfill D | Landfill E |
|---|---|---|---|---|---|---|---|
| **Total** | ($ng/m^3$) | Range<br>Average | 601 – 676<br>632 | 158 – 234<br>204 | 423 – 427<br>425 | 723 – 751<br>740 | 1330 – 1650<br>1460 [a] |
| | ($X10^{-6}$ ppmv) | Range<br>Average | 72.4 – 81.4<br>76.1 | 17.7 – 26.2<br>22.8 | 50.9 – 51.4<br>51.2 | 87.0 – 90.4<br>89.1 | 149 – 184<br>163.5 [a] |
| **Dimethyl** | ($ng/m^3$) | Range<br>Average | R | R | 6.5 – 20.9<br>14.8 | 49.7 – 53.1<br>51.0 | 17.4 – 99.8<br>52.5 [a] |
| | ($X10^{-6}$ ppmv) | Range<br>Average | R | R | 0.7 – 2.2<br>1.5 | 5.2 – 5.6<br>5.3 | 1.82 – 10.5<br>5.5 [a] |
| **Monomethyl** | ($ng/m^3$) | Range<br>Average | ND – 1.2<br>0.4 | 1.1 – 1.3<br>1.2 | 3.1 – 5.4<br>3.9 | 2.40 - 2.64<br>2.47 | 3.4 – 8.2<br>5.4 [a] |
| | ($X10^{-6}$ ppmv) | Range<br>Average | ND – 0.13<br>0.04 | 0.12 – 0.15<br>0.13 | 0.35 – 0.60<br>0.44 | 0.264 – 0.296<br>0.278 | 0.380 – 0.920<br>0.61 |
| **Elemental** | ($ng/m^3$) | Range<br>Average | 280 – 325<br>308 | 53 – 61<br>58 | 90 – 103<br>99 | 265 – 290<br>278 | 437 – 445<br>440 |
| | ($X10^{-6}$ ppmv) | Range<br>Average | 33.7 – 39.1<br>37.1 | 6.4 - 7.3<br>7.0 | 10.8 – 12.4<br>11.9 | 31.9 – 34.9<br>33.5 | 52.6 – 53.6<br>53.0 |

R – Data rejected because spike recovery for these measurements were below acceptable range

ND – Constituent not detected at the detection limit of 0.63 $ng/m^3$

[a] - Values are averages of Frontier and Geochimica results

#### 4.1.2.2.7 Metals by Method 29

The standard Method 29 is the reference method to determine trace concentrations of the toxic metals. However, the method was designed for sample streams that are not rich in organic constituents because it uses a strong oxidizer, potassium permanganate solution, to capture the metals. The concern with applying this method to LFG was that the potassium permanganate might react violently with the organic constituents in the LFG. If that happened, the measurement would be invalidated and analysis might also pose safety risk to the sampling personnel. Therefore, it was not included in the test program.

## 4.2 Control Equipment Stack

The following subsections present the results obtained from measurements made at the control equipment stack.

### 4.2.1 Gas Flow Rate and Temperature

Table 4-7 presents the exhaust gas flowrates and their temperatures at the stack of the five control devices. The flowrates were obtained by velocity traverse measurements performed according to EPA Method 2. The flowrates reflected the size of the control equipment and ranged from 1310 scfm for the Landfill A engine to more then 28000 scfm for the Landfill E boiler.

The enclosed flares had the highest temperatures, at about 1400 °F. This was consistent with the nature of the process. Flares do not have active heat utilization and removal. The measured temperatures were lower than the expected flame temperatures because of the introduction of dilution air.

The boiler in Landfill E had the lowest exit temperature at about 480 °F. The observed temperature was consistent with typical boiler operations. The two reciprocating IC engines resulted in exhaust temperature around 735 °F for Landfill A's Caterpillar 3412 and 1000 °F for Landfill C's Caterpillar 3516. The Caterpillar 3516 was more than twice the size of the Caterpillar 3412.

**Table 4-7. Control Equipment Exit Stack Flow Rate and Temperature**

| | | Landfill A | Landfill B | Landfill C | Landfill D | Landfill E |
|---|---|---|---|---|---|---|
| Control Technology | | Reciprocating IC Engine | Enclosed Flare | Reciprocating IC Engine | Enclosed Ground Flare | Boiler |
| Unit Model | | Caterpillar 3412 | Perennial Energy | Caterpillar 3516 | John Zink Model 72 | Combustion Engineering 33-7KT-10 A Type |
| Size or Capacity | | 1649 cu. in displacement, 470KW | 10.8 to 54 MMBtu/hr | 4210 cu. in displacement, 800KW | 4.0 to 20.9 MMBtu/hr | 80,000 lb/hr 250 psi steam |
| LFG Flowrate into Equipment (scfm) [a] | | 150 | 1500 | 300 | 400 | 2430 |
| Exit Flowrate (dscfm) | Range | 1290 – 1340 | 19700 – 22000 | 1890 – 2000 | 7830 – 8290 | 26820 – 30400 |
| | Average | 1310 | 20700 | 1950 | 8080 | 28690 |
| Exit Gas Temperature (°F) | Range | 732 – 738 | 1359 – 1419 | 997 – 1038 | 1412 – 1446 | 476 – 488 |
| | Average | 735 | 1389 | 1016 | 1437 | 479 |

a – This is a crude estimate based on the measured exit flow rate, the measured exit oxygen concentration and the major constituent analysis of the LFG.

### 4.2.2 Exhaust Gas Constituent Concentrations

The following sections present the concentration and emission rates of the combustion products $O_2$, $CO_2$, CO, $SO_2$, $NO_X$, THCs, HCl, dioxin /furans, PAHs, and toxic heavy metals.

#### *4.2.2.1 CEM Constituents ($O_2$, CO, $CO_2$, $SO_2$, $NO_X$)*

Table 4-8 presents the average concentrations of $O_2$, CO, $CO_2$, $SO_2$, and $NO_X$ found in the control devices' exhaust gases. For the most part, they are unremarkable, except for the very apparent and substantially higher concentrations of CO, THC and $NO_X$ that are produced by the engines. The boiler was by far the most efficient combustion device as it produced the lowest concentrations of CO and THCs. The flares tended to produce more CO, especially if the more highly diluted flare exhaust gas was accounted for. In addition to producing higher concentrations of CO and THC, the engines also produced significantly higher concentrations of $NO_X$. The Landfill C engine, in particular, produced about 2700 ppm of $NO_X$, an alarmingly high level by any measure.

**Table 4-8. Control Equipment Exit $O_2$, CO, $CO_2$, $SO_2$, $NO_X$**

| | | Landfill A | Landfill B | Landfill C | Landfill D | Landfill E |
|---|---|---|---|---|---|---|
| $O_2$ (% v/v) | Range | 7.4 – 7.6 | 12.5 – 16.1 | 2.3 – 3.2 | 13.5 -13.5 | 7.2 – 7.9 |
| | Average | 7.5 | 14.9 | 2.7 | 13.5 | 7.5 |
| $CO_2$ (% v/v) | Range | 12.8 – 13.2 | 2.9 – 4.8 | 15.6 – 16.5 | 6.3 – 6.4 | 12.1 -12.5 |
| | Average | 12.9 | 4.2 | 16.3 | 6.4 | 12.3 |
| Moisture (% v/v) | Range | 11.3 – 12.5 | 5.8 – 7.3 | 16.2 - 18.3 | 7.9 – 10.3 | 11.6 – 14.1 |
| | Average | 12.1 | 6.5 | 17.0 | 8.4 | 12.6 |
| CO (ppmv) | Range | 549 – 570 | 11 – 13 | 556 – 585 | 69 -92 | ND – 14 |
| | Average | 560 | 10 | 568 | 80 | 9 |
| $SO_2$ (ppmv) | Range | 29 – 39 | 3 – 8 | –ND | ND | 41 – 68 |
| | Average | 34 | 6 | ND | ND | 55 |
| $NO_X$ (ppmv) | Range | 142 – 183 | 10 – 12 | 2280 – 3150 | 7.7 – 9.7 | 3 – 21 |
| | Average | 166 | 11 | 2730 | 8.5 | 13 |
| Remarks | | | 0.6 sec at 1400 °F | | | |

ND – Constituent not detected at the detection limit of 2.0 ppmv

4.2.2.2 Other Constituents

4.2.2.2.1 THCs by Method 25A

Table 4-9 presents the concentrations of organic materials found in the control device exhaust gases. The measurement was made with a continuous emission monitor, in

**Table 4-9. Control Equipment Exit Total Hydrocarbon**

| | | Landfill A | Landfill B | Landfill C | Landfill D | Landfill E |
|---|---|---|---|---|---|---|
| As Propane, (ppmv) | Range | 645 – 786 | ND – 6 | 893 – 994 | 31.3 – 35.6 | ND |
| | Average | 730 | 4 | 940 | 34.1 | ND |
| As Hexane, (ppmv) | Range | 323 – 393 | ND – 3 | 447 – 497 | 15.7 – 17.8 | ND |
| | Average | 365 | 2 | 470 | 17.1 | ND |

ND – Constituent not detected at the detection limit of 1.0 ppmv accordance with Method 25A. Hydrocarbons concentrations were low for Landfill E's boiler, fluctuating near the bottom of the instruments zero point. They were also very low for Landfill B's flare. Landfill D's flare had a bit more THC in its stack gas, at about 17 ppm hexane. In contrast, both IC engines produced exhaust gases that contained more than 350 ppm of hexane-equivalent hydrocarbons.

The purpose of this measurement was to determine the amount of hydrocarbons in the exhaust gases. Method 25A is suitable for this purpose. Moreover, identification and quantitation of individual organic compounds were not objectives of this test program. For future field tests, when there is a requirement to identify organic constituent species in engine exhausts, we would recommend using EPA Method 40, which is well suited to identify and quantify volatile organic compounds.

This project included measurements for PCDD/PCDFs and PAHs in the stack gases and these data are presented later in this report.

###### 4.2.2.2.2 Dioxin/Furans by Method 23 with 8290

Combustion processes with chlorinated compounds have the potential of producing polychlorinated dioxins and furans (PCDD/PCDF). This is particularly relevant if the combustion is not efficient and if the combustion products are allowed to cool down slowly where they can come into contact with a particle-laden surface.

Sampling for PCDD/PCDFs was performed for all landfills except for Landfill D, which used an enclosed flare. The decision to exclude Landfill D was based on two considerations. Tests at Landfill B where enclosed flare was used resulted in PCDD/PCDF data that were mostly below detection limits. Further, these findings were consistent with the understanding that the flare exit gases could not possibly be cooled to reach temperatures that were favorable to dioxin formation. Given the high cost of sampling and analysis for PCDD/OCDF, it was decided not to conduct PCDD/PCDFs at the second enclosed flare site.

Table 4-10 presents the PCDD/PCDF concentrations. As can be seen, PCDD/PCDFs were mostly below detection limits, except for Landfill E. The boiler in Landfill E is a device that is understood to have the potential to present the conditions that favors PCDD/PCDF formation, which was confirmed.

###### 4.2.2.2.3 PAHs by Method 0010 with 8270

Table 4-11 presents the concentrations of PAHs in the combustion stack gases. Consistent with the THC data presented earlier, the IC engines resulted in the highest concentrations of PAHs. In an attempt to provide a means of comparing the control technologies, Table 4-11 included a normalized PAH emission factor expressed as the amount of PAHs emitted per cu. ft. of LFG combusted. As shown, the IC engine at Landfill C was found to emit the highest amount of PAHs at 0.01 mg/cu. ft. LFG. In contrast, the boiler at Landfill E and the flare at Landfill B were both found to emit 0.003 mg/cu. ft. LFG.

##### 4.2.2.2.4 HCl by Method 26A

Table 4-12 presents the HCl concentrations at the control device stacks. They ranged from about 0.9 to 14 ppmv (1.4 to 21 mg/m$^3$).

##### 4.2.2.2.5 Metals by Method 29

Table 4-13 presents the metals found in the control equipment stack. The flares and the engines have low emission rates compared to the boiler. The reason for the generally higher metal emissions from the boiler is not understood.

**Table 4-10. Control Equipment Exit Dioxins and Furans Average Concentrations [a]**

| **Concentration (x10$^{-3}$ ng/dscm)** | **Landfill A** | **Landfill B** | **Landfill C** | **Landfill E** |
|---|---|---|---|---|
| **Number of Samples Contributing to Average** | 1 | 1 | 3 | 3 |
| **Dioxins** | | | | |
| 2,3,7,8-TCDD | ND | ND | ND | 0.926 |
| Other TCDD | 22.0 | 11.3 | 8.2 | 75.5 |
| 1,2,3,7,8-PeCDD | ND | ND | ND | 2.6 |
| Other PeCDD | 3.4 | 13.6 | 3.4 | 76.6 |
| 1,2,3,4,7,8-HxCDD | ND | ND | ND | 3.3 |
| 1,2,3,6,7,8-HxCDD | ND | ND | ND | 6.2 |
| 1,2,3,7,8,9-HxCDD | ND | ND | ND | 4.5 |
| Other HxCDD | 0.2393 | 4.1 | 1.2 | 71.1 |
| 1,2,3,4,6,7,8-HpCDD | ND | ND | ND | 28.0 |
| Other HpCDD | 0 | 2.4 | 0 | 28.5 |
| 1,2,3,4,6,7,8,9-OCDD | ND | ND | 3.7 | 43.6 |
| Total CDD | **< 33.8** | **<34.7** | **ND** | **341** |
| **Furans** | | | | |
| 2,3,7,8-TCDF | ND | 0.5867 | ND | 5.8 |
| Other TCDF | 46.6 | 0.0088 | 0.75 | 176 |
| 1,2,3,7,8-PeCDF | ND | 1.1 | ND | 9.2 |

| **Concentration ($x10^{-3}$ ng/dscm)** | **Landfill A** | **Landfill B** | **Landfill C** | **Landfill E** |
|---|---|---|---|---|
| **Number of Samples Contributing to Average** | 1 | 1 | 3 | 3 |
| **Dioxins** | | | | |
| 2,3,4,7,8-PeCDF | ND | 1.0 | ND | 12.8 |
| Other PeCDF | 3.4 | 110 | 0 | 119 |
| 1,2,3,4,7,8-HxCDF | ND | 1.1 | ND | 11.8 |
| 1,2,3,6,7,8-HxCDF | ND | 0.166 | ND | 11.6 |
| 2,3,4,6,7,8-HxCDF | ND | 0.194 | ND | 11.8 |
| 1,2,3,7,8,9-HxCDF | ND | 0.218 | ND | 3.1 |
| Other HxCDF | 1.3 | 34.7 | 0 | 59.4 |
| 1,2,3,4,6,7,8-HpCDF | ND | 0.158 | ND | 29.6 |
| 1,2,3,4,7,8,9-HpCDF | ND | 0.215 | ND | 3.8 |
| Other HpCDF | 0 | 4.6 | 0 | 10.8 |
| 1,2,3,4,6,7,8,9-OCDF | ND | 1.1 | ND | 11.1 |
| Total CDF | **13.9** | **156** | **ND** | **300** |
| Total CDD/CDF | **< 47.6** | **190** | **ND** | **640** |

a – Landfill D was not measured for PCDD/PCDFs.

ND – Constituent not detected.

< - indicates that the concentration of the constituent is less than the listed value. In all cases the number reported is rounded up to the nearest tenth.

**Table 4-11. Control Equipment Exit Averaged PAH Emissions [a]**

| Concentration (ng/dscm) | Landfill A | Landfill B | Landfill C | Landfill E |
|---|---|---|---|---|
| | IC Reciprocating Engine | Enclosed Flare | IC Reciprocating Engine | Boiler |
| **Number of Samples Contributing to Average** | 1 | 1 | 3 | 3 |
| Acenaphthene | 521 | 16.2 | 555 | 49.3 |
| Acenaphthylene | 731 | 3.1 | 1,510 | 10.2 |
| Anthracene | 116 | 8.3 | 372 | 33.6 |
| Benzo(a)anthracene | 41 | 2.5 | 62.2 | 302 |
| Benzo(a)pyrene | 3.2 | 1.1 | 3.1 | 233 |
| Benzo(b)fluoranthene | 22 | 3.1 | 45.3 | 659 |
| Benzo(g,h,i)perylene | 15 | 2.5 | 6.1 | 248 |
| Benzo(k)fluoranthene | 6.4 | 1.0 | 10.8 | 240 |
| Chrysene | 144 | 2.5 | 165 | 512 |
| Dibenzo(a,h)anthracene | 3.2 | 0.3 | 2.9 | 63.3 |
| Fluoranthene | 154 | 22.4 | 361 | 1400 |
| Fluorene | 950 | 319 | 707 | 74.5 |
| Indeno(1,2,3-cd)pyrene | 6.6 | 1.2 | 8.3 | 277 |
| Naphthalene | 17,900 | 4,060 | 43,000 | 785 |
| Phenanthrene | 1,900 | 12 | 2,670 | 1,200 |
| Pyrene | 175 | 18 | 290 | 832 |
| 2-Methylnaphthalene | 7,580 | 3460 | 6,700 | 650 |
| Benzo(e)Pyrene | 17 | 2.5 | 30.8 | 355 |
| Perylene | 3.1 | 0.4 | 1.0 | 40.3 |
| Total PAH | 30,300 | 7,930 | 56,500 | 7,960 |
| Estimated LFG Inlet flow Rate (scfm) | 150 J | 1500 | 300 | 2430 |
| Measured Exit Gas Flow Rate, average (scfm) | 1,310 | 20,700 | 1,950 | 28,700 |
| Total Emission Rate, ($mg/ft^3$ LFG) | 0.007 | 0.003 | 0.010 | 0.003 |

[a] – Landfill D was not measured for PAHs.

J  Estimated value per EPA QA/G-8 guidance

**Table 4-12. Control Equipment Exit HCl**

| | | Landfill A | Landfill B | Landfill C | Landfill D | Landfill E |
|---|---|---|---|---|---|---|
| ($mg/m^3$) | Range | 4.1 – 4.4 | 1.4 – 2.1 | 13.8 - 20.6 | 2.0 – 2.2 | 2.0 – 2.4 |
| | Average | 4.3 | 1.7 | 18.0 | 2.2 | 2.1 |
| (ppmv) | Range | 2.7 – 2.8 | 0.9 – 1.4 | 9.1 – 14.3 | 1.3 – 1.3 | 1.3 – 1.6 |
| | Average | 2.7 | 1.1 | 12.0 | 1.3 | 1.4 |
| (lb/hr) | Range | 0.0197 – 0.0213 | 0.11 – 0.16 | 0.103 – 0.163 | 0.06 – 0.06 | 0.21 – 0.26 |
| | Average | 0.0203 | 0.13 | 0.136 | 0.06 | 0.23 |

**Table 4-13. Control Equipment Exit Metal Emissions**

| | | Landfill A | Landfill B | Landfill C | Landfill D | Landfill E |
|---|---|---|---|---|---|---|
| Estimated LFG Inlet flow Rate | (scfm) | ~ 150 | 1500 | 300 | 400 | 2430 |
| Arsenic | µg/dscm | 3.0 | 0.70 | 3.13 | 4.7 | 2.3 |
| | X $10^{-6}$ lb/hr | 15 | 66 | 22.6 | 142 | 221 |
| | X $10^{-9}$ lb/scf LFG | 1.7 | 0.7 | 1.3 | 5.91 | 1.5 |
| Cadmium | µg/dscm | 0.37 | 0.18 | 0.574 | 0.209 | 1.2 |
| | X $10^{-6}$ lb/hr | 1.8 | 14.5 | 4.1 | 6.3 | 135 |
| | X $10^{-9}$ lb/scf LFG | 0.2 | 0.16 | 0.23 | 0.26 | 0.93 |
| Chromium | µg/dscm | 8.5 | 1.7 | 4.4 | 4.1 | 10 |
| | X $10^{-6}$ lb/hr | 41.4 | 132 | 31.6 | 122 | 1,200 |
| | X $10^{-9}$ lb/scf LFG | 0.46 | 147 | 1.8 | 5.1 | 8.2 |
| Lead | µg/dscm | 6.1 | 0.65 | 0.52 | ND | 6.0 |
| | X $10^{-6}$ lb/hr | 29.5 | 52 | 3.7 | ND | 649 |
| | X $10^{-9}$ lb/scf LFG | 3.2 | 0.6 | 0.21 | ND | 4.5 |
| Manganese | µg/dscm | 13.5 | 8.3 | 5.4 | 7.9 | 4.0 |
| | X $10^{-6}$ lb/hr | 66.2 | 660 | 38.5 | 236 | 439 |
| | X $10^{-9}$ lb/scf LFG | 7.4 | 7.3 | 2.1 | 9.8 | 3.0 |
| Mercury | µg/dscm | ND | ND | ND | ND | 0.46 |
| | X $10^{-6}$ lb/hr | ND | ND | ND | ND | 50 |
| | X $10^{-9}$ lb/scf LFG | ND | ND | ND | ND | 0.23 |
| Nickel | µg/dscm | 9.5 | 1.8 | 18 | 4.8 | 47 |
| | X $10^{-6}$ lb/hr | 47 | 140 | 126 | 144 | 5300 |
| | X $10^{-9}$ lb/scf LFG | 5.2 | 1.6 | 7.0 | 6.0 | 36.4 |

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# 5. Discussions of results

## 5.1 Comparison with AP-42 Default Values

Table 5-1 provides a comparison of the field test results of the five landfills to existing AP-42 values for landfill gas. The table also identifies the test method and detection limit for each constituent evaluated in the raw landfill gas. Of the forty-four AP-42 values, twenty-nine constituents were found to have average concentrations that are half or lower than their corresponding AP-42 for all five landfills. Twelve of these twenty-nine constituents were present at average concentrations that were no more than one-tenth of the AP-42 values. These twelve compounds are: 1,1,1-trichloroethane; 1,1,2,2-tetrachloroethane; 1,2-dichloroethane; 1,2-dichloropropane; isopropyl alcohol; bromodichloromethane; dichlorodifluoromethane; ethane; ethanol; t-1,2-dichloroethene; trichloroethylene; and vinyl chloride. For acrylonitrile, non-detects were reported for each of the five landfills.

For sixteen constituents, at least one landfill has a concentration greater than the existing AP-42 value. The concentrations that are greater than the existing AP-42 values for at least on of the five landfills are highlighted in the table. These compounds were: acetone, carbon tetrachloride, chlorobenzene, chloroethane, chloroform, chloromethane, dichlorobenzene (1,4; 1,3; and 1,2), ethylbenzene, 1,2-dibromethane, hexane, hydrogen sulfide, methyl ethyl ketone, pentane, and nonmethane organic compounds. Four compounds were present at average concentrations at least three times their AP-42 default values [i.e., carbon tetrachloride (3.6x), chloroethane (6.7x), chloroform (12x), and 1,2-dibromoethane (10x)].

Twenty six compounds were found to be present in concentrations that are similar to the AP-42 default values, i.e. their averaged concentrations were between 50 to 300% the AP-42 default values. These compounds were: 1,1-dichloroethane; 1,1-dichloroethene; acetone; butane; carbon disulfide; chlorobenzene; chloromethane; 1,4-dichlorobenzene; 1,3-dichlorobenzene; 1,2-dichlorobenzene; methylene chloride; ethylbenzene; trichloromonofluoromethane; hexane; hydrogen sulfide; mercury (total); 2-butanone; 2-hexanone; pentane; tetrachloroethylene; propane; m/p-xylene; o-xylene; benzene; NMOC as Hexane; and toluene.

These data will be of help in providing: (1) QA of industry-supplied data; (2) filling data gaps in the existing sets of LFG emission factors; and (3) updating existing emission factors within AP-42. The inclusion of these data will undergo protocols for AP-42 emission factor development including addressing uncertainty and data quality.

### 5.2 Control Technology Assessment

Among the three tested control technologies (i.e., enclosed ground flare, IC engine and boiler) the boiler was the one capable of destroying the LFG most effectively, as evidenced by the very low concentrations of organic compounds that exited the boiler stack. However, the boiler does have a higher affinity to form PCDDs and PCDFs than the flares or the engines. A more detailed review of the PCDD/PCDF data may be warranted to assess the potential impacts of the levels of these compounds that were formed.

IC engines do not appear to destroy landfill gas constituents as effectively as boilers or flares. This could be due to tuning or maintenance of the engine. Also, engines are typically operated to minimize NOx and CO emissions which will result in decreasing NMOC destruction efficiency. In assessing potential impacts from use of IC engines for landfill gas control, pollution prevention tradeoffs can be considered from offsetting power generation at a coal-fired electric utility (EPA-600/R-95-089). Often electricity from IC engines powered on landfill gas is used to help meet peak load energy demands.

Enclosed ground flares are simple devices and are easier to maintain and operate as compared to a boiler or IC engine. They do not have the benefits of IC engines or boilers in offsetting fossil fuel use and providing methane for utilization. However, the two enclosed flares evaluated in this project were found to effectively control hydrocarbons and organic constituents.

### 5.3 Mercury Measurements

The technology of sampling and analyzing for mercury species is progressing steadily. The current state of technology requires very specific knowledge that does not transfer readily. The development of a method that can be promulgated as an EPA standard procedure would be helpful in future research with mercury emissions.

This not withstanding, mercury measurement technology appears to be on the cusp of becoming more “main-stream.” Mercury’s inclusion in future research studies should be considered favorably, especially if the per-sample cost will go down because of maturing of the technique and increased competition in the market place. However, the use of independent standards is recommended for primary standard verification, spike recoveries and blanks to provide quality assurance of the results.

Technical Systems Audits (TSAs) were conducted for the organo-mercury sampling and analysis since this is not a standard EPA test method. One potential source of error in any analysis is due to the standards used to calibrate the instrumentation. Several issues were noted concerning the calibration standards. The first issue was the apparent inability to verify the concentrations of the standards used to calibrate the instrumentation used to measure MMHg and DMHg. The lack of an independent standard to verify the primary standard is a cause of concern because any inaccuracies in the primary standard will be promulgated throughout the analyses. It is recommended that Frontier Geosciences or any other laboratory conducting organo-mercury analyses identify stable standards for use as an independent verification of the primary standard.

A second issue concerned how the calibration standards were stored. No expiration dates were available for either the MMHg and DMHg standard materials. All standards have a limited “shelf life” and should not be used after they have expired. It was not clear if records were kept to prevent use of expired standards. It is recommended that this become part of the standard operating procedures (SOPs) to prevent use of standards that have degraded over time.

A third issue was raised regarding how the standards were stored. The QA officer found the MMHg analytical standard stored in a clear Teflon bottle, un-refrigerated in front of a large window. The work plan had requested that samples and standards be kept refrigerated and away from light.

The QA officer also recommended that standard practice should include retaining an aliquot of spike solution or spiked traps when sending media to a field project.

The QA officer also noted several potential issues associated with the oragno-mercury analyses. One area of concern was the instability of the MMHg instrument. The analyst responsible for MMHg analysis indicated that it was common to have to recalibrate and reanalyze samples. One suggestion to improve the robustness of MMHg analysis is the inclusion of analytical spikes. Additionally calibration verification samples should be analyzed frequently to ensure that the calibration is still acceptable, i.e. the instrument has not drifted. Data validation of MMHg analyses must include verification of the initial calibration, spike recoveries and calibration stability. Another area of concern is the practice of forcing the calibration curve through zero. This procedure is not consistent with most EPA-promulgated methods. Retention times during MMHg analysis should be carefully monitored. This is critical given that identification of MMHg is determined by retention times or relative retention times.

Careful monitoring of retention times must become part of MMHg analysis. The final observation made by the ARCADIS QA officer was that the digestate dilution technique was not acceptably performed. The glassware used to bring the digested samples to volume was not calibrated to Class A or Class B glassware. Furthermore the glassware used was not compared against calibrated glassware. Inaccurate dilution of the digestates is a common source of error in analysis where dilution is required. It is recommended that Frontier Geosciences or any other lab performing these analyses should modify their procedures to ensure accurate dilution of samples. This can be done using calibrated glassware or by using a calibrated balance to determine the dilution gravimetrically.

In addition to the TSA, an internal performance audit was performed by the ARCADIS QA officer. Audit samples for THg, MMHg and DMHg were prepared by Cebam Analytical located in Seattle, Washington. These audit samples were analyzed by Frontier Geosciences as described in the report titled *Determination of Total, Dimethyl, and Monomethyl Mercury in Raw Landfill Gass at Pinconning and Montrose Michigan*. These results are present in Tables 5-3, 5-4, and 5-5. In summary the results met the MQOs for recovery and the RPD between duplicate samples was also acceptable. However, the recovery MQO of 50-150 percent makes it nearly impossible to reasonably close a mass balance around Mercury. The measurement of the MMHg audit samples showed the worst recoveries of the various Hg species, indicating that MMHg analyses are more than likely the least robust of the analyses. Inclusion of the suggestions listed above should increase the accuracy and precession of THg, MMHg, and DMHg analyses. Mercury measurements from landfill gas are still in development, but improvements have been made.

**Table 5-1. Comparison between LFG Constituent Concentrations and AP-42 Default Values**

| | | | | Concentration (ppmv) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Method** | **Compound** | **CAS Number** | **Formula Weight** | **Default Value** | **Landfill A** | **Landfill B** | **Landfill C** | **Landfill D** | **Landfill E** | **Detection Limit** |
| M-40 | 1,1,1-Trichloroethane | 71-55-6 | 133.42 | 0.48 | 0.005 | 0.031 | ND | ND | ND | 0.0003 |
| M-40 | 1,1,2,2-Tetrachloroethane | 79-34-5 | 167.85 | 1.11 | 0.0290 | ND | ND | ND | ND | 0.0002 |
| M-40 | 1,1-Dichloroethane (Ethylidene Dichloride) | 75-34-3 | 98.96 | 2.35 | 0.033 | 0.178 | 0.423 | 0.591 | ND | 0.0003 |
| M-40 | 1,1-dichloroethene | 75-35-4 | 96.94 | 0.20 | 0.002 | 0.008 | 0.055 | 0.021 | ND | 0.0002 |
| M-40 | 1,2-Dichloroethane | 107-06-2 | 98.96 | 0.41 | 0.001 | 0.005 | 0.037 | 0.022 | ND | 0.0003 |
| M-40 | 1,2-Dichloropropane | 78-87-5 | 112.98 | 0.18 | 0.001 | 0.005 | ND | ND | ND | 0.0003 |
| M-40 | Isopropyl alcohol (2-Propanol) | 67-63-0 | 60.11 | 50.10 | 0.114 | 0.356 | 1.280 | 6.63 | 2.36 | 0.0002 |
| M-40 | Acetone | 67-64-1 | 58.08 | 7.01 | 0.33 | 1.61 | 11.7 | 12.8 | 15.5 | 0.0003 |
| M-40 | Acrylontrile | 107-13-1 | 53.06 | 6.33 | ND | ND | ND | ND | ND | 0.02 |
| M-40 | Bromodichloromethane | 75-27-4 | 163.83 | 3.13 | 0.003 | 0.01 | ND | ND | ND | 0.0002 |
| M-40 | Butane | 106-97-8 | 58.12 | 5.03 | 4.87 | 3.3 | 37.9 | ND | 3.6 | 1 |
| M-40 | Carbon Disulfide | 75-15-0 | 76.13 | 0.58 | 0.014 | 0.134 | 0.157 | 0.093 | 0.34 | 0.0002 |
| M-40 | Carbon Tetrachloride | 56-23-5 | 153.84 | 0.004 | 0.00083 | 0.005 | ND | 0.038 | ND | 0.0005 |
| M-40 | Ethyl Mercaptan (Ethanediol) | 75-08-1 | 62.13 | 2.28 | ND | ND | ND | ND | ND | 0.02 |
| M-40 | Carbonyl Sulfide (Carbon Oxysulfide) | 463-58-1 | 60.07 | 0.49 | ND | ND | ND | ND | ND | 0.02 |
| M-40 | Chlorobenzene | 108-90-7 | 112.56 | 0.25 | 0.195 | 0.229 | 0.833 | 0.021 | 0.135 | 0.0002 |
| M-40 | Chloroethane (Ethyl Chloride) | 75-00-3 | 64.52 | 1.25 | 0.77 | 1.88 | 30.4 | 0.63 | ND | 0.0002 |
| M-40 | Chloroform | 67-66-3 | 119.39 | 0.03 | 0.040 | 0.19 | 0.744 | 0.485 | ND | 0.0003 |
| M-40 | Chloromethane | 74-87-3 | 50.49 | 1.21 | 0.012 | 0.072 | 1.26 | 0.232 | ND | 0.0001 |

| | | | | Concentration (ppmv) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Method** | **Compound** | **CAS Number** | **Formula Weight** | **Default Value** | **Landfill A** | **Landfill B** | **Landfill C** | **Landfill D** | **Landfill E** | **Detection Limit** |
| M-40 | 1,4-Dichlorobenzene | 106-46-7 | 147.00 | 0.21 | 0.043 | 0.255 | 0.328 | 0.686 | ND | 0.0003 |
| M-40 | 1,3-Dichlorobenzene | 541-73-1 | 147.00 | 0.21 | 0.00047 | 0.00203 | 0.394 | 0.650 | ND | 0.0002 |
| M-40 | 1,2-Dichlorobenzene | 95-50-1 | 147.01 | 0.21 | 0.0019 | 0.0004 | ND | 0.031 | ND | 0.0003 |
| M-40 | Dichlorodifluoromethane (Freon 12) | 75-71-8 | 120.91 | 15.70 | 0.118 | 0.468 | 1.60 | 1.24 | 0.232 | 0.0003 |
| M-40 | Dichlorofluoromethane (Freon 21) | 75-43-4 | 102.92 | 2.62 | ND | ND | ND | ND | ND | 0.02 |
| M-40 | Methylene Chloride (Dichloromethane) | 75-09-2 | 84.94 | 14.30 | 0.997 | 0.169 | 5.35 | 1.11 | 3.05 | 0.0001 |
| M-40 | Dimethyl Sulfide (Methyl Sulfide) | 75-18-3 | 62.13 | 7.82 | ND | ND | 0.68 | ND | ND | 0.02 |
| M-40 | Ethane | 74-84-0 | 30.07 | 889 | 6.2 | 4.6 | 14.3 | 5.6 | 13.5 | 1 |
| M-40 | Ethanol | 64-17-5 | 46.08 | 27.20 | 0.020 | 0.202 | 0.172 | 0.394 | 0.0002 | 0.0002 |
| M-40 | Ethylbenzene | 100-41-4 | 106.16 | 4.61 | 0.58 | 2.80 | 5.89 | 8.12 | ND | 0.0003 |
| M-40 | 1,2-Dibromoethane (Ethylene dibromide) | 106-93-4 | 187.88 | 0.001 | 0.001 | 0.007 | 0.021 | ND | ND | 0.0002 |
| M-40 | Trichloromonofluoromethane (Fluorotrichloromethane) (F11) | 75-69-4 | 137.38 | 0.76 | 0.051 | 0.327 | 0.504 | 0.116 | 0.0082 | 0.0002 |
| M-40 | Hexane | 110-54-3 | 86.18 | 6.57 | ND | ND | 4.94 | 3.98 | 0.597 | 0.0003 |
| M-11 | Hydrogen Sulfide | 7783-06-4 | 34.08 | 35.50 | 13.1 | 22.9 | 55.5 | 72.7 | 322 J | NR |
| Methods 101A & 324 | Mercury (Total) | | 215.63 | 253.0E-6 | 300.E-6 | 22.8E-6 | 51.2E-6 | 89.1E-6 | 163E-6 | 6.E-6 |
| M-40 | 2-Butanone (Methyl Ethyl Ketone) | 78-93-3 | 72.10 | 7.09 | 0.27 | 1.43 | 4.57 | 8.07 | 2.49 | 0.0003 |
| M-40 | 2-Hexanone (Methyl Butyl Ketone) | 591-78-6 | 100.16 | 1.87 | 0.557 | 0.441 | ND | ND | ND | 0.0002 |

| | | | | Concentration (ppmv) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Method** | **Compound** | **CAS Number** | **Formula Weight** | **Default Value** | **Landfill A** | **Landfill B** | **Landfill C** | **Landfill D** | **Landfill E** | **Detection Limit** |
| M-40 | Methyl Mercaptan (Methanethiol) | 74-93-1 | 48.11 | 2.49 | ND | ND | ND | ND | ND | 0.02 |
| M-40 | Pentane | 109-66-0 | 72.15 | 3.29 | 3.20 | 2.60 | 26.6 | 2.37 | 1.30 | 1 |
| M-40 | Tetrachloroethylene (Perchloroethylene) | 127-18-4 | 165.83 | 3.73 | 0.042 | 0.176 | 1.69 | 1.02 | 0.125 | 0.0003 |
| M-40 | Propane | 74-98-6 | 44.09 | 11.10 | 8.9 | 5.9 | 40.0 | 30.5 | 13.0 | 1 |
| M-40 | t-1,2-Dichloroethene | 156-60-5 | 96.94 | 2.84 | 0.003 | 0.009 | 0.042 | 0.053 | ND | 0.0003 |
| M-40 | Trichloroethylene (Trichloroethene) | 79-01-6 | 131.38 | 2.82 | 0.028 | 0.103 | 0.515 | 0.418 | 0.094 | 0.0002 |
| M-40 | Vinyl Chloride | 75-01-4 | 62.50 | 7.34 | 0.097 | 0.41 | 0.768 | 1.20 | 0.0634 | 0.0002 |
| M-40 | m/p-Xylene (Dimethyl Benzene) | 1330-20-7 | 106.16 | 12.10 | 3.73 | 3.98 | 9.21 | 13.6 | 9.00 | 0.00065 |
| M-40 | o-Xylene (Dimethyl Benzene) | 95-47-6 | 106.16 | 12.10 | 0.30 | 1.41 | 3.66 | 5.41 | 3.10 | 0.0003 |
| M-40 | Benzene (No-disposal or Unknown) | 71-43-2 | 78.11 | 1.91 | 0.073 | 0.251 | 1.63 | 1.20 | 0.887 | 0.0002 |
| M-25C | NMOC as Hexane (No-codispoal or Unknown) | | 86.17 | 595.00 | 373 | 355 | 5870 | 1006 | 233 | NR |
| M-40 | Toluene (Methyl Benzene) (No or Unknown) | 108-88-3 | 92.13 | 39.30 | 1.33 | 6.77 | 23.3 | 30.3 | 7.95 | 0.0003 |

ND - Constituent not detected at the stated method detection limits

NR – Constituent detection limit not reported by laboratory

## 6. Data Quality Assessment

Detailed assessments of this project's performance in terms of quality are included in the individual landfill test reports. With a few exceptions, the project was able to meet the Measurement Quality Objectives (MQOs) established in the QAPPs.

Table 6-1 shows a comprehensive overview of measurements that, for various reasons, did not meet the specified MQOs.

**Table 6-1. Summary of Sampling and Analyses Exceptions**

| | | Quality Assurance Observations | | | | |
|---|---|---|---|---|---|---|
| **Method** | **Measurement** | **Landfill A** | **Landfill B** | **Landfill C** | **Landfill D** | **Landfill E** |
| EPA Method 1 | Selection of traverse points | NI | NI | NI | NI | NI |
| EPA Method 2 | Determination of stack gas velocity and volumetric flow rate | NI | NI | NI | NI | NI |
| EPA Method 3A | Determination of stack gas $O_2$ and $CO_2$ for stack gas molecular weight calculations | CEM calibration and drift check exceeded criteria slightly. | CEM calibration and drift check exceeded criteria slightly | NI | NI | NI |
| EPA Method 3C | Determination of $CO_2$, $CH_4$, $N_2$, and $O_2$ in raw LFG | NI | NI | NI | NI | NI |
| EPA Method 4 | Determination of stack gas moisture | NI | NI | NI | NI | NI |
| EPA Method 6C | Determination of stack gas $SO_2$ | CEM calibration and drift check exceeded criteria slightly. | Drift and system bias checks exceeded criteria | NI | NI | NI |
| EPA Method 7E | Determination of stack gas $NO_X$ | CEM calibration and drift check exceeded criteria slightly. | Drift check exceeded criteria | NI | 1 drift check was at 3.3% | NI |
| EPA Method 10 | Determination of stack gas CO | NI | NI | NI | NI | NI |
| EPA Method 11 | Determination of raw LFG $H_2S$ | NI | NI | Exceeded hold time. | Exceeded hold time. | Did not do QAPP-specified spike. However method does not specify spike to be required. Data was flagged. |

| | | Quality Assurance Observations | | | | |
|---|---|---|---|---|---|---|
| **Method** | **Measurement** | **Landfill A** | **Landfill B** | **Landfill C** | **Landfill D** | **Landfill E** |
| EPA Method 23 | Determination of LFG PAHs by Method 8270 PCBs by Method 1668 | Extracts too concentrated for analysis. No data was produced | Extracts too concentrated for analysis. No data was produced | Not a specified measurement | Not a specified measurement | Not a specified measurement |
| EPA Method 23 | Determination of stack gas dioxins/furans by Method 8290 | 1 of 3 samples analyzed. Did not meet 90% completion goal | Exceeded hold time.<br>Detected some targets in blank. Data were notated.<br>1 of 3 samples analyzed. Did not meet 90% completion goal. | NI | Not a specified measurement | NI |
| EPA Method 23 | Determination of stack gas PAHs by Method 8270 | 1 of 3 samples analyzed. Did not meet 90% completion goal | Exceeded hold time.<br>Detected some targets in blank. Data were notated.<br>1 of 3 samples analyzed. Did not meet 90% completion goal. | Detected targets in blank.<br>Data reported and flagged.<br>Recovery of $d_{12}$-perylene was low<br>Relevant data were flagged. | Not a specified measurement | Detected targets in blank.<br>Data reported and flagged. |
| EPA Method 25A | Determination of flare stack gas NMOCs, as THCs | NI | Drift check exceeded criteria | NI | NI | NI |

| | | Quality Assurance Observations | | | | |
|---|---|---|---|---|---|---|
| **Method** | **Measurement** | **Landfill A** | **Landfill B** | **Landfill C** | **Landfill D** | **Landfill E** |
| EPA Method 25C | Determination of raw LFG NMOCs | Exceeded hold time. Detected 2 ppmv hexane in field blank. | Exceeded hold time. Detected 8.5 ppmv hexane in field blank. | NI | $N_2$ and $O_2$ exceeded threshold.<br>Data flagged | Exceeded hold time<br>Detected 3 ppmv hexane in field blank.<br>1 sample had $N_2$ and $O_2$ exceeded threshold. |
| EPA Method 26A | Determination of stack gas HCl | NI | NI | NI | NI | NI |
| EPA Method 29 | Determination of stack gas metals | NI | NI | Nickel CCV at 10.6 and 14.0% | Nickel CCV at 10.6 and 14.0% | Nickel CCV at 10.6 and 12.2% |
| EPA Method 40/TO-15 | Determination of raw LFG VOCs | Detected low concentrations of a few targets in field blank<br>Spike recovery exceeded criteria for ethanol and m/p Xylene.<br>RSD for hexane and isopropyl alcohol exceeded criteria.<br>Affected data were flagged | Detected low concentrations of a few targets in field blank,<br>Spike recovery for chlorobenzene exceeded criteria.<br>RSD for Methylene chloride exceeded criteria.<br>Affected data were flagged | Detected low concentrations of a few targets in field blank.<br>Data were flagged. | Detected low concentrations of a few targets in field blank.<br>Cyclohexane RSD 41.2%<br>Heptane RSD 57.4%<br>Data were flagged. | Detected low concentrations of a few targets in field blank.<br>Ethanol spike recovery 2.4%, m/p-xylene recovery 230%<br>Isopropyl alcohol RSD 56.3%<br>Hexane RSD 40.7% |
| SW-846 Method 0100/TO-11 | Determination of raw LFG carbonyls (formaldehyde, acetaldehyde) | Formaldehyde levels in samples are near the MDL. Results are flagged as estimates "J" | Detected 0.07µg formaldehyde in field blank | NI | NI | NI |

| | | Quality Assurance Observations | | | | |
|---|---|---|---|---|---|---|
| **Method** | **Measurement** | **Landfill A** | **Landfill B** | **Landfill C** | **Landfill D** | **Landfill E** |
| LUMEX instrument | Determination of raw LFG $Hg^0$ | NI | NI | NI | NI | Sampled at compressor exit |
| Organic mercury methods (Frontier) | Determination of raw LFG monomethyl mercury. | Exceeded 14-day hold time<br>RSD exceeded criteria | Exceeded 14-day hold time<br>RSD exceeded criteria | Exceeded 14-day hold time.<br>1 of 6 samples was damaged. | NI | Exceeded 14-day hold time |
| Organic mercury methods (Frontier) | Determination of raw LFG dimethyl mercury | Exceeded 14-day hold time<br>Spike recovery less than 40%. Data rejected. | Exceeded 14-day hold time<br>Spike recovery less than 40%. Data rejected. | NI | NI | Exceeded 14-day hold time |
| Organic mercury methods (Frontier) | Determination of raw LFG total mercury. | Exceeded 14-day hold time | Exceeded 14-day hold time | Exceeded 14-day hold time | Exceeded 14-day hold time | Exceeded 14-day hold time |
| Organic mercury methods (Geochimica) | Determination of raw LFG monomethyl mercury. | Not a specified measurement | Not a specified measurement | Not a specified measurement | Not a specified measurement | NI |
| Organic mercury methods (Geochimica) | Determination of raw LFG dimethyl mercury | Not a specified measurement | Not a specified measurement | Not a specified measurement | Not a specified measurement | NI |
| Organic mercury methods (Geochimica) | Determination of raw LFG total mercury. | Not a specified measurement | Not a specified measurement | Not a specified measurement | Not a specified measurement | NI |

NI – No issues or QA exceptions

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## 7. Conclusions

The test data collected during this test program provides updated information concerning the constituents in landfill gas and combustion by-products from five MSW landfills.  Ideally, it would be preferable to have collected data from a wider range of landfills covering different gas control technology, geographic areas, landfill size and age, and variations in waste composition.  The data are considered useful in providing a detailed and comprehensive set of data.  It also helps in evaluating how representative data are that have been supplied by industry, state and local regulatory authorities, and others.

The average concentrations of constituents in landfill gas for the five landfills were half or lower of their corresponding AP-42 values. For sixteen constituents, at least one landfill had an average concentration greater than the existing AP-42 value.   The details of the sampling at each site are provided in the appendices to this report.

Limitations in the data include lack of data from a wider range of combustion technology. Also, the field test measurements did not include wet or bioreactor landfills. Not clear if there will be an increase in air toxics resulting from increased levels of metals due to leachate recirculation and addition of sewage sludge or other liquid additions. Also, this study did not include turbines since they are not as widely used as boilers, IC engines, and flares. With increasing use of micro-turbines, it would be helpful to have data on combustion by-product emissions to compare to other technologies in use.

With respect to project QA, while a few of the measurements presented some challenges, the project succeeded in producing a comprehensive data set. Therefore, this project met its data quality objective of "*performing tests by using EPA reference test methods, or when not applicable, sound methodology and that tests are reported in enough detail for adequate validation and raw data are provided that can be used to duplicate the emission results presented in the report.*"

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# Field Test Measurements at Five Municipal Solid Waste Landfills with Landfill Gas Control Technology

## Appendix A
## SOURCE TEST REPORT
## FOR LANDFILL A

**This report presents the results of a field test conducted at Landfill A that is located in the northeastern U.S. Testing took place on November 1 and 2, 2002.**

## Tables

## Figures

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## Acronym List

| | |
|---|---|
| %D | Percent drift |
| AP-42 | Compilation of Air Pollutant Emission Factors |
| APPCD | Air Pollution Prevention Control Division |
| ARCADIS | ARCADIS G&M, Inc. |
| As | Arsenic |
| AS | Alternative standard |
| CCVs | Continuing calibration verification samples |
| Cd | Cadmium |
| CEMS | Continuous emission monitoring system |
| $CH_4$ | Methane |
| $Cl_2$ | Chlorine |
| CO | Carbon monoxide |
| $CO_2$ | Carbon dioxide |
| Cr | Chromium |
| DMHg | Dimethyl mercury |
| EPA | US Environmental Protection Agency |
| ES | Extraction standard |
| FID | Flame ionization detector |
| GC | Gas chromatograph |
| GC/FID | Gas chromatograph/flame ionization detector |
| GC/MS | Gas chromatograph/mass spectrometer |
| HCl | Hydrogen chloride |
| Hg | Mercury |
| $H_2S$ | Hydrogen sulfide |
| IC | Internal combustion |
| ICVs | Internal calibration verification samples |
| LFG | Landfill gas |
| MDL | Method Detection Limit |

| | |
|---|---|
| MMHg | Monomethyl mercury |
| Mn | Manganese |
| MQOs | Measurement quality objectives |
| MSW | Municipal solid waste |
| $N_2$ | Nitrogen |
| Ni | Nickel |
| NMOCs | Non-methane organic compounds |
| $NO_X$ | Nitrogen oxides |
| $O_2$ | Oxygen |
| PAHs | Polynuclear aromatic hydrocarbons |
| Pb | Lead |
| PCBs | Polychlorinated biphenyls |
| QA | Quality Assurance |
| QAPP | Quality Assurance Project Plan |
| QC | Quality control |
| RF | Response factor |
| RPD | Relative percent difference |
| RRF | Relative response factors |
| RSD | Relative standard deviation |
| RTP | Research Triangle Park |
| $SO_2$ | Sulfur dioxide |
| SS | Sampling standards |
| TCDD/TCDFs | Dioxins/furans |
| THCs | Total hydrocarbons |
| TICs | Tentatively identified compounds |
| TSR | Technical system review |
| VOCs | Volatile organic compounds |
| WC | Water column |

## 1. Introduction

Large municipal solid waste landfills are subject to Clean Air Act regulations because of concerns related to their emissions and their potential adverse effects to human health and the environment. Landfills are listed as a source of air toxics in the Urban Air Toxics Strategy for future evaluation of residual risk. Existing emission factors for landfill gas (LFG) were largely developed using data from the 1980s and early 1990s. A database was developed summarizing data from approximately 1,200 landfills, along with emissions information from the literature, and test reports prepared by state and local government agencies and industry. These data were summarized in *Compilation of Air Pollutant Emission Factors (AP-42)*, Chapter 2.4. 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 overall purpose of this testing program was to generate data that may be used to update AP-42 and include data that reflect current waste management operating practices.

This report presents the results of a field test conducted at Landfill A that is located in the northeastern U.S. Testing took place on November 1 and 2, 2002.

The site uses four internal combustion engine/electric generator sets to reclaim the energy content in the LFG. A standby enclosed flare is used for the destruction of any excess LFG. A more detailed description of the engine system is presented in Section 2. The specific purpose of the testing program was to determine the concentrations of constituents in the raw LFG and emissions from the stack of one of the engines. The constituents of interest in the raw LFG were volatile organic compounds (VOCs), non-methane organic compounds (NMOCs), hydrogen sulfide ($H_2S$), carbonyls (acetaldehyde and formaldehyde), polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and mercury (Hg) compounds. The pollutants of interest for the treated LFG, in this case at the engine stack, were carbon monoxide (CO), nitrogen oxides ($NO_X$), sulfur dioxide ($SO_2$), NMOCs as total hydrocarbons (THCs), hydrogen chloride (HCl), dioxins/furans (PCDD/PCDFs), PAHs, total Hg, and metals.

ARCADIS G&M, Inc. (ARCADIS), as contractor to the US Environmental Protection Agency's (EPA) Air Pollution Prevention Control Division (APPCD), performed this work under Work Assignment 4-1 of the Onsite Laboratory Support Contract (68-C-

99-201). The testing activities followed the specifications of the approved "*Site-Specific Quality Assurance Project Plan for the Field Evaluations of Landfill Gas Control Technologies* - *Landfill A*". This report was prepared under Work Assignment 2-26 of the continuing Onsite Laboratory Support Contract (EP-C-04-023).

## 2. Landfill Facility Descriptions

Available information indicated that the site began operation in 1972. By 2003, Landfill A had 2,700,000 tons of waste placed over an area of 56 acres. The landfill used 3,375 feet of horizontal collectors to collect the LFG. The gases generated in the landfill were extracted with 29 vertical wells. The collected LFG was piped to the engine and enclosed flare system where it was combusted.

### 2.1 Landfill Gas (LFG) Destruction Process Description and Operation

Figure 2-1 shows a simplified process schematic of the engine and flare system at Landfill A. The landfill utilizes a bank of four engine generator sets for destruction of LFG and generation of electricity. The engines are Caterpillar 3412 four-stoke internal combustion (IC) engines, adapted for LFG. The Caterpillar 3412 is a spark-ignited V-12 engine with displacement of 1649 cubic inches. The engine is turbocharged and after-cooled, and has a cylinder bore diameter of 5.4 inches and a stroke of 6.0 inches. Engine #2 was tested and was connected to a Caterpillar SR4 Generator that is rated at 470KW.

### 2.2 Control Equipment Description

The engines did not have pollution control equipment installed.

### 2.3 Excess Landfill Gas (LFG) Flare

A Perennial Energy Enclosed Ground Flare Station, rated at maximum LFG input rate of 1500 scfm, received and destroyed excess LFG not needed by the four engines. The enclosed flare was not part of the test program. Measurement of emissions from the landfill flare system was the focus of testing at two other landfills, as an integral part of the research program.

A condensate removal system prevents liquids from entering into the engine and flare burners. A flame arrestor prevents flame from propagating from the burner array back into the LFG collection and flow control system.

### 2.4 Sampling Locations

Gas sampling was conducted at the raw LFG pipe that fed the engines and flare, and at Engine #2 stack, as depicted in Figure 2-1.

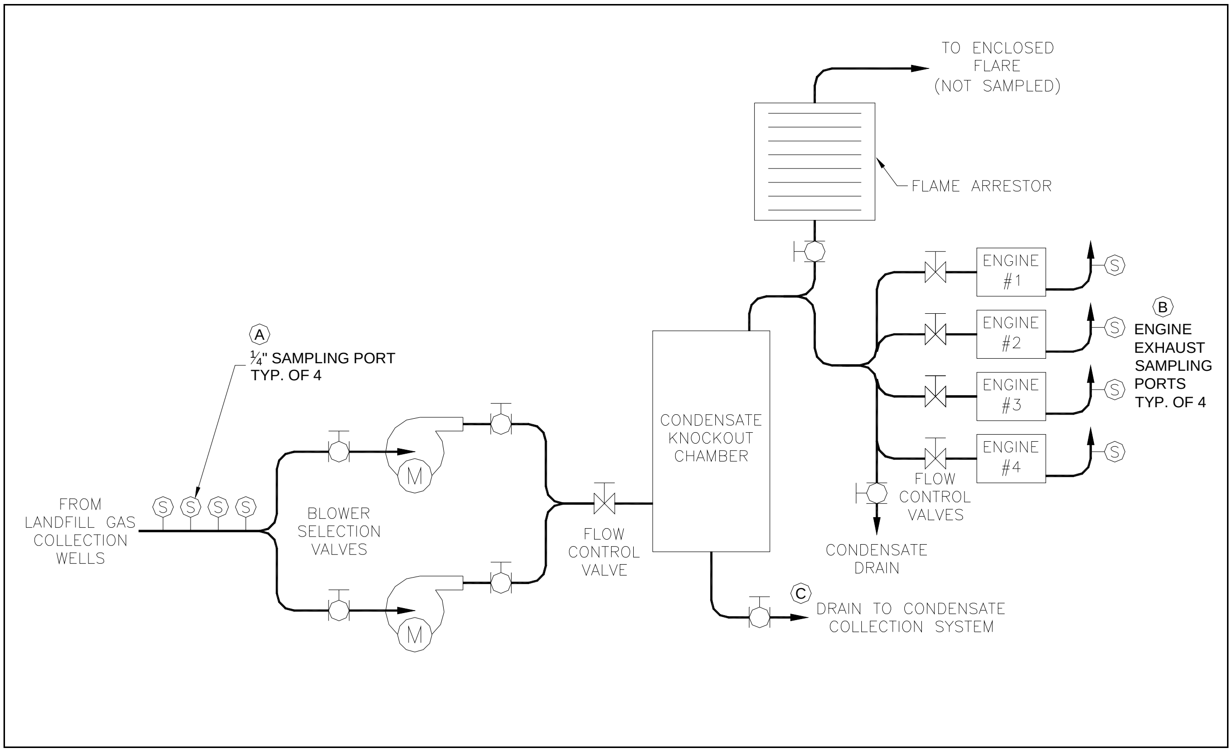


**Figure 2-1. Simplified Engine and Flare Process Flow Diagram and Sampling Points**

### 2.4.1 Raw Landfill Gas (LFG) Header Pipe

Raw LFG samples were collected from the header pipe as it emerged from the ground and upstream of any processing units. Figure 2-2 shows the raw LFG inlet pipe. The pipe was 12 inches in diameter as it emerged vertically from the ground and turned 90 degrees to run horizontally towards the LFG control-and-process system. At the sampling point, which was about 8 feet after the bend, four ¼" gas taps were installed on the top of the horizontal pipe, at approximately 6-inch spacing. Through these ports, gases were withdrawn to obtain the test samples.

Comparing the physical arrangement of this header pipe with requirements of standard sampling methodologies indicated that the header configuration rendered isokinetic sampling at the gas collection pipe impossible. Therefore, isokinetic sampling was not attempted at this location. Further discussions on this topic are presented in Section 3.3.1.1.

**Figure 2-2. Landfill Gas Collection Pipe**

### 2.4.2 Engine #2 Stack

Engine #2 is shown in Figure 2-3. The exhaust gas of the engine was ducted outside of the engine room via a pipe. The engine stack is 8.25 inches in diameter and has two 4-inch sampling ports installed 90 degrees apart. Figure 2-4 is a schematic of the engine stack and includes the locations of the sample traverse points. Isokinetic sampling was possible at this location and was followed.

**Figure 2-3. Engine/Generator Set #2**

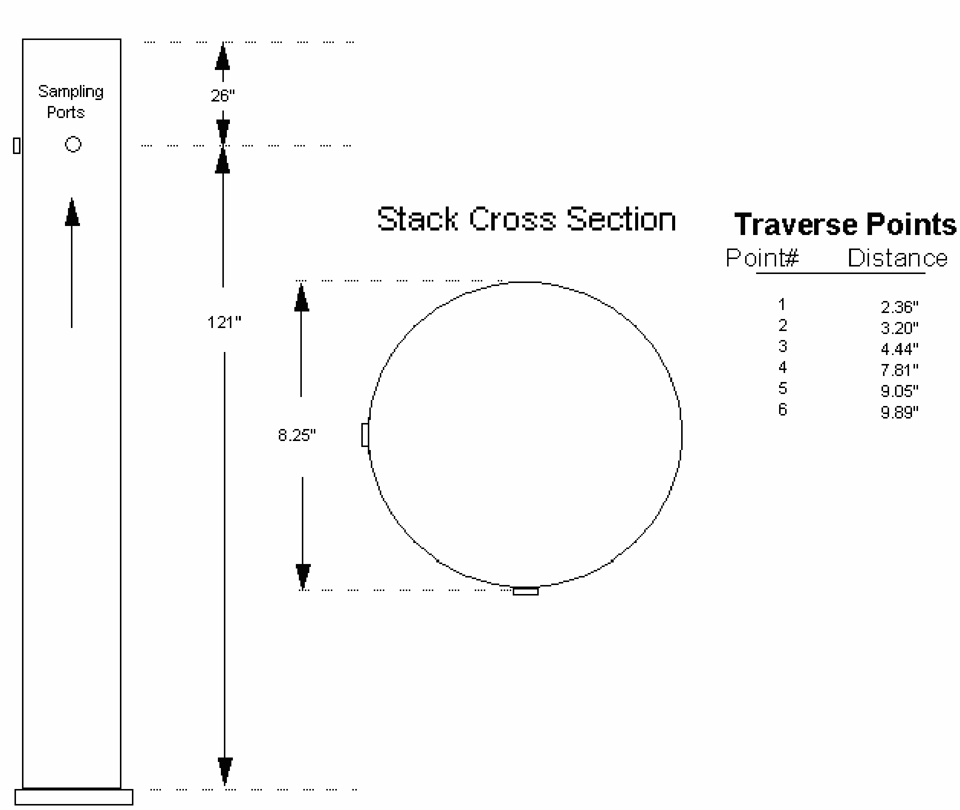


**Figure 2-4. Engine Stack Dimension and Sampling Traverse Locations**

# 3. Test Operations

As stated previously, the purpose of the sampling program was to determine the concentrations of the target analytes in the raw LFG at the header pipe and emissions from the engine stack.

## 3.1 Test Team

The tests were conducted by a team of seven individuals. In addition, ARCADIS' Quality Assurance (QA) Officer conducted an internal technical system review (TSR) during this test. The Work Assignment Leader provided general oversight. The team members and their primary duties are listed in Table 3-1.

**Table 3-1. ARCADIS Test Team Members and Responsibilities**

| Role | Primary Duty |
|---|---|
| Test Engineer | Chief |
| Technician | CEM operator |
| Technician | Sample train preparation and recovery |
| Technician | Sample train operator at raw LFG inlet pipe |
| Test engineer | Sample train operator at stack |
| Technician | Sample train operator at stack |
| Test engineer | Mercury measurements |
| Quality Assurance Officer | QA Technical Systems Review (Internal) |
| Work Assignment Leader | Observer and general over-sight |

## 3.2 Test Log

### 3.2.1 Planned Test Sample Matrices

The list of target samples to be collected and measurements to be conducted are specified in the Quality Assurance Project Plan (QAPP) dated October 29 2002. These are reiterated here for completeness. Table 3-2 lists the target compounds of interest for the raw LFG samples. Table 3-3 lists the target compounds of interest for the treated gas, collected from the engine stack.

**Table 3-2. Target Analytes for the Raw Landfill Gas and Sample Condensate Collected at the Gas Header**

| Volatile compounds | Volatile compounds (continued) | Carbonyls |
|---|---|---|
| Methane | Ethylene dibromide | Acetaldehyde |
| Ethane | Ethylene dichloride | Formaldehyde |
| Propane | Methyl chloroform | |
| Butane | Methyl isobutyl ketone | **Polycyclic aromatic hydrocarbons** |
| Pentane | Methylene chloride | |
| Hexane | Propylene dichloride | **Polychlorinated biphenyls** |
| Carbonyl sulfide | t-1,2-Dichloroethene | |
| Chlorodifluoromethane | Tetrachloroethene | **Mercury** |
| Chloromethane | Toluene | Organo-mercury compounds |
| Dichlorodifluoromethane | Trichlorethylene | Total |
| Dichlorofluoromethane | Vinyl chloride | Elemental |
| Ethyl chloride | Vinylidene chloride | |
| Fluorotrichloromethane | Ethanol | **Gases** |
| 1,3-Butadiene | Methyl ethyl ketone | Carbon dioxide |
| Acetone | 2-Propanol | Oxygen |
| Acrylonitrile | 1,4-Dichlorobenzene | |
| Benzene | Ethylbenzene | **Moisture** |
| Bromodichloromethane | Xylenes | |
| Carbon disulfide | | |
| Carbon tetrachloride | | |
| Chlorobenzene | **Non-methane organic carbons** | |
| Chloroform | | |
| Dimethyl sulfide | **Reduced sulfur compounds** | |
| Ethyl mercaptan | Hydrogen sulfide | |

**Table 3-3. Target Analytes for the Engine Stack Gas Stream**

| Gases | Dioxins/Furans (PCDD/PCDFs) |
|---|---|
| Oxygen | |
| Carbon dioxide | **Polycyclic Aromatic Hydrocarbons (PAHs)** |
| Carbon monoxide | |
| Nitrogen oxide | **Mercury** |
| Sulfur dioxide | Total |
| Total hydrocarbons | |
| **Non-methane organic compounds** | **Metals** |
| | Lead, arsenic, cadmium, chromium, manganese, nickel |
| **Hydrogen chloride** | |

### 3.2.2 Raw Landfill Gas (LFG) (Inlet)

Sample collection took two days to complete. Figure 3-1 shows the sampling team in action at this sample location. Table 3-4 lists the samples that were collected from the raw LFG pipe.

**Figure 3-1. Sampling Operations at the Raw Landfill Gas Inlet**

**Table 3-4. Raw Landfill Gas Sample Log and Collection Times**

| Sampling Method | Run Number | Analyte(s) | Sample Class | Date | Run Period |
|---|---|---|---|---|---|
| EPA Method 40 (TO-15, 25C, 3C) | | | | | |
| | A-Pre-M40-110202-01 | VOCs/NMOCs/$O_2$/$CO_2$,$N_2$ | Test | 11/02/02 | 10:30 - 10:58 |
| | A-Pre-M40-110202-02 | VOCs/NMOCs/$O_2$/$CO_2$,$N_2$ | Test | 11/02/02 | 11:40 - 12:18 |
| | A-Pre-M40-110202-03 | VOCs/NMOCs/$O_2$/$CO_2$,$N_2$ | Test | 11/02/02 | 12:37 - 13:09 |
| EPA Method 23 | | | | | |
| | A-Pre-M23-110102-01 | PAHs, PCBs | Test | 11/01/02 | 11:05 - 14:08 |
| | A-Pre-M23-110102-02 | PAHs, PCBs | Test | 11/01/02 | 11:05 - 14:05 |
| | A-Pre-M23-110102-03 | PAHs, PCBs | Test | 11/01/02 | 15:46 - 18:46 |
| EPA Method 0100 | | | | | |
| | A-Pre-M0100-110202-01 | Carbonyls | Test | 11/02/02 | 11:23 - 11:53 |
| | A-Pre-M0100-110202-02 | Carbonyls | Test | 11/02/02 | 12:10 - 12:40 |
| | A-Pre-M0100-110202-03 | Carbonyls | Test | 11/02/02 | 13:03 - 13:33 |
| EPA Method 11 | | | | | |
| | A-Pre-M0011-110202-01 | $H_2S$ | Test | 11/02/02 | 14:33 - 14:43 |
| | A-Pre-M0011-110202-02 | $H_2S$ | Test | 11/02/02 | 15:40 - 15:50 |
| | A-Pre-M0011-110202-03 | $H_2S$ | Test | 11/02/02 | 16:25 - 16:35 |
| Lumex Instrument | | | | | |
| | A-Pre-EM-110202-01 | Elemental Hg [a] | Test | 11/02/02 | 14:49 - 16:00 |
| | A-Pre-EM-110202-02 | Elemental Hg [a] | Test | 11/02/02 | 14:49 - 16:00 |
| | A-Pre-EM-110202-03 | Elemental Hg [a] | Test | 11/02/02 | 14:49 - 16:00 |
| Frontier | | | | | |
| | A-Pre-TGM-110102-FB01 | Total gaseous Hg | Field Blank | 11/01/02 | 14:45 |
| | A-Pre-TGM-110102-01 | Total gaseous Hg | Test | 11/01/02 | 11:20 - 11:55 |
| | A-Pre-TGM-110102-02 | Total gaseous Hg | Test | 11/01/02 | 12:26 - 13:03 |
| | A-Pre-TGM-110102-03 | Total gaseous Hg | Test | 11/01/02 | 13:49 - 14:23 |
| Frontier | | | | | |
| | A-Pre-MMM-110202-SP01 | Monomethyl Hg | Spike | 11/02/02 | 15:50 - 14:24 |
| | A-Pre-MMM-110202-FB01 | Monomethyl Hg | Field Blank | 11/02/02 | 13:30 - 13:35 |
| | A-Pre-MMM-110202-01 | Monomethyl Hg | Test | 11/02/02 | 10:15 - 10:44 |

| Sampling Method | Run Number | Analyte(s) | Sample Class | Date | Run Period |
|---|---|---|---|---|---|
| | A-Pre-MMM-110202-02 | Monomethyl Hg | Test | 11/02/02 | 11:08 - 11:40 |
| | A-Pre-MMM-110202-03 | Monomethyl Hg | Test | 11/02/02 | 12:13 - 12:45 |
| Frontier | | | | | |
| | A-Pre-DMM-110202-SP01 | Dimethyl Hg | Spike | 11/02/02 | 08:46 - 09:12 |
| | A-Pre-DMM-110202-FB01 | Dimethyl Hg | Field Blank | 11/02/02 | 08:10 - 08:15 |
| | A-Pre-DMM-110202-01 | Dimethyl Hg | Test | 11/02/02 | 15:19 - 15:44 |
| | A-Pre-DMM-110202-02 | Dimethyl Hg | Test | 11/02/02 | 16:31 - 17:00 |
| | A-Pre-DMM-110202-03 | Dimethyl Hg | Test | 11/02/02 | 17:26 - 17:55 |

[a] Represents average of 3 readings, each of 30-second duration

### 3.2.3 Engine Stack

Sampling at the engine stack was conducted by accessing the sampling ports with the aid of a scaffold. Figure 3-2 shows the engine and the sampling scaffold platform.

The engine stack was sampled for NMOCs (as THCs), PCDDs/PCDFs, PAHs, HCl, lead (Pb), arsenic (As), cadmium (Cd), chromium (Cr), manganese (Mn), nickel (Ni), total Hg, $SO_2$, $NO_X$, CO, carbon dioxide ($CO_2$), and oxygen ($O_2$). Table 3-5 lists the test samples that were collected from the engine stack.

The engine stack cross-section was divided into 6 equal areas according to EPA Method 1. Sampling at the engine stack was conducted at isokinetic conditions. Sample collection times for the Method 26 HCl train and the Method 29 metals train were 60-minutes. Run time for the Method 23 PCDDs/PCDFs trains was 180 minutes. Run time for continuous emission monitoring system (CEMS) parameters ($SO_2$, $NO_X$, CO, $O_2$, $CO_2$, and THCs) varied.

**Figure 3-2. Engine #2 Stack and Sampling Scaffold**

**Table 3-5. Engine Stack Test Sample Log and Collection Times**

| Sampling Method | Run Number | Analyte(s) | Sample Class | Date | Run Period |
|---|---|---|---|---|---|
| EPA Method 3A (CEM) | | | | | |
| | A-Post-M3A-110102-01 | $O_2$ | Test | 11/01/02 | 12:03 - 14:50 |
| | A-Post-M3A-110102-02 | $O_2$ | Test | 11/01/02 | 16:42 - 19:00 |
| | A-Post-M3A-110202-03 | $O_2$ | Test | 11/02/02 | 09:50 - 15:20 |
| EPA Method 3A (CEM) | | | | | |
| | A-Post-M3A-110102-01 | $CO_2$ | Test | 11/01/02 | 12:03 - 14:50 |
| | A-Post-M3A-110102-02 | $CO_2$ | Test | 11/01/02 | 16:42 - 19:00 |
| | A-Post-M3A-110202-03 | $CO_2$ | Test | 11/02/02 | 09:50 - 15:20 |
| EPA Method 10 (CEM) | | | | | |
| | A-Post-M10-110102-01 | CO | Test | 11/01/02 | 12:03 - 14:50 |
| | A-Post-M10-110102-02 | CO | Test | 11/01/02 | 16:42 - 19:00 |
| | A-Post-M10-110202-03 | CO | Test | 11/02/02 | 09:50 - 15:20 |
| EPA Method 7E (CEM) | | | | | |
| | A-Post-M7E-110102-01 | $NO_X$ | Test | 11/01/02 | 12:03 - 14:50 |
| | A-Post-M7E-110102-02 | $NO_X$ | Test | 11/01/02 | 16:42 - 19:00 |
| | A-Post-M7E-110202-03 | $NO_X$ | Test | 11/02/02 | 09:50 - 15:20 |
| EPA Method 6C (CEM) | | | | | |
| | A-Post-M6C-110102-01 | $SO_2$ | Test | 11/01/02 | 12:03 - 14:50 |
| | A-Post-M6C-110102-02 | $SO_2$ | Test | 11/01/02 | 16:42 - 19:00 |
| | A-Post-M6C-110202-03 | $SO_2$ | Test | 11/02/02 | 09:50 - 15:20 |
| EPA Method 25A (CEM) | | | | | |
| | A-Post-M25A-110102-01 | NMOCs (THC) | Test | 11/01/02 | 12:03 - 14:50 |
| | A-Post-M25A-110102-02 | NMOCs (THC) | Test | 11/01/02 | 16:42 - 19:00 |
| | A-Post-M25A-110202-03 | NMOCs (THC) | Test | 11/02/02 | 09:50 - 15:20 |
| Lumex Instrument | | | | | |
| | A-Post-EM-110202-01 | Elemental Hg [a] | Test | 11/02/02 | 14:49 - 16:00 |
| | A-Post-EM-110202-02 | Elemental Hg [a] | Test | 11/02/02 | 14:49 - 16:00 |

| Sampling Method | Run Number | Analyte(s) | Sample Class | Date | Run Period |
|---|---|---|---|---|---|
| EPA Method 26 | | | | | |
| | A-Post-M26-110102-01 | HCl | Test | 11/01/02 | 15:32 - 16:57 |
| | A-Post-M26-110102-02 | HCl | Test | 11/01/02 | 15:34 - 16:59 |
| | A-Post-M26-110202-03 | HCl | Test | 11/02/02 | 13:10 - 14:17 |
| EPA Method 23 | | | | | |
| | A-Post-M23-110102-01 | Dioxins/furans, PAHs | Test | 11/01/02 | 11:09 - 13:30 |
| | A-Post-M23-110102-02 | Dioxins/furans, PAHs | Test | 11/01/02 | 11:12 - 14:33 |
| | A-Post-M23-110202-03 | Dioxins/furans, PAHs | Test | 11/02/02 | 09:01 - 12:14 |
| EPA Method 29 | | | | | |
| | A-Post-M29-110102-01 | Metals | Test | 11/01/02 | 17:42 - 18:55 |
| | A-Post-M29-110102-02 | Metals | Test | 11/01/02 | 17:44 - 18:57 |
| | A-Post-M29-110202-03 | Metals | Test | 11/02/02 | 13:13 - 14:21 |

[a] Represents 3 readings, each 30 seconds in duration

## 3.3 Field Test Changes and Deviations from QAPP Specifications

### 3.3.1 Variation from Test Methods and/or Planned Activities

#### *3.3.1.1 Sampling at the Raw Landfill Gas (LFG) Pipe*

Because of the configuration of the raw LFG inlet pipe, isokinetic sampling at this location was not possible and hence was not attempted. The gas collection pipe is 12 inches in diameter (see Figure 2-2). Isokinetic sampling requires a 4-inch port to accommodate the sampling probe. During the pre-test site survey, facility could only install ¼-inch sampling ports on the gas pipe because of safety concerns. Therefore, collecting the samples isokinetically was not possible.

Isokinetic sampling would be of value if collecting particulate samples were needed. Little particulate matter was expected in the raw LFG pipe and this speculation was corroborated by the observation that the glass fiber filters on several of the sampling trains did not reveal the presence of particulates.

#### *3.3.1.2 Landfill Gas (LFG) Inlet Pipe Condensate Sample*

The facility used a condensate knock-out vessel to separate the condensate from the gas stream. During these tests, the condensate drain valve was in the “closed” position. According to the site operator, that was the typical operation configuration for the unit. There were not provisions to withdraw a condensate sample from the knock-out vessel. However, the pipe that delivers the raw LFG to the engines runs along the outside of the engine room. A condensate drain pipe with a valve was in place. A sample of the condensate was collected at that location and placed in archive storage so that it would be available if analysis were deemed necessary. The condensate sample was not analyzed.

#### *3.3.1.3 Landfill Gas (LFG) Flow Rate Measurement*

Gas flow as indicated by the LFG flow control station was recorded. However, the accuracy of these measurements could not be verified because of the inability to measure gas velocity accurately. The test team was able to make crude velocity measurements by inserting a velocity probe part-way into the gas pipe. The accuracies of these measurements are uncertain, even though they appear to agree with the facility’s flow control station readings.

### 3.3.2 Application of Test Methods

The sampling and, where applicable, analytical methods used in this test program follow those specified in the QAPP. Table 3-6 lists the applicable measurement and analysis methods and their corresponding performing organizations.

**Table 3-6. Test Methods and Performing Organizations**

| Procedure | Description | Organization Performing Analysis |
|---|---|---|
| EPA Method 1 | Selection of traverse points | ARCADIS G&M |
| EPA Method 2 | Determination of stack gas velocity and volumetric flow rate | ARCADIS G&M |
| EPA Method 3A | Determination of stack gas $O_2$ and $CO_2$ for flare stack gas molecular weight calculations | ARCADIS G&M |
| EPA Method 3C | Determination of $CO_2$, $CH_4$, $N_2$, and $O_2$ in raw LFG | Triangle Environmental Services |
| EPA Method 4 | Determination of stack gas moisture | ARCADIS G&M |
| EPA Method 6C | Determination of stack gas $SO_2$ | ARCADIS G&M |
| EPA Method 7E | Determination of stack gas $NO_X$ | ARCADIS G&M |
| EPA Method 10 | Determination of stack gas CO | ARCADIS G&M |
| EPA Method 11 | Determination of raw LFG $H_2S$ | Oxford Laboratories |
| EPA Method 23 | Determination of stack gas<br>Dioxins/furans by Method 8290<br>PAHs by Method 8270<br>PCBs by Method 1668 | ALTA Analytical Perspectives |
| EPA Method 25A | Determination of flare stack gas NMOCs, as THCs when total organic concentration is less than the 50 ppm Method 25C applicability threshold | ARCADIS G&M |
| EPA Method 25C | Determination of raw LFG NMOCs | Triangle Environmental Services |
| EPA Method 26A | Determination of stack gas HCl | Resolution Analytics |
| EPA Method 29 | Determination of stack gas metals | First Analytical Laboratories |
| EPA Method 40/TO-15 | Determination of raw LFG VOCs | Research Triangle Park Laboratories |
| SW-846 Method 0100/TO-11 | Determination of raw LFG carbonyls (formaldehyde, acetaldehyde) | Resolution Analytics |
| LUMEX instrument | Determination of raw LFG $Hg^0$ | ARCADIS G&M |
| Organic mercury methods | Determination of raw LFG:<br>Monomethyl mercury<br>Dimethyl mercury<br>Total mercury. | Frontier Geosciences |

#### 3.3.3 Test Method Exceptions

Laboratory analytical procedures followed those prescribed by the specified methods, with the following exceptions:

Raw LFG

- Carbonyls were analyzed by Method TO-11 instead of SW-846 Method 8315. (Method TO-11 and Method 8315 closely resemble each other.)

- Polycyclic aromatic hydrocarbons (PAHs) were analyzed by SW-846 Method 8270 as specified in the QAPP. However, the sample extracts were found to contain excessive amounts of non-PAH organics. In order to make the extracts safe to be injected into the gas chromatograph/mass spectrometer (GC/MS), samples had to be diluted excessively. The high dilution made the method detection levels for the target PAHs too high, resulting in “non-detects” at the high detection limits. The planned analysis method could not produce the desired results at the needed detection levels. At the time of report writing, alternative analysis method had not been identified. The sample extracts are in storage and may be submitted for analysis if a suitable method becomes available.

- Polychlorinated biphenyls (PCBs) were analyzed by EPA Method 1668 (EPA 812/R-97-001) as specified in the QAPP. However, similar to the difficulties experienced for the PAH analysis, in order to make the extracts safe to be injected inject into the gas chromatograph (GC), they had to be diluted excessively. The planned analysis method could not produce the desired results at the needed detection levels.

- For raw LFG inlet samples, VOCs were analyzed by EPA Method TO-15. Methane ($CH_4$) was analyzed by GC/FID and additionally by Method 3C.

Engine Stack

- Non-methane organic compounds (NMOCs) - Method 25A was used instead of the specifically applicable Method 25C.

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# 4. Presentation of Test Results

Testing took place at Landfill A on November 1-2, 2002. Results of the testing are presented in this section. Detailed test results are included in the Appendices for close examination by the reader. The following subsections provide concise summaries of the test results.

## 4.1 Raw Landfill Gas (LFG) Results

As depicted in Figure 2-2, sampling was conducted by extracting samples from the four ¼-inch ports installed in the raw LFG pipe.

### 4.1.1 Raw Landfill Gas (LFG) Flow Rate and Temperature

#### *4.1.1.1 Direct Measurements*

The facility process system has a flow measurement system that displays the flow rate on an instrument panel meter. The panel meter read between 1650 and 1700 scfm.

The small size of the sampling ports precluded the proper measurement of the velocity profile all the way across the gas pipe. Nonetheless, measurements with a velocity probe ranged from 1935 ft/min to 2075 ft/min. At these velocities, and with pipe inside diameter of 12 inches, the volumetric flow rate was estimated to be about 1580 cu ft/min. Vacuum at the raw LFG pipe was 34 to 35 inch water column (WC).

A direct measurement with thermocouples showed the raw LFG temperature was 57°F.

#### *4.1.1.2 Landfill Gas (LFG) Flow Rate Combined Estimate*

The raw LFG flow rate was based on two independent measurements: 1650 to 1700 scfm by the facility's flow rate indicator and 1580 scfm by the crude pitot probe measurement. This resulted in an estimated average of 1640 scfm.

### 4.1.2 Raw Landfill Gas (LFG) Constituents

The concentrations of the constituents of interest in the raw LFG are presented in the following Subsections 4.1.2.1 through 4.1.2.5. Following the presentation of the constituent concentrations, Section 4.3 summarizes the data and presents a comparison with the AP-42 default emission concentration values. The section also presents the estimated mass flow rates of the constituents at the raw LFG pipe.

In computing averages, when all measurements are “non-detect” (ND), the average is reported as ND. When one or more measurement is above detection, the ND measurement is treated as 50 percent of the stated method detection limit (MDL). If MDL is not reported, a ND measurement is treated as zero.

#### *4.1.2.1 Volatile Organic Compounds (VOCs)*

Concentrations of VOCs were obtained by collecting summa canister samples using Method 40 procedures. Analysis was performed by Method TO-15, with gas chromatography and mass spectrometry (GC/MS). The alkanes (C2 through C6), being present in much higher concentrations, were analyzed by GC flame ionization detection (FID) on the same summa canister samples.

Table 4-1 lists the results of these analyses. Tentatively identified compounds (TICs) can be seen in the Research Triangle Park (RTP) Laboratory reports in Appendix A.

**Table 4-1. Raw Landfill Gas VOC Concentrations**

| Compound | Unit | MDL | Concentration | | | |
|---|---|---|---|---|---|---|
| | | | Run 1 | Run 2 | Run 3 | Average [a] |
| **By GC/FID** | | | | | | |
| Ethane | ppmv | 1 | 5.9 | 6.5 | 6.1 | 6.2 |
| Propane | ppmv | 1 | 8.5 | 9.0 | 9.3 | 8.9 |
| Butane | ppmv | 1 | 4.4 | 4.7 | 5.5 | 4.9 |
| Pentane | ppmv | 1 | 3.2 | 2.7 | 3.7 | 3.2 |
| Hexane | ppmv | 1 | ND | ND | ND | ND |
| **By TO-15 GC/MS** | | | | | | |
| Dichlorodifluoromethane (Freon 12) | ppbv | 0.2 | 126 | 132 | 96 | 118 |
| 1,2-Chloro-,1,2,2-Tetrafluoroethane (CFC114) | ppbv | 0.2 | 8.2 | 8.0 | 7.1 | 7.8 |
| Chloromethane | ppbv | 0.2 | ND | 36 | ND | 12 |
| Vinyl chloride | ppbv | 0.2 | 101 | 103 | 87 | 97 |
| 1,3-Butadiene (Vinylethylene) | ppbv | 0.2 | 24 | 22 | 20 | 22 |

| Compound | Unit | MDL | Concentration | | | |
|---|---|---|---|---|---|---|
| | | | Run 1 | Run 2 | Run 3 | Average [a] |
| Bromomethane (Methyl Bromide) [c] | ppbv | 0.2 | 5.7 | 5.7 | 35.6 | 15.6 |
| Chloroethane (Ethyl Chloride) | ppbv | 0.2 | 951 | 1100 | 256 | 770 |
| Trichloromonofluoromethane (CFC11) | ppbv | 0.2 | 60 | 51 | 43 | 51 |
| 1,1-Dichloroethene | ppbv | 0.2 | 1.7 | 1.7 | 1.6 | 1.7 |
| 1,1,2-Trichloro-1,2,2-trifluoroethane (CFC113) | ppbv | 0.2 | 2.2 | 2.1 | 1.8 | 2.0 |
| Carbon Disulfide | ppbv | 0.2 | 15.9 | 11.8 | 15.6 | 14.4 |
| Ethanol [d] | ppbv | 0.2 | 23.4 J | 20.1 J | 15.7 J | 19.7 J |
| Isopropyl Alcohol (2-Propanol) [e] | ppbv | 0.2 | 145 J | 160 J | 36.1 J | 114 J |
| Methylene chloride (Dichloromethane) [c] | ppbv | 0.2 | 871 | 1070 | 1050 | 997 |
| Acetone [c] | ppbv | 0.2 | 381 | 325 | 278 | 328 |
| t-1,2-dichloroethene | ppbv | 0.2 | 2.9 | 2.6 | 2.6 | 2.7 |
| Hexane [e] | ppbv | 0.2 | 2270 J | 2370 J | 2780 J | 2470 J |
| Methyl-t-butyl ether (MTBE) | ppbv | 0.2 | 60.6 | 52.4 | 50.2 | 54.4 |
| 1,1-Dichloroethane | ppbv | 0.2 | 17.8 | 57.0 | 25.5 | 33.4 |
| Vinyl Acetate | ppbv | 0.2 | 435 | 265 | 27 | 242 |
| cis-1,2-Dichloroethene | ppbv | 0.2 | 79.9 | 69.7 | 72.7 | 74.1 |
| Cyclohexane | ppbv | 0.2 | 177 | 167 | 151 | 165 |
| Chloroform | ppbv | 0.2 | 44.0 | 36.6 | 38.7 | 39.8 |
| Ethyl Acetate | ppbv | 0.2 | ND | 2670 | 2810 | 1830 |
| Carbon Tetrachloride | ppbv | 0.2 | 1.3 | 1.1 | ND | 0.8 |
| Tetrahydrofuran (Diethylene Oxide) | ppbv | 0.2 | 980 | 1070 | 1510 | 1180 |
| 1,1,1-Trichloroethane | ppbv | 0.2 | 5.6 | 4.9 | 4.3 | 4.9 |
| 2-Butanone (Methyl Ethyl Ketone) | ppbv | 0.2 | 289 | 249 | 281 | 273 |
| Heptane | ppbv | 0.2 | 262 | 238 | 225 | 242 |
| Benzene | ppbv | 0.2 | 79.3 | 70.2 | 69.6 | 73.0 |
| 1,2-Dichloroethane | ppbv | 0.2 | 1.1 | 0.9 | 1.1 | 1.0 |
| Trichloroethylene (Trichloroethene) | ppbv | 0.2 | 31.1 | 26.2 | 26.6 | 28.0 |

| Compound | Unit | MDL | Concentration | | | |
|---|---|---|---|---|---|---|
| | | | Run 1 | Run 2 | Run 3 | Average [a] |
| 1,2-Dichloropropane | ppbv | 0.2 | 0.8 | 0.7 | 0.8 | 0.8 |
| Bromodichloromethane | ppbv | 0.2 | 3.6 | 2.2 | 2.1 | 2.6 |
| 1,4-Dioxane (1,4-Diethylene Dioxide) | ppbv | 0.2 | 3.1 | 2.6 | ND | 1.9 |
| cis-1,3-Dichloropropene | ppbv | 0.2 | ND | ND | 0.5 | 0.2 |
| Toluene (Methyl Benzene) | ppbv | 0.2 | 680 | 1620 | 1670 | 1330 |
| 4-Methyl-2-pentanone (MIBK) | ppbv | 0.2 | 1250 | 1320 | 650 | 1070 |
| t-1,3-Dichloropropene | ppbv | 0.2 | 0.6 | 0.2 | ND | 0.3 |
| Tetrachloroethylene (Perchloroethylene) | ppbv | 0.2 | 45.1 | 40.0 | 41.1 | 42.1 |
| 1,1,2-Trichloroethane | ppbv | 0.2 | 7.5 | 7.5 | 7.9 | 7.6 |
| Dibromochloromethane | ppbv | 0.2 | ND | ND | ND | ND |
| 1,2-Dibromoethane (Ethylene dibromide) | ppbv | 0.2 | 0.8 | 0.7 | 1.7 | 1.1 |
| 2-Hexanone (Methyl Butyl Ketone) | ppbv | 0.2 | 380 | 494 | 796 | 557 |
| Ethylbenzene | ppbv | 0.2 | 612 | 545 | 570 | 575 |
| Chlorobenzene | ppbv | 0.2 | 74.4 | 64.8 | 445 | 195 |
| m/p-Xylene (Dimethyl Benzene) [d] | ppbv | 0.2 | 3200 J | 3540 J | 4450 J | 3730 J |
| o-Xylene (Dimethyl Benzene) | ppbv | 0.2 | 312 | 290 | 298 | 300 |
| Styrene (Vinylbenzene) | ppbv | 0.2 | 41.5 | 38.2 | 8.8 | 29.5 |
| Tribromomethane (Bromoform) | ppbv | 0.2 | 1.1 | ND | ND | 0.4 |
| 1,1,2,2-Tetrachloroethane | ppbv | 0.2 | 49.1 | ND | 40.4 | 29.9 |
| 1-Ethyl-4-methylbenzene [b] (4-Ethyl Toluene) | ppbv | 0.2 | 81.9 J | 77.4 J | 78.6 J | 79.3 J |
| 1,3,5-Trimethylbenzene [b] | ppbv | 0.2 | 81.9 J | 77.4 J | 78.6 J | 79.3 J |
| 1,2,4-Trimethylbenzene | ppbv | 0.2 | 199 | 186 | 194 | 193 |
| 1,4-Dichlorobenzene | ppbv | 0.2 | 44.5 | 42.3 | 43.2 | 43.4 |
| 1,3-Dichlorobenzene | ppbv | 0.2 | 0.6 | 0.7 | ND | 0.5 |
| Benzyl Chloride | ppbv | 0.2 | 3.8 | 4.5 | 10.5 | 6.3 |
| 1,2-Dichlorobenzene | ppbv | 0.2 | 2.8 | 2.7 | ND | 1.9 |

| Compound | Unit | MDL | Concentration | | | |
|---|---|---|---|---|---|---|
| | | | Run 1 | Run 2 | Run 3 | Average [a] |
| 1,1,2,3,4,4-Hexachloro-1,3-butadiene | ppbv | 0.2 | 1.1 | 1.3 | 1.3 | 1.2 |
| 1,2,4-Trichlorobenzene | ppbv | 0.2 | 0.5 | 1.3 | 1.2 | 1.0 |
| Acrylontrile | ppbv | 20 | ND | ND | ND | ND |
| Dichlorofluoromethane (Freon 21) | ppbv | 20 | ND | ND | ND | ND |
| Chlorodiflouromethane (Freon 22) | ppbv | 20 | ND | ND | ND | ND |
| Ethyl Mercaptan (Ethanediol) | ppbv | 20 | ND | ND | ND | ND |
| Carbonyl Sulfide (Carbon oxysulfide) | ppbv | 20 | ND | ND | ND | ND |

ND – Constituent not detected at the stated detection limits

J – Value is categorized as an estimate per EPA QA/G-8 guidance

[a] In computing averages, when all measurements are ND, the average is reported as ND. When one or more measurement is above detection, the ND measurement is treated as 50 percent of the stated MDL. If MDL is not reported, a ND measurement is treated as zero.

[b] 1-Ethyl-4-methylbenzene (4-Ethyl Toluene) and 1,3,5-Trimethylbenzene co-eluted from the GC and also have the same quantitation ions, thus making them indistinguishable. Therefore, the reported values represent the combined concentrations of these two compounds.

[c] Analyte detected in blank sample: acetone = 3.3 ppbv, methylene chloride = 1.4 ppbv, bromomethane = 1.03 ppbv

[d] Spike recovery: ethanol = 2-4 percent, m/p-xylene = 230 percent

[e] RSD: isopropyl alcohol – 56.3 percent, hexane = 40.7 percent

#### *4.1.2.2 Non-methane Organic Compounds (NMOCs)*

Non-methane organic compounds (NMOCs) in the raw LFG were analyzed by Method 25C on the Method 40 samples. The NMOC concentrations in the raw LFG are presented in Table 4-2. This table also includes concentrations of $CH_4$, $CO_2$, $O_2$, and nitrogen ($N_2$) that are results obtained as part of the NMOC analyses. The moisture concentration data were obtained from the Method 23 PAH/PCB sample train measurements.

The other analytes, oxygen ($O_2$), carbon dioxide ($CO_2$), and moisture, are not pollutants but are of interest as they are useful indicators of the “quality” of the raw LFG. The concentrations of nitrogen ($N_2$) and $O_2$ are also indicators of the extent of ambient air infiltration into the LFG collection. Method 25C for NMOC determination specifically recommends that these measurements be made to determine potential air infiltration. Therefore, while measurements for methane ($CH_4$), $CO_2$, $O_2$, and $N_2$ by Method 3C were not included in the original QAPP, these measurements were included and performed.

**Table 4-2. Raw Landfill Gas Non-Methane Organic Compound (NMOC) Concentrations**

| | NMOC (ppmv as Hexane) | $CH_4$ (% v/v) | | $CO_2$ (% v/v) | | $O_2$ (%v/v) | $N_2$ (% v/v) | Moisture (% v/v) |
|---|---|---|---|---|---|---|---|---|
| | Method 25C | Method 25C | Method 3C | Method 25C | Method 3C | Method 3C | Method 3C | Method 23 |
| Run 1 | 297 | 48.0 | 43.5 | 38.1 | 35.2 | 1.6 | 12.7 | 12.3 |
| Run 2 | 334 | 48.7 | 44.5 | 38.6 | 36.1 | 1.8 | 13.4 | 12.0 |
| Run 3 | 492 | 49.8 | 45.4 | 39.4 | 36.9 | 1.7 | 13.1 | 11.6 |
| **Average** | **374** | **48.8** | **44.5** | **38.7** | **36.1** | **1.7** | **13.1** | **12.0** |

Concentrations are reported without correction for nitrogen.

Method 25C analysis hold time was up to 51 days. Method specified hold time was 30 days.

#### *4.1.2.3 Hydrogen Sulfide ($H_2S$)*

Raw LFG pipe $H_2S$ concentrations were obtained by collecting and analyzing the samples in accordance with EPA Method 11. These results are presented in Table 4-3.

**Table 4-3. Raw Landfill Gas Hydrogen Sulfide Concentrations**

| | $H_2S$ Concentration | |
|---|---|---|
| | (mg/m$^3$) | (ppmv) |
| Run 1 | 26.1 | 18.4 |
| Run 2 | 18.7 | 13.2 |
| Run 3 | 10.7 | 7.6 |
| **Average** | **18.5** | **13.0** |

#### *4.1.2.4 Carbonyls*

The target carbonyl compounds, formaldehyde and acetaldehyde, were analyzed by Method TO-11 on samples collected by EPA Method 0100. The analysis results are presented in Table 4-4.

**Table 4-4. Raw Landfill Gas Carbonyls Concentrations**

| | Formaldehyde [a] | | Acetaldehyde | |
|---|---|---|---|---|
| | ($\mu g/m^3$) | ($x10^{-3}$ ppmv) | ($\mu g/m^3$) | ($x10^{-3}$ ppmv) |
| MDL | 2.1 | 1.7 | 4.2 | 2.3 |
| Run 1 | 2.3 J | 1.8 J | 18.9 | 10.3 |
| Run 2 | 5.0 J | 4.0 J | 67.8 | 37.0 |
| Run 3 | 5.0 J | 4.0 J | 50.3 | 27.4 |
| **Average** | **4.1 J** | **3.3 J** | **45.7** | **24.9** |

[a] Measured formaldehyde values were near MDL

*4.1.2.5 Mercury (Hg)*

Mercury (Hg) can exist in several forms. This test program focused on the elemental, monomethyl, and dimethyl forms of Hg, and total Hg. Elemental Hg was measured with the LUMEX instrument. Organic monomethyl Hg, dimethyl Hg, and total Hg were sampled and analyzed using the organic mercury method.

4.1.2.5.1 Total Mercury (Hg) Samples

To collect the total Hg samples, an iodated charcoal trap was used as a sorbent. A backup tube was also 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. A silica gel impinger was used to collect and quantify the water vapor from the stream. A diaphragm air pump was used to pull samples through the train and collect the samples. A dry gas meter capable of measuring the volume in 10 ml increments was used to monitor and quantify the volume of gas sampled.

Table 4-5 presents the total Hg concentrations in the raw LFG. They ranged from 601 to 676 ng/m$^3$ with an average of 632 ng/m$^3$. Spike recovery for total Hg samples was 95 percent.

**Table 4-5. Raw Landfill Gas Total Mercury Concentrations**

| | Total Mercury Concentration | |
|---|---|---|
| | (ng/m$^3$) | (x10$^{-6}$ ppm) |
| MDL | 50 | 6.0 |
| Run 1 | 676 | 81.4 |
| Run 2 | 618 | 74.4 |
| Run 3 | 601 | 72.4 |
| Average | 632 | 76.1 |

Sample hold time exceeded 14 days

#### 4.1.2.5.2 Dimethyl Mercury (Hg) Samples

To collect the dimethyl Hg sample, a Carbotrap was used as a sorbent. A backup tube was also present to assess any breakthrough. A third iodated carbon trap was also present to collect any elemental Hg present. The sorbent tube was heated to above the dew point of the gas stream to prevent condensation on the sorbent. A silica gel impinger was used to collect and quantify the water vapor from the stream. A diaphragm air pump was used to pull sample through the train and collect the sample. A dry gas meter capable of measuring the volume in 10 ml increments was used to monitor and quantify the volume of gas sampled.

Table 4-6 presents the dimethyl Hg concentrations in the raw LFG. The analyzed concentrations ranged from 5.1 to 8.2 ng/m$^3$ with an average of 7.1 ng/m$^3$. However, spike recovery for the dimethyl Hg traps was only 41 percent, well below normally acceptable levels. The spiked traps, without being exposed to the raw LFG, had recoveries from 68 to 98 percent with an average of 83 percent. Recoveries were low in the spiked traps possibly because of the presence of an unknown interfering compound either destroying or masking the detection of the dimethyl Hg. For this reason, dimethyl Hg concentrations data were flagged with “R” to indicate that the data were rejected. Further development of this procedure was being undertaken by Frontier Geosciences. More studies are needed to develop an acceptable method to determine the actual dimethyl Hg concentrations more accurately.

**Table 4-6. Raw Landfill Gas Dimethyl Mercury Concentrations**

| | Dimethyl Mercury Concentration | |
|---|---|---|
| | ($ng/m^3$) | ($x10^{-6}$ ppmv) |
| MDL | 0.5 | 0.05 |
| Run 1 | 5.1 R | 0.53 R |
| Run 2 | 8.0 R | 1.8 R |
| Run 3 | 8.2 R | 1.9 R |
| Average | 7.1 R | 0.74 R |

Sample hold time exceeded 14 days

Spike recoveries were 0 – 5 percent

R – Results are rejected due to serious deficiencies per EPA QA/G-8 guidance

#### 4.1.2.5.3 Monomethyl Mercury (Hg) Samples

To collect the sample, a set of three impingers filled with 0.001 M HCl was used to collect the monomethyl Hg. An empty forth impinger was used to knockout any impinger solution carryover to the pump and meter system. A diaphragm air pump was used to pull the sample through the train and collect the sample. A dry gas meter capable of measuring the volume in 10 ml increments was used to monitor and quantify the volume of gas sampled.

As shown in Table 4-7, monomethyl Hg concentrations in the raw LFG ranged from non-detect to 1.2 $ng/m^3$. Spike recovery for the monomethyl Hg sample was 70 percent.

**Table 4-7. Raw Landfill Gas Monomethyl Mercury Concentrations**

| | Monomethyl Mercury Concentration | |
|---|---|---|
| | ($ng/m^3$) | ($x10^{-6}$ ppmv) |
| MDL | 0.13 | 0.014 |
| Run 1 | ND | ND |
| Run 2 | ND | ND |
| Run 3 | 1.2 | 0.13 |
| Average | 0.4 | 0.04 |

Sample hold time exceeded 14 days

Relative standard deviation (RSD) of replicate sample exceeded ±30 percent

#### 4.1.2.5.4 Elemental Mercury (Hg)

Elemental Hg was determined by the LUMEX instrument and the results are presented in Table 4-8.

**Table 4-8. Raw Landfill Gas Elemental Mercury Concentrations**

| | Concentration [a] | | | |
|---|---|---|---|---|
| | Background [b] | | Gas Pipe | |
| | ($ng/m^3$) | ($x10^{-6}$ppmv) | ($ng/m^3$) | ($x10^{-6}$ ppmv) |
| Run 1 | 0.001 | 0 | 280 | 33.7 |
| Run 2 | 0.001 | 0 | 325 | 39.1 |
| Run 3 | 0.000 | 0 | 320 | 38.5 |
| Average | 0.001 | 0 | 308 | 37.1 |

[a] Average of three readings, each of 30-second duration

[b] Background measurement was made by sampling ambient air drawn through ice-chilled empty impinger

## 4.2 Engine Stack Results

The engine stack was sampled for NMOCs (as THCs), PCDD/PCDFs, PAHs, HCl, metals (Pb, As, Cd, Cr, Mn, Ni, total Hg), $SO_2$, $NO_X$, CO, $CO_2$, and $O_2$. The stack cross section was divided into 6 equal areas according to EPA Method 1. Sampling run time for HCl and metals was 60 minutes. Run time for PCDD/PCDFs sampling was 180 minutes. Run time for CEMS parameters ($SO_2$, $NO_X$, CO, $O_2$, $CO_2$, and THCs) varied.

### 4.2.1 Engine Stack Gas Flow Rate and Temperature

Sampling at the engine stack was conducted at isokinetic conditions. The procedures provided stack gas velocity distribution across the engine stack and reliable measurements of stack gas flow rates. Table 4-9 lists the volumetric flow rates and temperatures at the engine stack measured during the various sampling runs.

### 4.2.2 Engine Stack Gas Constituents

The concentrations of the constituents of interest in the engine stack are presented in the following Subsections 4.2.2.1 through 4.2.2.7.

**Table 4-9. Engine Stack Gas Operating Conditions Measured during Sampling**

| Run Number | Date | Time | Average Stack Temp (°F) | Carbon Dioxide (%) [a] | Oxygen (%) [b] | Moisture (%) | Velocity (actual ft/sec) | Volumetric Flow Rate (acfm) | Volumetric Flow Rate (dscfm) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |
| A-Post-M26-110102-01 | 11/01/02 | 15:32 - 16:57 | 732 | 12.8 | 7.5 | 12.3 | 149 | 3330 | 1290 |
| A-Post-M26-110102-02 | 11/01/02 | 15:34 - 16:59 | 732 | 12.8 | 7.5 | 12.3 | 149 | 3330 | 1290 |
| A-Post-M26-110202-03 | 11/02/02 | 13:10 - 14:17 | 734 | 13.2 | 7.4 | 12.5 | 154 | 3430 | 1330 |
| | | | | | | | | | |
| A-Post-M29-110102-01 | 11/01/02 | 17:42 - 18:55 | 737 | 12.8 | 7.5 | 11.9 | 150 | 3340 | 1300 |
| A-Post-M29-110102-02 | 11/01/02 | 17:44 - 18:57 | 737 | 12.8 | 7.5 | 11.3 | 150 | 3340 | 1310 |
| A-Post-M29-110202-03 | 11/02/02 | 13:13 - 11:21 | 734 | 13.2 | 7.4 | 12.4 | 154 | 3430 | 1330 |
| | | | | | | | | | |
| A-Post-M23-110102-01 | 11/01/02 | 11:09 - 13:30 | 738 | 12.8 | 7.5 | 12.3 | 150 | 3350 | 1290 |
| A-Post-M23-110102-02 | 11/01/02 | 11:12 - 14:33 | 738 | 12.8 | 7.5 | 12.0 | 150 | 3350 | 1300 |
| A-Post-M23-110202-03 | 11/02/02 | 09:01 - 12:14 | 733 | 13.2 | 7.4 | 11.6 | 154 | 3430 | 1340 |
| | | | | | | | | | |
| **Average** | | | **735** | **12.9** | **7.5** | **12.1** | **151** | **3370** | **1310** |

Engine stack cross-section flow area is 0.37 sq. ft.

[a] Calibration bias = 2.2 – 3.3%, System bias = 1.1 – 4.3%, Drift = 2.2 – 5.4%

[b] Calibration bias = 0 – 3.3%, System bias = 0 – 2.2%, Drift = 2.2 – 3.3%

#### *4.2.2.1 Engine Stack Oxygen and Carbon Dioxide*

Oxygen ($O_2$) and $CO_2$ concentrations provide an overall indication of the combustion process. Figure 4-1 shows the $O_2$ and $CO_2$ concentrations measured by the CEMs during the two days of testing. The plotted data included the CEM responses to the instrument zeroing and calibration periods on November 1, 2002. The end-of-test calibration data were included on the November 2, 2003 plot. These periods manifest as the peaking and bottoming of the recorded values. Table 4-10 presents the daily averages of $O_2$ and $CO_2$ concentrations.

#### *4.2.2.2 Engine Stack Total Hydrocarbon (THC) Concentrations*

Engine stack THC concentrations were measured by EPA Method 25A that used a CEMs. At the engine stack, hydrocarbon (including NMOCs) concentrations were found to be below 50 ppmv. The low concentrations rendered Method 25C, the method designed specifically for NMOC measurement, unsuitable to be applied at this location.

Instead, EPA Method 25A produced concentrations of all hydrocarbons that respond to FID analysis. Real-time continuous instrument responses are shown in Figure 4-2. The time-averaged concentrations are presented in Table 4-11. As can be seen, the concentrations of THC ranged from 323 to 393 ppmv as hexane.

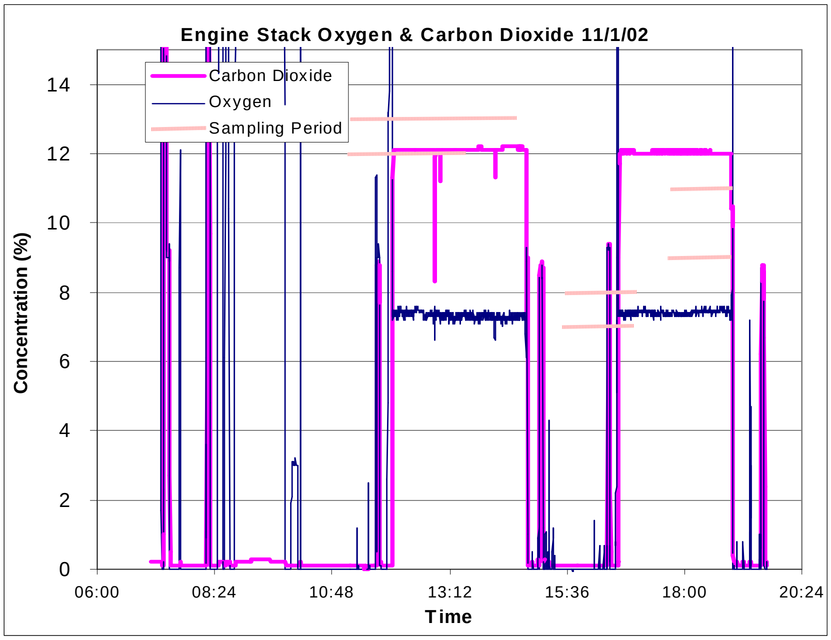
#### *4.2.2.3 Engine Stack Dioxin/Furan (PCDD/PCDFs) Emissions*

Three EPA Method 23 sampling runs were performed. As a cost-saving measure, only the samples from one run (Run 3) were analyzed. Samples from runs 1 and 2 have been extracted and are being held in the laboratory and are available for possible future analysis, if deemed necessary.

Table 4-12 presents the engine stack PCDD/PCDF-emissions data. Table 4-13 presents the same data, but expressed in terms of Toxicity Equivalent emissions.

#### *4.2.2.4 Engine Stack Polycyclic Aromatic Hydrocarbon (PAH) Emissions*

The concentrations of PAHs were obtained by analyzing a Method 23 sample using Method 8270. As a cost-saving measure, only the sample from Run 3 was analyzed. Two additional samples were collected and extracted but not analyzed. The PAH concentrations in the Run 3 sample are presented in Table 4-14.



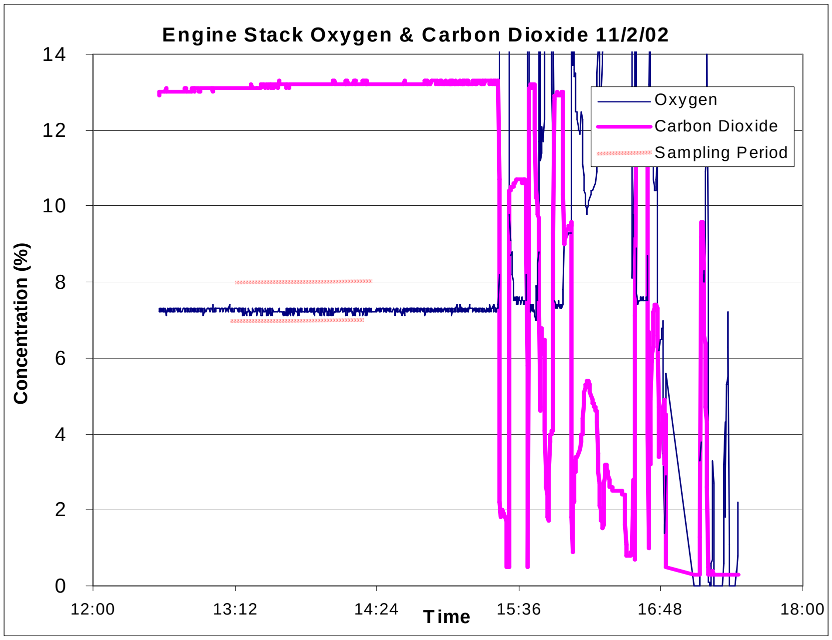




**Figure 4-1. Engine Stack Oxygen and Carbon Dioxide Concentrations**

**Table 4-10. Engine Stack Combustion Product Concentrations.**

| | $O_2$ (% v) [a] | $CO_2$ (% v) [b] |
|---|---|---|
| Run 1 | 7.4 | 12.7 |
| Run 2 | 7.6 | 12.8 |
| Run 3 | 7.4 | 13.2 |
| **Average** | **7.5** | **12.9** |

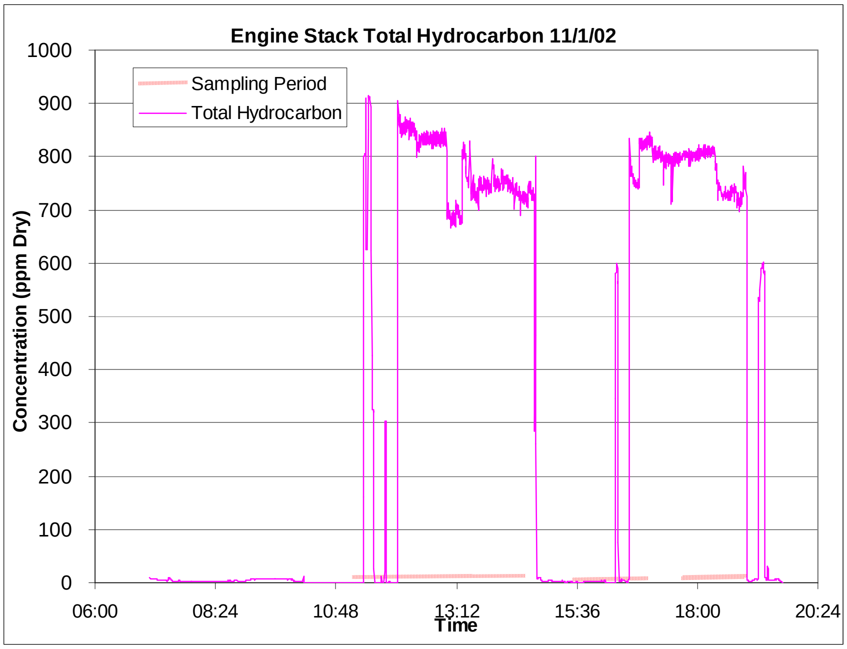
[a] Calibration bias = 2.2 – 3.3%, System bias = 1.1 – 4.3%, Drift = 2.2 – 5.4%

[b] Calibration bias = 0 – 3.3%, System bias = 0 – 2.2%, Drift = 2.2 – 3.3%

**Table 4-11. Engine Stack THC Concentrations**

| | THC (ppmdv as propane) | THC (ppmdv as hexane) |
|---|---|---|
| Run 1 | 759 | 380 |
| Run 2 | 786 | 393 |
| Run 3 | 645 | 323 |
| **Average** | **730** | **365** |

Calibration bias = 0 – 3.8%, System bias = 0 – 3.8%, Drift = 0 – 3.3%



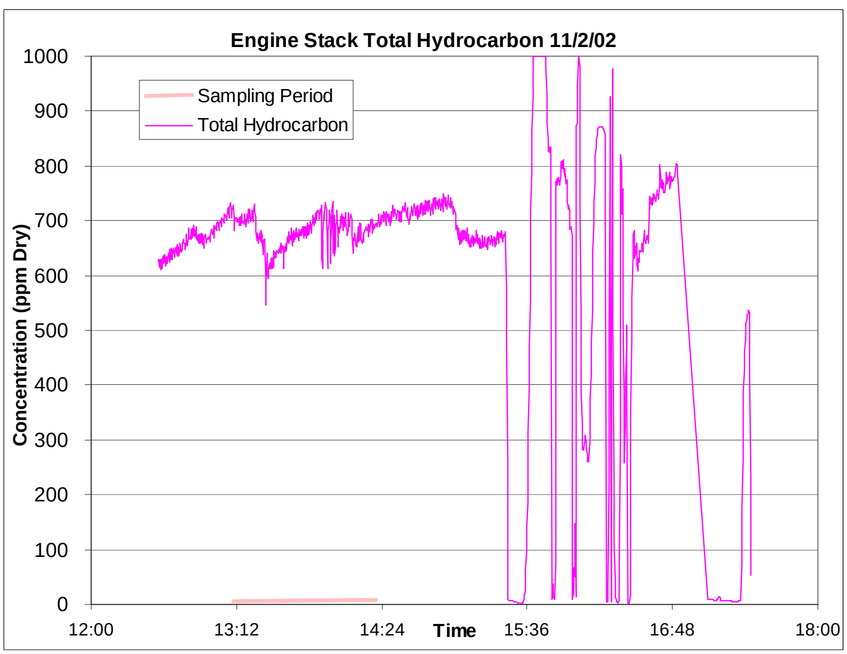




**Figure 4-2. Engine Stack Total Hydrocarbon Concentrations**

**Table 4-12. Engine Stack Dioxins and Furans Emissions**

| Analyte | A-POST-M23-110202-03 | | |
|---|---|---|---|
| | Concentration | Emission Rate | |
| | ($x10^{-3}$ ng/dscm) | ($x10^{-9}$ g/hr) | ($x10^{-12}$ lb/hr) |
| **Dioxins** | | | |
| 2,3,7,8-TCDD | <0.48 | <1.1 | <2.4 |
| Other TCDD | 22.0 | 50.1 | 110.5 |
| 1,2,3,7,8-PeCDD | <0.37 | <0.84 | <1.8 |
| Other PeCDD | 3.4 | 7.6 | 16.9 |
| 1,2,3,4,7,8-HxCDD | <1.2 | <2.8 | <6.1 |
| 1,2,3,6,7,8-HxCDD | <1.1 | <2.6 | <5.7 |
| 1,2,3,7,8,9-HxCDD | <1.2 | <2.6 | <5.8 |
| Other HxCDD | 0.239 | 0.545 | 1.2 |
| 1,2,3,4,6,7,8-HpCDD | <1.8 | <4.1 | <9.1 |
| Other HpCDD | 0.0 | 0.0 | 0.0 |
| 1,2,3,4,6,7,8,9-OCDD | <2.0 | <4.6 | <10.2 |
| **Total CDD** | **<33.8** | **<77.0** | **<170** |
| **Furans** | | | |
| 2,3,7,8-TCDF | <0.70 | <1.6 | <3.5 |
| Other TCDF | 46.6 | 106 | 234 |
| 1,2,3,7,8-PeCDF | <0.64 | <1.5 | <3.2 |
| 2,3,4,7,8-PeCDF | <0.59 | <1.4 | <3.0 |
| Other PeCDF | 3.4 | 7.7 | 16.9 |
| 1,2,3,4,7,8-HxCDF | <1.3 | <3.0 | <6.7 |
| 1,2,3,6,7,8-HxCDF | <1.3 | <3.0 | <6.7 |
| 2,3,4,6,7,8-HxCDF | <1.3 | <3.0 | <6.7 |
| 1,2,3,7,8,9-HxCDF | <0.28 | <0.65 | <1.4 |
| Other HxCDF | 1.3 | 3.0 | 6.6 |
| 1,2,3,4,6,7,8-HpCDF | <1.5 | <3.4 | <7.6 |
| 1,2,3,4,7,8,9-HpCDF | <0.16 | <0.36 | <0.80 |
| Other HpCDF | 0.0 | 0.0 | 0.0 |
| 1,2,3,4,6,7,8,9-OCDF | <1.3 | <3.0 | <6.6 |
| Total CDF | 13.9 | 138 | 304 |
| **Total CDD/CDF** | **<47.6** | **<214.8** | **<473.6** |

Two additional samples were collected, extracted and held in the laboratory for possible future analyses: A-POST-M23-110102-01 and A-POST-M23-110102-02

"<" denotes the measurement was non-detect. The value following the "<" sign is the detection limit.

**Table 4-13. Engine Stack Dioxins and Furans Toxicity Equivalent Emissions**

| Pollutant | A-POST-M23-110202-03 | | | 1989 Toxicity Equivalency Factor | Toxicity Equivalent Emissions | | |
|---|---|---|---|---|---|---|---|
| | Concentration | Emission Rate | | | Concentration | Emission Rate | |
| | ($x10^{-3}$ ng/dscm) | ($x10^{-9}$ g/hr) | ($x10^{-12}$ lb/hr) | | ($x10^{-3}$ ng/dscm) | ($x10^{-9}$ g/hr) | ($x10^{-12}$ lb/hr) |
| **Dioxins** | | | | | | | |
| 2,3,7,8-TCDD | <0.48 | <1.1 | <2.4 | 1 | <0.48 | <1.1 | <2.4 |
| Other TCDD | 22.0 | 50.1 | 111 | --- | NA | NA | NA |
| 1,2,3,7,8-PeCDD | <0.37 | <0.84 | <1.8 | 0.5 | <0.18 | <0.42 | <0.92 |
| Other PeCDD | 3.4 | 7.6 | 17 | --- | NA | NA | NA |
| 1,2,3,4,7,8-HxCDD | <1.2 | <2.8 | <6.1 | 0.1 | <0.12 | <0.28 | <0.61 |
| 1,2,3,6,7,8-HxCDD | <1.1 | <2.6 | <5.7 | 0.1 | <0.11 | <0.26 | <0.57 |
| 1,2,3,7,8,9-HxCDD | <1.2 | <2.6 | <5.8 | 0.1 | <0.12 | <0.26 | <0.58 |
| Other HxCDD | 0.239 | 0.545 | 1.2 | --- | NA | NA | NA |
| 1,2,3,4,6,7,8-HpCDD | <1.8 | <4.1 | <9.1 | 0.01 | <0.018 | <0.041 | <0.091 |
| Other HpCDD | 0.0 | 0.0 | 0.0 | --- | NA | NA | NA |
| 1,2,3,4,6,7,8,9-OCDD | <2.0 | <4.6 | <10.2 | 0.001 | <0.0020 | <0.0046 | <0.0102 |
| **Total CDD** | **<33.8** | **77.0** | **170** | **---** | **<1.0** | **2.4** | **5.2** |
| **Furans** | | | | | | | |
| 2,3,7,8-TCDF | <0.70 | <1.6 | <3.5 | 0.1 | <0.070 | <0.16 | <0.35 |
| Other TCDF | 46.6 | 106 | 234 | --- | NA | NA | NA |
| 1,2,3,7,8-PeCDF | <0.64 | <1.5 | <3.2 | 0.05 | <0.032 | <0.073 | <0.16 |

| Pollutant | A-POST-M23-110202-03 | | | 1989 Toxicity Equivalency Factor | Toxicity Equivalent Emissions | | |
|---|---|---|---|---|---|---|---|
| | Concentration | Emission Rate | | | Concentration | Emission Rate | |
| | ($x10^{-3}$ ng/dscm) | ($x10^{-9}$ g/hr) | ($x10^{-12}$ lb/hr) | | ($x10^{-3}$ ng/dscm) | ($x10^{-9}$ g/hr) | ($x10^{-12}$ lb/hr) |
| 2,3,4,7,8-PeCDF | <0.59 | <1.4 | <3.0 | 0.5 | <0.30 | <0.68 | <1.5 |
| Other PeCDF | 3.4 | 7.7 | 17 | --- | NA | NA | NA |
| 1,2,3,4,7,8-HxCDF | <1.3 | <3.0 | <6.7 | 0.1 | <0.13 | <0.30 | <0.67 |
| 1,2,3,6,7,8-HxCDF | <1.3 | <3.0 | <6.7 | 0.1 | <0.13 | <0.30 | <0.67 |
| 2,3,4,6,7,8-HxCDF | <1.3 | <3.0 | <6.7 | 0.1 | <0.13 | <0.30 | <0.67 |
| 1,2,3,7,8,9-HxCDF | <0.28 | <0.65 | <1.4 | 0.1 | <0.028 | <0.065 | <0.14 |
| Other HxCDF | 1.3 | 3.0 | 6.6 | --- | NA | NA | NA |
| 1,2,3,4,6,7,8-HpCDF | <1.5 | <3.4 | <7.6 | 0.01 | <0.015 | <0.034 | <0.076 |
| 1,2,3,4,7,8,9-HpCDF | <0.16 | <0.36 | <0.80 | 0.01 | <0.0016 | <0.0036 | <0.008 |
| Other HpCDF | 0.0 | 0.0 | 0.0 | --- | NA | NA | NA |
| 1,2,3,4,6,7,8,9-OCDF | <1.3 | <3.0 | <6.6 | 0.001 | <0.0013 | <0.0030 | <0.0066 |
| **Total CDF** | **<13.9** | **<138** | **<304** | **---** | **<0.844** | **<1.9** | **<4.2** |
| **Total CDD/CDF** | **<47.6** | **<216** | **<474** | **---** | **<1.9** | **<4.3** | **<9.5** |

NA – Not applicable because no Toxicity Equivalent Factor is available

"<" denotes the measurement was non-detect. The value following the "<" sign is the detection limit.

**Table 4-14. Engine Stack Polycyclic Aromatic Hydrocarbons Emissions**

| Analyte | Formula Weight | A-POST-M23-110202-03 | | | |
|---|---|---|---|---|---|
| | | Concentration | | Emission Rate | |
| | | (x10$^{-6}$ ppmv) | (ng/dscm) | (x10$^{-6}$ g/hr) | (x10$^{-6}$ lb/hr) |
| Acenaphthene | 154.21 | 81.3 | 521 | 1200 | 2.6 |
| Acenaphthylene | 152.20 | 116 | 731 | 1700 | 3.7 |
| Anthracene | 178.23 | 15.7 | 116 | 265 | 0.58 |
| Benzo(a)anthracene | 228.30 | 4.3 | 41 | 94 | 0.21 |
| Benzo(a)pyrene | 252.32 | 0.31 | 3.2 | 7.3 | 0.016 |
| Benzo(b)fluoranthene | 252.32 | 2.1 | 22 | 50 | 0.11 |
| Benzo(g,h,i)perylene | 276.34 | 1.3 | 15 | 34 | 0.074 |
| Benzo(k)fluoranthene | 252.32 | 0.61 | 6.4 | 15 | 0.032 |
| Chrysene | 228.29 | 15.2 | 144 | 329 | 0.725 |
| Dibenzo(a,h)anthracene | 278.35 | 0.27 | 3.2 | 7.2 | 0.016 |
| Fluoranthene | 202.26 | 18.3 | 154 | 351 | 0.774 |
| Fluorene | 166.22 | 138 | 950 | 2200 | 4.8 |
| Indeno(1,2,3-cd)pyrene | 288.35 | 0.555 | 6.6 | 15 | 0.033 |
| Naphthalene | 128.17 | 3400 | 17900 | 40800 | 90 |
| Phenanthrene | 178.23 | 256 | 1900 | 4300 | 9.5 |
| Pyrene | 202.26 | 20.8 | 175 | 400 | 0.88 |
| 2-Methylnaphthalene | 142.20 | 1300 | 7580 | 17300 | 38 |
| Benzo(e)Pyrene | 252.32 | 1.6 | 17 | 38 | 0.085 |
| Perylene | 253.31 | 0.29 | 3.1 | 7.0 | 0.016 |

Two additional samples were collected, extracted and held in the laboratory for possible future analyses: A-POST-M23-110102-01 and A-POST-M23-110102-02

Samples were extracted within method-specified 14-day hold time. The Run 3 sample extract was analyzed 50 days after extraction. The method specified extract hold time to be 40 days.

### 4.2.3 Hydrogen Chloride (HCl) Emission Results

Engine stack HCl emissions results are presented in Table 4-15.

**Table 4-15. Engine Stack Hydrogen Chloride Emissions**

| | HCl Concentration | | HCl Emission Rate | |
|---|---|---|---|---|
| | (ppmdv) | (mg/m$^3$) | (lb/hr) | (g/hr) |
| Run 1 | 2.7 | 4.1 | 0.0197 | 8.9 |
| Run 2 | 2.7 | 4.3 | 0.0200 | 9.1 |
| Run 3 | 2.8 | 4.4 | 0.0213 | 9.7 |
| **Average** | **2.7** | **4.3** | **0.0203** | **9.2** |

#### *4.2.3.1 Metals Emissions Results*

Toxic heavy metals in the engine stack gases were measured by Method 29. Manganese was determined by inductively coupled plasma – mass spectroscopy (ICP-MS). Arsenic (As), Cd, Cr, Pb, and Ni were determined by graphite furnace atomic absorption spectroscopy (GFAAS). Mercury was determined by cold vapor (CV) AA and was not detected in any of the samples. Table 4-16 presents the engine stack metals emissions results.

Elemental mercury ($Hg^O$) concentration was separately measured by the LUMEX instrument and those results are also included in Table 4-16.

**Table 4-16. Engine Stack Metal Emissions**

| Analyte | A-POST-M29-110102-01 | | | A-POST-M29-110102-02 | | | A-POST-M29-110202-03 | | | Average | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Concentration | Emission Rate | | Concentration | Emission Rate | | Concentration | Emission Rate | | Concentration | Emission Rate | |
| | (µg/dscm) | ($x10^{-3}$ g/hr) | ($x10^{-6}$lb/hr) | (µg/dscm) | ($x10^{-3}$ g/hr) | ($x10^{-6}$lb/hr) | (µg/dscm) | ($x10^{-3}$ g/hr) | ($x10^{-6}$lb/hr) | (µg/dscm) | ($x10^{-3}$ g/hr) | ($x10^{-6}$lb/hr) |
| Arsenic | 3.6 | 7.9 | 17.5 | 3.0 | 6.6 | 15 | 2.3 | 5.2 | 11.5 | 3.0 | 6.6 | 14.5 |
| Cadmium | 0.78 | 1.7 | 3.8 | 0.18 | 0.4 | 0.87 | 0.144 | 0.3 | 0.716 | 0. 367 | 0.8 | 1.8 |
| Chromium | 9.6 | 21 | 46.6 | 11.0 | 24 | 53.7 | 4.8 | 11 | 24.0 | 8.5 | 18.8 | 41.4 |
| Lead | 11.9 | 26.3 | 58.1 | 5.5 | 12 | 27.1 | 0.69 | 1.5 | 3.4 | 6.1 | 13.4 | 29.5 |
| Manganese | 12.1 | 26.8 | 59.0 | 8.4 | 19 | 41.0 | 19.8 | 44.7 | 98.5 | 13.5 | 30 | 66.2 |
| Nickel | 2.0 | 4.4 | 9.8 | 16.0 | 34.4 | 78.2 | 11.1 | 25 | 55.1 | 9.5 | 21.3 | 46.9 |
| Mercury (Total by Method 29) | <1.7 | <0.004 | <8.2 | <1.6 | <0.004 | <8.0 | <1.5 | <0.003 | <7.6 | ND | ND | ND |
| | RUN 1 | | | RUN 2 | | | RUN 3 | | | Average | | |
| Mercury (Elemental by LUMEX) | 0.027 | 0.060 | 0.13 | 0.032 | 0.071 | 0.16 | NM | NM | NM | 0.030 | 0.066 | 0.14 |

*4.2.3.2 Gaseous Concentrations: Carbon Monoxide (CO), Sulfur Dioxide ($SO_2$), and Nitrogen Oxides ($NO_X$)*

Gaseous emissions were measured with CEMs and included CO, $SO_2$ and $NO_X$. These results are summarized in Table 4-17. The detailed CEM measurement plots are shown in Figures 4-3 through 4-5.

**Table 4-17. Engine Stack CO, $SO_2$, $NO_X$ Concentrations**

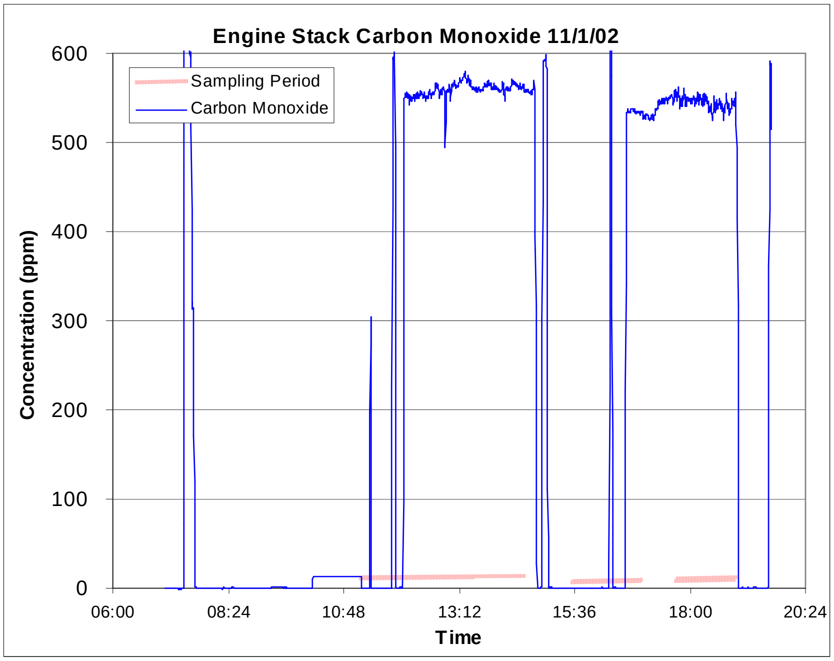
| | Concentration (ppmdv) | | |
|---|---|---|---|
| | CO | $SO_2$ | $NO_X$ (as NO) |
| Run 1 | 562 | NM | 172 |
| Run 2 | 549 | 39 | 142 |
| Run 3 | 570 | 29 | 183 |
| **Average** | **560** | **34** | **166** |

NM = Not measured. Instrument was not ready.

#### 4.3 Comparison with AP-42 Default Values

One of the major objectives of the test program was to expand on the database of LFG constituent compounds and their concentrations. If warranted, these data may contribute towards updating the AP-42 default values.

Table 4-18 presents the concentrations of LFG constituents to provide direct comparisons with AP-42 default emission concentration values. Table 4-19 presents the concentration of other constituents targeted by the various analyses but not listed in AP-42. An expanded discussion and comparison is included in the overall project summary report.



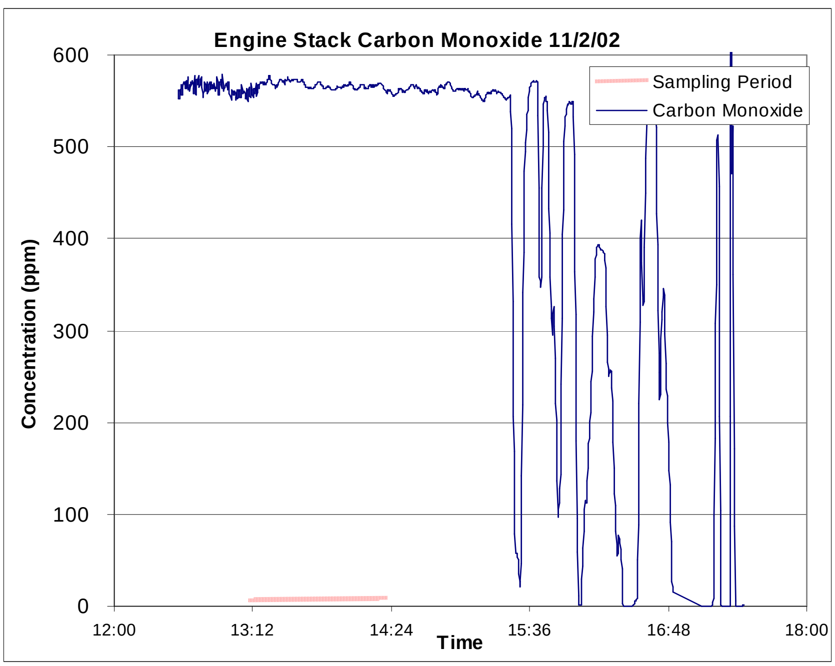
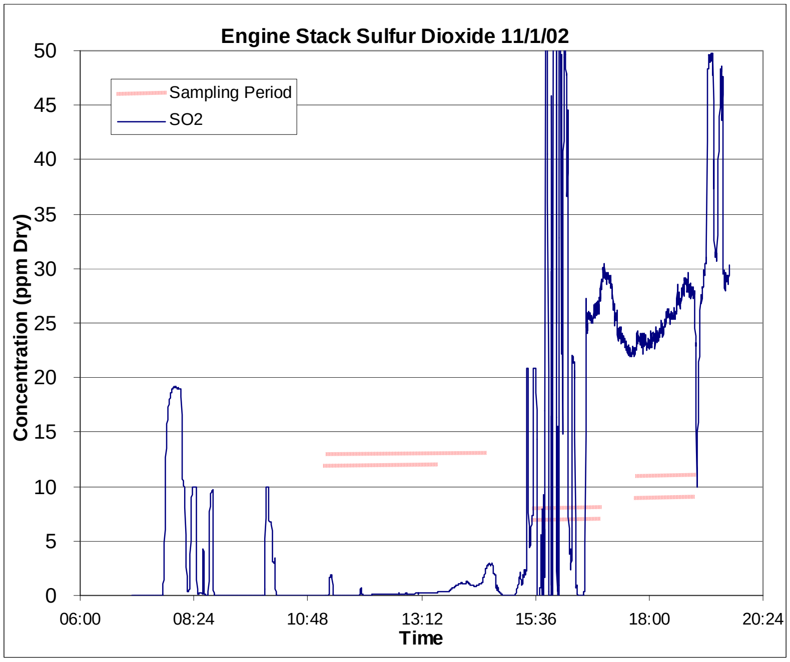




**Figure 4-3. Engine Stack Carbon Monoxide Concentrations**



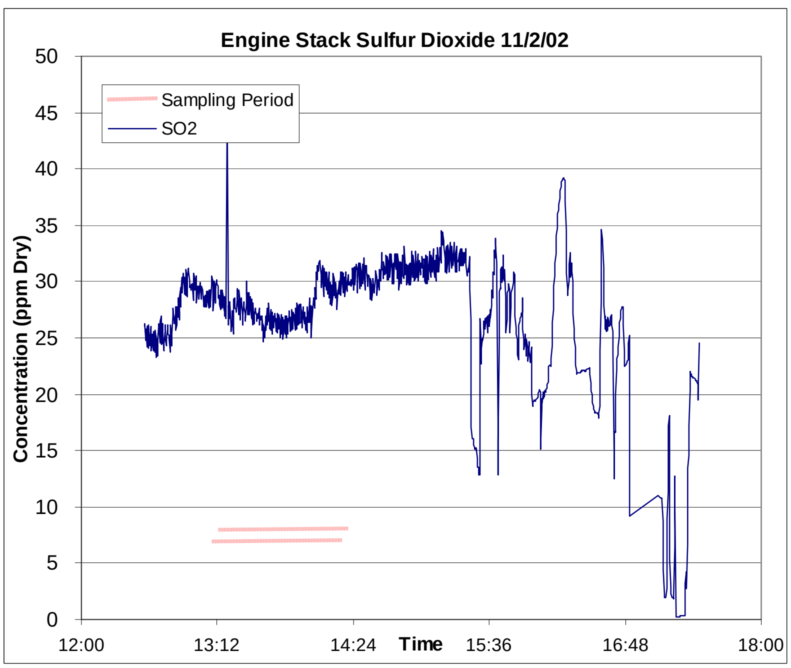
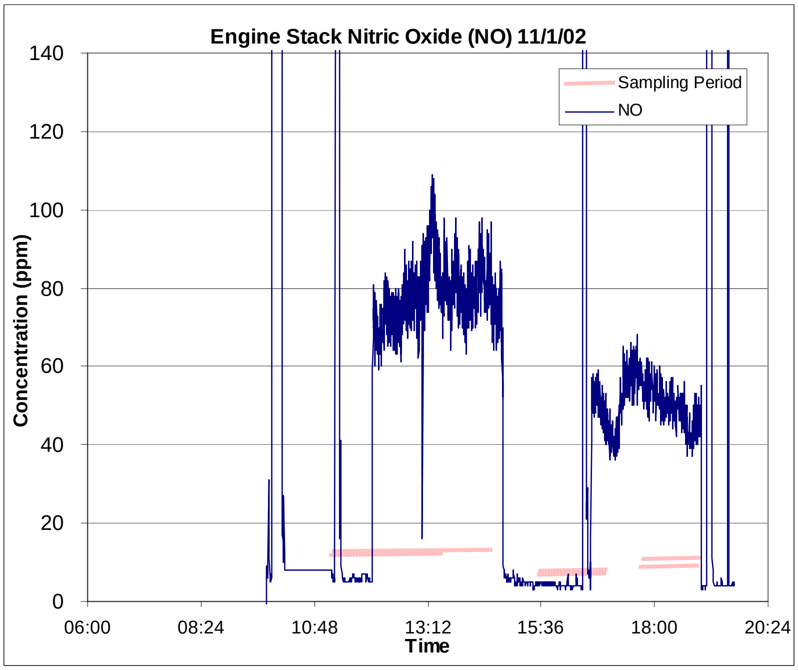




**Figure 4-4. Engine Stack Sulfur Dioxide Concentrations**



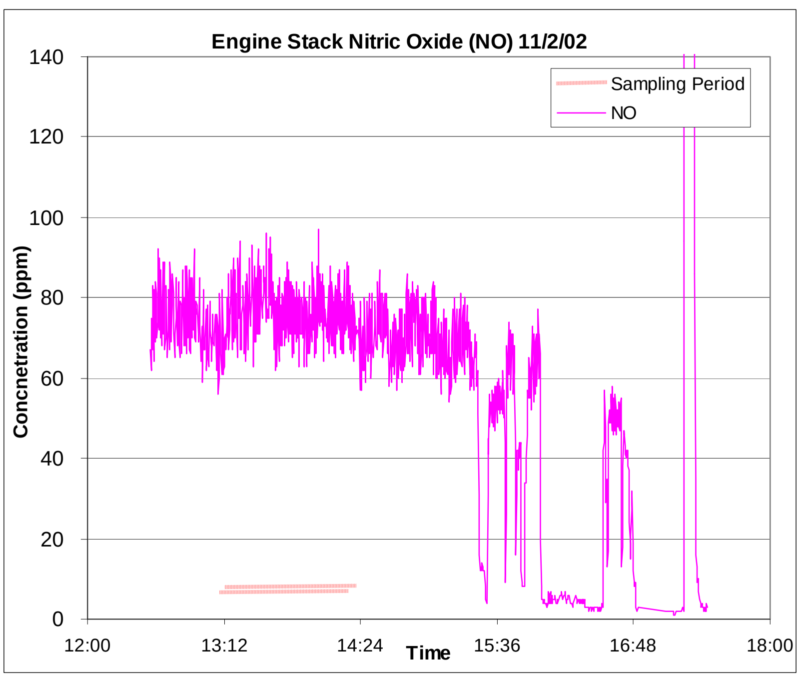




**Figure 4-5. Engine Stack Nitric Oxide Concentrations**

**Table 4-18. Comparison of Raw Landfill Gas Constituent Concentrations with AP-42 Default Values**

| Method | Compound | CAS Number | Formula Wt. | Default Value (ppmv) | Detection Limit (ppmv) | Measured Average | Concentration in Inlet LFG | | Mass Flow Rate in Inlet LFG Stream | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | (ppmv) | ($x10^{-9}$ lb/ft$^3$) | (µg/m$^3$) | (mg/hr) | ($x10^{-3}$ lb/hr) |
| M-40 | 1,1,1-Trichloroethane | 71-55-6 | 133.42 | 0.48 | 0.0002 | 0.005 | 1.7 | 27 | 73 | 0.16 |
| M-40 | 1,1,2,2-Tetrachloroethane | 79-34-5 | 167.85 | 1.11 | 0.0002 | 0.0297 | 12.9 | 206 | 554 | 1.2 |
| M-40 | 1,1-Dichloroethane (Ethylidene Dichloride) | 75-34-3 | 98.96 | 2.35 | 0.0002 | 0.033 | 8.6 | 140 | 368 | 0.811 |
| M-40 | 1,1-dichloroethene | 75-35-4 | 96.94 | 0.20 | 0.0002 | 0.002 | 0.420 | 6.7 | 18 | 0.040 |
| M-40 | 1,2-Dichloroethane | 107-06-2 | 98.96 | 0.41 | 0.0002 | 0.001 | 0.264 | 4.2 | 11 | 0.025 |
| M-40 | 1,2-Dichloropropane | 78-87-5 | 112.98 | 0.18 | 0.0002 | 0.001 | 0.227 | 3.6 | 9.8 | 0.022 |
| M-40 | Isopropyl alcohol (2-Propanol) | 67-63-0 | 60.11 | 50.10 | 0.0002 | 0.114 | 17.7 | 283 | 759 | 1.70 |
| M-40 | Acetone | 67-64-1 | 58.08 | 7.01 | 0.0002 | 0.33 | 49.2 | 788 | 2120 | 4.70 |
| M-40 | Acrylontrile | 107-13-1 | 53.06 | 6.33 | 0.0002 | ND | ND | ND | ND | ND |
| M-40 | Bromodichloromethane | 75-27-4 | 163.83 | 3.13 | 0.0002 | 0.003 | 1.1 | 18 | 48 | 0.10 |
| M-40 | Butane | 106-97-8 | 58.12 | 5.03 | | 4.87 | 731 | 11700 | 31400 | 69.3 |
| M-40 | Carbon Disulfide | 75-15-0 | 76.13 | 0.58 | 0.0002 | 0.014 | 2.8 | 46 | 120 | 0.269 |
| No Test | Carbon Monoxide | 630-08-0 | 28.01 | 141 | | NM | NM | NM | NM | NM |
| M-40 | Carbon Tetrachloride | 56-23-5 | 153.84 | 0.004 | 0.0002 | 0.00083 | 0.33 | 5.3 | 14 | 0.031 |
| No Test | Carbonyl Sulfide (Carbon oxysulfide) | 463-58-1 | 60.07 | 0.49 | 0.0002 | NM | NM | NM | NM | NM |
| M-40 | Chlorobenzene | 108-90-7 | 112.56 | 0.25 | 0.0002 | 0.195 | 56.6 | 907 | 2440 | 5.40 |
| M-40 | Chlorodiflouromethane (Freon 22) | 75-45-6 | 86.47 | 1.30 | 0.0002 | ND | ND | ND | ND | ND |
| M-40 | Chloroethane (Ethyl Chloride) | 75-00-3 | 64.52 | 1.25 | 0.0002 | 0.77 | 128 | 2060 | 5520 | 12.2 |
| M-40 | Chloroform | 67-66-3 | 119.39 | 0.03 | 0.0002 | 0.040 | 12 | 200 | 530 | 1.20 |

| Method | Compound | CAS Number | Formula Wt. | Default Value (ppmv) | Detection Limit (ppmv) | Measured Average | Concentration in Inlet LFG | | Mass Flow Rate in Inlet LFG Stream | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | (ppmv) | ($x10^{-9}$ lb/ft$^3$) | (µg/m$^3$) | (mg/hr) | ($x10^{-3}$ lb/hr) |
| M-40 | Chloromethane | 74-87-3 | 50.49 | 1.21 | 0.0002 | 0.012 | 1.6 | 25 | 68 | 0.15 |
| M-40 | 1,4-Dichlorobenzene | 106-46-7 | 147.00 | 0.21 | 0.0002 | 0.043 | 17 | 260 | 708 | 1.6 |
| M-40 | 1,3-Dichlorobenzene | 541-73-1 | 147.00 | 0.21 | 0.0002 | 0.00047 | 0.18 | 2.9 | 7.7 | 0.0169 |
| M-40 | 1,2-Dichlorobenzene | 95-50-1 | 147.01 | 0.21 | 0.0002 | 0.00203 | 0.77 | 12 | 33 | 0.0731 |
| M-40 | Dichlorodifluoromethane (Freon 12) | 75-71-8 | 120.91 | 15.70 | 0.0002 | 0.118 | 36.8 | 590 | 1580 | 3.50 |
| M-40 | Dichlorofluoromethane (Freon 21) | 75-43-4 | 102.92 | 2.62 | 0.0002 | ND | ND | ND | ND | ND |
| M-40 | Methylene Chloride (Dichloromethane) | 75-09-2 | 84.94 | 14.30 | 0.0002 | 0.997 | 219 | 3510 | 9410 | 20.8 |
| No Test | Dimethyl Sulfide (Methyl sulfide) | 75-18-3 | 62.13 | 7.82 | | NM | NM | NM | NM | NM |
| M-40 | Ethane | 74-84-0 | 30.07 | 889 | | 6.2 | 480 | 7800 | 21000 | 45.4 |
| M-40 | Ethanol | 64-17-5 | 46.08 | 27.20 | 0.0002 | 0.020 | 2.4 | 38 | 100 | 0.22 |
| M-40 | Ethyl Mercaptan (Ethanediol) | 75-08-1 | 62.13 | 2.28 | 0.020 | ND | ND | ND | ND | ND |
| M-40 | Ethylbenzene | 100-41-4 | 106.16 | 4.61 | 0.0002 | 0.58 | 160 | 2500 | 6800 | 15 |
| M-40 | 1,2-Dibromoethane (Ethylene dibromide) | 106-93-4 | 187.88 | 0.001 | 0.0002 | 0.001 | 0.5 | 8.3 | 22 | 0.049 |
| M-40 | Trichloromonofluoromethane (Fluorotrichloromethane) (F11) | 75-69-4 | 137.38 | 0.76 | 0.0002 | 0.051 | 18 | 290 | 790 | 1.7 |
| M-40 | Hexane | 110-54-3 | 86.18 | 6.57 | 0.0002 | 2.47 | 550 | 8810 | 23700 | 52.1 |
| M-11 | Hydrogen Sulfide | 7783-06-4 | 34.08 | 35.50 | | 13.1 | 1200 | 18400 | 49500 | 109 |
| Organic mercury | Mercury (Dimethyl) | | 230.66 | Not Listed | 0.05E-06 | R | R | R | R | R |

| Method | Compound | CAS Number | Formula Wt. | Default Value (ppmv) | Detection Limit (ppmv) | Measured Average | Concentration in Inlet LFG | | Mass Flow Rate in Inlet LFG Stream | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | (ppmv) | ($x10^{-9}$ lb/ft$^3$) | (µg/m$^3$) | (mg/hr) | ($x10^{-3}$ lb/hr) |
| LUMEX | Mercury (Elemental) | 7439-97-6 | 200.61 | Not Listed | | 37E-06 | 0.019 | 0.31 | 0.83 | 0.0018 |
| Organic mercury | Mercury (Monomethyl) | | 215.62 | Not Listed | 0.014E-06 | 130E-09 | 0.000073 | 0.0012 | 0.0031 | 0.0000069 |
| Organic mercury | Mercury (Total) | | 215.63 | 253.0E-6 | 6E-06 | 300E-06 | 0.17 | 2.7 | 7.1 | 0.016 |
| M-40 | 2-Butanone (Methyl Ethyl Ketone) | 78-93-3 | 72.10 | 7.09 | 0.0002 | 0.27 | 51 | 820 | 2200 | 4.8 |
| M-40 | 2-Hexanone (Methyl Butyl Ketone) | 591-78-6 | 100.16 | 1.87 | 0.0002 | 0.557 | 144 | 2310 | 6200 | 14 |
| M-40 | Methyl Mercaptan (Methanethiol) | 74-93-1 | 48.11 | 2.49 | 0.020 | ND | ND | ND | ND | ND |
| M-40 | Pentane | 109-66-0 | 72.15 | 3.29 | 1 | 3.20 | 597 | 9560 | 25700 | 56.6 |
| M-40 | Tetrachloroethylene (Perchloroethylene) | 127-18-4 | 165.83 | 3.73 | 0.0002 | 0.042 | 18 | 290 | 780 | 1.7 |
| M-40 | Propane | 74-98-6 | 44.09 | 11.10 | 1 | 8.9 | 1000 | 16000 | 44000 | 97 |
| M-40 | t-1,2-Dichloroethene | 156-60-5 | 96.94 | 2.84 | 0.0002 | 0.003 | 0.7 | 11 | 29 | 0.064 |
| M-40 | Trichloroethylene (Trichloroethene) | 79-01-6 | 131.38 | 2.82 | 0.0002 | 0.028 | 9.5 | 150 | 410 | 0.90 |
| M-40 | Vinyl Chloride | 75-01-4 | 62.50 | 7.34 | 0.0002 | 0.097 | 15.7 | 251 | 674 | 1.5 |
| M-40 | m/p-Xylene (Dimethyl Benzene) | 1330-20-7 | 106.16 | 12.10 | 0.0002 | 3.73 | 1000 | 16400 | 44000 | 97 |
| M-40 | o-Xylene (Dimethyl Benzene) | 95-47-6 | 106.16 | 12.10 | 0.0002 | 0.30 | 82 | 1300 | 3500 | 7.8 |
| M-40 | Benzene (Co-disposal) | 71-43-2 | 78.11 | 11.10 | 0.0002 | 0.073 | 15 | 240 | 634 | 1.4 |

| Method | Compound | CAS Number | Formula Wt. | Default Value (ppmv) | Detection Limit (ppmv) | Measured Average | Concentration in Inlet LFG | | Mass Flow Rate in Inlet LFG Stream | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | (ppmv) | ($x10^{-9}$ lb/ft$^3$) | (µg/m$^3$) | (mg/hr) | ($x10^{-3}$ lb/hr) |
| M-40 | Benzene (No-disposal or Unknown) | 71-43-2 | 78.11 | 1.91 | 0.0002 | 0.073 | 15 | 240 | 634 | 1.4 |
| M-25C | NMOC as Hexane (Co-disposal) | | 86.17 | 2420.00 | | 373 | 83100 | 1330000 | 3570000 | 79000 |
| M-25C | NMOC as Hexane (No-codispoal or Unknown) | | | 595.00 | | 373 | 83100 | 1330000 | 3570000 | 79000 |
| M-40 | Toluene (Methyl Benzene) (Co-disposal) | 108-88-3 | 92.13 | 165.00 | 0.0002 | 1.33 | 316 | 5050 | 13600 | 29.9 |
| M-40 | Toluene (Methyl Benzene) (No or Unknown) | | | 39.30 | 0.0002 | 1.33 | 316 | 5050 | 13600 | 29.9 |

ND – Non detected at the stated detection limit

R – Data were rejected because of serious deficiency in spike recovery

Table 4-19. Raw Landfill Gas Constituent Concentrations for Compounds without AP-42 Default Values

| Method | Compound | CAS Number | Formula Wt. | Detection Limit (ppmv) | Measured Average (ppmv) | Concentration in Inlet LFG | | Mass Flow Rate in Inlet LFG Stream | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | ($x10^{-9}$ lb/ft$^3$) | (µg/m$^3$) | (mg/hr) | ($x10^{-3}$ lb/hr) |
| M-0100/ TO-11 | Acetaldehyde | 75-07-0 | 44.05 | 0.0023 | 0.025 | 2.9 | 46 | 125 | 0.275 |
| M-0100/ TO-11 | Formaldehyde | 50-00-0 | 30.03 | 0.0017 | 0.0033 | 0.259 | 4.14 | 11.1 | 0.0245 |
| M-23 | Dioxins/Furans | | | | NM | NM | NM | NM | NM |
| M-23 | PAHs | | | | NM | NM | NM | NM | NM |
| M-25C | Carbon Dioxide | 124-38-9 | 44.01 | | 387000 | 44.0E6 | 705E6 | 1.89E9 | 4.17E6 |
| M-25C | Methane | 74-82-8 | 16.04 | | 488000 | 20.2E6 | 324E6 | 0.871E9 | 1.92E6 |
| M-25C | Oxygen | 7782-44-7 | 32.00 | | 17000 | 1.4E6 | 23E6 | 0.061E9 | 0.133E6 |
| M-40 | 1,1,2,3,4,4-Hexachloro-1,3-butadiene | 87-68-3 | 260.76 | 0.0002 | 0.001 | 0.8 | 13.4 | 36.0 | 0.0794 |
| M-40 | 1,1,2-Trichloro-1,2,2-trifluoroethane (CFC113) | 76-13-1 | 187.38 | 0.0002 | 0.002 | 0.983 | 15.8 | 42.3 | 0.0932 |
| M-40 | 1,1,2-Trichloroethane | 79-00-5 | 133.42 | 0.0002 | 0.008 | 2.6 | 42 | 113 | 0.249 |
| M-40 | 1,2,4-Trichlorobenzene | 120-82-1 | 181.46 | 0.0002 | 0.001 | 0.460 | 7.4 | 19.8 | 0.0436 |
| M-40 | 1,2,4-Trimethylbenzene | 95-63-6 | 120.19 | 0.0002 | 0.19 | 60.0 | 961 | 2580 | 5.7 |
| M-40 | 1,2-Chloro-,1,2,2-Tetrafluoroethane (CFC114) | 76-14-2 | 170.92 | 0.0002 | 0.008 | 3.4 | 55 | 148 | 0.325 |
| M-40 | 1,3,5-Trimethylbenzene | 108-67-8 | 120.19 | 0.0002 | 0.079 | 24.6 | 395 | 1060 | 2.3 |
| M-40 | 1,3-Butadiene (Vinylethylene) | 106-99-0 | 54.09 | 0.0002 | 0.022 | 3.1 | 49 | 132 | 0.291 |
| M-40 | 1,4-Dioxane (1,4-Diethylene Dioxide) | 123-91-1 | 88.10 | 0.0002 | 0.00203 | 0.462 | 7.4 | 20 | 0.0438 |

| Method | Compound | CAS Number | Formula Wt. | Detection Limit (ppmv) | Measured Average (ppmv) | Concentration in Inlet LFG | | Mass Flow Rate in Inlet LFG Stream | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | ($x10^{-9}$ lb/ft$^3$) | (µg/m$^3$) | (mg/hr) | ($x10^{-3}$ lb/hr) |
| M-40 | 1-Ethyl-4-methylbenzene (4-Ethyl Toluene) | 622-96-8 | 120.20 | 0.0002 | 0.079 | 24.6 | 395 | 1060 | 2.3 |
| M-40 | 4-Methyl-2-pentanone (MIBK) | 108-10-1 | 100.16 | 0.0002 | 1.07 | 278 | 4450 | 12000 | 26.3 |
| M-40 | Benzyl Chloride (Chloromethyl Benzene) | 100-44-7 | 126.58 | 0.0002 | 0.006 | 2.0 | 33 | 88 | 0.19 |
| M-40 | Bromomethane (Methyl bromide) | 74-83-9 | 94.95 | 0.0002 | 0.016 | 3.8 | 62 | 165 | 0.36 |
| M-40 | cis-1,2-Dichloroethene | 156-59-2 | 96.94 | 0.0002 | 0.074 | 18.6 | 297 | 798 | 1.8 |
| M-40 | cis-1,3-Dichloropropene | 10061-01-5 | 110.98 | 0.0002 | 0.00023 | 0.065 | 1.0 | 2.8 | 0.0062 |
| M-40 | Cyclohexane | 110-82-7 | 84.16 | 0.0002 | 0.165 | 35.9 | 575 | 1540 | 3.4 |
| M-40 | Dibromochloromethane | 124-48-1 | 208.29 | 0.0002 | ND | ND | ND | ND | ND |
| M-40 | Ethyl Acetate | 141-78-6 | 88.10 | 0.0002 | 1.83 | 416 | 6660 | 17900 | 39.4 |
| M-40 | Heptane | 142-82-5 | 100.20 | 0.0002 | 0.24 | 62.7 | 1000 | 2700 | 5.9 |
| M-40 | Methyl-t-butyl Ether (MTBE) | 1634-044 | 88.15 | 0.0002 | 0.054 | 12.4 | 200 | 530 | 1.2 |
| M-40 | Styrene (Vinylbenzene) | 100-42-5 | 104.14 | 0.0002 | 0.030 | 7.9 | 127 | 342 | 0.753 |
| M-40 | t-1,3-Dichloropropene | 1006-02-6 | 110.98 | 0.0002 | 0.00032 | 0.092 | 1.5 | 3.9 | 0.0087 |
| M-40 | Tetrahydrofuran (Diethylene Oxide) | 109-99-9 | 72.10 | 0.0002 | 1.18 | 221 | 3540 | 9490 | 20.9 |
| M-40 | Tribromomethane (Bromoform) | 75-25-2 | 252.77 | 0.0002 | 0.000423 | 0.276 | 4.43 | 11.9 | 0.0262 |
| M-40 | Vinyl Acetate | 108-05-4 | 86.09 | 0.0002 | 0.242 | 53.9 | 864 | 2350 | 5.1 |

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## 5. Quality Assurance/Quality Control

This project produced data that qualified to receive the “A” rating with respect to the rating system described in section 4.4.2 of the *Procedures for preparing Emission Factor Documents* (EPA-454/R-95-015). The cited EPA document provides a clear description of the requirements for an “A” data quality rating. Tests were performed by using an EPA reference test method, or when not applicable, a sound methodology. Tests were reported in enough detail for adequate validation and raw data were provided that could be used to duplicate the emission results presented in this report.

Throughout the results sections of this report, notations and footnotes were included to flag data that, for various reasons, did not meet their associated measurement quality objectives.

### 5.1 Assessment of Measurement Quality Objectives

Measurement quality objectives (MQOs) were established for each critical measurement and documented in the *Site-Specific QAPP for the Field Evaluation of Landfill Gas Control Technologies-Landfill A*. The following subsections assess MQOs for each measurement to determine if goals were achieved. When applicable, data validation elements performed on laboratory analytical reports are also included.

#### 5.1.1 Continuous Emissions Monitors (CEMs)

The combustion gases $O_2$, $CO/CO_2$, $SO_2$, $NO_X$ and THC were measured in the field using CEMs. The following MQOs were established for CEM measurements for Landfill A:

- Direct calibration bias: ±2 percent
- System bias checks: ±5 percent
- Zero and drift: ±3 percent
- Completeness: >90 percent

Direct calibrations were performed daily prior to testing with certified calibration gases at zero and a minimum of two other concentrations (typically a mid-level concentration and one point near the full-scale end of the instrument range). System bias checks were performed pre-test and post-test. Drift checks were performed daily post-test. Table 5-1 summarizes these quality control (QC) checks for all instruments. Not all MQOs were met for all CEM measurements. However, if the calibration and drift check criteria were relaxed to ±5 percent, then all MQO would have been met. The fact that the original QAPP MQOs were not fully met did not affect the usability of these data. The reported data were notated accordingly.

**Table 5-1. CEM MQO Summary for Landfill A**

| Instrument and Range | Direct Calibration (±2% criteria) | | | System Bias Checks (±5% criteria) | | | Drift Checks (±3% criteria) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Total (#) | Bias Range (%) | Complete (%) | Total (#) | Bias Range (%) | Complete (%) | Total (#) | Bias Range (%) | Complete (%) |
| Servomex $O_2$ Analyzer (0-21%) | 6 | 0 - 3.3 | 17 | 3 | 0 - 2.2 | 100 | 6 | 2.2 - 3.3 | 100 |
| Cal Analytical $CO_2$ Analyzer (0-20%) | 6 | 2.2 - 3.3 | 17 | 3 | 1.1 - 4.3 | 100 | 6 | 2.2 – 5.4 | 83 |
| Cal Analytical CO Analyzer (0-650 ppm) | 6 | 0 - 1.7 | 100 | 3 | 0.2 - 1.2 | 100 | 6 | 1.2 – 1.7 | 100 |
| Cal Analytical $SO_2$ Analyzer (0-500 ppm) | 6 | 0 - 3.0 | 67 | 3 | 1.0 2.8 | 100 | 6 | 0.4 – 2.8 | 67 |
| TECO THC Analyzer (0-1000 ppm) | NA [a] | NA [a] | NA [a] | 3 | 0 - 3.8 | 100 | 3 | 0 – 3.3 | 67 |
| TECO $NO_X$ Analyzer (0-4000 ppm) | 6 | 0.6 – 7.1 | 50 | 3 | 0.6 - 4.7 | 100 | 3 | 1.4 – 7.1 | 67 |

[a] The method called for calibration gases to be introduced at a point of the sampling system close to the sampling probe for them to flow through the heated sample line. Calibration gases were not injected directly to the analyzer

#### 5.1.2 Carbonyls (TO-11)

The following MQOs were established in the QAPP for this method:

- Recovery (formaldehyde): 50-150 percent
- Precision: ±20 percent relative standard deviation (RSD)

- Completeness: >90 percent

Four samples (including three raw LFG samples and one field blank) were submitted to Resolution Analytics for formaldehyde and acetaldehyde determination. Results were reported in RFA# 992014. The report included information on instrument calibration and internal QC checks. Samples collected on October 31 and November 2, 2002 were received by the laboratory on November 14, 2002 and analyzed on November 22, 2002. This met the 30-day hold-time limitation.

Analytical detection limits were reported as 13 ppb for formaldehyde and 9 ppb for acetaldehyde in the extract. With an extract volume of 5 ml and sample gas volume of about 31 standard liters, the MDLs were 1.7 $x10^{-3}$ and 2.3 $x10^{-3}$ ppmv for formaldehyde respectively.

The field blank did not have detectable levels of acetaldehyde and showed 0.073µg formaldehyde detected. To assess accuracy, an external performance evaluation audit sample containing 0.25 ppm formaldehyde and acetaldehyde was analyzed with the sample set. Recovery was 101.6 percent% for formaldehyde and 96.3 percent for acetaldehyde, which meets the 50-150 percent MQO. One project sample was injected in duplicate and the percent drift (%D) range for formaldehyde was 0.7 percent and for acetaldehyde was 3.2 percent. All MQOs were met for this method for a completeness of 100 percent.

The test samples produced very low detection responses for formaldehyde. Therefore, even though the detected levels of formaldehyde were higher than formaldehyde's MDL, the reported concentrations for formaldehyde should be flagged as estimates and notated with a "J".

#### 5.1.3 Hydrogen Sulfide ($H_2S$) (EPA Method 11)

The following MQOs were established in the Landfill A QAPP for this method:

- Accuracy: ±5 percent bias
- Precision: ±5 percent relative standard deviation (RSD)
- Completeness: >90 percent

Three collected samples, a reagent field blank, and two laboratory in-house reagent blanks were submitted to Oxford Laboratories for $H_2S$ analysis by EPA Method 11. The samples were collected on November 2, 2002, and submitted to the laboratory on November 14, 2002. The results report was dated November 22, 2002. Therefore, the analysis met the 30-day hold time criteria.

The field blank submitted did not have quantifiable concentrations of $H_2S$. A laboratory spike was performed and the recovery was 101 percent. The three test samples produced results of similar concentrations. Duplicate analysis of the Rn#2 sample resulted in 1.7 percent relative standard deviation (RSD). All MQOs were met for this method for a completeness of 100 percent.

#### 5.1.4 Dioxins and Furans (PCDD/PCDFs) (EPA Method 23/0011)

The following MQOs were established in the QAPP for this method:

- Recovery: 50-150 percent
- Completeness: >90 percent

Four sample sets (including one set of reagent blank and sample train rinsates) were submitted to ALTA Analytical Perspectives for PCDD/PCDF analysis. The samples were collected on November 1, 2002, and delivered to the laboratory on November 14, 2002. The samples were extracted on November 20, 2002 and analyzed on November 27, 2002. That met the 14-day hold-time for extraction and 40-day hold time for analysis.

The field blank did not have detectable levels of the target analytes. Detection limits for the various congeners were in the single-digit picogram level. To assess accuracy, each sample train was spiked with standard Method 23 spiking compounds and analysis of the samples yielded extraction standard (ES) recovery from 84 to 99 percent. Recovery of sampling standards (SS) ranged from 106 to 108 percent. These recoveries were well within the 50-150 percent MQO.

Because a decision was made to analyze only one of the three sample extracts, the completeness goal of 90% was not achieved. However, all other MQOs were met for this method.

### 5.1.5 Polycyclic Aomatic Hydrocarbons (PAHs) (EPA Method 23/0011)

#### *5.1.5.1 Raw Landfill Gas (LFG) Samples*

The Method 23 samples collected from the raw LFG could not be concentrated below 750 to 1000 µL. The produced cleaned up extracts contained gasoline-like hydrocarbons and prevented the preparation of final extracts for PAH analysis.

Therefore the MQOs for this sample group was 0 percent complete.

#### *5.1.5.2 Engine Stack Samples*

The following MQOs were established in the QAPP for this method:

- Recovery: 50-150 percent
- Completeness: >90 percent

Four samples (including one reagent blank) collected from the engine stack were submitted to ALTA Analytical Perspectives for PAH analysis. The report included information on instrument calibration and internal QC checks. Samples collected on November 1, 2002 were received by the laboratory on November 14, 2002. These were extracted on November 20, 2002 and analyzed on January 9, 2003. That met the 14-day hold-time for extraction but missed the analysis 40-day hold time by 10 days. The data were reported with the appropriate notations.

Analysis of the field blank yielded detectable but low levels of a few of the target compounds with all PAH analytes totaling to 15762 ng. In contrast, the test samples showed total PAH level of 113974 ng. Recovery of ES ranged from 65 to 124 percent. Recoveries of SS, $d_{10}$-fluorene and $d_{14}$-terphenyl were not reported. Recovery of the alternative standard (AS) $d_{10}$-anthracene was 57.9 percent. The reported recoveries were within the 50 to 150 percent MQO.

Because a decision was made to analyze only one of the three sample extracts, the completeness goal of 90% was not achieved. However, all other MQOs were met for this method.

#### 5.1.6 Polychlorinated Biphenyls (PCBs)

The same Method 23 samples collected from the raw LFG were earmarked for analysis for PCBs. Since the cleaned up extracts could not be concentrated below 750 to 1000 µL because of the presence of gasoline-like hydrocarbons, final extracts could not be prepared for the planned PCB analysis. Therefore the MQO for this sample group was 0 percent complete.

#### 5.1.7 Non-Methane Organic Compounds (NMOCs) (Method 25C)

The following MQOs were established in the QAPP for Landfill A:

- Recovery: 50 to 150 percent
- Precision: ±30 percent RSD
- Completeness: >90 percent

Four canister samples (including a field blank) were submitted from Landfill A for NMOC analysis by Method 25-C to Triangle Environmental Services. The samples were collected on November 2, 2002, submitted on December 3, 2002, and analyzed between December 3 and 23, 2002. Therefore the analysis did not meet the 30 day hold time requirements. The apparent delay in sample delivery was partly attributed to the fact that the same canisters had to be analyzed by RTP Laboratory for volatile organics first. The impact of exceeding the prescribed 30-day hold time by up to 21 days is unknown. The laboratory report included information on instrument calibration and internal QC checks.

The only detected NMOC in the field blank was at 2 ppmv as hexane. Accuracy for the method was assessed by evaluating results of response factor (RF) check samples that were run prior to and following sample analysis. Acceptance criteria established by the method is that the RF must be within 10 percent of the response factor from initial calibration. All response factor checks ranged from 0.9 to 7.4 percent of the initial calibration, well within the 10 percent acceptance criteria. The %D between the pre and post-test checks were less than 2 percent, ranging from 0.5 to 1.2 percent. Samples were run in triplicate and all %RSDs for samples were less than 3.4 percent.

All MQOs were met for this method for a completeness of 100 percent. The reported data were notated for the hold time exceedance.

### 5.1.8 Hydrogen Chloride (HCl) (EPA Method 26A)

The following MQOs were established in the QAPP for Landfill A:

- Accuracy: ±10 percent bias
- Precision: ±10 percent RSD
- Completeness: >90 percent

Four samples (including one field blank) were submitted to Resolution Analytics for HCl and chlorine ($Cl_2$) determination. The results were reported in RFA# 992014. The report included information on instrument calibration and internal QC checks. Samples were collected on October 31 and November 2, 2002. These were received by the laboratory on November 14, 2002, and analyzed on November 27, 2002, which met the 4 week hold-time requirement. Analytical detection limits were reported as 0.41 ppm HCl.

The field blank did not contain detectable levels of HCl. In-house audit samples were analyzed with each respective group of field samples and the measured concentrations fell within method criteria of 10 percent of their expected values.

A matrix spike was performed on Sample #1 (A POSST-01). A 0.8 ml sample was spiked with 0.8 ml of standard (50 ppm chloride) and analyzed in duplicate. The laboratory reported 97.1 percent recovery of the HCl spike with a 0.02 percent deviation in duplicate injections. This meets the MQO of ±10 percent with very good precision. Calculated bias for internal QC check was <2.2 percent. All MQOs were met for 100 percent completeness.

### 5.1.9 Metals (EPA Method 29)

The following MQOs were established in the Landfill A QAPP for this method:

- Accuracy: ±25 percent bias
- Precision: ±20 percent RSD
- Completeness: >90 percent

Four sets of Method 29 Multi-Metals trains (including one field blank) were submitted to First Analytical Laboratories for As, Cd, Cr, Pb, Mn, Hg, and Ni determination. Results were reported in Project #21110. The report included information on instrument calibration and internal QC checks. Samples were collected on October 31 and November 2, 2002, received by the laboratory on November 12, 2002, and analyzed on November 14, 2002, which met the 14 day hold-time requirement. Method detection limits for each of the target metals were reported as follows:

- As = 5.0 µg/L
- Cd = 0.2 µg/L
- Cr = 5.0 µg/L
- Pb = 5.0 µg/L
- Mn = 5 µg/L
- Ni = 10 µg/L
- Hg = 0.2 µg/L

Traces of Cr, Mn and Ni were found in the blanks, which is not unusual.

All samples were spiked prior to analysis. Spike recoveries ranged from 82 to 110 percent and were within the acceptable range of 75-125 percent. In addition to spiking the samples, for each metal, internal calibration verification samples (ICVs) and continuing calibration verification samples (CCVs) were performed. ICVs were run at the beginning of each run set and CCVs were run at a frequency of one for every 10 samples. ICV and CCV measured values were all $<\pm10$ percent for all metals. Therefore the MQO for this measurement was 100 percent and met the objective set in the QAPP.

#### 5.1.10 Organo-Mercury (Hg) and Total Mercury (Hg) (Frontier)

The following MQOs were established in the Landfill A QAPP for this method:

- Recovery: 50-150 percent

- Precision: ±20 percent RSD
- Completeness: >90 percent

Mercury (Hg) analysis was performed by Frontier Geosciences. Four total Hg samples (including a field blank) were taken at Landfill A. Samples were collected on November 1 and 2, 2002 and analyzed in December 2002. That analysis schedule exceeded the 14-day hold-time specified in the QAPP. All other quality assurance measures indicated that the analysis of the traps were under good control. All field blanks were consistent with historical values and indicate the detection limit is likely to be at or below the previous estimated value of 50 $ng/m^3$. Spike recoveries were 95.4 and 95.2 percent and relative percent difference (RPD) between replicates was 6.2 percent, which meets MQOs and are therefore 100 percent complete.

Five monomethyl mercury (MMHg) samples (including a field blank and field spike) were collected on November 2, 2002. These samples were analyzed December 2005 which exceeded the 14-day hold-time. Analysis of these samples was under good control with acceptable distillation spike recoveries and distillation duplicates. All CCV standards had acceptable recoveries. Field spike recovery was 75 percent and matrix spike recovery was 122 percent, which meets MQOs. The only prominent incoherency of the MMHg data from Landfill A is the disagreement among the replicates. Samples 021102-01 and 021102-02 had measured concentrations below the estimated method detection limit but sample 021102-03 was reported at a concentration of 1.2 $ng/m^3$. This does not meet the ±30 percent RSD criteria for replicate samples. Possible explanations for the differences between replicates include variability in the landfill gas concentration or undetected sampling or analytical error. The data were notated accordingly.

Five dimethyl mercury (DMHg) samples (including a field blank and field spike) were collected on November 1 and 2, 2002. These samples were analyzed in December 2002 and did not meet the 14-day hold-time. Field spike recoveries for all DMHg analysis were consistently low 0-40 percent. Because of recovery issues, DMHg concentrations are likely biased low and the degree of bias is likely significant. QA measures in place support the following conclusions:

- Replicate samples taken at each site reported similar concentrations which indicated that the properties of the DMHg sampling train and landfill gas were consistent and biases was not attributable to trap media or landfill sample gas.

- Continuous calibration verifications (CCVs) used during the analysis indicates that the detection systems were measuring accurately.

- Dimethyl Hg (DMHg) field blanks indicated that the trap media, handling procedures and analytical techniques did not contribute to the problems with recovery.

- Trip spikes (traps spike in the laboratory, shipped to the field but not used for sampling) indicated that the laboratory standards, trap media and trap handling procedures do not create significant bias.

- Field spikes (traps spiked in the lab and used to collect a replicate sample) indicated that some property or action during sampling either destroyed or evaded the DMHg adsorbed to the Carbotrap

The RSD between the three replicate samples was 23.9 percent, which meets the MQO of ±30 percent, but because recovery MQOs were not met for any of the field spikes, DMHg analysis was 0 percent complete. The data were reported with the appropriate notations.

#### 5.1.11 Volatile Organic Compounds (VOCs) and Methane ($CH_4$) (Method TO-15)

The following MQOs were established in the Landfill A QAPP for this method:

- Accuracy: 50-150 percent recovery

- Precision: ±30 percent RSD

- Completeness: >90 percent

Four SUMMA canisters (including one field blank) were submitted from Landfill A to RTP Laboratories for VOC and $CH_4$ determination by EPA Method TO-15. Results were reported in Project #347-02. Samples were collected on November 2, 2002 and analysis was completed by November 27, 2002, which met the 30 day hold-time requirement.

Analysis of the field blank found 3.3 ppbv of acetone, 1.4 ppbv of methylene chloride, and 1.03 ppbv of bromomethane. Other targets were either found at <1 ppbv or not detected at the MDL of 0.2 ppb.

Accuracy was assessed using results of a 10 ppbv laboratory control sample containing all target compounds. For all but two compounds, recoveries ranged from 60-150 percent, which met the established acceptance criteria of 50-150 percent. The recovery reported for ethanol was 2.4 percent, and 230 percent for m/p-xylene. Results for these two compounds should be flagged as estimated ("J").

Sample 062205-04 was spiked with 200 ppbv of chlorobenzene prior to dilution with helium and analysis. The recovery of chlorobenzene was 89.5 percent.

Precision was demonstrated through multiple injections of standards at five concentration levels. The RSD between the calculated relative response factors (RRF) must be <30% with allowances that two may be >40 percent. The average RSD was 13.8 percent and method criteria were met for all compounds except isopropyl alcohol with an RSD of 56.3 percent and hexane with an RSD of 40.7 percent. Results for these compounds should be flagged as estimated ("J"). Valid data was received for all SUMMA canisters submitted, and these analyses were considered to be 100 percent complete.

### 5.2 Audits

This project was designated as QA Category II effort. Hence, audits were required. The internal and external audits performed for this project were completed earlier and their findings were included in a separate report for Landfill D of this project.

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# Field Test Measurements at Five Municipal Solid Waste Landfills with Landfill Gas Control Technology
# Final Report

## Appendix B

## SOURCE TEST REPORT

## FOR LANDFILL B

## Tables

## Figures

## Appendices

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## Acronym List

| | |
|---|---|
| %D | Percent drift |
| AP-42 | Compilation of Air Pollutant Emission Factors |
| APPCD | Air Pollution Prevention Control Division |
| ARCADIS | ARCADIS G&M, Inc. |
| As | Arsenic |
| AS | Alternative standard |
| CCVs | Continuing calibration verification samples |
| Cd | Cadmium |
| CEMS | Continuous emission monitoring system |
| $CH_4$ | Methane |
| $Cl_2$ | Chlorine |
| CO | Carbon monoxide |
| $CO_2$ | Carbon dioxide |
| Cr | Chromium |
| DMHg | Dimethyl mercury |
| EPA | US Environmental Protection Agency |
| ES | Extraction standard |
| FID | Flame ionization detector |
| GC | Gas chromatograph |
| GC/FID | Gas chromatograph/flame ionization detector |
| GC/MS | Gas chromatograph/mass spectrometer |
| HCl | Hydrogen chloride |
| Hg | Mercury |
| $H_2S$ | Hydrogen sulfide |
| ICVs | Internal calibration verification samples |
| LFG | Landfill gas |
| MMHg | Monomethyl mercury |
| Mn | Manganese |

| | |
|---|---|
| MQOs | Measurement quality objectives |
| MSW | Municipal solid waste |
| $N_2$ | Nitrogen |
| Ni | Nickel |
| NMOCs | Non-methane organic compounds |
| $NO_X$ | Nitrogen oxides |
| $O_2$ | Oxygen |
| PAHs | Polynuclear aromatic hydrocarbons |
| Pb | Lead |
| PCBs | Polychlorinated biphenyls |
| QA | Quality Assurance |
| QAPP | Quality Assurance Project Plan |
| QC | Quality control |
| RF | Response factor |
| RPD | Relative percent difference |
| RRF | Relative response factors |
| RSD | Relative standard deviation |
| RTP | Research Triangle Park |
| $SO_2$ | Sulfur dioxide |
| SS | Sampling standards |
| TCDD/TCDFs | Dioxins/furans |
| THCs | Total hydrocarbons |
| TICs | Tentatively identified compounds |
| VOCs | Volatile organic compounds |

## 1. Introduction

Large municipal solid waste (MSW) landfills are subject to Clean Air Act regulations because of concerns related to their emissions and their potential adverse effects to human health and the environment. Landfills are listed as a source of air toxics in the Urban Air Toxics Strategy for future evaluation of residual risk. Existing emission factors for landfill gas (LFG) were largely developed using data from the 1980s and early 1990s. A database was developed summarizing data from approximately 1,200 landfills, along with emissions information from literature, and from test reports prepared by state and local government agencies and industry. These data were summarized in *Compilation of Air Pollutant Emission Factors (AP-42)*, Chapter 2.4. 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 overall purpose of this testing program was to generate data that may be used to update AP-42 and to include data that reflect current waste management operating practices.

This report presents the results of a field test conducted at the Landfill B located in the northeast U.S. Testing took place on November 4 and 5, 2002.

The site used an enclosed flare for destruction of the LFG. A more detailed description of the flare system is presented in Section 2. The specific purpose of the testing program was to determine emissions from the LFG pipe feeding the enclosed flare and from the flare stack. The pollutants of interest for the raw untreated LFG were volatile organic compounds (VOCs), non-methane organic compounds (NMOCs), hydrogen sulfide ($H_2S$), carbonyls (acetaldehyde, formaldehyde), polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and mercury (Hg) compounds. The pollutants of interest for the treated LFG, in this case at the enclosed flare stack, were carbon monoxide (CO), nitrogen oxides ($NO_X$), sulfur dioxide ($SO_2$), NMOCs as total hydrocarbons (THCs), hydrogen chloride (HCl), dioxins/furans (PCDD/PCDFs), PAHs, total Hg, and metals.

ARCADIS G&M, Inc. (ARCADIS), as contractor to the US Environmental Protection Agency's (EPA) Air Pollution Prevention Control Division (APPCD), performed this work under Work Assignment 4-1 of Onsite Laboratory Support Contract. The testing activities followed the specifications of the approved "*Site-Specific Quality Assurance Project Plan for the Field Evaluations of Landfill Gas Control Technologies Landfill B*" dated October 29, 2002.

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## 2. Landfill Facility Descriptions

Available information indicated that Landfill B began operation in 1967. As of 2003, the site had 4,000,000 tons of waste in place, over an area of 40 acres. Raw LFG was collected through 2,500 feet of horizontal collectors. The gases generated in the landfill were extracted with 49 vertical wells. All collected LFG was piped to the enclosed flare system and combusted.

### 2.1 Flare Process Description and Operation

A Perennial Energy Enclosed Ground Flare Station, rated at maximum LFG input rate of 1500 scfm, received and destroyed the collected LFG. Figure 2-1 shows a simplified process schematic of the flare system. A burner array and an automatic louvre system controlled gas and combustion air distribution to achieve proper combustion. A condensate removal system prevented liquids from entering into the flare burners. A flame arrestor prevented flame from propagating from the burner array back into the LFG collection and flow control system. The unit could be operated satisfactorily within a 5-to-1 turndown ratio (from 54.0 to 10.8 MMBtu/hr). The system did not have provisions for heat recovery.

According to manufacturer information, the Perennial Energy Enclosed Ground Flare Station was designed to afford the combustion gases a minimum residence time of 0.6 seconds at 1400°F to insure thermal destruction of CO and hydrocarbons, with minimal production of $NO_X$. Specific information related to the system's ability to destroy or reduce other potential pollutants was not available.

### 2.2 Landfill Gas (LFG) Sampling Locations

Gas sampling was conducted at the raw LFG pipe and at the Perennial Energy Enclosed Ground Flare stack, as depicted in Figure 2-1.

#### 2.2.1 Landfill Gas (LFG) Header Pipe

Raw LFG samples were collected from the header pipe at the point where it emerged from the ground and upstream of any processing units. Figure 2-2 is a photograph of the raw LFG pipe. The pipe was 11 inches in diameter as it emerged from the ground and expanded to 14 inches in diameter before passing through a wall into the building that housed the gas control-and-process system. At the sampling point, four ¼-inch gas taps were installed, and gases were withdrawn through these ports to obtain the test samples.

Comparing the physical arrangement of this header pipe with requirements of standard sampling methodologies indicated that the header configuration rendered isokinetic sampling at the gas collection pipe impossible. Therefore, isokinetic sampling was not attempted at this location. Further discussions on this topic are presented in Section 3.3.1.1.

### 2.2.2 Flare Stack

Figure 2-3 shows the flare stack and the arrangement of the sampling ports. The flare stack was 118 inches in diameter and has four 4-inch sampling ports installed 90 degrees apart. Figure 2-4 is a schematic of the flare stack and includes the locations of the sample traverse points. Isokinetic sampling was possible at this location.

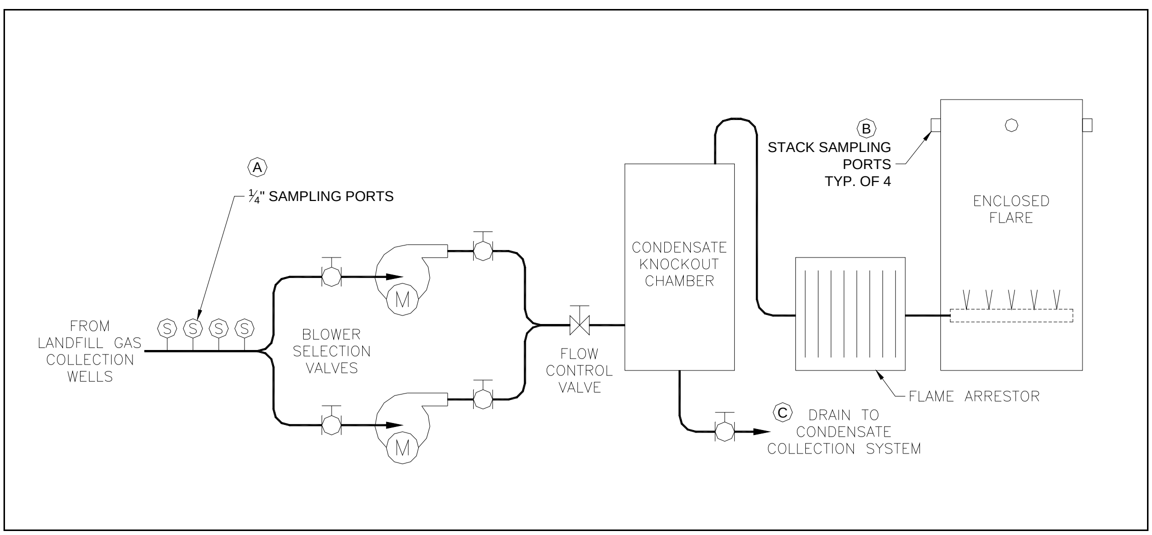


**Figure 2-1. Simplified Flare Process Flow Diagram and Sampling Points**

**Figure 2-2. Landfill Gas Collection Pipe**

**Figure 2-3. Enclosed Flare Unit Showing Stack Sampling Ports**

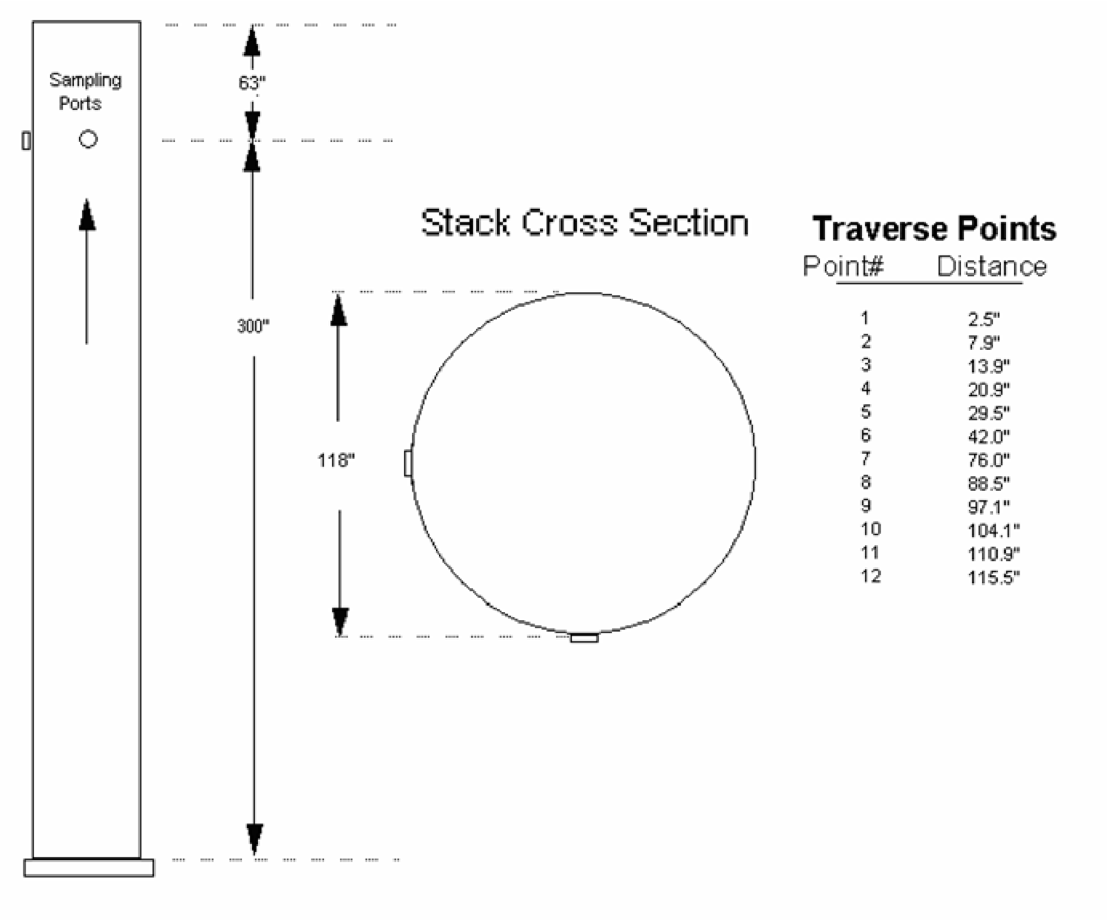


**Figure 2-4. Flare Stack Dimension and Sampling Traverse Locations**

# 3. Test Operations

As stated previously, the purpose of the sampling program was to determine the chemical constituents of raw LFG and flare stack emissions.

## 3.1 Test Team

The tests were conducted by a team of eight individuals and a representative of the landfill company. The team members and their primary duties are listed in Table 3-1.

**Table 3-1. Test Team Members and Responsibilities**

| Role | Primary Duty |
|---|---|
| Test Engineer | Chief |
| Technician | CEM operator |
| Technician | Sample train preparation and recovery |
| Technician | Sample train operator at raw LFG inlet pipe |
| Test engineer | Sample train operator at stack |
| Technician | Sample train operator at stack |
| Test engineer | Mercury measurements |
| Air Programs Manager | Observer |

## 3.2 Test Log

### 3.2.1 Planned Test Sample Matrices

The target list of samples and measurements to be collected were specified in the Quality Assurance Project Plan (QAPP) dated October 29, 2002. These are reiterated here for completeness. Tables 3-2 lists the target compounds of interest for the raw LFG. Table 3-3 lists the target compounds of interest for the treated gas at the flare stack.

### 3.2.2 Landfill Gas (LFG) Pipe (Inlet)

Sample collection took two days to complete. Table 3-4 lists the samples that were collected from the raw LFG pipe. Figure 3-1 is a photograph of the sampling team in action at this sample location.

**Table 3-2. Target Analytes for the Landfill Gas Stream and Sample Condensate Collected at the Gas Header**

| **Volatile compounds** | **Volatile compounds (continued)** | **Carbonyls** |
|---|---|---|
| Methane | Ethylene dibromide | Acetaldehyde |
| Ethane | Ethylene dichloride | Formaldehyde |
| Propane | Methyl chloroform | |
| Butane | Methyl isobutyl ketone | **Polycyclic aromatic hydrocarbons** |
| Pentane | Methylene chloride | |
| Hexane | Propylene dichloride | **Polychlorinated biphenyls** |
| Carbonyl sulfide | t-1,2-Dichloroethene | |
| Chlorodifluoromethane | Tetrachloroethene | **Mercury** |
| Chloromethane | Toluene | Organo-mercury compounds |
| Dichlorodifluoromethane | Trichlorethylene | Total |
| Dichlorofluoromethane | Vinyl chloride | Elemental |
| Ethyl chloride | Vinylidene chloride | |
| Fluorotrichloromethane | Ethanol | **Gases** |
| 1,3-Butadiene | Methyl ethyl ketone | Carbon dioxide |
| Acetone | 2-Propanol | Oxygen |
| Acrylonitrile | 1,4-Dichlorobenzene | |
| Benzene | Ethylbenzene | **Moisture** |
| Bromodichloromethane | Xylenes | |
| Carbon disulfide | | |
| Carbon tetrachloride | | |
| Chlorobenzene | **Non-methane organic carbons** | |
| Chloroform | | |
| Dimethyl sulfide | **Reduced sulfur compounds** | |
| Ethyl mercaptan | Hydrogen sulfide | |

**Table 3-3. Target Analytes for the Flare Stack Outlet Gas Stream**

| **Gases** | **Dioxins/Furans** |
|---|---|
| Oxygen | |
| Carbon dioxide | **PAHs** |
| Carbon monoxide | |
| Nitrogen oxide | **Mercury** |
| Sulfur dioxide | Total |
| Total hydrocarbons | |
| **Non-methane organic compounds** | **Metals** |
| | Lead, arsenic, cadmium, chromium, manganese, nickel |
| **Hydrogen chloride** | |

**Figure 3-1. Sampling Operations at the Landfill Gas Pipe Inlet**

**Table 3-4. Landfill Gas Inlet Sample Log and Collection Times**

| Sampling Method | Run Number | Analyte(s) | Sample Class | Date | Run Period |
|---|---|---|---|---|---|
| EPA Method 40 (TO-15, 25C, 3C) | | | | | |
| | B-Pre-M40-110402-01 | VOCs/NMOCs/$O_2$/$CO_2$,$N_2$ | Test | 11/04/02 | 11:02 - 11:16 |
| | B-Pre-M40-110402-02 | VOCs/NMOCs/$O_2$/$CO_2$,$N_2$ | Test | 11/04/02 | 12:13 - 12:24 |
| | B-Pre-M40-110402-03 | VOCs/NMOCs/$O_2$/$CO_2$,$N_2$ | Test | 11/04/02 | 13:21 - 13:34 |
| EPA Method 23 | | | | | |
| | B-Pre-M23-110402-01 | PAHs, PCBs | Test | 11/04/02 | 12:41 - 15:41 |
| | B-Pre-M23-110402-02 | PAHs, PCBs | Test | 11/04/02 | 12:42 - 15:42 |
| | B-Pre-M23-110502-03 | PAHs, PCBs | Test | 11/05/02 | 09:38 - 12:41 |
| EPA Method 0100 | | | | | |
| | B-Pre-M0100-110502-01 | Carbonyls | Test | 11/05/02 | 09:48 - 10:28 |
| | B-Pre-M0100-110502-02 | Carbonyls | Test | 11/05/02 | 10:45 - 11:15 |
| | B-Pre-M0100-110502-03 | Carbonyls | Test | 11/05/02 | 11:27 - 11:58 |
| EPA Method 11 | | | | | |
| | B-Pre-M0011-110502-01 [a] | $H_2S$ | Test | 11/05/02 | 12:51 - 13:01 |
| | B-Pre-M0011-110502-02 | $H_2S$ | Test | 11/05/02 | 13:22 - 13:32 |
| | B-Pre-M0011-110502-03 | $H_2S$ | Test | 11/05/02 | 14:20 - 14:30 |
| | B-Pre-M0011-110502-04 | $H_2S$ | Test | 11/05/02 | 14:58 - 15:08 |
| Lumex Instrument | | | | | |
| | B-Pre-EM-110502-01 | Elemental Hg [b] | Test | 11/05/02 | 16:35 - 17:00 |
| | B-Pre-EM-110502-02 | Elemental Hg [b] | Test | 11/05/02 | 16:35 - 17:00 |
| | B-Pre-EM-110502-03 | Elemental Hg [b] | Test | 11/05/02 | 16:35 - 17:00 |
| Frontier | | | | | |
| | B-Pre-TGM-110402-FB01 | Total gaseous Hg | Field Blank | 11/04/02 | 13:22 - 13:25 |
| | B-Pre-TGM-110402-01 | Total gaseous Hg | Test | 11/04/02 | 10:52 - 11:32 |
| | B-Pre-TGM-110402-02 | Total gaseous Hg | Test | 11/04/02 | 11:44 - 12:21 |
| | B-Pre-TGM-110402-03 | Total gaseous Hg | Test | 11/04/02 | 12:33 - 13:11 |

| Sampling Method | Run Number | Analyte(s) | Sample Class | Date | Run Period |
|---|---|---|---|---|---|
| Frontier | | | | | |
| | B-Pre-MMM-110502-SP01 | Monomethyl Hg | Spike | 11/05/02 | 10:41 - 11:07 |
| | B-Pre-MMM-110502-FB01 | Monomethyl Hg | Field Blank | 11/05/02 | 8:30 - 8:35 |
| | B-Pre-MMM-110502-01 | Monomethyl Hg | Test | 11/05/02 | 08:43 - 08:58 |
| | B-Pre-MMM-110502-02 | Monomethyl Hg | Test | 11/05/02 | 09:22 - 09:46 |
| | B-Pre-MMM-110502-03 | Monomethyl Hg | Test | 11/05/02 | 10:02 - 10:27 |
| Frontier | | | | | |
| | B-Pre-DMM-110502-SP01 | Dimethyl Hg | Spike | 11/05/02 | 15:40 - 16:02 |
| | B-Pre-DMM-110502-FB01 | Dimethyl Hg | Field Blank | 11/05/02 | 16:15 - 16:20 |
| | B-Pre-DMM-110502-01 | Dimethyl Hg | Test | 11/05/02 | 13:42 - 14:07 |
| | B-Pre-DMM-110502-02 | Dimethyl Hg | Test | 11/05/02 | 14:22 - 14:50 |
| | B-Pre-DMM-110502-03 | Dimethyl Hg | Test | 11/05/02 | 15:00 - 15:28 |

[a] Did not purge train at end of run; run was repeated

[b] Represents average of 3 readings, each of 30-second duration

### 3.2.3 Flare Stack

Sampling at the flare stack was conducted by accessing the sampling ports with the aid of a scaffold. Figure 3-2 shows the flare and the sampling scaffold platform. Figure 3-3 shows one of the sampling ports with a sampling probe in place during sample collection.

Figure 3-2. Sampling Operations at the Enclosed Flare


Figure 3-3. Sampling Port with Probe in Place

The flare stack was sampled for NMOCs (as THCs), PCDD/PCDFs, PAHs, HCl, metals (lead [Pb], arsenic [As], cadmium [Cd], chromium [Cr], manganese [Mn], nickel [Ni]), total Hg, $SO_2$, $NO_X$, CO, carbon dioxide ($CO_2$), and oxygen ($O_2$). Table 3-5 lists the test samples that were collected from the flare stack.

The flare stack cross-section was divided into 24 equal areas according to EPA Method 1. Sampling at the flare stack was conducted at isokinetic conditions. Sample collection times for the Method 26 HCl train and Method 29 metals train were 60-minutes. Run time for the Method 23 PCDD/PCDFs trains was 180 minutes. Run time for continuous emission monitoring system (CEM) parameters ($SO_2$, $NO_X$, CO, $O_2$, $CO_2$, and THCs) varied due to the CEM sampling system developing problems shortening the useable measurement periods

**Table 3-5. Flare Stack Test Sample Log and Collection Times**

| | Run Number | Analyte(s) | Sample Class | Date | Run Period |
|---|---|---|---|---|---|
| EPA Method 3A (CEM) [b] | | | | | |
| | B-Post-M3A-110402-01 | $O_2$ | Test | 11/04/02 | 12:10 - 17:45 |
| | B-Post-M3A-110502-02 | $O_2$ | Test | 11/05/02 | 13:15 - 14:45 |
| EPA Method 3A (CEM) [b] | | | | | |
| | B-Post-M3A-110402-01 | $CO_2$ | Test | 11/04/02 | 12:10 - 17:45 |
| | B-Post-M3A-110502-02 | $CO_2$ | Test | 11/05/02 | 13:15 - 14:45 |
| EPA Method 10 (CEM) [b] | | | | | |
| | B-Post-M10-110402-01 | CO | Test | 11/04/02 | 12:10 - 17:45 |
| | B-Post-M10-110502-02 | CO | Test | 11/05/02 | 13:15 - 14:45 |
| EPA Method 7E (CEM) [b] | | | | | |
| | B-Post-M7E-110402-01 | $NO_X$ | Test | 11/04/02 | 12:10 - 17:45 |
| | B-Post-M7E-110502-02 | $NO_X$ | Test | 11/05/02 | 13:15 - 14:45 |
| EPA Method 6C (CEM) [b] | | | | | |
| | B-Post-M6C-110402-01 | $SO_2$ | Test | 11/04/02 | 12:10 - 17:45 |
| | B-Post-M6C-110502-02 | $SO_2$ | Test | 11/05/02 | 13:15 - 14:45 |
| EPA Method 25A (CEM) [b] | | | | | |
| | B-Post-M25A-110402-01 | NMOCs (THC) | Test | 11/04/02 | 12:10 - 17:45 |
| | B-Post-M25A-110502-2 | NMOCs (THC) | Test | 11/05/02 | 13:15 - 14:45 |

| | Run Number | Analyte(s) | Sample Class | Date | Run Period |
|---|---|---|---|---|---|
| Lumex Instrument | | | | | |
| | B-Post-EM-110502-01 | Elemental Hg [a] | Test | 11/05/02 | 16:10 - 16:35 |
| | B-Post-EM-110502-02 | Elemental Hg [a] | Test | 11/05/02 | 16:10 - 16:35 |
| | B-Post-EM-110502-03 | Elemental Hg [a] | Test | 11/05/02 | 16:10 - 16:35 |
| | B-Post-EM-110502-04 | Elemental Hg [a] | Test | 11/05/02 | 16:10 - 16:35 |
| EPA Method 26A | | | | | |
| | B-Post-M26-110402-01 | HCl | Test | 11/04/02 | 17:05 - 18:19 |
| | B-Post-M26-110402-02 | HCl | Test | 11/04/02 | 17:07 - 18:21 |
| | B-Post-M26-110502-03 | HCl | Test | 11/05/02 | 14:03 - 15:15 |
| EPA Method 23 | | | | | |
| | B-Post-M23-110402-01 | Dioxins/furans, PAHs | Test | 11/04/02 | 12:30 - 15:39 |
| | B-Post-M23-110402-02 | Dioxins/furans, PAHs | Test | 11/04/02 | 12:31 - 15:41 |
| | B-Post-M23-110502-03 | Dioxins/furans, PAHs | Test | 11/05/02 | 09:40 - 12:51 |
| EPA Method 29 | | | | | |
| | B-Post-M29-110402-01 | Metals | Test | 11/05/02 | 09:40 - 10:53 |
| | B-Post-M29-110402-02 | Metals | Test | 11/05/02 | 11:29 - 12:42 |
| | B-Post-M29-110502-03 | Metals | Test | 11/05/02 | 14:05 - 15:17 |

[a] Represents average of 3 readings, each of 30-second duration

[b] The CEM sampling system developed problems and cut short the useable measurement periods.

## 3.3 Field Test Changes and Deviations from Quality Assurance Project Plan (QAPP) Specifications

### 3.3.1 Variation from Test Methods or Planned Activities

#### *3.3.1.1 Sampling at the Landfill Gas (LFG) Inlet Pipe*

Because of the configuration of the raw LFG inlet pipe, isokinetic sampling at this location was not possible or attempted. The gas collection pipe was 11 inches in diameter and had a continuous curvature (Figure 2-2). Furthermore, the pipe diameter changed to 14 inches abruptly near the ¼-inch sampling port, most likely introducing additional undesirable flow disturbances. As such, the pipe did not have sufficient straight lengths of pipe-run upstream and downstream of the sample ports. The lack of straight-run pipe precluded accurate velocity measurements.

Isokinetic sampling would be of value if particulate sampling was needed. Little particulate matter was expected in the raw LFG and this was confirmed by the observation of glass fiber filters on several of the sampling trains that did not reveal particulate catch.

#### *3.3.1.2 Landfill Gas (LFG) Inlet Pipe Condensate Sample*

The raw LFG inlet pipe condensate sample was not collected because it was not a part of the QAPP-specified samples.

#### *3.3.1.3 Landfill Gas (LFG) Flow Rate Measurement*

LFG flow rates were recorded as indicated by the Perennial Energy Enclosed Ground Flare Station control panel. The accuracy of the flow rates indicated measurement could not be independently verified because of the inability to measure gas velocity accurately, as discussed in the previous section. The test team was only able to make crude velocity measurements by traversing the pipe using a standard pitot probe. The accuracies of these measurements were uncertain, even though they appeared to be similar to the facility's flow rate readings.

### 3.3.2 Application of Test Methods

The sampling and, where applicable, analytical methods used in this test program follow those specified in the QAPP. Table 3-6 lists the applicable measurement and analyses methods and their corresponding performing organizations.

**Table 3-6. Test Methods and Performing Organizations**

| Procedure | Description | Organization Performing Analysis |
|---|---|---|
| EPA Method 1 | Selection of traverse points | ARCADIS G&M |
| EPA Method 2 | Determination of stack gas velocity and volumetric flow rate | ARCADIS G&M |
| EPA Method 3A | Determination of oxygen ($O_2$) and carbon dioxide ($CO_2$) for flare stack gas molecular weight calculations | ARCADIS G&M |
| EPA Method 3C | Determination of carbon dioxide ($CO_2$), methane ($CH_4$), nitrogen ($N_2$), and oxygen ($O_2$) in raw LFG | Triangle Environmental Services |
| EPA Method 4 | Determination of stack gas moisture | ARCADIS G&M |
| EPA Method 6C | Determination of sulfur dioxide ($SO_2$) | ARCADIS G&M |
| EPA Method 7E | Determination of nitrogen oxides ($NO_X$) | ARCADIS G&M |
| EPA Method 10 | Determination of carbon monoxide (CO) | ARCADIS G&M |
| EPA Method 11 | Determination of hydrogen sulfide ($H_2S$) | Oxford Laboratories |
| EPA Method 23 | Determination of dioxins/furans, PAHs, and PCBs | ALTA Analytical Perspectives |
| EPA Method 25A | Determination of flare stack gas NMOCs, as THCs when total organic concentration was less than the 50 ppm Method 25C applicability threshold | ARCADIS G&M |
| EPA Method 25C | Determination of raw LFG NMOCs | Triangle Environmental Services |
| EPA Method 26A | Determination of hydrogen chloride (HCl) | Resolution Analytics |
| EPA Method 29 | Determination of metals | First Analytical Laboratories |
| EPA Method 40 | Determination of VOCs | Research Triangle Park Laboratories |
| SW-846 Method 0100/TO-11 | Determination of carbonyls (formaldehyde, acetaldehyde) | Resolution Analytics |
| LUMEX instrument | Determination of elemental mercury ($Hg^0$) | ARCADIS G&M |
| Organic mercury methods | Determination of raw LFG:<br>Monomethyl mercury<br>Dimethyl mercury<br>Total mercury. | Frontier Geosciences |

### 3.3.3 Test Method Exceptions

Laboratory analytical procedures followed those prescribed by the specified methods, with the following exceptions:

Raw Landfill at Inlet

- Carbonyls were analyzed by Method TO-11 instead of SW-846 Method 8315. (Method TO-11 and Method 8315 closely resemble each other.)

- Polycyclic aromatic hydrocarbons (PAHs) were analyzed by SW-846 Method 8270. The sample extracts were found to contain excessive amounts of non-PAH organics. In order to make the extracts safe to be injected into the gas chromatograph/mass spectrometer (GC/MS), the sample had to be diluted excessively. The high dilution made the method detection limit (MDL) for the target PAHs too high, resulting in "non-detects" (ND) at the high detection limits. The planned analysis method could not produce the desired results at the needed detection levels. At the present time, an alternative analysis method was not identified. The sample extracts are in storage and may be submitted for analysis if a suitable method is available.

- Polychlorinated biphenyls (PCBs) were analyzed by EPA Method 1668 (EPA 812/R-97-001) as specified in the QAPP. However, similar to the difficulties experienced for the PAH analysis, in order to make the extracts safe to be injected inject into the gas chromatograph (GC), the sample had to be diluted excessively. The planned analysis method could not produce the desired results at the needed detection levels

- For raw LFG inlet samples, VOCs were analyzed by EPA Method TO-15. Methane ($CH_4$) was analyzed by GC/FID and additionally by Method 3C.

Flare Stack

- Non-Methane Organic Compounds (NMOCs) - Method 25A was used instead of the specifically applicable Method 25C. This was necessitated by the low overall organic compound concentrations in the flare stack gas, which were significantly below the Method 25C's applicability threshold minimum level of 50 ppmv.

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# 4. Presentation of Test Results

Testing took place at the Landfill B on November 4-5, 2002. Results of the testing are presented in this section, and detailed test results are included in the Appendices. The following subsections provide concise summaries of the test results.

## 4.1 Raw Landfill Gas (LFG) Pipe Results

As shown in Figure 2-2, sampling was conducted by extracting samples via the four ¼-inch ports installed in the raw LFG pipe.

### 4.1.1 Raw Landfill Gas (LFG) Flow Rate and Temperature

#### *4.1.1.1 Direct Measurements*

The facility process system had a flow measurement system, which displayed the flow rate on an instrument panel meter. The panel meter read a constant 1496% scfm. The "%" symbol in the display was indicative that the flow measurement system was over-ranged.

The small size of the sampling ports and lack of an adequately long straight pipe run upstream of the sampling ports precluded the proper measurement of the LFG velocity profile within this pipe. Nonetheless, attempted measurements with a velocity probe returned readings ranging from 1400 ft/min near the bottom (inside curve) of the pipe, to 5000 ft/min near the top (outside curve) of the pipe. Approximating the velocity, using the arithmetic average velocity of 3160 ft/min and pipe inside diameter of 10 inches, the volumetric flow rate was estimated to be about 1745 cu ft/min.

A direct measurement with thermocouples showed the raw LFG temperature to be 62°F.

#### *4.1.1.2 Flow Rate Estimate by Stoichiometric Calculations*

The volumetric flow rate of the raw LFG was estimated by using the measured volumetric flow rate of the flare stack exhaust, the composition of the flare stack exhaust gas ($O_2$ and $CO_2$ concentrations) and the composition of the raw LFG (organic constituents, $CO_2$, $O_2$, nitrogen [$N_2$], etc) to input into a stoichiometric computation algorithm. This approach resulted in an estimated raw LFG flow rate of about 1300 dscfm. A worksheet outlining the stoichiometric calculations is shown in Appendix O.

#### *4.1.1.3 Landfill Gas (LFG) Flow Rate Combined Estimate*

Based on the three independent sources of the flow rate estimates, 1496 scfm by the facility's flow rate indicator, 1745 scfm by the crude pitot probe measurement, and 1300 scfm by stoichiometric calculation, a reasonable combined estimate is 1500 scfm. Because the flow rate is an estimate, any mass emission rates calculated based on this raw LFG flow rate will also be recognized as estimates.

### 4.1.2 Raw Landfill Gas (LFG) Constituents

The concentrations of the constituents of interest in the raw LFG are presented in the following Subsections 4.1.2.1 through 4.1.2.5. Following the presentation of the constituent concentrations, Section 4.3 summarizes the data and presents a comparison with the AP-42 default values. This section also presents the estimated mass flow rates of the constituents at the raw LFG pipe.

#### *4.1.2.1 Volatile Organic Compounds (VOCs)*

Concentrations of VOCs were obtained collecting summa canister samples using Method 40 procedures. Analysis was performed by Method TO-15, with gas chromatography and mass spectrometry (GC/MS). The alkanes (C2 through C6), being present in much higher concentrations, were analyzed by GC flame ionization detection (FID) on the same summa canister samples.

Table 4-1 lists the results of these analyses. Tentatively identified compounds (TICs) can be seen in the Research Triangle Park (RTP) Laboratory reports in Appendix A.

#### *4.1.2.2 Non-methane Organic Compounds (NMOCs)*

Non-methane organic compounds (NMOCs) in the raw LFG were analyzed by Method 25C on the Method 40 samples. NMOC concentrations in the raw LFG are presented in Table 4-2. This table also includes the concentrations of $CH_4$, $CO_2$ and $O_2$, which are results obtained as part of the NMOC analyses. The moisture concentration data were obtained from the Method 23 PAH/PCB sample train measurements.

The other analytes, oxygen ($O_2$), carbon dioxide ($CO_2$), and moisture, are not pollutants but are of interest as they are useful indicators of the "quality" of the raw LFG. The concentrations of nitrogen ($N_2$) and $O_2$ are also indicators of the extent of ambient air infiltration into the LFG collection. Method 25C for NMOC determination specifically recommends that these measurements be made to determine potential air infiltration. Therefore, while measurements for methane ($CH_4$), $CO_2$, $O_2$, and $N_2$ by Method 3C were not included in the original QAPP, these measurements were included and performed.

**Table 4-1. Raw Landfill Gas VOC Concentrations**

| Compound | Unit | MDL | Concentration | | | |
|---|---|---|---|---|---|---|
| | | | Run 1 | Run 2 | Run 3 | Average [a] |
| **By GC/FID** | | | | | | |
| Ethane | ppmv | 1 | 4.6 | 4.4 | 4.9 | 4.6 |
| Propane | ppmv | 1 | 6.0 | 5.7 | 5.9 | 5.9 |
| Butane | ppmv | 1 | 3.0 | 2.9 | 4.1 | 3.3 |
| Pentane | ppmv | 1 | 3.3 | 2.1 | 2.4 | 2.6 |
| Hexane | ppmv | 1 | ND | ND | ND | ND |
| | | | | | | |
| **By TO-15 GC/MS** | | | | | | |
| Dichlorodifluoromethane (Freon 12) | ppbv | 0.2 | 648 | 672 | 83 | 468 |
| 1,2-Chloro-,1,2,2-Tetrafluoroethane (CFC114) | ppbv | 0.2 | 58 | 65 | 9 | 44 |
| Chloromethane | ppbv | 0.2 | ND | 217 | ND | 72 |
| Vinyl chloride [c] | ppbv | 0.2 | 560 | 585 | 86 | 410 |
| 1,3-Butadiene (Vinylethylene) [c] | ppbv | 0.2 | 111 | 136 | 21 | 89 |
| Bromomethane (Methyl Bromide) [c] | ppbv | 0.2 | 39 | 46 | 52 | 46 |
| Chloroethane (Ethyl Chloride) | ppbv | 0.2 | 2660 | 2820 | 157 | 1880 |
| Trichloromonofluoromethane (CFC11) | ppbv | 0.2 | 417 | 488 | 77 | 327 |
| 1,1-Dichloroethene | ppbv | 0.2 | 10 | 12 | 2 | 8 |
| 1,1,2-Trichloro-1,2,2-trifluoroethane (CFC113) | ppbv | 0.2 | 14 | 17 | 3 | 11 |
| Carbon Disulfide | ppbv | 0.2 | 155 | 214 | 32 | 134 |
| Ethanol | ppbv | 0.2 | 261 | 314 | 31 | 202 |
| Isopropyl Alcohol (2-Propanol) [c] | ppbv | 0.2 | 206 | 848 | 14 | 356 |
| Methylene chloride (Dichloromethane) [c] | ppbv | 0.2 | 163 | 156 | 186 | 169 |
| Acetone [c] | ppbv | 0.2 | 1900 | 2480 | 440 | 1610 |

| Compound | Unit | MDL | Concentration | | | |
|---|---|---|---|---|---|---|
| | | | Run 1 | Run 2 | Run 3 | Average [a] |
| t-1,2-dichloroethene | ppbv | 0.2 | 11 | 14 | 2 | 9 |
| Hexane | ppbv | 0.2 | 1700 | 1770 | 2370 | 1950 |
| Methyl-t-butyl ether (MTBE) | ppbv | 0.2 | 221 | 254 | 54 | 177 |
| 1,1-Dichloroethane | ppbv | 0.2 | 231 | 282 | 20 | 178 |
| Vinyl Acetate | ppbv | 0.2 | 598 | 1430 | 28 | 686 |
| cis-1,2-Dichloroethene | ppbv | 0.2 | 346 | 454 | 76 | 292 |
| Cyclohexane | ppbv | 0.2 | 862 | 1160 | 185 | 734 |
| Chloroform | ppbv | 0.2 | 205 | 325 | 41 | 190 |
| Ethyl Acetate | ppbv | 0.2 | 2130 | 2570 | 2240 | 2310 |
| Carbon Tetrachloride | ppbv | 0.2 | 6 | 9 | 1 | 5 |
| Tetrahydrofuran (Diethylene Oxide) | ppbv | 0.2 | 717 | 925 | 1000 | 882 |
| 1,1,1-Trichloroethane | ppbv | 0.2 | 37 | 49 | 7 | 31 |
| 2-Butanone (Methyl Ethyl Ketone) | ppbv | 0.2 | 1600 | 2210 | 484 | 1430 |
| Heptane | ppbv | 0.2 | 1240 | 1230 | 282 | 918 |
| Benzene [c] | ppbv | 0.2 | 312 | 373 | 69 | 251 |
| 1,2-Dichloroethane | ppbv | 0.2 | 6.8 | 7 | 1 | 5 |
| Trichloroethylene (Trichloroethene) | ppbv | 0.2 | 129 | 151 | 28 | 103 |
| 1,2-Dichloropropane | ppbv | 0.2 | 10 | 4 | 2 | 5 |
| Bromodichloromethane | ppbv | 0.2 | 11 | 12 | 7 | 10 |
| 1,4-Dioxane (1,4-Diethylene Dioxide) | ppbv | 0.2 | 10 | 18 | ND | 9.4 |
| cis-1,3-Dichloropropene | ppbv | 0.2 | 2 | 2 | ND | 1.4 |
| Toluene (Methyl Benzene) [c] | ppbv | 0.2 | 8300 | 10200 | 1810 | 6770 |
| 4-Methyl-2-pentanone (MIBK) [c] | ppbv | 0.2 | 946 | 1080 | 633 | 886 |
| t-1,3-Dichloropropene | ppbv | 0.2 | 4 | 4 | 1 | 3 |
| Tetrachloroethylene (Perchloroethylene) | ppbv | 0.2 | 219 | 263 | 46 | 176 |
| 1,1,2-Trichloroethane | ppbv | 0.2 | 50 | 57 | 10 | 39 |
| Dibromochloromethane | ppbv | 0.2 | 47 | 1 | ND | 16 |
| 1,2-Dibromoethane (Ethylene dibromide) | ppbv | 0.2 | 15 | 5 | 1 | 7 |
| 2-Hexanone (Methyl Butyl Ketone) | ppbv | 0.2 | ND | 226 | 1096 | 441 |
| Ethylbenzene | ppbv | 0.2 | 3430 | 4190 | 762 | 2800 |
| Chlorobenzene [d] | ppbv | 0.2 | 98 J | 60 J | 529 J | 229 J |

| Compound | Unit | MDL | Concentration | | | |
|---|---|---|---|---|---|---|
| | | | Run 1 | Run 2 | Run 3 | Average [a] |
| m/p-Xylene (Dimethyl Benzene) | ppbv | 0.2 | 3510 | 3890 | 4530 | 3980 |
| o-Xylene (Dimethyl Benzene) | ppbv | 0.2 | 1710 | 2160 | 373 | 1410 |
| Styrene (Vinylbenzene) | ppbv | 0.2 | 265 | 345 | 55 | 222 |
| Tribromomethane (Bromoform) | ppbv | 0.2 | ND | ND | ND | ND |
| 1,1,2,2-Tetrachloroethane | ppbv | 0.2 | ND | ND | ND | ND |
| 1-Ethyl-4-methylbenzene (4-Ethyl Toluene) [b] | ppbv | 0.2 | 476 J | 578 J | 103 J | 386 J |
| 1,3,5-Trimethylbenzene [b] | ppbv | 0.2 | 476 J | 578 J | 103 J | 386 J |
| 1,2,4-Trimethylbenzene [c] | ppbv | 0.2 | 1140 | 1450 | 255 | 949 |
| 1,4-Dichlorobenzene [c] | ppbv | 0.2 | 304 | 393 | 66 | 255 |
| 1,3-Dichlorobenzene | ppbv | 0.2 | 5 | 1 | ND | 2.03 |
| Benzyl Chloride | ppbv | 0.2 | 23 | 27 | 10 | 20 |
| 1,2-Dichlorobenzene | ppbv | 0.2 | ND | 1 | ND | 0.4 |
| 1,1,2,3,4,4-Hexachloro-1,3-butadiene [c] | ppbv | 0.2 | 8 | 6 | 2 | 5 |
| 1,2,4-Trichlorobenzene [c] | ppbv | 0.2 | 7 | 8 | ND | 5 |
| Acrylontrile | ppbv | 20 | ND | ND | ND | ND |
| Dichlorofluoromethane (Freon 21) | ppbv | 20 | ND | ND | ND | ND |
| Chlorodiflouromethane (Freon 22) | ppbv | 20 | ND | ND | ND | ND |
| Ethyl Mercaptan (Ethanediol) | ppbv | 20 | ND | ND | ND | ND |
| Carbonyl Sulfide (Carbon oxysulfide) | ppbv | 20 | ND | ND | ND | ND |

ND – Constituent not detected at the stated detection limits.

[a] In computing averages, when all measurements are ND, the average is reported as ND. When one or more measurement is above detection, the ND measurement is treated as 50 percent of the stated MDL. If MDL is not reported, a ND measurement is treated as zero.

[b] 1-Ethyl-4-methylbenzene (4-Ethyl Toluene) and 1,3,5-Trimethylbenzene co-eluted from the GC and also have the same quantitation ions, thus making them indistinguishable. Therefore, the reported values represent the combined concentrations of these two compounds.

[c] Analyte detected in blank sampled 0.21 to 3.03 ppbv. See Table 5-2 for analyte-specific detected levels.

[d] Chlorobenzene spike recovery was 211 percent.

**Table 4-2. Raw Landfill Gas Non-Methane Organic Compound (NMOC) Concentrations**

| | NMOC (ppmv as Hexane) | $CH_4$ (% v/v) | | $CO_2$ (% v/v) | | $O_2$ (%v/v) | $N_2$ (% v/v) | Moisture (% v/v) |
|---|---|---|---|---|---|---|---|---|
| | **Method 25C** | **Method 25C** | **Method 3C** | **Method 25C** | **Method 3C** | **Method 3C** | **Method 3C** | **Method 23** |
| Run 1 | 377 | 40.6 | 37.3 | 31.9 | 29.9 | 6.0 | 24.4 | 2.1 |
| Run 2 | 314 | 39.2 | 35.8 | 30.7 | 28.8 | 6.6 | 26.2 | 1.8 |
| Run 3 | 374 | 37.7 | 35.2 | 29.5 | 28.2 | 6.6 | 26.2 | 2.1 |
| **Average** | **355** | **39.2** | **36.1** | **30.7** | **29.0** | **6.4** | **25.6** | **2.0** |

Concentrations are reported without correction for nitrogen

Method 25C hold time was 49 days; 19 days longer than the specified 30 days

*4.1.2.3 Hydrogen Sulfide ($H_2S$)*

Landfill gas (LFG) pipe $H_2S$ concentrations were obtained by collecting and analyzing the samples in accordance with EPA Method 11. These analytical results are presented in Table 4-3.

**Table 4-3. Raw Landfill Gas Hydrogen Sulfide ($H_2S$) Concentrations**

| | $H_2S$ Concentration | |
|---|---|---|
| | **($mg/m^3$)** | **(ppmv)** |
| Run 1 [a] | 26.4 | 18.7 |
| Run 2 | 36.1 | 25.6 |
| Run 3 | 27.1 | 19.2 |
| Run 4 | 33.8 | 24.0 |
| Average [b] | 32.3 | 22.9 |

[a] Did not purge at end of Run 1. Added Run 4 to complete set.

[b] Run 1 data was not included in averaged value

*4.1.2.4 Carbonyls*

The target carbonyl compounds, formaldehyde and acetaldehyde, were analyzed by Method TO-11 on samples collected by EPA Method 0100. The analysis results are presented in Table 4-4.

**Table 4-4. Raw Landfill Gas Pipe Carbonyls Concentrations**

| | Formaldehyde [a] | | Acetaldehyde | |
|---|---|---|---|---|
| | (µg/m$^3$) | (x10$^{-3}$ ppmv) | (µg/m$^3$) | (x10$^{-3}$ ppmv) |
| MDL | 2 | 1.6 | 4 | 2.2 |
| Run 1 | 3.31 J | 2.65 J | 35.0 | 19.1 |
| Run 2 | 4.07 J | 3.26 J | 21.9 | 12.0 |
| Run 3 | 3.45 J | 2.76 J | 24.1 | 13.2 |
| **Average** | **3.61 J** | **2.89 J** | **27.0** | **14.8** |

[a] Measured formaldehyde values were near MDL

#### *4.1.2.5 Mercury (Hg)*

Mercury (Hg) can exist in several forms. This test program focused on the elemental, monomethyl, and dimethyl forms of Hg, and total Hg. Elemental Hg was measured with the LUMEX instrument. Organic monomethyl Hg, dimethyl Hg and total Hg were sampled and analyzed using the organic mercury method.

##### 4.1.2.5.1 Total Mercury (Hg) Samples

To collect the total Hg samples, an iodated charcoal trap was used as a sorbent. A backup tube was also 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. A silica gel impinger was used to collect and quantify the water vapor from the stream. A diaphragm air pump was used to pull sample through the train and collect the sample. A dry gas meter capable of measuring the volume in 10 ml increments was used to monitor and quantify the volume of gas sampled.

Table 4-5 presents the total Hg concentrations in the raw LFG. They ranged from 158 to 234 ng/m$^3$ with an average of 204 ng/m$^3$. Spike recovery for total Hg samples was 95 percent.

**Table 4-5. Raw Landfill Gas Total Mercury Concentrations**

| | Total Mercury Concentration | |
|---|---|---|
| | **($ng/m^3$)** | **($x10^{-6}$ ppm)** |
| MDL | 50 | 6.0 |
| Run 1 | 219 | 24.5 |
| Run 2 | 234 | 26.2 |
| Run 3 | 158 | 17.7 |
| **Average** | **204** | **22.8** |

Sample hold time exceeded 14 days

Hold times exceeded 14 days

#### 4.1.2.5.2 Dimethyl Mercury (Hg) Samples

To collect the dimethyl Hg sample, a carbotrap was used with a sorbent. A backup tube was also present to assess any breakthrough. A third iodated carbon trap was also present to collect any elemental Hg present. The sorbent tube was heated to above the dew point of the gas stream to prevent condensation on the sorbent. A silica gel impinger was used to collect and quantify the water vapor from the stream. A diaphragm air pump was used to pull sample through the train and collect the sample. A dry gas meter capable of measuring the volume in 10 ml increments was used to monitor and quantify the volume of gas sampled.

Table 4-6 presents the dimethyl Hg concentrations in the raw LFG. These ranged from 1.6 to 2.1 $ng/m^3$ with an average of 1.9 $ng/m^3$. Spike recoveries for the dimethyl Hg traps ranged from 1.5 to 4.4 percent, well below normally acceptable levels. The spiked traps, without being exposed to the raw LFG, had recoveries from 68 to 98 percent with an average of 83 percent. Recoveries were low in the spiked traps possibly because of the presence of an unknown interfering compound either destroying or masking the detection of the dimethyl Hg. For this reason, dimethyl Hg concentrations data were flagged with “R” to indicate that the data were rejected. Further development of this procedure is being undertaken by Frontier Geosciences. More studies are needed to develop an acceptable method to more accurately determine the actual dimethyl Hg concentrations.

**Table 4-6. Raw Landfill Gas Dimethyl Mercury Concentrations**

| | Dimethyl Mercury Concentration | |
|---|---|---|
| | **($ng/m^3$)** | **($x10^{-6}$ ppmv)** |
| MDL | 0.5 | 0.05 |
| Run 1 | 2.0 R | 0.209 R |
| Run 2 | 2.1 R | 0.220 R |
| Run 3 | 1.6 R | 0.168 R |
| Average | 1.9 R | 0.200 R |

Sample hold times exceeded 14 days

Spike recoveries were 0 – 5 percent

R – The results are rejected due to serious deficiencies per EPA QA/G-8 guidance

4.1.2.5.3 Monomethyl Mercury (Hg) Samples

To collect the sample, a set of three impingers filled with 0.001 M HCl was used to collect the monomethyl Hg. An empty forth impinger was used to knockout 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. A dry gas meter capable of measuring the volume in 10 ml increments was used to monitor and quantify the volume of gas sampled.

As shown in Table 4-7, monomethyl Hg concentrations in the raw LFG ranged from 1.1 to 1.3 $ng/m^3$ with an average amount of 1.2 $ng/m^3$. Spike recovery for the monomethyl Hg sample was 70 percent.

**Table 4-7. Raw Landfill Gas Monomethyl Mercury Concentrations**

| | Monomethyl Mercury Concentration | |
|---|---|---|
| | **($ng/m^3$)** | **($x10^{-6}$ ppmv)** |
| MDL | 0.13 | 0.014 |
| Run 1 | 1.3 | 0.146 |
| Run 2 | 1.1 | 0.123 |
| Run 3 | 1.1 | 0.123 |
| Average | 1.2 | 0.134 |

Sample hold time exceeded 14 days

Relative standard deviation (RSD) of replicate sample exceeded ±30 percent

#### 4.1.2.5.4 Elemental Mercury (Hg)

Elemental mercury (Hg) was determined by the LUMEX instrument and the results are presented in Table 4-8. Before any measurement was made, the LUMEX instrument was zeroed. The background measurements were made by drawing a sample of ambient air through and ice-chilled empty impinger and recording the LUMEX instrument reading.

**Table 4-8. Raw Landfill Gas Elemental Mercury Concentrations**

| | Concentration [a] | | | |
|---|---|---|---|---|
| | Background [b] | | Gas Pipe | |
| | (ng/m$^3$) | (x10$^{-6}$ ppmv) | (ng/m$^3$) | (x10$^{-6}$ ppmv) |
| Run 1 | 0 | 0 | 61 | 7.3 |
| Run 2 | 0 | 0 | 53 | 6.4 |
| Run 3 | 0 | 0 | 60 | 7.2 |
| Average | 0 | 0 | 58 | 7.0 |

[a] Average of three readings, each of 30-seconds duration

[b] Background measurement was made by sampling ambient air drawn through ice-chilled empty impinger

## 4.2 Flare Stack Results

The flare stack was sampled for NMOCs (as THCs), PCDD/PCDFs, PAHs, HCl, Pb, As, Cd, Cr, Mn, Ni, total Hg, $SO_2$, $NO_X$, CO, $CO_2$, and $O_2$. The stack cross section was divided into 24 equal areas according to EPA Method 1. Sampling run time for HCl and metals was 60 minutes. Run time for PCDD/PCDFs sampling was 180 minutes. Run time for CEMS parameters ($SO_2$, $NO_X$, CO, $O_2$, $CO_2$, and THCs) varied.

### 4.2.1 Flare Stack Gas Flow Rate and Temperature

Sampling at the flare stack was conducted at isokinetic conditions. The procedures provided stack gas velocity distribution across the flare stack and reliable measurements of stack gas flow rates. Table 4-9 lists the volumetric flow rates and temperatures at the flare stack measured during the various sampling runs.

**Table 4-9. Flare Stack Gas Operating Conditions, Measured during Sampling**

| Run Number | Duration | Average Stack Temp (°F) | Carbon Dioxide (%) | Oxygen (%) | Moisture (%) | Velocity (actual ft/sec) | Vol. Flow Rate (acfm) | Vol. Flow Rate (dscfm) |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |
| B-POST-M26-110402-01 | 11/4/02 17:05-18:19 | 1419 | 4.8 | 16.1 | 7.3 | 17.0 | 77400 | 20200 |
| B-POST-M26-110402-02 | 11/4/02 17:07-18:21 | 1418 | 4.8 | 16.1 | 6.6 | 16.9 | 77000 | 20300 |
| B-POST-M26-110402-03 | 11/5/02 14:03-15:15 | 1374 | 2.9 | 12.5 | 5.8 | 16.9 | 77000 | 21000 |
| | | | | | | | | |
| B-POST-M29-110502-01 | 11/4/02 9:40-10:53 | 1359 | 4.8 | 16.1 | 6.1 | 17.5 | 79900 | 21900 |
| B-POST-M29-110502-02 | 11/5/02 11:29-12:42 | 1368 | 4.8 | 16.1 | 6.1 | 16.7 | 76100 | 20800 |
| B-POST-M29-110502-03 | 11/5/02 14:05-15:17 | 1380 | 2.9 | 12.5 | 6.7 | 17.0 | 77500 | 20900 |
| | | | | | | | | |
| B-POST-M23-110402-01 | 11/4/02 12:30-15:39 | 1414 | 4.8 | 16.1 | 7.0 | 16.4 | 74800 | 19700 |
| B-POST-M23-110402-02 | 11/4/02 12:31-15:41 | 1411 | 4.8 | 16.1 | 6.5 | 16.4 | 74500 | 19700 |
| B-POST-M23-110502-03 | 11/5/02 09:40-12:51 | 1359 | 2.9 | 12.5 | 6.2 | 17.6 | 80200 | 22000 |
| | | | | | | | | |
| **Average** | | **1389** | **4.2** | **14.9** | **6.5** | **16.9** | **77200** | **20700** |

Flare stack cross-section flow area was 75.94 sq. ft.

#### *4.2.1.1 Flare Stack Oxygen ($O_2$) and Carbon Dioxide ($CO_2$)*

Oxygen ($O_2$) and $CO_2$ concentrations provide an overall indication of the combustion process. Figure 4-1 shows the $O_2$ and $CO_2$ concentrations measured by the CEMs during the two days of testing. The plotted data included the CEM responses to the instrument zeroing and calibration periods. These periods manifest as the peaking and bottoming of the recorded values. Table 4-10 presents the daily averages of $O_2$ and $CO_2$ concentrations.

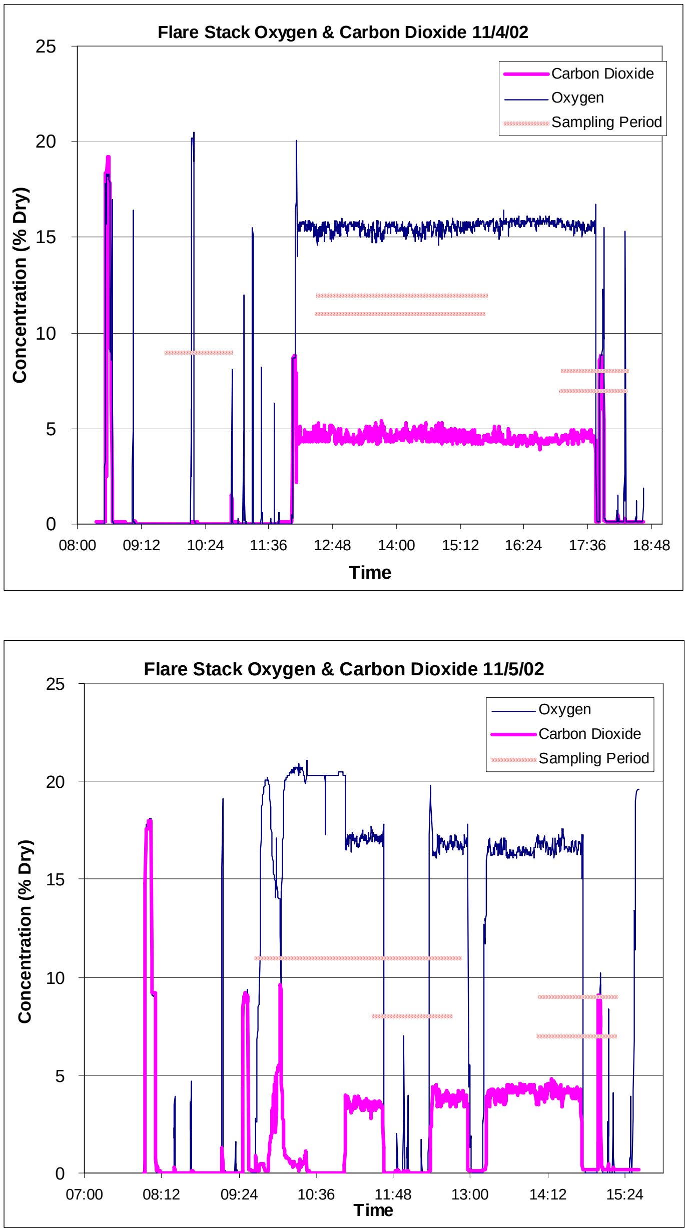



**Figure 4-1. Flare Stack Oxygen and Carbon Dioxide Concentrations**

**Table 4-10. Flare Stack Combustion Products Concentrations**

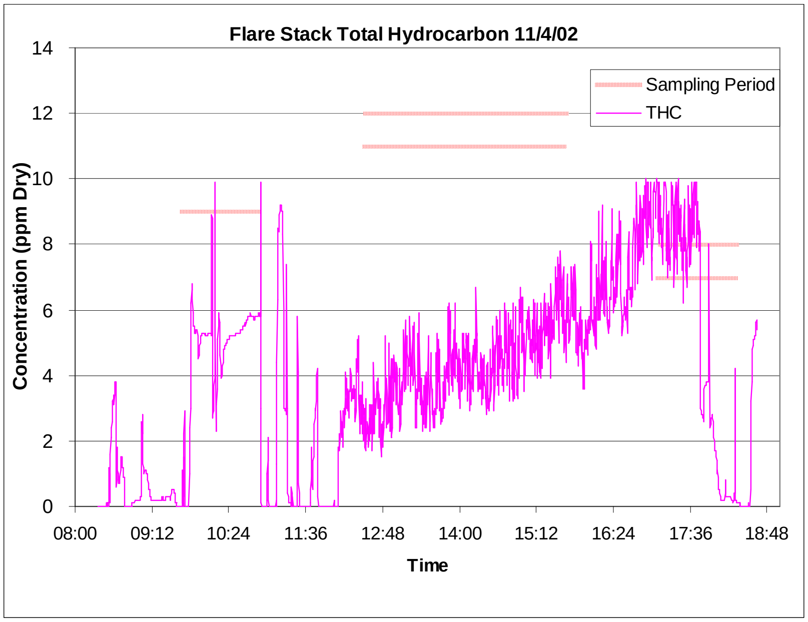
| | $O_2$ (% v) | $CO_2$ (% v) |
|---|---|---|
| Run 1 | 16.1 | 4.8 |
| Run 2 | 17.0 | 4.2 |
| **Average** | **16.6** | **4.5** |

CEM sampling system malfunctioned and reduced the amount of useable data

#### *4.2.1.2 Flare Stack Total Hydrocarbon (THC) Emissions*

Flare stack THC emissions were measured by EPA Method 25A, which used a CEM. At the flare stack, hydrocarbon (including NMOCs) concentrations were found to be below 50 ppmv. The low concentrations rendered Method 25C, the method designed specifically for NMOC measurement, unsuitable to be applied at this location.

In its place, EPA Method 25A produced concentrations of all hydrocarbons that respond to flame ionization detector (FID) analysis. Real-time continuous instrument responses are shown in Figure 4-2. The time-averaged concentrations are presented in Table 4-11. As can be seen, the concentrations of THCs were low and less than 10 ppmv. The duration of valid measurements made during the second test day (Run 2) was limited because of the failure of the temperature controller that maintained the temperature of the heated sample line. The sample line was overheated and out-gassed, as evidenced by the wild fluctuations in measured hydrocarbons during most of the early part of the day. Although towards the end of the test, the test team was able to restore operation of the hydrocarbon measurement system, the hydrocarbon test results during Run 2 need to be viewed with caution.



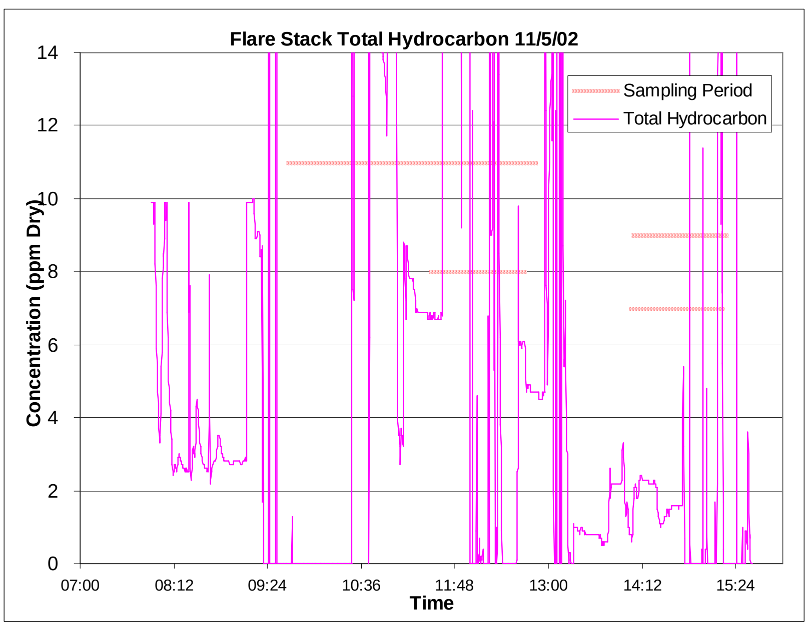




**Figure 4-2. Flare Stack Total Hydrocarbons Concentrations**

**Table 4-11. Flare Stack THC Concentrations**

| | THC (ppmdv as propane) | THC (ppmdv as hexane) |
|---|---|---|
| Run 1 | 6 | 2 |
| Run 2 | 1[a] | 0.5 |
| **Average** | **4** | **2** |

[a] Based on limited data near the end of test

#### *4.2.1.3 Flare Stack Dioxin/Furan Emissions (PCDD/PCDFs)*

Three EPA Method 23 sampling runs were performed. As a cost-saving measure, only the samples from one run (Run 3) were analyzed. Samples from runs 1 and 2 have been extracted and are being held in the laboratory for possible future analysis.

Table 4-12 presents the flare stack PCDD/PCDFs emissions data. Concentrations for most targets were below their detection limit and these were denoted by the less than ("<") sign, followed by the detection concentration level of that target. The mass emission rates were calculated based on the target concentrations and the exhaust gas flow rates measured at the sampling location.

Table 4-13 presents the same data, but expressed in terms of Toxicity Equivalent emissions.

#### *4.2.1.4 Flare Stack Polycyclic Aromatic Hydrocarbon (PAH) Emissions*

The concentrations of PAHs were obtained by Method 23 analyses. The results are presented in Table 4-14.

**Table 4-12. Flare Stack Dioxins and Furans Emissions**

| Analyte | B-POST-M23-110502-03 | | |
|---|---|---|---|
| | Concentration | Emission Rate | |
| | ($x10^{-3}$ ng/dscm) | ($x10^{-9}$ g/hr) | ($x10^{-12}$ lb/hr) |
| **Dioxins** | | | |
| 2,3,7,8-TCDD | < 0.346 | < 12.9 | 28.5 |
| Other TCDD | 11.3 | 421 | 929 |
| 1,2,3,7,8-PeCDD | < 0.291 | < 10.9 | 23.9 |
| Other PeCDD | 13.6 | 507 | 1100 |
| 1,2,3,4,7,8-HxCDD | <0.504 | < 18.8 | 41.5 |
| 1,2,3,6,7,8-HxCDD | < 0.468 | < 17.4 | 38.4 |
| 1,2,3,7,8,9-HxCDD | < 0.477 | < 17.8 | 39.2 |
| Other HxCDD | 4.1 | 154 | 339 |
| 1,2,3,4,6,7,8-HpCDD | < 0.254 | < 9.5 | 20.9 |
| Other HpCDD | 2.4 | 88.8 | 196 |
| 1,2,3,4,6,7,8,9-OCDD | < 0.983 | < 36.7 | 80.9 |
| **Total CDD** | **34.7** | **1300** | **2900** |
| **Furans** | | | |
| 2,3,7,8-TCDF | 0.587 | 21.9 | 48.2 |
| Other TCDF | 0.0088 | 8800 | 19400 |
| 1,2,3,7,8-PeCDF | 1.1 | 40.9 | 90.3 |
| 2,3,4,7,8-PeCDF | 1.0 | 38.0 | 83.7 |
| Other PeCDF | 110 | 4100 | 9100 |
| 1,2,3,4,7,8-HxCDF | 1.1 | 42.7 | 94.2 |
| 1,2,3,6,7,8-HxCDF | 0.166 | 6.2 | 13.7 |
| 2,3,4,6,7,8-HxCDF | 0.194 | 7.2 | 16.0 |
| 1,2,3,7,8,9-HxCDF | 0.218 | 8.1 | 18.0 |
| Other HxCDF | 34.7 | 1300 | 2900 |
| 1,2,3,4,6,7,8-HpCDF | 0.158 | 5.9 | 13.0 |
| 1,2,3,4,7,8,9-HpCDF | 0.215 | 8.0 | 17.7 |
| Other HpCDF | 4.6 | 170 | 375 |
| 1,2,3,4,6,7,8,9-OCDF | 1.1 | 42.5 | 93.7 |
| Total CDF | 156 | 14600 | 32200 |
| **Total CDD/CDF** | **190** | **15900** | **35000** |

Two additional samples were collected, extracted and held in the laboratory for possible future analyses: B-POST-M23-110402-01 and B-POST-M23-110402-02

"<" denotes the measurement was non-detect. The value following the "<" sign is the detection limit.

**Table 4-13. Flare Stack Dioxins and Furans Toxicity Equivalent Emissions**

| Pollutant | Concentration | Emission Rate | | 1989 Toxicity Equivalency Factor | Toxicity Equivalent Emissions | | |
|---|---|---|---|---|---|---|---|
| | | | | | Concentration | Emission Rate | |
| | ($x10^{-3}$ ng/dscm) | ($x10^{-9}$ g/hr) | ($x10^{-12}$ lb/hr) | | ($x10^{-3}$ ng/dscm) | ($x10^{-9}$ g/hr) | ($x10^{-12}$ lb/hr) |
| **Dioxins** | | | | | | | |
| 2,3,7,8-TCDD | < 0.346 | < 12.9 | < 28.5 | 1 | < 0.346 | < 12.9 | < 28.5 |
| Other TCDD | 11.3 | 421 | 929 | --- | NA | NA | NA |
| 1,2,3,7,8-PeCDD | < 0.291 | < 10.9 | < 23.9 | 0.5 | < 0.146 | < 5.4 | < 12.0 |
| Other PeCDD | 13.6 | 507 | 1100 | --- | NA | NA | NA |
| 1,2,3,4,7,8-HxCDD | < 0.504 | < 18.8 | < 41.5 | 0.1 | < 0.0504 | < 1.9 | < 4.2 |
| 1,2,3,6,7,8-HxCDD | < 0.468 | < 17.4 | < 38.4 | 0.1 | < 0.0468 | < 1.7 | < 3.8 |
| 1,2,3,7,8,9-HxCDD | < 0.477 | < 17.8 | < 39.2 | 0.1 | < 0.0477 | < 1.8 | < 3.9 |
| Other HxCDD | 4.1 | 154 | 339 | --- | NA | NA | NA |
| 1,2,3,4,6,7,8-HpCDD | < 0.254 | < 9.5 | < 20.9 | 0.01 | < 0.00254 | < 0.095 | < 0.209 |
| Other HpCDD | 2.4 | 89 | 196 | --- | NA | NA | NA |
| 1,2,3,4,6,7,8,9-OCDD | < 0.983 | < 36.7 | < 80.9 | 0.001 | < 0.000983 | < 0.0367 | < 0.0809 |
| **Total CDD** | **34.7** | **1300** | **2900** | **---** | **0.640** | **23.9** | **52.6** |
| **Furans** | | | | | | | |
| 2,3,7,8-TCDF | 0.587 | 21.9 | 48.2 | 0.1 | 0.0587 | 2.2 | 4.8 |
| Other TCDF | 0.0088 | 8800 | 19400 | --- | NA | NA | NA |
| 1,2,3,7,8-PeCDF | 1.1 | 41 | 90 | 0.05 | 0.055 | 2.0 | 4.5 |

| Pollutant | Concentration | Emission Rate | | 1989 Toxicity Equivalency Factor | Toxicity Equivalent Emissions | | |
|---|---|---|---|---|---|---|---|
| | | | | | Concentration | Emission Rate | |
| | ($x10^{-3}$ ng/dscm) | ($x10^{-9}$ g/hr) | ($x10^{-12}$ lb/hr) | | ($x10^{-3}$ ng/dscm) | ($x10^{-9}$ g/hr) | ($x10^{-12}$ lb/hr) |
| 2,3,4,7,8-PeCDF | 1.0 | 38 | 84 | 0.5 | 0.51 | 19.0 | 42 |
| Other PeCDF | 110 | 4100 | 9100 | --- | NA | NA | NA |
| 1,2,3,4,7,8-HxCDF | 1.1 | 43 | 94 | 0.1 | 0.11 | 4.3 | 9.4 |
| 1,2,3,6,7,8-HxCDF | 0.166 | 6.2 | 14 | 0.1 | 0.0166 | 0.62 | 1.4 |
| 2,3,4,6,7,8-HxCDF | 0.194 | 7.2 | 16 | 0.1 | 0.0194 | 0.72 | 1.6 |
| 1,2,3,7,8,9-HxCDF | 0.218 | 8.1 | 18 | 0.1 | 0.0218 | 0.81 | 1.8 |
| Other HxCDF | 34.7 | 1300 | 2900 | --- | NA | NA | NA |
| 1,2,3,4,6,7,8-HpCDF | 0.158 | 5.9 | 13 | 0.01 | 0.00158 | 0.059 | 0.13 |
| 1,2,3,4,7,8,9-HpCDF | 0.215 | 8.0 | 18 | 0.01 | 0.00215 | 0.080 | 0.18 |
| Other HpCDF | 4.6 | 170 | 375 | --- | NA | NA | NA |
| 1,2,3,4,6,7,8,9-OCDF | 1.1 | 43 | 94 | 0.001 | 0.0011 | 0.043 | 0.094 |
| **Total CDF** | **155** | **14600** | **32200** | **---** | **0.800** | **29.8** | **65.8** |
| **Total CDD/CDF** | **190** | **15900** | **35000** | **---** | **1.4** | **53.7** | **118.4** |

In computing averages, when all measurements are ND, the average is reported as ND. When one or more measurement is above detection, the ND measurement is treated as 50 percent of the stated MDL. If MDL is not reported, a ND measurement is treated as zero.

“<” denotes the measurement was non-detect. The value following the “<” sign is the detection limit.

**Table 4-14. Flare Stack Polycyclic Aromatic Hydrocarbons Emissions**

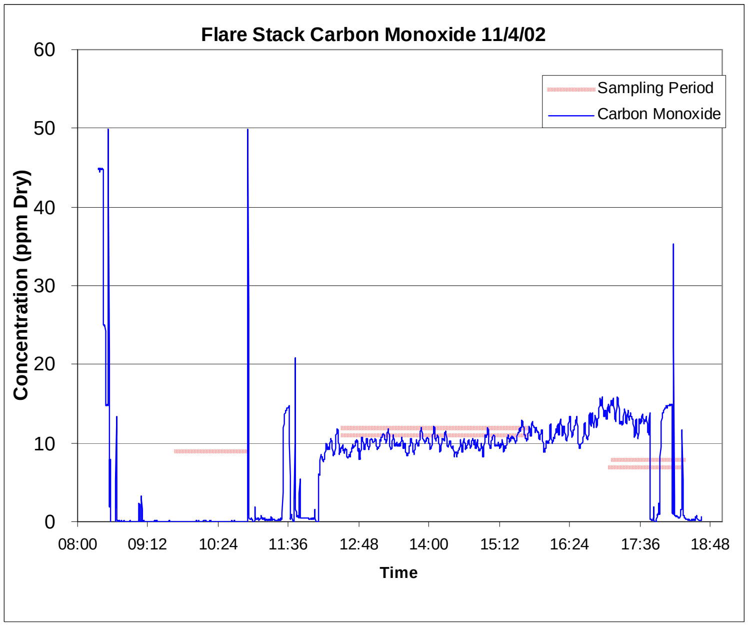
| Analyte | Formula Weight | B-POST-M23-110502-03 | | | |
|---|---|---|---|---|---|
| | | Concentration | | Emission Rate | |
| | | ($x10^{-6}$ ppmv) | (ng/dscm) | ($x10^{-6}$ g/hr) | ($x10^{-6}$ lb/hr) |
| Acenaphthene | 154.21 | 2.5 | 16.2 | 604 | 1.30 |
| Acenaphthylene | 152.20 | 0.489 | 3.1 | 115 | 0.254 |
| Anthracene | 178.23 | 1.1 | 8.3 | 308 | 0.678 |
| Benzo(a)anthracene | 228.30 | 0.261 | 2.5 | 92.3 | 0.204 |
| Benzo(a)pyrene | 252.32 | 0.106 | 1.1 | 41.5 | 0.092 |
| Benzo(b)fluoranthene | 252.32 | 0.299 | 3.1 | 117 | 0.258 |
| Benzo(g,h,i)perylene | 276.34 | 0.219 | 2.5 | 94 | 0.207 |
| Benzo(k)fluoranthene | 252.32 | 0.092 | 1.0 | 36 | 0.079 |
| Chrysene | 228.29 | 0.266 | 2.5 | 94 | 0.207 |
| Dibenzo(a,h)anthracene | 278.35 | 0.025 | 0.3 | 11 | 0.024 |
| Fluoranthene | 202.26 | 2.7 | 22.4 | 837 | 1.8 |
| Fluorene | 166.22 | 46.1 | 319 | 11900 | 26.2 |
| Indeno(1,2,3-cd)pyrene | 288.35 | 0.0969 | 1.2 | 43 | 0.096 |
| Naphthalene [a] | 128.17 | 761 | 4060 | 151000 | 333 |
| Phenanthrene | 178.23 | 1.5 | 12 | 430 | 0.94 |
| Pyrene | 202.26 | 2.1 | 18 | 670 | 1.5 |
| 2-Methylnaphthalene | 142.20 | 585 | 3460 | 129000 | 285 |
| Benzo(e)Pyrene | 252.32 | 0.238 | 2.5 | 93 | 0.205 |
| Perylene | 253.31 | 0.0371 | 0.4 | 14.5 | 0.032 |

Two additional samples were collected, extracted and held in the laboratory for possible future analyses: B-POST-M23-110402-01 and B-POST-M23-110402-02

Analysis hold time was 50 days. Method specified hold time is 40 days.

Spike recovery ranged from 57.9 to 124 percent

a – 1920 ng found in reagent blank. More than 60000 ng found in test sample



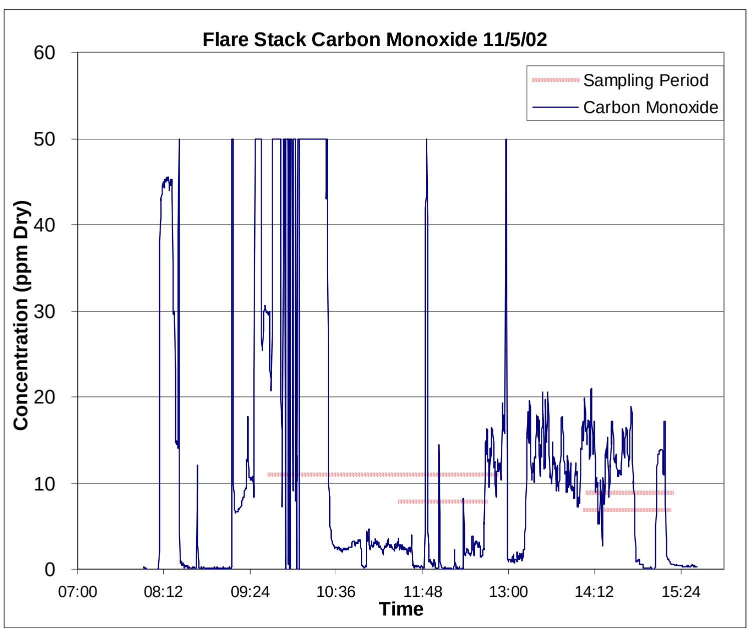
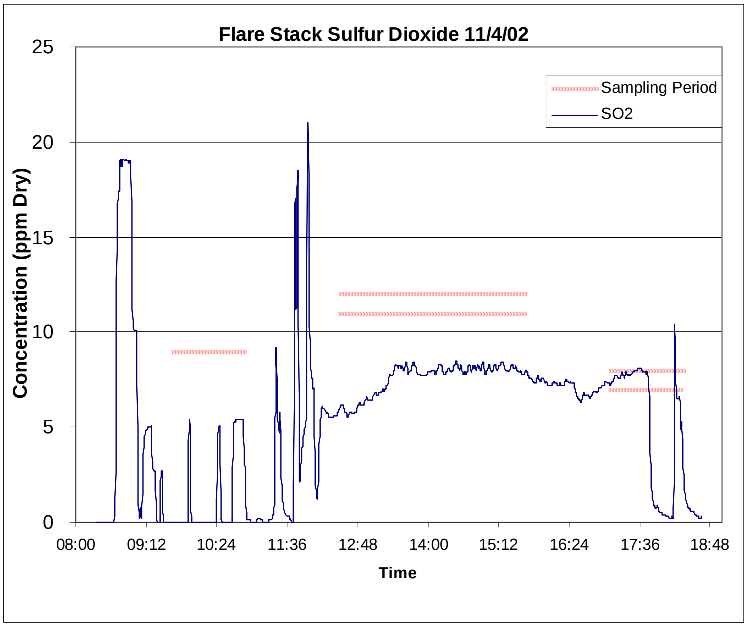




**Figure 4-3. Flare Stack Carbon Monoxide Concentrations**



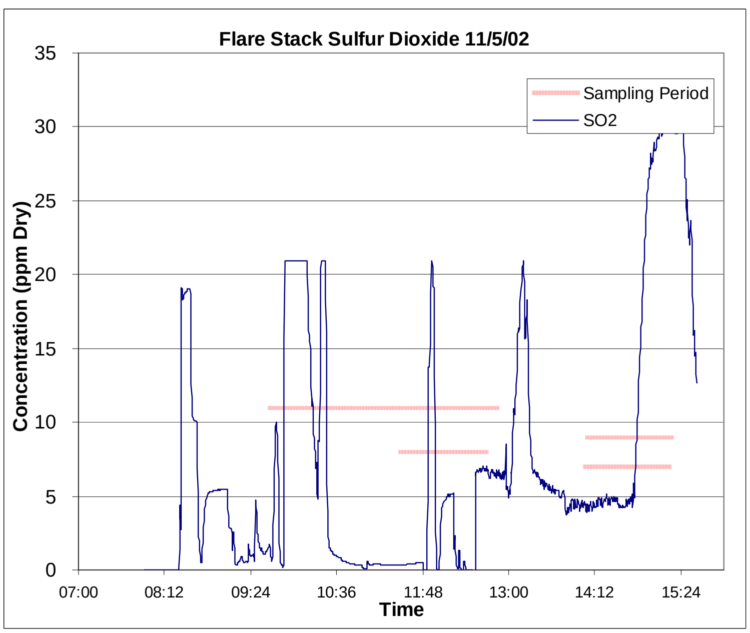
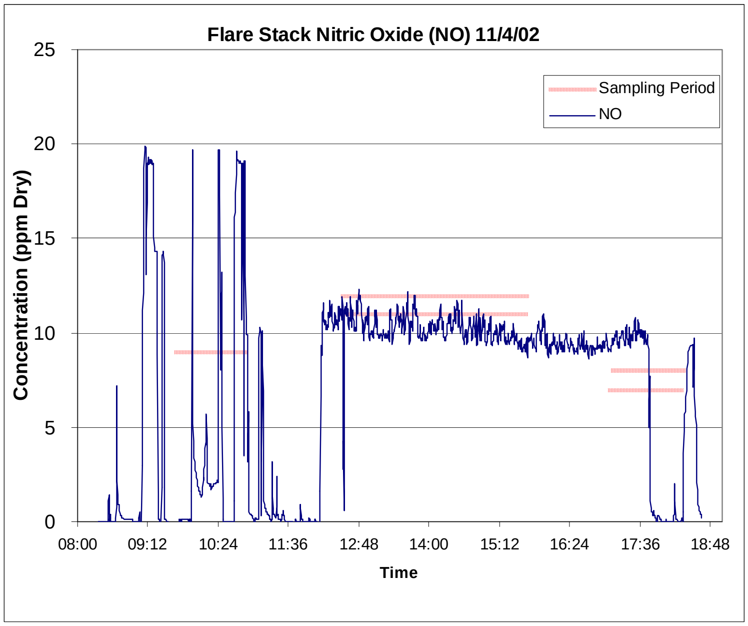




**Figure 4-4. Flare Stack Sulfur Dioxide Concentrations**



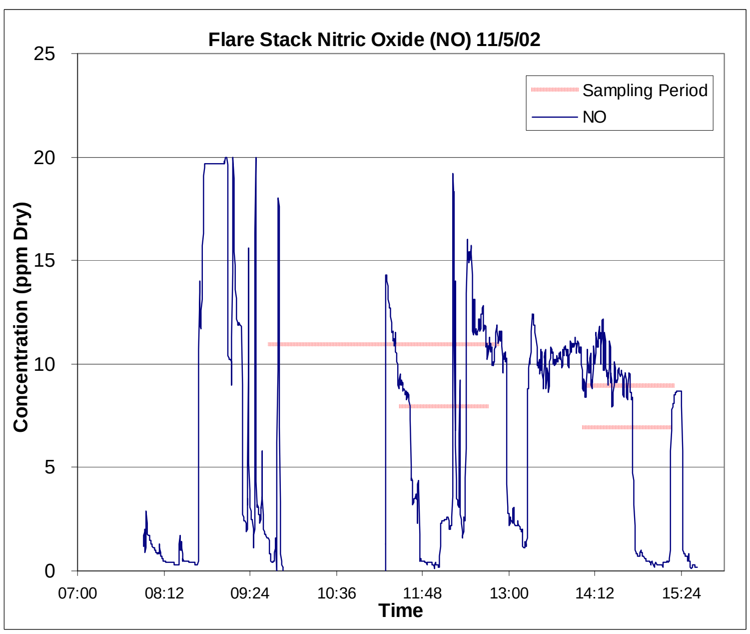
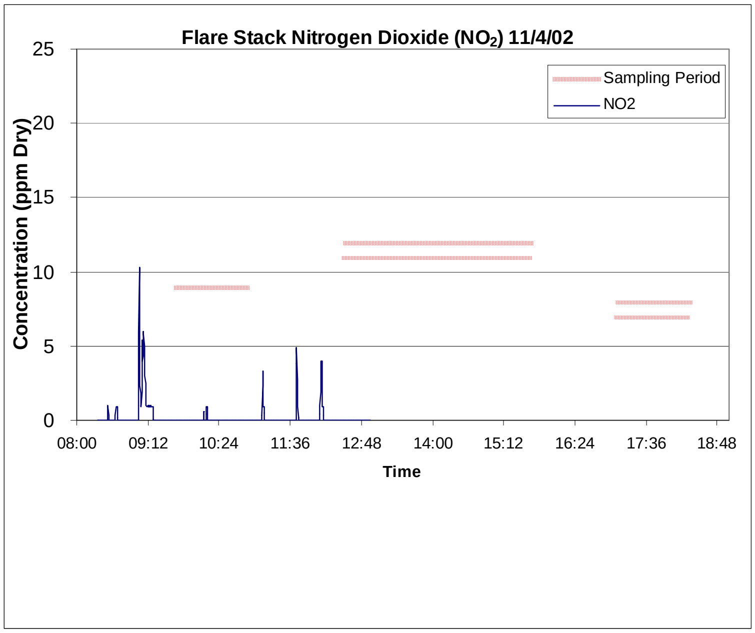




**Figure 4-5. Flare Stack Nitric Oxide Concentrations**



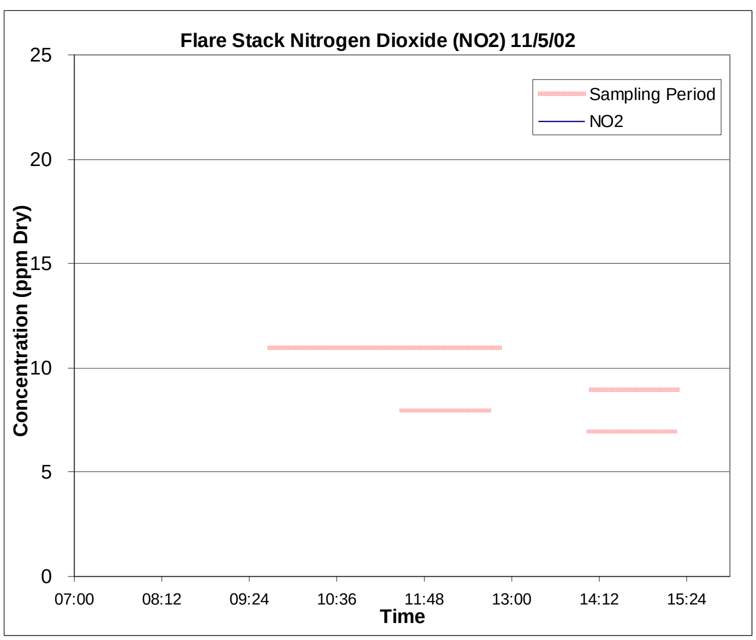




**Figure 4-6. Flare Stack Nitrogen Dioxide Concentrations**

### 4.2.2 Hydrogen Chloride (HCl) Emission Results

Flare stack HCl emissions results are presented in Table 4-15.

**Table 4-15. Flare Stack Hydrogen Chloride Emissions**

| | **HCl Concentrations** | | **HCl Emission Rate** | |
|---|---|---|---|---|
| | **(ppmdv)** | **(mg/m$^3$)** | **(lb/hr)** | **(g/hr)** |
| Run 1 | 1.4 | 2.1 | 0.16 | 72 |
| Run 2 | 1.0 | 1.5 | 0.12 | 52 |
| Run 3 | 0.9 | 1.4 | 0.11 | 48 |
| **Average** | **1.1** | **1.7** | **0.13** | **57** |

#### *4.2.2.1 Metals Emissions Results*

Toxic heavy metals in the flare stack gases were measured by Method 29. Manganese was determined by inductively coupled plasma – mass spectroscopy (ICP-MS). Arsenic (As), Cd, Cr, Pb, and Ni were determined by graphite furnace atomic absorption spectroscopy (GFAAS). Mercury was determined by cold vapor (CV) AA and was not detected in any of the samples. Table 4-16 presents the flare stack metals emissions results.

Mercury (Hg) concentration (elemental) was separately measured by the LUMEX instrument and those results are also included in Table 4-16.

**Table 4-16. Flare Stack Metals Emissions**

| Analyte | B-POST-M29-110502-01 | | | B-POST-M29-110502-02 | | | B-POST-M29-110502-03 | | | Average | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Concentration | Emission Rate | | Concentration | Emission Rate | | Concentration | Emission Rate | | Concentration | Emission Rate | |
| | (µg/dscm) | ($x10^{-3}$ g/hr) | ($x10^{-6}$lb/hr) | (µg/dscm) | ($x10^{-3}$ g/hr) | ($x10^{-6}$lb/hr) | (µg/dscm) | ($x10^{-3}$ g/hr) | ($x10^{-6}$lb/hr) | (µg/dscm) | ($x10^{-3}$ g/hr) | ($x10^{-6}$lb/hr) |
| Arsenic | 0.90 | 34 | 74 | < 0.80 | < 0.028 | 62 | 0.79 | 28 | 62 | 0.70 | 30 | 66 |
| Cadmium | 0.24 | 8.7 | 19 | 0.065 | 2.3 | 5.1 | 0.25 | 8.7 | 19 | 0.18 | 6.6 | 14.5 |
| Chromium | 1.8 | 67 | 150 | 1.4 | 5.1 | 110 | 1.7 | 61.3 | 140 | 1.7 | 60 | 132 |
| Lead | 0.66 | 24.5 | 54 | 0.62 | 22 | 48 | 0.69 | 24.3 | 54 | 0.65 | 23.5 | 52 |
| Manganese | 6.4 | 240 | 530 | 5.2 | 180 | 410 | 13 | 470 | 1000 | 8.3 | 300 | 660 |
| Nickel | 2.1 | 80 | 180 | 1.6 | 56 | 120 | 1.6 | 56 | 120 | 1.8 | 64 | 140 |
| Mercury (Total by method 29) | < 3.9 | < 0.14 | < 320 | < 4.1 | < 0.15 | < 320 | < 4.1 | < 0.15 | < 320 | ND | ND | ND |
| | RUN 1 | | | RUN 2 | | | RUN 3 | | | Average | | |
| Mercury (Elemental by LUMEX) | 0.001 | .036 | 0.079 | 0.004 | 0.14 | 0.32 | 0.005 | 0.18 | 0.40 | 0.0033 | 0.12 | 0.26 |

*4.2.2.2 Gaseous Emissions: Carbon Monoxide (CO), Sulfur Dioxide ($SO_2$), and Nitrogen Oxides ($NO_X$)*

Gaseous emissions measured with CEMs include CO, $SO_2$, and $NO_X$. These results are presented in Table 4-17.

**Table 4-17. Flare Stack CO, $SO_2$, $NO_X$ Concentrations**

| | Concentration (ppmdv) | | |
|---|---|---|---|
| | CO | $SO_2$ [a] | $NO_X$ (as NO) [b] |
| Run 1 | 11 | 8 | 10 |
| Run 2 | 13 | 3 | 12 |
| Average | 10 | 6 | 11 |

[a] System bias = 1 – 24 percent, Drift check = 1 – 180 percent

[b] Drift check = 0 – 13 percent

### 4.3 Comparison with AP-42 Default Values

One of the major objectives of the test program is to expand on the database of LFG constituent compounds and their concentrations. If warranted, these data may contribute towards updating the AP-42 default values.

Table 4-18 presents the concentrations of LFG constituents to provide direct comparisons with AP-42 default values. Table 4-19 presents the concentration of other constituents targeted by the various analyses but are not listed in AP-42. An expanded discussion and comparison is included in the overall project summary report.

**Table 4-18. Comparison of Raw Landfill Gas Constituent Concentrations with AP-42 Default Values**

| Method | Compound | CAS Number | Formula Wt. | Default Value (ppmv) | Detection Limit (ppmv) | Measured Average (ppmv) | Concentration in Inlet LFG | | Mass Flow Rate in Inlet LFG Stream | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | ($x10^{-9}$ lb/ft$^3$) | (µg/m$^3$) | (mg/hr) | ($x10^{-3}$ lb/hr) |
| M-40 | 1,1,1-Trichloroethane | 71-55-6 | 133.42 | 0.48 | 0.0002 | 0.031 | 10.7 | 171 | 436 | 0.962 |
| M-40 | 1,1,2,2-Tetrachloroethane | 79-34-5 | 167.85 | 1.11 | 0.0002 | ND | ND | ND | ND | ND |
| M-40 | 1,1-Dichloroethane Ethylidene Dichloride) | 75-34-3 | 98.96 | 2.35 | 0.0002 | 0.178 | 45.5 | 729 | 1860 | 4.1 |
| M-40 | 1,1-dichloroethene | 75-35-4 | 96.94 | 0.20 | 0.0002 | 0.008 | 2.0 | 32 | 82 | 0.18 |
| M-40 | 1,2-Dichloroethane | 107-06-2 | 98.96 | 0.41 | 0.0002 | 0.005 | 1.3 | 21 | 52 | 0.12 |
| M-40 | 1,2-Dichloropropane | 78-87-5 | 112.98 | 0.18 | 0.0002 | 0.005 | 1.5 | 23 | 60 | 0.13 |
| M-40 | Isopropyl alcohol (2-Propanol) | 67-63-0 | 60.11 | 50.10 | 0.0002 | 0.356 | 55.3 | 886 | 2260 | 5.0 |
| M-40 | Acetone | 67-64-1 | 58.08 | 7.01 | 0.0002 | 1.61 | 242 | 3870 | 9860 | 21.7 |
| M-40 | Acrylontrile | 107-13-1 | 53.06 | 6.33 | 0.020 | ND | ND | ND | ND | ND |
| M-40 | Bromodichloromethane | 75-27-4 | 163.83 | 3.13 | 0.0002 | 0.010 | 4.2 | 68 | 170 | 0.381 |
| M-40 | Butane | 106-97-8 | 58.12 | 5.03 | 1 | 3.30 | 496 | 7940 | 20200 | 44.6 |
| M-40 | Carbon Disulfide | 75-15-0 | 76.13 | 0.58 | 0.0002 | 0.134 | 26.4 | 422 | 1080 | 2.4 |
| No Test | Carbon Monoxide | 630-08-0 | 28.01 | 141.00 | | NM | NM | NM | NM | NM |
| M-40 | Carbon Tetrachloride | 56-23-5 | 153.84 | 0.004 | 0.0002 | 0.005 | 2.0 | 32 | 81 | 0.18 |
| M-40 | Carbonyl Sulfide (Carbon oxysulfide) | 463-58-1 | 60.07 | 0.49 | 0.020 | ND | ND | ND | ND | ND |
| M-40 | Chlorobenzene | 108-90-7 | 112.56 | 0.25 | 0.0002 | 0.229 | 66.6 | 1070 | 2720 | 6.0 |
| M-40 | Chlorodiflouromethane (Freon 22) | 75-45-6 | 86.47 | 1.30 | 0.020 | ND | ND | ND | ND | ND |
| M-40 | Chloroethane (Ethyl Chloride) | 75-00-3 | 64.52 | 1.25 | 0.0002 | 1.88 | 314 | 5020 | 12800 | 28.2 |

| Method | Compound | CAS Number | Formula Wt. | Default Value (ppmv) | Detection Limit (ppmv) | Measured Average (ppmv) | Concentration in Inlet LFG | | Mass Flow Rate in Inlet LFG Stream | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | (x10$^{-9}$ lb/ft$^3$) | (µg/m$^3$) | (mg/hr) | (x10$^{-3}$ lb/hr) |
| M-40 | Chloroform | 67-66-3 | 119.39 | 0.03 | 0.0002 | 0.190 | 58.6 | 939 | 2390 | 5.3 |
| M-40 | Chloromethane | 74-87-3 | 50.49 | 1.21 | 0.0002 | 0.072 | 9.4 | 150 | 390 | 0.85 |
| M-40 | 1,2-Dichlorobenzene | 95-50-1 | 147.01 | 0.21 | 0.0002 | 0.0004 | 0.15 | 2.4 | 6.2 | 0.014 |
| M-40 | 1,3-Dichlorobenzene | 541-73-1 | 147.00 | 0.21 | 0.0002 | 0.00203 | 0.771 | 12.4 | 31.5 | 0.0694 |
| M-40 | 1,4-Dichlorobenzene | 106-46-7 | 147.00 | 0.21 | 0.0002 | 0.255 | 96.9 | 1550 | 3960 | 8.7 |
| M-40 | Dichlorodifluoromethane (Freon 12) | 75-71-8 | 120.91 | 15.70 | 0.0002 | 0.468 | 146 | 2340 | 5970 | 13.2 |
| M-40 | Dichlorofluoromethane (Freon 21) | 75-43-4 | 102.92 | 2.62 | 0.020 | ND | ND | ND | ND | ND |
| M-40 | Methylene Chloride (Dichloromethane) | 75-09-2 | 84.94 | 14.30 | 0.0002 | 0.169 | 37.1 | 594 | 1510 | 3.3 |
| No Test | Dimethyl Sulfide (Methyl sulfide) | 75-18-3 | 62.13 | 7.82 | | NM | NM | NM | NM | NM |
| M-40 | Ethane | 74-84-0 | 30.07 | 889.00 | 1 | 4.6 | 360 | 5730 | 14600 | 32.2 |
| M-40 | Ethanol | 64-17-5 | 46.08 | 27.20 | 0.0002 | 0.202 | 24.1 | 385 | 980 | 2.2 |
| M-40 | Ethyl Mercaptan (Ethanediol) | 75-08-1 | 62.13 | 2.28 | 0.020 | ND | ND | ND | ND | ND |
| M-40 | Ethylbenzene | 100-41-4 | 106.16 | 4.61 | 0.0002 | 2.80 | 767 | 12300 | 31300 | 69.0 |
| M-40 | 1,2-Dibromoethane (Ethylene dibromide) | 106-93-4 | 187.88 | 0.001 | 0.0002 | 0.007 | 3.4 | 55 | 140 | 0.306 |
| M-40 | Trichloromonofluoromethane (Fluorotrichloromethane) (F11) | 75-69-4 | 137.38 | 0.76 | 0.0002 | 0.327 | 116 | 1860 | 4740 | 10.5 |
| M-40 | Hexane | 110-54-3 | 86.18 | 6.57 | 0.0002 | 1.95 | 434 | 6950 | 17700 | 39.0 |
| M-11 | Hydrogen Sulfide | 7783-06-4 | 34.08 | 35.50 | | 22.9 | 0.0020 | 32400 | 82500 | 182 |

| Method | Compound | CAS Number | Formula Wt. | Default Value (ppmv) | Detection Limit (ppmv) | Measured Average (ppmv) | Concentration in Inlet LFG | | Mass Flow Rate in Inlet LFG Stream | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | ($x10^{-9}$ lb/ft$^3$) | (µg/m$^3$) | (mg/hr) | ($x10^{-3}$ lb/hr) |
| Organic mercury | Mercury (Dimethyl) | | 230.66 | Not Listed | 0.05E-06 | R | R | R | R | R |
| LUMEX | Mercury (Elemental) | 7439-97-6 | 200.61 | Not Listed | | 7.0E-6 | 0.0036 | 0.058 | 0.15 | 0.000326 |
| Organic mercury | Mercury (Monomethyl) | | 215.62 | Not Listed | 0.014E-06 | .134E-6 | 0.0000747 | 0.00120 | 0.00305 | 0.0000067 |
| Organic mercury | Mercury (Total) | | 215.63 | 2.53E-04 | 6E-06 | 22.8E-6 | 0.0127 | 0.204 | 0.52 | 0.00114 |
| M-40 | 2-Butanone (Methyl Ethyl Ketone) | 78-93-3 | 72.10 | 7.09 | 0.0002 | 1.43 | 267 | 4280 | 10900 | 24.0 |
| M-40 | 2-Hexanone (Methyl Butyl Ketone) | 591-78-6 | 100.16 | 1.87 | 0.0002 | 0.441 | 114 | 1830 | 4660 | 10.3 |
| No Test | Methyl Mercaptan (Methanethiol) | 74-93-1 | 48.11 | 2.49 | | NM | NM | NM | NM | NM |
| M-40 | Pentane | 109-66-0 | 72.15 | 3.29 | 1 | 2.60 | 485 | 7770 | 19800 | 43.6 |
| M-40 | Tetrachloroethylene (Perchloroethylene) | 127-18-4 | 165.83 | 3.73 | 0.0002 | 0.176 | 75.4 | 1210 | 3080 | 6.8 |
| M-40 | Propane | 74-98-6 | 44.09 | 11.10 | 1 | 5.9 | 670 | 10800 | 27500 | 60.5 |
| M-40 | t-1,2-Dichloroethene | 156-60-5 | 96.94 | 2.84 | 0.0002 | 0.009 | 2.3 | 36 | 92 | 0.20 |
| M-40 | Trichloroethylene (Trichloroethene) | 79-01-6 | 131.38 | 2.82 | 0.0002 | 0.103 | 35.0 | 560 | 1430 | 3.1 |
| M-40 | Vinyl Chloride | 75-01-4 | 62.50 | 7.34 | 0.0002 | 0.410 | 66.2 | 1060 | 2700 | 6.0 |
| M-40 | m/p-Xylene (Dimethyl Benzene) | 1330-20-7 | 106.16 | 12.10 | 0.0002 | 3.98 | 1100 | 17500 | 44600 | 98.2 |
| M-40 | o-Xylene (Dimethyl Benzene) | 95-47-6 | 106.16 | 12.10 | 0.0002 | 1.41 | 388 | 6210 | 15800 | 34.9 |

| Method | Compound | CAS Number | Formula Wt. | Default Value (ppmv) | Detection Limit (ppmv) | Measured Average (ppmv) | Concentration in Inlet LFG | | Mass Flow Rate in Inlet LFG Stream | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | ($x10^{-9}$ lb/ft$^3$) | (µg/m$^3$) | (mg/hr) | ($x10^{-3}$ lb/hr) |
| M-40 | Benzene (Co-disposal) | 71-43-2 | 78.11 | 11.10 | 0.0002 | 0.251 | 50.7 | 812 | 2070 | 4.6 |
| M-40 | Benzene (No-disposal or Unknown) | 71-43-2 | 78.11 | 1.91 | 0.0002 | 0.251 | 50.7 | 812 | 2070 | 4.6 |
| M-25C | NMOC as Hexane (Co-disposal) | | 86.17 | 2420.00 | | 355 | 79100 | 1270000 | 3230000 | 7.1 |
| M-25C | NMOC as Hexane (No-codispoal or Unknown) | | | 595 | | 355 | 79100 | 1270000 | 3230000 | 7.1 |
| M-40 | Toluene (Methyl Benzen) (Co-disposal) | 108-88-3 | 92.13 | 165.00 | 0.0002 | 6.77 | 1600 | 25800 | 65800 | 145 |
| M-40 | Toluene (Methyl Benzene) (No or Unknown) | | | 39.30 | 0.0002 | 6.77 | 1600 | 25800 | 65800 | 145 |

R – Data were rejected because of serious deficiency in spike recovery

**Table 4-19. Raw Landfill Gas Constituent Concentrations for Compounds without AP-42 Default Values**

| Method | Compound | CAS Number | Formula Wt. | Detection Limit (ppmv) | Measured Average (ppmv) | Concentration in Inlet LFG | | Mass Flow Rate in Inlet LFG Stream | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | (x$10^{-9}$ lb/ft$^3$) | (µg/m$^3$) | (mg/hr) | (x$10^{-3}$ lb/hr) |
| M-0100 | Acetaldehyde | 75-07-0 | 44.05 | 0.0023 | 0.015 | 1.7 | 27 | 69 | 0.15 |
| M-0100 | Formaldehyde | 50-00-0 | 30.03 | 0.0017 | 0.0029 | 0.23 | 3.6 | 9.3 | 0.020 |
| M-23 | Dioxins/Furans | | | | NM | NM | NM | NM | NM |
| M-23 | PAHs | | | | NM | NM | NM | NM | NM |
| M-25C | Carbon Dioxide | 124-38-9 | 44.01 | | 307000 | 34900000 | 559000000 | 1430000000 | 3100000 |
| M-25C | Methane | 74-82-8 | 16.04 | | 392000 | 16300000 | 260000000 | 663000000 | 1500000 |
| M-25C | Oxygen | 7782-44-7 | 32.00 | | 64000 | 5300000 | 85000000 | 220000000 | 476400 |
| M-40 | 1,1,2,3,4,4-Hexachloro-1,3-butadiene | 87-68-3 | 260.76 | 0.0002 | 0.005 | 3.4 | 54 | 140 | 0.30 |
| M-40 | 1,1,2-Trichloro-1,2,2-trifluoroethane (CFC113) | 76-13-1 | 187.38 | 0.0002 | 0.011 | 5.3 | 85 | 220 | 0.48 |
| M-40 | 1,1,2-Trichloroethane | 79-00-5 | 133.42 | 0.0002 | 0.039 | 14 | 220 | 550 | 1.2 |
| M-40 | 1,2,4-Trichlorobenzene | 120-82-1 | 181.46 | 0.0002 | 0.00503 | 2.4 | 38 | 96 | 0.21 |
| M-40 | 1,2,4-Trimethylbenzene | 95-63-6 | 120.19 | 0.0002 | 0.95 | 290 | 4700 | 12000 | 27 |
| M-40 | 1,2-Chloro-,1,2,2-Tetrafluoroethane (CFC114) | 76-14-2 | 170.92 | 0.0002 | 0.044 | 19 | 310 | 790 | 1.7 |
| M-40 | 1,3,5-Trimethylbenzene | 108-67-8 | 120.19 | 0.0002 | 0.386 | 120 | 1920 | 4900 | 10.8 |
| M-40 | 1,3-Butadiene (Vinylethylene) | 106-99-0 | 54.09 | 0.0002 | 0.089 | 12 | 200 | 510 | 1.1 |
| M-40 | 1,4-Dioxane (1,4-Diethylene Dioxide) | 123-91-1 | 88.10 | 0.0002 | 0.009 | 2.1 | 34 | 87 | 0.19 |
| M-40 | 1-Ethyl-4-methylbenzene (4-Ethyl Toluene) | 622-96-8 | 120.20 | 0.0002 | 0.386 | 120 | 1920 | 4900 | 10.8 |

| Method | Compound | CAS Number | Formula Wt. | Detection Limit (ppmv) | Measured Average (ppmv) | Concentration in Inlet LFG | | Mass Flow Rate in Inlet LFG Stream | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | ($x10^{-9}$ lb/ft$^3$) | (µg/m$^3$) | (mg/hr) | ($x10^{-3}$ lb/hr) |
| M-40 | 4-Methyl-2-pentanone (MIBK) | 108-10-1 | 100.16 | 0.0002 | 0.89 | 230 | 3700 | 9400 | 21 |
| M-40 | Benzyl Chloride (Chloromethyl Benzene) | 100-44-7 | 126.58 | 0.0002 | 0.020 | 6.5 | 110 | 270 | 0.59 |
| M-40 | Bromomethane (Methyl bromide) | 74-83-9 | 94.95 | 0.0002 | 0.046 | 11 | 180 | 460 | 1.0 |
| M-40 | cis-1,2-Dichloroethene | 156-59-2 | 96.94 | 0.0002 | 0.292 | 73.2 | 1170 | 2990 | 6.6 |
| M-40 | cis-1,3-Dichloropropene | 10061-01-5 | 110.98 | 0.0002 | 0.0014 | 0.39 | 6.3 | 16 | 0.035 |
| M-40 | Cyclohexane | 110-82-7 | 84.16 | 0.0002 | 0.734 | 160 | 2560 | 6520 | 14.4 |
| M-40 | Dibromochloromethane | 124-48-1 | 208.29 | 0.0002 | 0.0160 | 8.6 | 138 | 352 | 0.775 |
| M-40 | Ethyl Acetate | 141-78-6 | 88.10 | 0.0002 | 2.31 | 526 | 8430 | 21500 | 47.4 |
| M-40 | Heptane | 142-82-5 | 100.20 | 0.0002 | 0.92 | 240 | 3800 | 9700 | 21 |
| M-40 | Methyl-t-butyl Ether (MTBE) | 1634-044 | 88.15 | 0.0002 | 0.177 | 40.3 | 646 | 1650 | 3.6 |
| M-40 | Styrene (Vinylbenzene) | 100-42-5 | 104.14 | 0.0002 | 0.222 | 59.8 | 957 | 2440 | 5.4 |
| M-40 | t-1,3-Dichloropropene | 1006-02-6 | 110.98 | 0.0002 | 0.003 | 0.86 | 14 | 35 | 0.078 |
| M-40 | Tetrahydrofuran (Diethylene Oxide) | 109-99-9 | 72.10 | 0.0002 | 0.88 | 164 | 2630 | 6710 | 14.8 |
| M-40 | Tribromomethane (Bromoform) | 75-25-2 | 252.77 | 0.0002 | ND | ND | ND | ND | ND |
| M-40 | Vinyl Acetate | 108-05-4 | 86.09 | 0.0002 | 0.686 | 153 | 2450 | 6230 | 13.7 |

## 5. Quality Assurance/Quality Control

This project produced data that qualified to receive the “A” rating with respect to the rating system described in section 4.4.2 of the *Procedures for preparing Emission Factor Documents* (EPA-454/R-95-015). The cited EPA document provides a clear description of the requirements for an “A” data quality rating. Tests were performed by using an EPA reference test method, or when not applicable, a sound methodology. Tests were reported in enough detail for adequate validation and raw data were provided that could be used to duplicate the emission results presented in this report.

Throughout the results sections of this report, notations and footnotes were included to flag data that, for various reasons, did not meet their associated measurement quality objectives.

### 5.1 Assessment of Measurement Quality Objectives (MQOs)

Measurement quality objectives (MQOs) were established for each critical measurement and documented in the *Site-Specific QAPP for the Field Evaluation of Landfill Gas Control Technologies-Landfill B*. The following subsections assess MQOs for each measurement to determine if goals were achieved. When applicable, data validation elements performed on laboratory analytical reports are also included.

#### 5.1.1 Continuous Emissions Monitors (CEMs)

Combustion produced gases $O_2$, CO, $CO_2$, $SO_2$, $NO_X$ and THC were measured in the field using CEMs. The following MQOs were established for CEM measurements for Landfill B:

- Direct calibration bias: ±2 percent
- System bias checks: ±5 percent
- Zero and drift: ±3 percent
- Completeness: >90 percent

Direct calibrations were performed daily prior to testing, with certified calibration gases at zero and a minimum of two other concentrations (typically a mid-level concentration and one point towards the full-scale end of the instrument range). System bias checks were performed pre-test and post-test. Drift checks were performed daily, post-test. Table 5-1 summarizes these quality control (QC) checks for all instruments. Not all MQOs were met for all CEM measurements. The $SO_2$ analyzer exhibited excessive bias (1 to 24 percent) and drift (1 to 180 percent). The $NO_X$ instrument also exhibited slightly elevated drift (0 to 13 percent). The other instruments performed well and within the QAPP-specified criteria. The fact that the original QAPP MQOs were not fully met is not believed to affect the usability of these data. Results that did not meet the specified MQOs were presented with the appropriate notations.

**Table 5-1. Continuous Emissions Monitor Measurement Quality Objectives Summary for Landfill B**

| Instrument and Range | Direct Calibration (±2% criteria) | | | System Bias Checks (±5% criteria) | | | Drift Checks (±3% criteria) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Total (#) | Bias Range (%) | Complete (%) | Total (#) | Bias Range (%) | Complete (%) | Total (#) | Bias Range (%) | Complete (%) |
| Servomex $O_2$ Analyzer (0-21%) | 6 | 0 – 0 | 100 | 4 | 0 – 3.3 | 100 | 4 | 0 – 3.3 | 75 |
| Cal Analytical $CO_2$ Analyzer (0-20%) | 6 | 0 – 2.2 | 67 | 4 | 0 – 3.3 | 100 | 4 | 0 – 2.2 | 100 |
| Cal Analytical CO Analyzer (0-650 ppm) | 8 | 0 – 0 | 100 | 2 | 0.7 – 2.0 | 100 | 4 | 0 – 1.1 | 100 |
| Cal Analytical $SO_2$ Analyzer (0-500 ppm) | 8 | 0.0 – 1.0 | 100 | 2 | 1 – 24 | 50 | 4 | 1 – 180 | 50 |
| TECO $NO_X$ Analyzer (0-4000 ppm) | 6 | 0 – 2 | 100 | 2 | 1 – 3 | 100 | 4 | 0 – 13 | 50 |
| TECO THC Analyzer (0-1000 ppm) | NA[a] | NA[a] | NA[a] | 8 | 0 – 3 | 100 | 4 | 1.1 - 4 | 50 |

[a]The method called for calibration gases to be introduced at a point of the sampling system close to the sampling probe for them to flow through the heated sample line. Calibration gases were not injected directly to the analyzer

### 5.1.2 Carbonyls (Method TO-11)

The following MQOs were established in the QAPP for this method:

- Recovery (formaldehyde): 50-150 percent
- Precision: ±20 percent relative standard deviation (RSD)

- Completeness: >90 percent

Four samples (including three raw LFG samples and one field blank) were submitted to Resolution Analytics for formaldehyde and acetaldehyde determination. Results were reported in RFA# 992014. The report included information on instrument calibration and internal QC checks. Samples collected on November 4 and 5, 2002, were received by the laboratory on November 14, 2002 and analyzed on November 22, 2002. That met the 30-day hold-time limitation. Analytical detection limits were reported as 13 ppb for formaldehyde and 26 ppb for acetaldehyde in the sample extracts. Based on a 5 ml extract, the detection limits were 65 ng for formaldehyde and 130 ng for acetaldehyde. Based on sample volumes ranging from 32 to 42 l at standard conditions, the MDLs were 1.3 ppb for formaldehyde and 1.7 ppb for acetaldehyde.

The field blank did not have detectable levels of acetaldehyde and showed 0.070µg formaldehyde detected. To assess accuracy, an external performance evaluation audit sample containing 0.25 ppm formaldehyde and acetaldehyde was analyzed with the sample set. Recovery was 101.6 percent for formaldehyde and 96.3 percent for acetaldehyde, which meets the 50-150 percent MQO. One project sample was injected in duplicate and the percent drift (%D) range for formaldehyde was 4.3 percent and for acetaldehyde was 5.4 percent. All MQOs were met for this method for a completeness of 100 percent.

#### 5.1.3 Hydrogen Sulfide ($H_2S$) (EPA Method 11)

The following MQOs were established in the Landfill B QAPP for this method:

- Accuracy: ±5 percent bias
- Precision: ±5 percent RSD
- Completeness: >90 percent

Eight samples (including three reagent blanks and one field blank) plus two laboratory in-house reagent blanks were submitted to Oxford Laboratories for $H_2S$ analysis by EPA Method 11. The samples were collected on November 5, 2002, submitted to the laboratory on November 14, 2002, and the results report was dated November 22, 2002. Therefore the analysis met the 30-day hold time criteria.

The field blank submitted did not have quantifiable concentrations of $H_2S$. A laboratory spike was performed and the recovery was 101 percent. The three test samples produced results of similar concentrations. Duplicate analysis of a sample within the same batch of samples resulted in 1.7 percent RSD. Spike recovery for the

Run #1 samples was 101 percent. All MQOs were met for this method for a completeness of 100 percent.

#### 5.1.4 Dioxins and Furans (PCDD/PCDFs) (EPA Method 23)

The following MQOs were established in the QAPP for this method:

- Recovery: 50-150 percent
- Completeness: >90 percent

Four sample sets (including one set of reagent blank and sample train rinsates) were submitted to ALTA Analytical Perspectives for PCDD/PCDFs analysis. The samples were collected on November 4, 2002, and delivered to the laboratory on November 14, 2002. The samples were extracted on November 20, 2002 and analyzed on November 27, 2002. This met the 14-day hold-time for extraction and 40-day hold time for analysis.

The field blank did not have detectable levels of the target analytes. Detection limits for the various congeners were in the single-digit picogram level. To assess accuracy, each sample train was spiked with standard Method 23 spiking compounds and analysis of the samples yielded extraction standard (ES) recovery from 84 to 99 percent. Recovery of sampling standards (SS) ranged from 106 to 108 percent. These recoveries are well within the 50-150 percent MQO.

Because a decision was made to analyze only one of the three sample extracts, the completeness goal of 90% was not achieved. However, all other MQOs were met for this method.

#### 5.1.5 Polycyclic Aromatic Hydrocarbons (PAHs) (EPA Method 23/0011)

##### *5.1.5.1 Raw Landfill Gas (LFG) Samples*

Three sets of samples were sent to ALTA Analytical Perspectives for PAH analysis. The Method 23 samples collected from the raw LFG could not be concentrated below 750 to 1000 µL. The produced cleaned-up extracts contained gasoline-like hydrocarbons and prevented the preparation of final extracts of PAH analysis.

No results were reported. Therefore, the MQOs for this sample group were 0 percent complete.

#### *5.1.5.2 Flare Stack Samples*

The following MQOs were established in the QAPP for this method:

- Recovery: 50-150 percent
- Completeness: >90 percent

Four samples (including one reagent blank) collected from the flare stack were submitted to ALTA Analytical Perspectives for PAH analysis. The report included information on instrument calibration and internal QC checks. Samples collected on November 4, 2002 were received by the laboratory on November 14, 2002. These were extracted on November 20, 2002 and analyzed on January 9, 2003. This met the 14-day hold-time for extraction but missed the analysis 40-day hold time by 10 days. The results were reported with notation of this hold-time exceedance.

Analysis of the field blank yielded detectable but low levels of a few of the target compounds with all PAH analytes totaling to 15762 ng. In contrast, the test samples showed total PAH level of 113974 ng. Recovery of ES ranged from 65 to 124 percent. Recoveries of SS, $d_{10}$-fluorene and $d_{14}$-terphenyl were not reported. Recovery of the alternative standard (AS) $d_{10}$-anthracene was 57.9 percent. The reported recoveries were within the 50 to 150 percent MQO.

Because a decision was made to analyze only one of the three sample extracts, the completeness goal of 90% was not achieved. However, all other MQOs were met for this method.

### 5.1.6 Polychlorinated Biphenyls (PCBs)

The same Method 23 samples collected from the raw LFG were earmarked for analysis for PCBs. Since the cleaned up extracts could not be concentrated below 750 to 1000 µL because of the presence of gasoline-like hydrocarbons, final extracts could not be prepared for the planned PCB analysis. No PCBs results were reported.

Therefore the MQO for this sample group was 0 percent complete.

### 5.1.7 Non-Methane Organic Compounds (NMOCs) (Method 25C)

The following MQOs were established in the QAPP for Landfill B:

- Recovery: 50 to 150 percent

- Precision: ±30 percent RSD
- Completeness: >90 percent

Four canister samples (including a field blank) were submitted from Landfill B for NMOC analysis by Method 25-C to Triangle Environmental Services. The samples were collected on November 4, 2002, submitted on December 3, 2002, and analyzed between December 3 and 23, 2002. Therefore the analysis did not meet the 30 day hold time requirements. The apparent delay in sample delivery was partly attributed to the fact that the same canisters had to be analyzed by RTP Laboratory for volatile organics first. The impact of exceeding the prescribed 30-day hold time by up to 19 days is unknown. The results were reported with a notation of the hold-time exceedances.

The laboratory report included information on instrument calibration and internal QC checks.

NMOC in the field blank was at 8.5 ppmv as hexane. Accuracy for the method was assessed by evaluating results of response factor check samples that were run prior to and following sample analysis. Acceptance criteria established by the method is that the response factor (RF) must be within 10 percent of the response factor from initial calibration. All response factor checks ranged from 0.9 to 7.4 percent of the initial calibration, well within the 10 percent acceptance criteria. The %D between the pre and post-test checks were less than 2 percent, ranging from 0.5 to 1.2 percent. Samples were run in triplicate and all %RSD for samples were less than 3.4 percent.

All MQOs were met for this method for a completeness of 100 percent.

#### 5.1.8 Hydrogen Chloride (HCl) (EPA Method 26A)

The following MQOs were established in the QAPP for Landfill B:

- Accuracy: ±10 percent bias
- Precision: ±10 percent RSD
- Completeness: >90 percent

Four samples (including one field blank) were submitted to Resolution Analytics for HCl and chlorine ($Cl_2$) determination. The results were reported in RFA# 992014. The report included information on instrument calibration and internal QC checks. Samples were collected on November 4, 2002. These were received by the laboratory on

November 14, 2002, and analyzed on November 27, 2002, which met the 4 week hold-time requirement. Analytical detection limits were reported as 0.41 ppm HCl.

The field blank did not contain detectable levels of HCl. In-house audit samples were analyzed with each respective group of field samples and the measured concentrations fell within method criteria of 10 percent of their expected values.

A matrix spike was performed on a sample (B POSST-01) that was a part of this sample batch. An 0.8 ml sample was spiked with 0.8 ml of standard (50 ppm chloride) and analyzed in duplicate. The laboratory reported 97.1 percent recovery of the HCl spike with a 0.02 percent deviation in duplicate injections. This meets the MQO of ±10 percent with very good precision. Calculated bias for internal QC check was <2.2 percent. All MQOs were met for 100 percent completeness.

#### 5.1.9 Metals (EPA Method 29)

The following MQOs were established in the Landfill B QAPP for this method:

- Accuracy: ±25 percent bias
- Precision: ±20 percent RSD
- Completeness: >90 percent

Four sets of Method 29 Multi-Metal trains (including one field blank) were submitted to First Analytical Laboratories for As, Cd, Cr, Pb, Mn, Hg, and Ni determination. Results were reported in Project #21110. The report included information on instrument calibration and internal QC checks. Samples were collected on November 4 and 5, 2002, received by the laboratory on November 12, 2002, and analyzed on November 14, 2002, which met the 14 day hold-time requirement. Method detection limits for each of the target metals were reported as follows:

- As = 5.0 µg/L
- Cd = 0.2 µg/L
- Cr = 5.0 µg/L
- Pb = 5.0 µg/L
- Mn = 5 µg/L

- Ni = 10 µg/L
- Hg = 0.2 µg/L

Traces of Cr, Mn and Ni were found in the blanks, which is not unusual.

All samples were spiked prior to analysis. Spike recoveries ranged from 82 to 110 percent and were within the acceptable range of 75-125 percent. In addition to spiking the samples, for each metal, internal calibration verification samples (ICVs) and continuing calibration verification samples (CCVs) were performed. ICVs were run at the beginning of each run set and CCVs were run at a frequency of one for every 10 samples. ICV and CCV measured values were all <±10 percent for all metals. Therefore the MQO for this measurement was 100 percent and met the objective set in the QAPP.

#### 5.1.10 Organo-mercury (Hg) and Total mercury (Hg) (Frontier)

The following MQOs were established in the Landfill B QAPP for this method:

- Recovery: 50-150 percent
- Precision: ±20 percent RSD
- Completeness: >90 percent

Total Hg analysis was performed by Frontier Geosciences. Four total Hg samples (including a field blank) were taken at Landfill B. Samples were collected on November 4, 2002 and analyzed in December 2002. That analysis schedule exceeded the 14-day hold-time specified in the QAPP. All other quality assurance measures indicated that the analysis of the traps were under good control. All field blanks were consistent with historical values and indicate the detection limit is likely to be at or below the previous estimated value of 50 $ng/m^3$. Spike recoveries were 95.4 and 95.2 percent; and relative percent difference (RPD) between replicates was 6.2 percent, which meets MQOs and are therefore 100 percent complete. The exceedance of 14-day hold times was noted in the reported results.

Five monomethyl Hg (MMHg) samples (including a field blank and field spike) were collected on November 5, 2002. These samples were analyzed December 2005 which exceeded the 14-day hold-time. Analysis of these samples was under good control with acceptable distillation spike recoveries and distillation duplicates. All CCVs had acceptable recoveries. Field spike recovery was 70 percent and matrix spike recovery was 116 percent, which met MQOs. The exceedance of 14-day hold times was noted in the reported results.

Five dimethyl Hg (DMHg) samples (including a field blank and field spike) were collected on November 4, 2002. Analysis of these samples took place in December 2002 and did not meet the 14-day hold-time. Field spike recoveries for all DMHg analysis were consistently low 0-5 percent. With the extremely low recovery, DMHg concentrations are considered biased low and the degree of bias is significant. QA measures in place support the following conclusions:

- Replicate samples taken at each site report similar concentrations which indicated that the properties of the DMHg sampling train and LFG were consistent and biases were not attributable to trap media or landfill sample gas.
- Continuous calibration verifications (CCVs) used during the analysis indicated that the detection systems were measuring accurately.
- Dimethyl Hg (DMHg) field blanks indicated that the trap media, handling procedures, and analytical techniques did not contribute to the problems with recovery.
- Trip spikes (traps spike in the laboratory, shipped to the field but not used for sampling) indicated that the laboratory standards, trap media, and trap handling procedures did not create significant bias.
- Field spikes (traps spiked in the laboratory and used to collect a replicate sample) indicated that some property or action during sampling either destroyed or evaded the DMHg adsorbed to the Carbotrap

The RSD between the three replicate samples was 23.9 percent, which meets the MQO of ±30 percent, but because recovery MQOs were not met for any of the field spikes, DMHg analysis was 0 percent complete. The exceedance of 14-day hold times was noted in the reported results. The results were categorized as “R” to indicate that the results were rejected due to serious deficiencies as per EPA QA/G-8 Guidance.

#### 5.1.11 Volatile Organic Compounds (VOCs) and Methane ($CH_4$) (Method TO-15)

The following MQOs were established in the Landfill B QAPP for this method:

- Accuracy: 50-150 percent recovery
- Precision: ±30 percent RSD
- Completeness: >90 percent

Four SUMMA canisters (including one field blank) were submitted from Landfill B to RTP Laboratories for VOC and $CH_4$ determination by EPA Method TO-15. Results were reported in Project #347-02. Samples were collected on November 2, 2002 and analysis was completed by November 27, 2002, which met the 30 day hold-time requirement.

Analysis of the field blank found 3.03 ppbv of acetone and 1.24 ppbv of methylene chloride. Table 5-2 lists the compounds that were found above the detection limit of 0.2 ppbv. Other target analytes were not detected. The average test sample concentrations were significantly higher than the concentrations in the blank sample. Therefore, the presence of these analytes in the blank sample did not affect the conclusions that were drawn from these VOC data. Nonethelss, the results were reported with the appropriate notations.

The summa canister of the Run #3 sample was spiked to 213 ppbv of chlorobenzene. The recovery of chlorobenzene was 211 percent and was outside of the established criteria. This out-of-criteria spike recovery was noted in the reported results.

Precision was demonstrated through multiple injections of standards at five concentration levels. The RSD between the calculated relative response factors (RRF) must be <30 percent with allowances that two may be >40 percent. The average RSD was 10.18 percent and method criteria were met for all compounds except methylene chloride with an RSD of 37.9 percent. Results for this compound are flagged as estimated, “J”. Valid data was received for all SUMMA canisters submitted, and these analyses were considered to be 100 percent complete.

### 5.2 Audits

This project was designated as Quality Assurance (QA) Category II effort. Hence, audits were required. The internal and external audits performed for this project were completed and their findings were included in a separate report for Landfill D of this project.

**Table 5-2. VOC detected in Method 40 Blank Sample and Test Samples**

| Compound | Concentration, (ppbv) | Average Concentration in Test Samples (ppbv) |
|---|---|---|
| Vinyl chloride | 0.27 | 410 |
| 1,3-Butadiene | 0.41 | 89 |
| Bromomethane | 0.92 | 46 |
| Isopropyl alcohol | 0.26 | 356 |
| Methylene chloride | 1.24 | 169 |
| Acetone | 3.03 | 1610 |
| Benzene | 0.21 | 251 |
| Toluene | 0.21 | 6770 |
| 4-Methyl-2-pentanone (MIBK) | 0.25 | 886 |
| 1,2,4-trimethylbenzene | 0.22 | 949 |
| 1,4-dichlorobenzene | 0.21 | 255 |
| 1,1,2,3,4,4-hexachloro-1,3-butadiene | 0.5 | 5 |
| 1,2,4-trichlorobenzene | 0.34 | 5 |

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# Field Test Measurements at Five Municipal Solid Waste Landfills with Landfill Gas Control Technology
# Final Report

## Appendix C

## SOURCE TEST REPORT
## FOR LANDFILL C

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## Tables

## Figures

## Appendices

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## Acronym List

| | |
|---|---|
| %D | Percent difference |
| AP-42 | Compilation of Air Pollutant Emission Factors |
| APPCD | Air Pollution Prevention Control Division |
| ARCADIS | ARCADIS G&M, Inc. |
| As | Arsenic |
| CCVs | Continuing calibration verification samples |
| Cd | Cadmium |
| CEMS | Continuous emission monitoring system |
| $CH_4$ | Methane |
| $Cl_2$ | Chlorine |
| CO | Carbon monoxide |
| $CO_2$ | Carbon dioxide |
| Cr | Chromium |
| DMHg | Dimethyl mercury |
| EF | Efficiency factor |
| EPA | US Environmental Protection Agency |
| ES | Extraction standards |
| FID | Flame ionization detector |
| Frontier | Frontier Geosciences |
| GC/MS | Gas chromatograph/mass spectrometer |
| HCl | Hydrogen chloride |
| Hg | Mercury |
| $H_2S$ | Hydrogen sulfide |
| ICVs | Internal calibration verification samples |
| LFG | Landfill gas |
| MMHg | Monomethyl mercury |
| Mn | Manganese |
| MQOs | Measurement quality objectives |

## Acronym List

| | |
|---|---|
| MSW | Municipal solid waste |
| Ni | Nickel |
| NIST | National Institute of Standards and Technology |
| NMOCs | Non-methane organic compounds |
| $NO_X$ | Nitrogen oxides |
| $O_2$ | Oxygen |
| PAHs | Polynuclear aromatic hydrocarbons |
| Pb | Lead |
| PEA | Performance evaluation audit |
| QA | Quality Assurance |
| QAPP | Quality Assurance Project Plan |
| QC | Quality control |
| RF | Response factor |
| RPD | Relative percent difference |
| RRF | Relative response factors |
| RSD | Relative standard deviation |
| RTP | Research Triangle Park |
| $SO_2$ | Sulfur dioxide |
| SOPs | Standard operating procedures |
| SVOC | Semi-volatile organic compounds |
| TCDD/TCDFs | Dioxins/furans |
| TEQ | Toxicity Equivalent |
| THCs | Total hydrocarbons |
| TICs | Tentatively identified compounds |
| TSA | Technical systems audit |
| VOCs | Volatile organic compounds |

## 1. Introduction

Large municipal solid waste (MSW) landfills are subject to Clean Air Act regulations because of concerns related to their emissions and their potential adverse effects to human health and the environment. Landfills are listed as a source of air toxics in the Urban Air Toxics Strategy for future evaluation of residual risk. Existing emission factors for landfill gas (LFG) were largely developed using data from the 1980s and early 1990s. A database was developed summarizing data from approximately 1,200 landfills, along with emissions information from literature and test reports prepared by state and local government agencies and industry. These data were summarized in *Compilation of Air Pollutant Emission Factors (AP-42)*, Chapter 2.4. 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 overall purpose of this testing program was to generate data to be used to update AP-42 and include data that reflect current waste management operating practices. This report presents the results of a field test conducted at Landfill C. Testing took place on May 13 and 14, 2004.

The site uses two internal combustion engine/electric generator sets to reclaim the energy content in the landfill gas. A standby enclosed flare is used for the destruction of any excess landfill gases not consumed by the engine/generator-sets. A more detailed description of the engine system is presented in Section 2. The specific purpose of the testing program was to determine the gas concentrations in the landfill gas pipe leading to the engines and the enclosed flare, and gas emissions from the stack of one of the engines. The pollutants of interest for the raw untreated landfill gas were volatile organic compounds (VOCs), non-methane organic compounds (NMOCs), hydrogen sulfide ($H_2S$), carbonyls (acetaldehyde, formaldehyde), and mercury (Hg) compounds. The pollutants of interest for the treated LFG, in this case at the engine stack, were carbon monoxide (CO), nitrogen oxides ($NO_X$), sulfur dioxide ($SO_2$), NMOCs as total hydrocarbons (THCs), hydrogen chloride (HCl), dioxins/furans (PCDD/PCDFs), polycyclic aromatic hydrocarbons (PAHs), total Hg, and metals.

ARCADIS G&M, Inc. (ARCADIS), as contractor to the US Environmental Protection Agency's (EPA) Air Pollution Prevention and Control Division (APPCD), performed this work under Work Assignment 0-27 of the Onsite Laboratory Support Contract. The testing activities followed the specifications of the approved "*Site-Specific Quality Assurance Project Plan for the Field Evaluations of Landfill Gas Control Technologies Landfill C.*"

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# 2. Landfill Facility Descriptions

Landfill C is located in a midwestern industrial state and began operation in 1992. Based on information provided by the site operator,  Landfill C has approximately 6,400,000 tons of waste in place as of August 2004, covering an area of 63 acres.. The LFG generated in the landfill was extracted with 54 vertical wells, at a rate of 600 cfm. All collected LFG was piped to the engines and enclosed flare system where it was combusted.

## 2.1 Landfill Gas (LFG) Destruction Process Description and Operation

Figure 2-1 shows a simplified process schematic of the engine and flare system. Landfill C utilizes a bank of two Caterpillar generator-sets for destruction of LFG and generation of electricity. The engines were Caterpillar 3516 four-stoke spark ignition (SI) engines, adapted for LFG fuel. The Caterpillar 3516 was a spark-ignited V-16 engine with 4210 cubic inches displacement. The engine was turbocharged and after-cooled, and had a 6.7-inch diameter cylinder bore and a 7.5-inch stroke. A Caterpillar SR4 Generator rated at 800KW (at a 0.8 power factor) was driven by the engine. Engine #1 was selected arbitrarily and tested.

## 2.2 Control Equipment Description

The engines did not have pollution control equipment installed.

## 2.3 Excess Landfill Gas (LFG) Flare

A John Zink Enclosed Ground Flare Station received and destroyed any excess LFG not needed by the two engines. The Enclosed Ground Flare was not part of this test program.

A condensate removal system prevented liquids from entering into the engine and flare burners. A flame arrestor prevented flame from propagating from the flare burner array back into the LFG collection and flow control system.

## 2.4 Landfill Gas (LFG) Sampling Locations

Gas sampling was conducted at the raw LFG pipe, which fed the engines and flare, and at Engine #1 stack as shown in Figure 2-1.

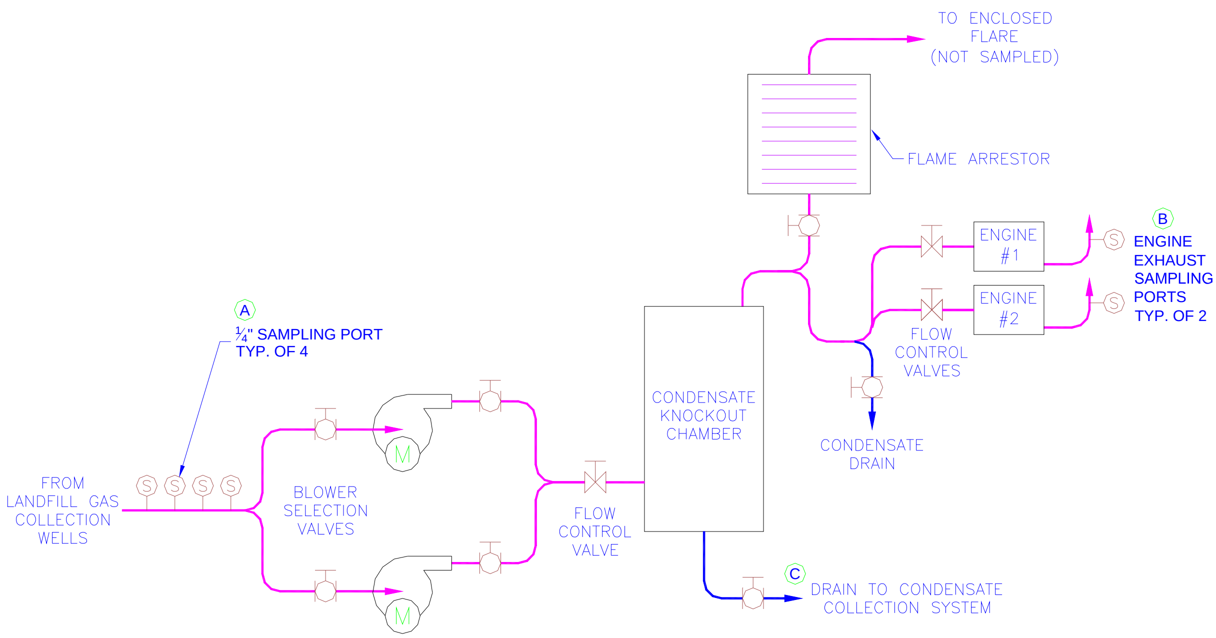



**Figure 2-1. Simplified Engine and Flare Process Flow Diagram and Sampling Points**

2.4.1 Landfill Gas (LFG) Header Pipe

Raw LFG samples were collected from the header pipe, which was exposed by excavating the soil around it. The sample ports were upstream of any processing units. Figure 2-2 is a photograph of the raw LFG inlet pipe. The pipe was 14 inches in diameter. At the sampling point, four ¼” gas taps were installed on the top of the horizontal pipe, at approximately 12-inch spacing. Through these ports, gases were withdrawn to obtain the test samples.

2.4.2 Engine #1 Stack

A picture of Engine #1 is shown in Figure 2-3. The exhaust gas of the engine was ducted outside of the engine room via a pipe. The engine stack was 10 inches in diameter and had two 4-inch sampling ports installed 90 degrees apart. Figure 2-4 is a schematic of the engine stack and includes the locations of the sample traverse points. Isokinetic sampling was possible at this location and followed.

**Figure 2-2. Raw Landfill Gas Collection Pipe**

**Figure 2-3. Engine/Generator Set #1**

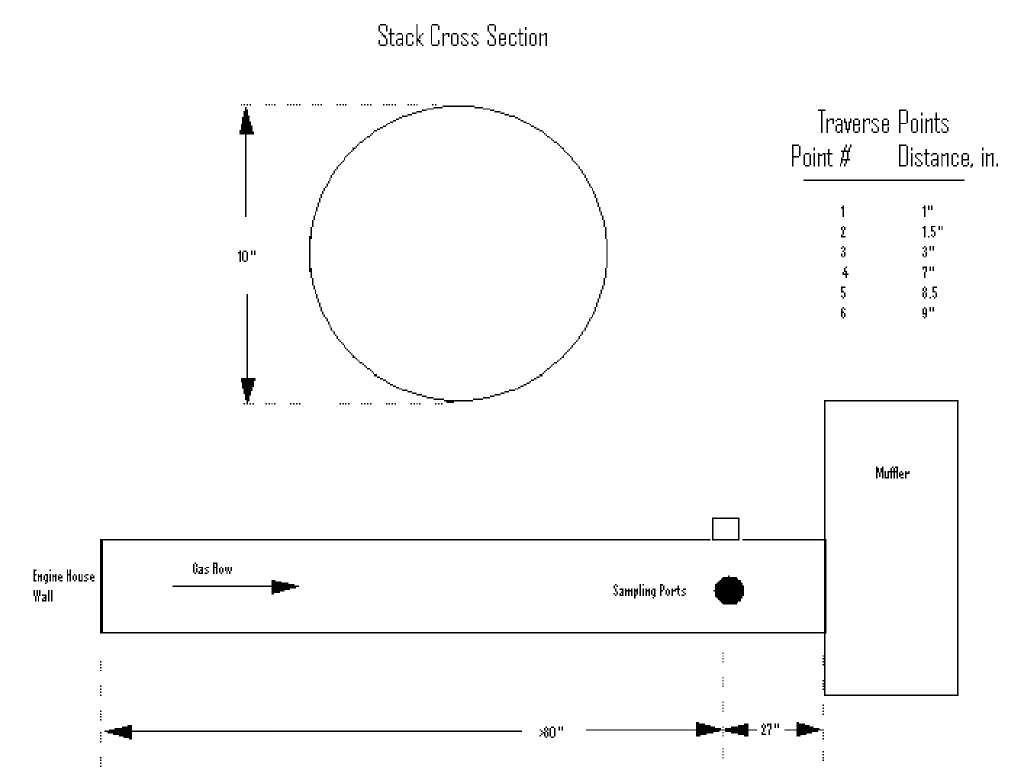



**Figure 2-4. Engine Stack Dimension and Sampling Traverse Locations**

# 3. Test Operations

As stated previously, the purpose of the sampling program was to determine the chemical composition of the raw LFG pipe and the emission from an engine stack.

## 3.1 Test Team

The tests were conducted by a team of seven individuals. The team members and their primary duties are listed in Table 3-1.

**Table 3-1. Test Team Members and Responsibilities**

| Role | Primary Duty |
|---|---|
| Test Engineer | Field Supervisor |
| Test Engineer | CEM operator |
| Test Engineer | Sample train preparation and recovery |
| Test Engineer | Sample train operator at raw LFG inlet pipe |
| Sampling Technician | Sample train operator at stack |
| Senior Chemist | Mercury measurements |
| Senior Chemist | Mercury measurements |
| Project Officer | Field Observer |
| Quality Assurance Officer | QA Technical Systems Audit |
| Quality Assurance Officer | QA Technical Audit Liaison and Oversight |

## 3.2 Test Log

### 3.2.1 Planned Test Sample Matrices

The list of target samples to be collected and measurements to be conducted are specified in the Quality Assurance Project Plan (QAPP) Revision 1 dated March 2004. These are reiterated here for completeness. Table 3-2 lists the target compounds of interest for the raw LFG, collected at the raw LFG pipe. Table 3-3 lists the target compounds of interest for the treated gas, at the engine stack.

**Table 3-2. Target Analytes for the Raw Landfill Gas Stream**

| Volatile compounds | Volatile compounds (continued) | Carbonyls |
|---|---|---|
| Methane | Ethylene dibromide | Acetaldehyde |
| Ethane | Ethylene dichloride | Formaldehyde |
| Propane | Methyl chloroform | |
| Butane | Methyl isobutyl ketone | **Mercury** |
| Pentane | Methylene chloride | Organo-mercury compounds |
| Hexane | Propylene dichloride | Total |
| Carbonyl sulfide | t -1,2-Dichloroethene | Elemental |
| Chlorodifluoromethane | Tetrachloroethene | |
| Chloromethane | Toluene | **Gases** |
| Dichlorodifluoromethane | Trichlorethylene | Carbon dioxide |
| Dichlorofluoromethane | Vinyl chloride | Oxygen |
| Ethyl chloride | Vinylidene chloride | |
| Fluorotrichloromethane | Ethanol | |
| 1,3-Butadiene | Methyl ethyl ketone | |
| Acetone | 2-Propanol | |
| Acrylonitrile | 1,4-Dichlorobenzene | |
| Benzene | Ethylbenzene | |
| Bromodichloromethane | Xylenes | |
| Carbon disulfide | | |
| Carbon tetrachloride | | |
| Chlorobenzene | **Non-methane organic compounds** | |
| Chloroform | | |
| Dimethyl sulfide | **Reduced sulfur compounds** | |
| Ethyl mercaptan | Hydrogen sulfide | |

### 3.2.2 Landfill Gas (LFG) Pipe (Inlet)

Sample collection took two days to complete. Table 3-4 lists the samples that were collected from the raw LFG pipe. Figure 3-1 is a photograph of the sampling team in action at this sample location.

**Table 3-3. Target Analytes for the Engine Stack Gas Stream**

| **Gases** | **Dioxins/Furans** |
|---|---|
| Oxygen | **Polycyclic aromatic hydrocarbons** |
| Carbon dioxide | |
| Carbon monoxide | |
| Nitrogen oxide | **Mercury** |
| Sulfur dioxide | Total |
| Total hydrocarbons | |
| **Non-methane organic compounds** | **Metals** |
| | Lead, arsenic, cadmium, chromium, manganese, nickel |
| **Hydrogen chloride** | |

**Figure 3-1. Sampling Operations at the Raw Landfill Gas Pipe Inlet**

**Table 3-4. Raw Landfill Gas Sample Log and Collection Times**

| Sampling Method | Run Number | Analyte(s) | Sample Class | Date | Run Period |
|---|---|---|---|---|---|
| EPA Method 40 (TO-15, 25C, 3C) | | | | | |
| | C-Pre-M40-051204-FB | VOCs/NMOCs/$O_2$/$CO_2$,$N_2$ | Field Blank | 5/12/04 | 13:06 – 14:03 |
| | C-Pre-M40-051304-01 | VOCs/NMOCs/$O_2$/$CO_2$,$N_2$ | Test | 5/13/04 | 09:36 – 10:32 |
| | C-Pre-M40-051304-02 | VOCs/NMOCs/$O_2$/$CO_2$,$N_2$ | Test | 5/13/04 | 12:44 – 13:35 |
| | C-Pre-M40-051304-03 | VOCs/NMOCs/$O_2$/$CO_2$,$N_2$ | Test | 5/13/04 | 15:00 – 15:59 |
| EPA Method 0100 | | | | | |
| | C-Pre-M0100-051304-FB | Carbonyls | Field Blank | 5/13/04 | 13:04 – 13:24 |
| | C-Pre-M0100-051304-01 | Carbonyls | Test | 5/13/04 | 13:22 – 13:54 |
| | C-Pre-M0100-051304-02 | Carbonyls | Test | 5/13/04 | 14:34 – 15:06 |
| | C-Pre-M0100-051304-03 | Carbonyls | Test | 5/13/04 | 15:25 – 15:56 |
| EPA Method 11 | | | | | |
| | C-Pre-M0011-051304-FB | $H_2S$ | Field Blank | 5/13/04 | Not recorded |
| | C-Pre-M011-051304-01 | $H_2S$ | Test | 5/13/04 | 09:50 – 11:01 |
| | C-Pre-M011-051304-02 | $H_2S$ | Test | 5/13/04 | 11:13 – 11:24 |
| | C-Pre-M011-051304-03 | $H_2S$ | Test | 5/13/04 | 11:55 – 12:06 |
| Lumex Instrument | | Hg | | | |
| | C-Pre-EM-051204-01 | Elemental Hg [a] | Test | 5/12/04 | 14:29 |
| | C-Pre-EM-051304-02 | Elemental Hg [a] | Test | 5/13/04 | 11:28 |
| | C-Pre-EM-051304-03 | Elemental Hg [a] | Test | 5/13/04 | 14:56 |
| | C-Pre-EM-051304-04 | Elemental Hg [a] | Test | 5/13/04 | 17:20 |
| Frontier | | | | | |
| | 040513-BR-STM2 Blk | Total gaseous Hg | Field Blank | 5/13/04 | 12:10 |
| | C – 052104 - 01 | Total gaseous Hg | Blind Spike | | Not recorded |
| | 040513-BR-STM1 | Total gaseous Hg | Test | 5/13/04 | 09:40 – 10:49 |
| | 040513-BR-STM3 | Total gaseous Hg | Test | 5/13/04 | 11:43 – 12:45 |
| | 040513-BR-STM4 | Total gaseous Hg | Test | 5/13/04 | 13:13 – 14:08 |
| Frontier | | | | | |
| | 040513-BR-MHg8 | Monomethyl Hg | Field Spike | 5/13/04 | 17:02 – 17:47 |
| | 040513-BR-MHg7 | Monomethyl Hg | Blind Spike | 5/13/04 | 15:32 |

| Sampling Method | Run Number | Analyte(s) | Sample Class | Date | Run Period |
|---|---|---|---|---|---|
| | 040513-BR-MHg2 | Monomethyl Hg | Field Blank | 5/13/04 | 11:10 |
| | 040513-BR-MHg1 | Monomethyl Hg | Test | 5/13/04 | 09:42 – 10:38 |
| | 040513-BR-MHg3 | Monomethyl Hg | Test | 5/13/04 | 11:46 – 12:40 |
| | 040513-BR-MHg4 | Monomethyl Hg | Test | 5/13/04 | 13:14 – 14:09 |
| | 040513-BR-MHg5 | Monomethyl Hg | Test | 5/13/04 | 14:59 – 15:52 |
| Frontier | | | | | |
| | ARCADIS DMM Spike #1 | Dimethyl Hg | Blind Spike | 5/13/04 | Not recorded |
| | ARCADIS DMM Spike #2 | Dimethyl Hg | Blind Spike | 5/13/04 | Not recorded |
| | 040513-BR-DMHg4 | Dimethyl Hg | Field Blank | 5/13/04 | 16:30 |
| | 040513-BR-DMHg5 | Dimethyl Hg | Trip Spike | 5/13/04 | 17:38 – 17:40 |
| | 040513-BR-DMHg6 | Dimethyl Hg | Trip Spike | 5/13/04 | Not recorded |
| | 040513-BR-DMHg1 | Dimethyl Hg | Test | 5/13/04 | 13:41 – 13:43 |
| | 040513-BR-DMHg2 | Dimethyl Hg | Test | 5/13/04 | 14:37 – 14:45 |
| | 040513-BR-DMHg3 | Dimethyl Hg | Test | 5/13/04 | 15:15 – 15:18 |

[a] Represents average of 3 readings, each 30-seconds in duration

### 3.2.3 Engine Stack

Sampling at the engine stack was conducted by accessing the sampling ports with the aid of a scaffold. Figure 3-2 shows the engine and the sampling scaffold platform.

The engine stack was sampled for NMOCs (as THCs), PCDD/PCDFs, PAHs, HCl, metals (lead [Pb], arsenic [As], cadmium [Cd], chromium [Cr], manganese [Mn], nickel [Ni]), total Hg, $SO_2$, $NO_X$, CO, carbon dioxide ($CO_2$), and ($O_2$). Table 3-5 lists the test samples that were collected from the engine stack.

The engine stack cross-section was divided into 6 equal areas for sample collection according to EPA Method 1. Sampling at the engine stack was conducted at isokinetic conditions except for the Method 26A samples which were extracted proportionally. Sample collection times for the Method 29 metals train were 60-minutes. Run time for the Method 23 PCDD/PCDFs trains was 180 minutes. Run time for the Method 26A HCl trains and the continuous emissions monitoring system (CEMS) parameters ($SO_2$, $NO_X$, CO, $O_2$, $CO_2$, and THCs) varied.

**Figure 3-2. Engine #1 Stack and Sampling Scaffold**

**Table 3-5. Engine Stack Test Sample Log and Collection Times**

| Sampling Method | Run Number | Analyte(s) | Sample Class | Date | Run Period |
|---|---|---|---|---|---|
| EPA Method 3A (CEM) | | | | | |
| | C-Post-M3A-051304-01 | $O_2$ | Test | 5/13/04 | 12:38 – 13:37 |
| | C-Post-M3A-051304-01 | $O_2$ | Test | 5/13/04 | 16:13 – 17:12 |
| | C-Post-M3A-051304-01 | $O_2$ | Test | 5/13/04 | 17:57 – 18:56 |
| | C-Post-M3A-051404-01 | $O_2$ | Test | 5/14/04 | 10:28 – 11:27 |
| | C-Post-M3A-051404-01 | $O_2$ | Test | 5/14/04 | 17:32 – 18:32 |
| EPA Method 3A (CEM) | | | | | |
| | C-Post-M3A-051304-01 | $CO_2$ | Test | 5/13/04 | 12:38 – 13:37 |
| | C-Post-M3A-051304-01 | $CO_2$ | Test | 5/13/04 | 16:13 – 17:12 |
| | C-Post-M3A-051304-01 | $CO_2$ | Test | 5/13/04 | 17:57 – 18:56 |
| | C-Post-M3A-051404-01 | $CO_2$ | Test | 5/14/04 | 10:28 – 11:27 |
| | C-Post-M3A-051404-01 | $CO_2$ | Test | 5/14/04 | 17:32 – 18:32 |
| EPA Method 10 (CEM) | | | | | |
| | C-Post-M10-051304-01 | CO | Test | 5/13/04 | 12:38 – 13:37 |
| | C-Post-M10-051304-01 | CO | Test | 5/13/04 | 16:13 – 17:12 |
| | C-Post-M10-051304-01 | CO | Test | 5/13/04 | 17:57 – 18:56 |
| | C-Post-M10-051404-01 | CO | Test | 5/14/04 | 10:28 – 11:27 |
| | C-Post-M10-051404-01 | CO | Test | 5/14/04 | 17:32 – 18:32 |
| EPA Method 7E (CEM) | | | | | |
| | C-Post-M7E-051304-01 | $NO_X$ | Test | 5/13/04 | 12:38 – 13:37 |
| | C-Post-M7E-051304-01 | $NO_X$ | Test | 5/13/04 | 16:13 – 17:12 |
| | C-Post-M7E-051304-01 | $NO_X$ | Test | 5/13/04 | 17:57 – 18:56 |
| | C-Post-M7E-051404-01 | $NO_X$ | Test | 5/14/04 | 10:28 – 11:27 |
| | C-Post-M7E-051404-01 | $NO_X$ | Test | 5/14/04 | 17:32 – 18:32 |
| EPA Method 6C (CEM) | | | | | |
| | C-Post-M6C-051304-01 | $SO_2$ | Test | 5/13/04 | 12:38 – 13:37 |
| | C-Post-M6C-051304-01 | $SO_2$ | Test | 5/13/04 | 16:13 – 17:12 |
| | C-Post-M6C-051304-01 | $SO_2$ | Test | 5/13/04 | 17:57 – 18:56 |
| | C-Post-M6C-051404-01 | $SO_2$ | Test | 5/14/04 | 10:28 – 11:27 |

| Sampling Method | Run Number | Analyte(s) | Sample Class | Date | Run Period |
|---|---|---|---|---|---|
| | C-Post-M6C-051404-01 | $SO_2$ | Test | 5/14/04 | 17:32 – 18:32 |
| EPA Method 25A (CEM) | | | | | |
| | C-Post-M25A-051304-01 | NMOCs (THC) | Test | 5/13/04 | 12:38 – 13:37 |
| | C-Post-M25A-051304-01 | NMOCs (THC) | Test | 5/13/04 | 16:13 – 17:12 |
| | C-Post-M25A-051304-01 | NMOCs (THC) | Test | 5/13/04 | 17:57 – 18:56 |
| | C-Post-M25A-051404-01 | NMOCs (THC) | Test | 5/14/04 | 10:28 – 11:27 |
| | C-Post-M25A-051404-01 | NMOCs (THC) | Test | 5/14/04 | 17:32 – 18:32 |
| Lumex Instrument | | | | | |
| | C-Post-EM-051304-01 | Elemental Hg [a] | Test | 5/13/04 | 11:13 |
| | C-Post-EM-051304-02 | Elemental Hg [a] | Test | 5/13/04 | 14:38 |
| | C-Post-EM-051304-03 | Elemental Hg [a] | Test | 5/13/04 | 17:40 |
| EPA Method 26A | | | | | |
| | C-Post-M26-051404-FB | HCl | Field Blank | | Not recorded |
| | C-Post-M26-051404-01 | HCl | Test | 5/14/04 | 15:41 – 16:13 |
| | C-Post-M26-051404-02 | HCl | Test | 5/14/04 | 17:11 – 18:01 |
| | C-Post-M26-051404-03 | HCl | Test | 5/14/04 | 18:26 – 19:06 |
| EPA Method 23 | | | | | |
| | C-Post-M23-051304-FB | PCDD/PCDFs, PAHs | Field Blank | 5/13/04 | 16:30 |
| | C-Post-M23-051304-01 | PCDD/PCDFs, PAHs | Test | 5/13/04 | 12:09 – 15:19 |
| | C-Post-M23-051304-02 | PCDD/PCDFs, PAHs | Test | 5/13/04 | 15:54 – 19:15 |
| | C-Post-M23-051404-03 | PCDD/PCDFs, PAHs | Test | 5/14/04 | 15:27 – 18:52 |
| EPA Method 29 | | | | | |
| | C-Post-M29-051404-FB | Metals | Field Blank | 5/14/04 | Not recorded |
| | C-Post-M29-051404-01 | Metals | Test | 5/14/04 | 09:25 – 10:35 |
| | C-Post-M29-051404-02 | Metals | Test | 5/14/04 | 11:07 – 12:27 |
| | C-Post-M29-051404-03 | Metals | Test | 5/14/04 | 12:29 – 13:39 |

[a] Represents 3 readings, each 30-seconds in duration

### 3.3 Field Test Changes and Deviations from Quality Assurance Project Plan (QAPP) Specifications

#### 3.3.1 Variation from Test Methods or Planned Activities

##### *3.3.1.1 Sampling at the Raw Landfill Gas (LFG) Pipe*

There were not variations from test methods or planned activities on the raw LFG pipe.

##### *3.3.1.2 Landfill Gas (LFG) Inlet Pipe Condensate Sample*

A raw LFG pipe condensation sample was not specified in the plan and was not collected.

##### *3.3.1.3 Landfill Gas (LFG) Flow Rate Measurement*

Gas flow as indicated by the LFG flow control station was recorded. The accuracy of the flow rate measurement could not be independently verified because of the inability to measure gas velocity accurately. Access to the raw LFG pipe was via ¼” ports, which were too small for method-specified velocity probes. The test team was able to make crude velocity measurements by inserting velocity probes part-way into the gas pipe. The accuracies of these measurements were uncertain, but they appeared to be similar to the facility’s flow rate readings.

##### *3.3.1.4 Engine #1 Stack*

Unforeseen conditions necessitated two deviations from the QAPP-specified sampling procedures.

One testing day was lost because of local electrical utility failure and engine problems. In order to complete the tests within the remaining time and available funds, the HCl test method was changed from EPA Method 26A, an isokinetic traversing procedure, to EPA Method 26, a single-point proportional procedure. This change allowed HCl sampling to be done simultaneously with the EPA Method 29 metals sampling train because inter-train probe interference was avoided. Since isokinetic sampling is only required for sampling particulate-laden gases, the absence of particulate matter in the engine exhaust is believed to be an acceptable alternative non-ioskinetic sampling method and would not result in sampling errors.

Secondly, because of error in received information on the engine stack diameter (10-inch actual instead of 12-inch reported previously), substituting EPA Method 1A for EPA Method 1 for sampling traverse point determination was necessary. Consequently, EPA Method 2C was substituted for EPA Method 2 for determination of engine stack velocity. A second set of sampling ports was installed to accommodate this change.

### 3.3.2 Application of Test Methods

Except for the deviations outlined above and immediately following, the sampling and analytical methods used in this test program followed those specified in the QAPP. Sampling methods are shown in Table 3-6.

**Table 3-6. Sampling Methods**

| Procedure | Description | Organization Performing Analysis |
|---|---|---|
| EPA Method 1A | Selection of engine stack traverse points | ARCADIS G&M |
| EPA Method 2C | Determination of engine stack gas velocity and volumetric flow rate | ARCADIS G&M |
| EPA Method 3A | Determination of engine stack oxygen ($O_2$) and carbon dioxide ($CO_2$) for gas molecular weight calculations | ARCADIS G&M |
| EPA Method 3C | Determination of raw LFG carbon dioxide ($CO_2$), methane ($CH_4$), nitrogen ($N_2$), and oxygen ($O_2$) in raw LFG | Triangle Environmental Services |
| EPA Method 4 | Determination of engine stack gas moisture | ARCADIS G&M |
| EPA Method 6C | Determination of engine stack sulfur dioxide ($SO_2$) | ARCADIS G&M |
| EPA Method 7E | Determination of engine stack nitrogen oxides ($NO_X$) | ARCADIS G&M |
| EPA Method 10 | Determination of engine stack carbon monoxide (CO) | ARCADIS G&M |
| EPA Method 11 | Determination of raw LFG hydrogen sulfide ($H_2S$) | Oxford Laboratories |
| EPA Method 23 | Determination of engine stack:<br>PCDD/PCDFs by Method 8290<br>Polycyclic aromatic hydrocarbons (PAHs) by Method 8270 | ALTA Analytical Perspectives |
| EPA Method 25A | Determination of engine stack gas non-methane organic carbons (NMOCs) (as THCs) when total organic concentration is less than the 50 ppm Method 25C applicability threshold | ARCADIS G&M |

| Procedure | Description | Organization Performing Analysis |
|---|---|---|
| EPA Method 25C | Determination of raw LFG NMOCs | Triangle Environmental Services |
| EPA Method 26 | Determination of engine stack hydrogen chloride (HCl) | Resolution Analytics |
| EPA Method 29 | Determination of engine stack metals | First Analytical Laboratories |
| EPA Method 40/TO-15 | Determination of raw LFG volatile organic carbons (VOCs) | Research Triangle Park Laboratories |
| SW-846 Method 0100/TO-11 | Determination of raw LFG carbonyls (formaldehyde, acetaldehyde) | Resolution Analytics |
| LUMEX instrument | Determination of raw LFG and engine stack elemental mercury ($Hg^0$) | ARCADIS G&M |
| Organic mercury methods | Determination of raw LFG:<br>Monomethyl mercury<br>Dimethyl mercury<br>Total mercury | Frontier Geosciences |

### 3.3.3 Test Method Exceptions

Laboratory analytical procedures followed those prescribed by the specified methods, with the following engine stack exceptions:

- Non-methane organic compounds (NMOCs) - Method 25A was used instead of the specifically applicable Method 25C.

- Polycyclic aromatic hydrocarbons (PAH) were analyzed by CARB Method 429 as opposed to Method 8270. However, these methods are comparable. CARB Method 429 contains procedures for sampling, sample recovery, clean-up, and analysis. Method 8270 is strictly an analytical method. CARB Method 429 is specific to 19 PAHs, the target analytes of this portion of the specified tests The 19 PAHs are a subset of the 200+ target analytes listed for Method 8270 for semi-volatile organic compounds (SVOCs). Though specific compounds called out for use in instrument performance verifications, internal standard preparation, surrogate standards, and continuing calibration verifications/calibration checks are slightly different, both methods require them. CARB Method 429 adds another level of quality control (QC) with a required recovery standard. Method performance and acceptance criteria for recoveries are better defined in CARB Method 429 and meet or exceed those stated in Method 8270C. As long as any additional compounds reported by the laboratory using CARB Method 429 are included in the calibration standards and acceptable response factors (RFs) are demonstrated, using CARB Method 429 is essentially equivalent to using SW-846 Method 8270.

# 4. Presentation of Test Results

Testing took place at Landfill C on May 13-14, 2004. Results of the testing are presented in this section. Detailed test results are included in the Appendices. The following subsections provide concise summaries of the test results.

## 4.1 Raw Landfill Gas (LFG) Results

As depicted in Figure 2-2, sampling was conducted by extracting samples via the four ¼-inch ports installed in the raw LFG pipe.

### 4.1.1 Raw Landfill Gas (LFG) Flow Rate and Temperature

#### *4.1.1.1 Direct Measurements*

The facility process system had a flow measurement system, which displayed the flow rate on an instrument panel meter. The panel meter displayed the gas flow rate to both engines only and was taken after gas drying. With both engines running, the meter read between 547 and 598 scfm during the tests, averaging at 574 scfm. During several periods when Engine # 2 was down and only Engine #1 was running, the panel meter indicated gas flow rate averaging at 299.5 scfm, within 2 percent deviation.

The small size of the sampling ports precluded full method-compliant measurement of the velocity profile all the way across the inlet gas pipe. Nonetheless, measurements with a velocity probe returned readings ranging from 634 ft/min to 824 ft/min (wet). At these velocities and with pipe inside diameter of 14 inches, the volumetric flow rate was estimated to be about 700 scfm. Vacuum at the raw LFG inlet gas stream was at approximately 21 inch water column.

A direct measurement with thermocouples showed the raw LFG temperature to be 56°F.

#### *4.1.1.2 Raw Landfill Gas (LFG) Flow Rate Combined Estimate*

Based on the two independent sources of the flow rate estimates, 574 scfm by the facility’s flow rate indicator and 700 scfm by the crude pitot probe measurement, an average value would be 637 scfm. Clearly, the value is only an estimate. Hence, any mass emission rates calculated based on this raw LFG flow rate will also, by necessity, have to be recognized as estimates.

### 4.1.2 Raw Landfill Gas (LFG) Constituents

The concentrations of the constituents of interest in the raw LFG are presented in the Subsections 4.1.2.1 through 4.1.2.5. Following the presentation of the constituent concentrations, Section 4.3 summarizes the data and presents a comparison with the AP-42 values. The section also presents the estimated mass flow rates of the constituents at the raw LFG pipe.

#### *4.1.2.1 Volatile Organic Compounds (VOCs)*

Concentrations of VOCs were obtained collecting summa canister samples using Method 40 procedures. Analysis was performed by Method TO-15, with gas chromatography and mass spectrometry (GC/MS). The alkanes (C2 through C6), being present in much higher concentrations, were analyzed by GC flame ionization detection (FID) on the same summa canister samples.

Table 4-1 lists the results of these analyses. Tentatively identified compounds (TICs) can be seen in the Research Triangle Park (RTP) Laboratory reports in Appendix A.

**Table 4-1. Raw Landfill Gas VOC Concentrations**

| Compound | Unit | MDL | Concentration | | | |
|---|---|---|---|---|---|---|
| | | | Run 1 | Run 2 | Run 3 | Average [a] |
| **By GC/FID** | | | | | | |
| Ethane | ppmv | 1 | 15.5 | 12.2 | 15.3 | 14.3 |
| Propane | ppmv | 1 | 39.6 | 39.5 | 40.8 | 40.0 |
| Butane | ppmv | 1 | 23.9 | 27.9 | 61.9 | 37.9 |
| Pentane | ppmv | 1 | 26.4 | 23.4 | 29.9 | 26.6 |
| Hexane | ppmv | 1 | 28.4 | 26.7 | 30.0 | 28.4 |
| | | | | | | |
| **By TO-15 GC/MS** | | | | | | |
| Dichlorodifluoromethane (Freon 12) | ppbv | 0.3 | 2270 | 1820 | 720 | 1600 |
| 1,2-Chloro-,1,2,2-Tetrafluoroethane (CFC114) | ppbv | 0.2 | 166 | 149 | 66 | 127 |
| Chloromethane | ppbv | 0.1 | 3790 | ND | ND | 1263 |
| Vinyl chloride | ppbv | 0.2 | 6 | 1620 | 679 | 768 |
| 1,3-Butadiene ((Vinylethylene) | ppbv | 0.3 | 891 | 709 | 325 | 642 |
| Bromomethane (Methyl Bromide) | ppbv | 0.2 | 6 | 57 | 7 | 23 |

| Compound | Unit | MDL | Concentration | | | |
|---|---|---|---|---|---|---|
| | | | Run 1 | Run 2 | Run 3 | Average [a] |
| Chloroethane (Ethyl Chloride) | ppbv | 0.2 | 50000 | 39200 | 2000 | 30400 |
| Trichloromonofluoromethane (CFC11) | ppbv | 0.2 | 721 | 572 | 218 | 504 |
| 1,1-Dichloroethene | ppbv | 0.2 | 79 | 62 | 25 | 55 |
| 1,1,2-Trichloro-1,2,2-trifluoroethane (CFC113) | ppbv | 0.2 | 53 | 44 | 21 | 39 |
| Carbon Disulfide | ppbv | 0.3 | 197 | 180 | 93 | 157 |
| Ethanol | ppbv | 0.2 | 225 | 222 | 68 | 172 |
| Isopropyl Alcohol (2-Propanol) [c] | ppbv | 0.2 | 2060 | 1530 | 250 | 1280 |
| Methylene chloride (Dichloromethane) [c] | ppbv | 0.1 | 8010 | 6750 | 1280 | 5350 |
| Acetone [c] | ppbv | 0.3 | 17700 | 14100 | 3300 | 11700 |
| t-1,2-dichloroethene | ppbv | 0.3 | 57 | 46 | 22 | 42 |
| Hexane | ppbv | 0.3 | 6180 | 5480 | 3150 | 4940 |
| Methyl-t-butyl ether (MTBE) | ppbv | 0.3 | 405 | 337 | 28 | 257 |
| 1,1-Dichloroethane | ppbv | 0.4 | ND | 660 | 608 | 423 |
| Vinyl Acetate | ppbv | 0.5 | 38 | 3 | 30 | 24 |
| cis-1,2-Dichloroethene | ppbv | 0.3 | 2240 | 1780 | 900 | 1640 |
| Cyclohexane | ppbv | 0.3 | 4560 | 3700 | 1650 | 3300 |
| Chloroform | ppbv | 0.3 | 1000 | 825 | 403 | 744 |
| Ethyl Acetate | ppbv | 0.3 | 1970 | ND | 2290 | 1420 |
| Carbon Tetrachloride | ppbv | 0.5 | ND | ND | ND | ND |
| Tetrahydrofuran (Diethylene Oxide) [c] | ppbv | 0.4 | 1140 | 545 | 1830 | 1170 |
| 1,1,1-Trichloroethane | ppbv | 0.3 | ND | ND | ND | ND |
| 2-Butanone (Methyl Ethyl Ketone) [c] | ppbv | 0.3 | 7150 | 6550 | ND | 4570 |
| Heptane [c] | ppbv | 0.2 | 3510 | 3240 | 1820 | 2860 |
| Benzene | ppbv | 0.2 | 2140 | 1790 | 950 | 1630 |
| 1,2-Dichloroethane | ppbv | 0.3 | 62 | 49 | ND | 37 |
| Trichloroethylene (Trichloroethene) | ppbv | 0.2 | 841 | 674 | 31 | 515 |
| 1,2-Dichloropropane | ppbv | 0.3 | ND | ND | ND | ND |
| Bromodichloromethane | ppbv | 0.2 | ND | ND | ND | ND |
| 1,4-Dioxane (1,4-Diethylene Dioxide) | ppbv | 0.2 | 3 | 7 | 10 | 7 |
| cis-1,3-Dichloropropene | ppbv | 0.2 | ND | ND | ND | ND |
| Toluene (Methyl Benzene) [c] | ppbv | 0.3 | 27400 | 24700 | 18000 | 23300 |
| 4-Methyl-2-pentanone (MIBK) [c] | ppbv | 0.2 | 3280 | 2850 | 390 | 2170 |
| t-1,3-Dichloropropene | ppbv | 0.2 | 40 | 35 | 23 | 33 |

| Compound | Unit | MDL | Concentration | | | |
|---|---|---|---|---|---|---|
| | | | Run 1 | Run 2 | Run 3 | Average [a] |
| Tetrachloroethylene (Perchloroethylene) [c] | ppbv | 0.3 | 2310 | 1900 | 860 | 1690 |
| 1,1,2-Trichloroethane [c] | ppbv | 0.2 | 675 | 660 | ND | 445 |
| Dibromochloromethane | ppbv | 0.2 | 13 | 11 | 2 | 9 |
| 1,2-Dibromoethane (Ethylene dibromide) | ppbv | 0.2 | 33 | 29 | ND | 21 |
| 2-Hexanone (Methyl Butyl Ketone) | ppbv | 0.2 | ND | ND | ND | ND |
| Ethylbenzene [c] | ppbv | 0.3 | 7450 | 6600 | 3630 | 5890 |
| Chlorobenzene | ppbv | 0.2 | ND | ND | 2500 | 833 |
| m/p-Xylene (Dimethyl Benzene) [c] | ppbv | 0.65 | 12100 | 11000 | 4500 | 9200 |
| o-Xylene (Dimethyl Benzene) [c] | ppbv | 0.3 | 4760 | 4020 | 2210 | 3660 |
| Styrene (Vinylbenzene) | ppbv | 0.1 | 1560 | 1490 | 750 | 1270 |
| Tribromomethane (Bromoform) | ppbv | 0.3 | 22 | 25 | ND | 16 |
| 1,1,2,2-Tetrachloroethane | ppbv | 0.2 | ND | ND | ND | ND |
| 1-Ethyl-4-methylbenzene (4-Ethyl Toluene) [b] | ppbv | 0.2 | 791 | 804 | 1090 | 894 |
| 1,3,5-Trimethylbenzene [b] | ppbv | 0.2 | 791 | 804 | 1090 | 894 |
| 1,2,4-Trimethylbenzene [c] | ppbv | 0.3 | 1750 | 1800 | 970 | 1510 |
| 1,4-Dichlorobenzene | ppbv | 0.3 | 363 | 401 | 221 | 328 |
| 1,3-Dichlorobenzene | ppbv | 0.2 | 341 | 356 | 185 | 294 |
| Benzyl Chloride | ppbv | 0.2 | ND | ND | ND | ND |
| 1,2-Dichlorobenzene | ppbv | 0.3 | ND | ND | ND | ND |
| 1,1,2,3,4,4-Hexachloro-1,3-butadiene | ppbv | 0.2 | ND | ND | ND | ND |
| 1,2,4-Trichlorobenzene | ppbv | 0.3 | ND | ND | ND | ND |
| Acrylonitrile | ppbv | 20 | ND | ND | ND | ND |
| Chlorodiflouromethane (Freon 22) | ppbv | 20 | ND | ND | ND | ND |

ND - Constituent not detected at the stated detection limits

[a] In computing averages, when all measurements are ND, the average is reported as ND. When one or more measurement is above detection, the ND measurement is treated as 50 percent of the stated MDL. If MDL is not reported, a ND measurement is treated as zero.

[b] 1-Ethyl-4-methylbenzene (4-Ethyl Toluene) and 1,3,5-Trimethylbenzene co-eluted from the GC and also have the same quantitation ions, thus making them indistinguishable. Therefore, the reported values represent the combined concentrations of these two compounds.

[c] Analyte detected in blank sampled 0.21 to 3.03 ppbv. See table 5-3 for analyte-specific detected levels.

#### *4.1.2.2 Non-methane Organic Compounds (NMOCs)*

Non-methane organic compounds (NMOCs) in the raw LFG were analyzed by Method 25C on the samples collected by Method 40. The NMOC concentrations in the raw LFG are presented in Table 4-2. The table also includes concentrations of methane ($CH_4$), $CO_2$, and $O_2$, which are results obtained as part of the NMOC analyses.

The other analytes, oxygen ($O_2$), carbon dioxide ($CO_2$), and moisture, are not pollutants but are of interest as they are useful indicators of the "quality" of the raw LFG. The concentrations of nitrogen ($N_2$) and $O_2$ are also indicators of the extent of ambient air infiltration into the LFG collection. Method 25C for NMOC determination specifically recommends that these measurements be made to determine potential air infiltration. Therefore, while measurements for methane ($CH_4$), $CO_2$, $O_2$, and $N_2$ by Method 3C were not included in the original QAPP, these measurements were included and performed.

There is good agreement between $CH_4$ and $CO_2$ values obtained from Method 25C and Method 3C.

**Table 4-2. Raw Landfill Gas Non-Methane Organic Compound (NMOC) Concentrations**

| | NMOC (ppmv as Hexane) | $CH_4$ (% v/v) | | $CO_2$ (% v/v) | | $O_2$ (%v/v) | $N_2$ (% v/v) | Moisture (% v/v) |
|---|---|---|---|---|---|---|---|---|
| | Method 25C | Method 25C | Method 3C | Method 25C | Method 3C | Method 3C | Method 3C | Method 23 |
| Run 1 | 3650 | 57.7 | 49.1 | 47.2 | 36.9 | 1.4 | 13.5 | NM |
| Run 2 | 4630 | 54.6 | 47.4 | 45.2 | 35.4 | 1.5 | 15.3 | NM |
| Run 3 | 9330 | 55.7 | 47.5 | 46.2 | 35.5 | 1.9 | 18.9 | NM |
| **Average** | **5870** | **56.0** | **48.0** | **46.2** | **35.9** | **1.6** | **15.9** | **NM** |

Concentrations are reported without correction for nitrogen

NM – not measured because Method 23 sampling train was not run. Data column is included to retain format consistency with reports for Landfills A and B.

#### *4.1.2.3 Hydrogen Sulfide ($H_2S$)*

Raw LFG pipe $H_2S$ concentrations were obtained by collecting and analyzing the samples in accordance with EPA Method 11. These results are presented in Table 4-3.

**Table 4-3. Raw Landfill Gas Hydrogen Sulfide ($H_2S$) Concentrations**

| | $H_2S$ Concentration | |
|---|---|---|
| | ($mg/m^3$) | (ppmv) |
| Run 1 | 98.0 | 69.4 |
| Run 2 | 26.8 | 19.0 |
| Run 3 | 110.0 | 78.0 |
| **Average** | **78.3** | **55.5** |

Sample hold times exceeded specified 30 days by 3 days

*4.1.2.4 Carbonyls*

The target carbonyl compounds, formaldehyde and acetaldehyde, were analyzed by SW-846 Method 8315 on samples collected by EPA Method 0100. The analysis results are presented in Table 4-4.

**Table 4-4. Raw Landfill Gas Carbonyls Concentrations**

| | Formaldehyde | | Acetaldehyde | |
|---|---|---|---|---|
| | ($\mu g/m^3$) | ($x10^{-3}$ppmv) | ($\mu g/m^3$) | ($x10^{-3}$ppmv) |
| MDL | 8.0 | 6.4 | 8.3 | 4.5 |
| Run 1 | 28.3 | 22.7 | 118 | 64.3 |
| Run 2 | 26.9 | 21.5 | 114 | 62.4 |
| Run 3 | 46.6 | 37.3 | 495 | 270 |
| **Average** | **33.9** | **27.2** | **242** | **132** |

*4.1.2.5 Mercury (Hg)*

Mercury (Hg) can exist in several forms. This test program focused on the elemental, monomethyl, and dimethyl forms of Hg, and total Hg. Elemental Hg was measured with the LUMEX instrument. Organic monomethyl Hg, dimethyl Hg, and total Hg were sampled and analyzed using the organic mercury method.

4.1.2.5.1 Total Mercury (Hg) Samples

To collect the total Hg samples, an iodated charcoal trap was used as a sorbent. A backup tube was also 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. A silica gel impinger was used to collect and quantify the water vapor from the stream. A diaphragm air pump was used to pull a sample through the train and collect the sample. A dry gas meter capable of measuring the volume in 10 ml increments was used to monitor and quantify the volume of gas sampled.

Table 4-5 presents the total Hg concentrations in the raw LFG. They ranged from 423 to 427 ng/m$^3$ with an average of 425 ng/m$^3$.

**Table 4-5. Raw Landfill Gas Total Mercury Concentrations**

| | Total Mercury Concentration | |
|---|---|---|
| | **(ng/m$^3$)** | **(x10$^{-6}$ ppm)** |
| MDL | 50 | 6.0 |
| Run 1 | 425 | 51.2 |
| Run 2 | 427 | 51.4 |
| Run 3 | 423 | 50.9 |
| **Average** | **425** | **51.2** |

Sample hold time was 15 days, exceeding the 14-day specification

#### 4.1.2.5.2 Dimethyl Mercury (Hg) Samples

To collect the dimethyl Hg sample, a Carbotrap was used as a sorbent. A backup tube was also present to assess any breakthrough. A third iodated carbon trap was also present to collect any elemental Hg present. The sorbent tube was heated to above the dew point of the gas stream to prevent condensation on the sorbent. A silica gel impinger was used to collect and quantify the water vapor from the stream. A diaphragm air pump was used to pull sample through the train and collect the sample. A dry gas meter capable of measuring the volume in 10 ml increments was used to monitor and quantify the volume of gas sampled.

Table 4-6 presents the dimethyl Hg concentrations in the raw LFG. The analyzed concentrations ranged from 6.5 to 20.9 ng/m$^3$ with an average of 14.8 ng/m$^3$.

**Table 4-6. Raw Landfill Gas Dimethyl Mercury Concentrations**

| | Dimethyl Mercury Concentration | |
|---|---|---|
| | **($ng/m^3$)** | **($x10^{-6}$ ppmv)** |
| MDL | 0.5 | 0.05 |
| Run 1 | 20.9 | 2.2 |
| Run 2 | 6.5 | 0.7 |
| Run 3 | 17.1 | 1.8 |
| **Average** | **14.8** | **1.5** |

#### 4.1.2.5.3 Monomethyl Mercury (Hg) Samples

To collect the sample, a set of three impingers filled with 0.001 M HCl was used to collect the monomethyl Hg. An empty forth impinger was used to knockout 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. A dry gas meter capable of measuring the volume in 10 ml increments was used to monitor and quantify the volume of gas sampled.

As shown in Table 4-7, monomethyl Hg concentrations in the raw LFG ranged from 3.1 to 5.4 $ng/m^3$.

**Table 4-7. Raw Landfill Gas Monomethyl Mercury Concentrations**

| | Monomethyl Mercury Concentration | |
|---|---|---|
| | **($ng/m^3$)** | **($x10^{-6}$ ppmv)** |
| MDL | 0.13 | 0.014 |
| Run 1 | 5.4 | 0.60 |
| Run 2 | 3.1 | 0.35 |
| Run 3 | 3.3 | 0.37 |
| Average | **3.9** | **0.44** |

Sample hold time was 15 days, exceeding the 14-day specification

#### 4.1.2.5.4 Elemental Mercury (Hg)

Elemental Hg was determined by the LUMEX instrument and the results are presented in Table 4-8. The analyzed concentrations ranged from 90 to 103 $ng/m^3$.

### 4.2 Engine Stack Results

The engine stack was sampled for NMOCs (as THCs), PCDD/PCDFs, PAHs, HCl, Pb, As, Cd, Cr, Mn, Ni, total Hg, $SO_2$, $NO_X$, CO, $CO_2$, and $O_2$. The stack cross section was divided into 12 equal areas according to EPA Method 1A. Sampling run time for metals was 60 minutes. Run time for HCl varied between 40 and 50 minutes. Run time for PCDD/PCDFs sampling was 180 minutes. Run time for CEMS parameters ($SO_2$, $NO_X$, CO, $O_2$, $CO_2$, and THCs) varied.

**Table 4-8. Raw Landfill Gas Elemental Mercury Concentrations**

| | Concentration [a] | | | |
|---|---|---|---|---|
| | Background | | Raw Landfill Gas | |
| | ($ng/m^3$) | ($x10^{-6}$ ppmv) | ($ng/m^3$) | ($x10^{-6}$ ppmv) |
| Run 1 | NM | NM | 101 | 12.2 |
| Run 2 | 2 | 0.2 | 103 | 12.4 |
| Run 3 | 20 | 2.4 | 103 | 12.4 |
| Run 4 | 3 | 0.4 | 90 | 10.8 |
| **Average** | **8** | **1.0** | **99** | **11.9** |

NM – Not measured

[a] Average of three repetitions

#### 4.2.1 Engine Stack Gas Flow Rate and Temperature

Sampling at the engine stack was conducted at isokinetic conditions with the exception of EPA Method 26 (HCl), which was conducted at proportional extraction rates. The procedures provided stack gas velocity distribution across the engine stack and reliable measurements of stack gas flow rates. Table 4-9 lists the volumetric flow rates and temperatures at the engine stack measured during the various sampling runs.

**Table 4-9. Engine Stack Gas Operating Conditions Measured during Sampling**

| Run Number | Date | Time | Average Stack Temp (°F) | Carbon Dioxide (%) | Oxygen (%) | Moisture (%) | Velocity (actual ft/sec) | Volumetric Flow Rate (acfm) | Volumetric Flow Rate (dscfm) |
|---|---|---|---|---|---|---|---|---|---|
| C-Post-M29-051404-01 | 05/14/04 | 09:25 – 10:35 | 1015 | 16.5 | 2.3 | 17.5 | 195 | 6390 | 1920 |
| C-Post-M29-051404-02 | 05/14/04 | 11:07 – 12:27 | 1028 | 16.5 | 2.3 | 17.5 | 200 | 6530 | 1950 |
| C-Post-M29-051404-03 | 05/14/04 | 12:29 – 13:39 | 1038 | 16.5 | 2.3 | 18.0 | 195 | 6390 | 1890 |
| | | | | | | | | | |
| C-Post-M23-051304-01 | 05/13/04 | 12:09 – 15:19 | 1005 | 15.6 | 3.2 | 16.2 | 200 | 6550 | 2000 |
| C-Post-M23-051304-02 | 05/13/04 | 15:54 – 19:15 | 1009 | 16.1 | 3.0 | 16.7 | 191 | 6260 | 1920 |
| C-Post-M23-051404-03 | 05/14/04 | 15:27 – 18:52 | 997 | 16.4 | 2.9 | 16.2 | 200 | 6460 | 2000 |
| | | | | | | | | | |
| **Average** | | | **1016** | **16.3** | **2.7** | **17.0** | **197** | **6430** | **1950** |

Engine stack cross-section flow area is 0.55 sq. ft.

### 4.2.2 Engine Stack Gas Constituents

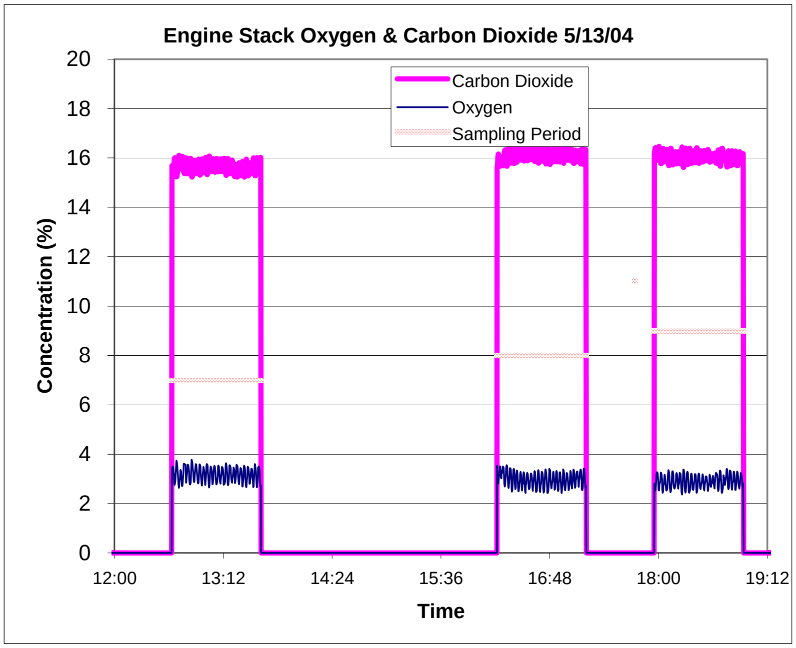
The concentrations of the constituents of interest in the engine stack are presented in the following Subsections 4.2.2.1 through 4.2.2.7.

#### *4.2.2.1 Engine Stack Oxygen ($O_2$) and Carbon Dioxide ($CO_2$)*

Oxygen ($O_2$) and $CO_2$ concentrations provide an overall indication of the combustion process. Figure 4-1 shows the $O_2$ and $CO_2$ concentrations measured by the CEMs during the two days of testing. The plotted data excluded the CEM responses during instrument zeroing and calibration periods. Table 4-10 presents the daily averages of $O_2$ and $CO_2$ concentrations.

**Table 4-10. Engine Stack Combustion Product Concentrations**

| | **$O_2$ (% v)** | **$CO_2$ (% v)** |
|---|---|---|
| Run 1 | 2.3 | 16.5 |
| Run 2 | 2.3 | 16.5 |
| Run 3 | 2.3 | 16.5 |
| Run 4 | 3.2 | 15.6 |
| Run 5 | 3.0 | 16.1 |
| Run 6 | 2.9 | 16.4 |
| **Average** | **2.7** | **16.3** |



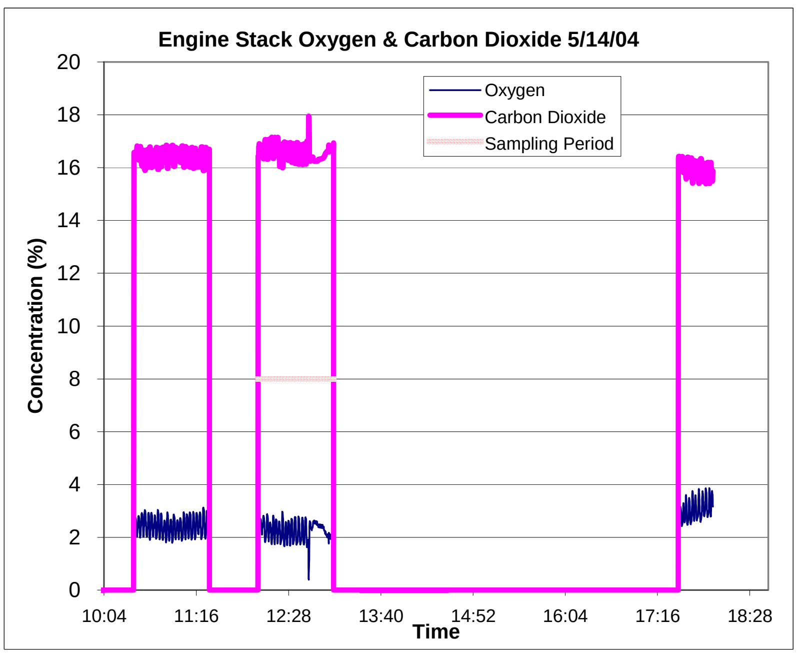




**Figure 4-1. Engine Stack Oxygen and Carbon Dioxide Concentrations**

#### *4.2.2.2 Engine Stack Total Hydrocarbon (THC) Concentrations*

Engine stack THC emissions were measured by EPA Method 25A, which used a CEMs. EPA Method 25A produces concentrations of all hydrocarbons that respond to flame ionization detector (FID) analysis; these hydrocarbons are regarded as the NMOCs reported as propane. Real-time continuous instrument responses are shown in Figure 4-2. The time-averaged concentrations are presented in Table 4-11. The instantaneous concentrations of total hydrocarbons ranged from 300 to 450 ppmv as hexane.

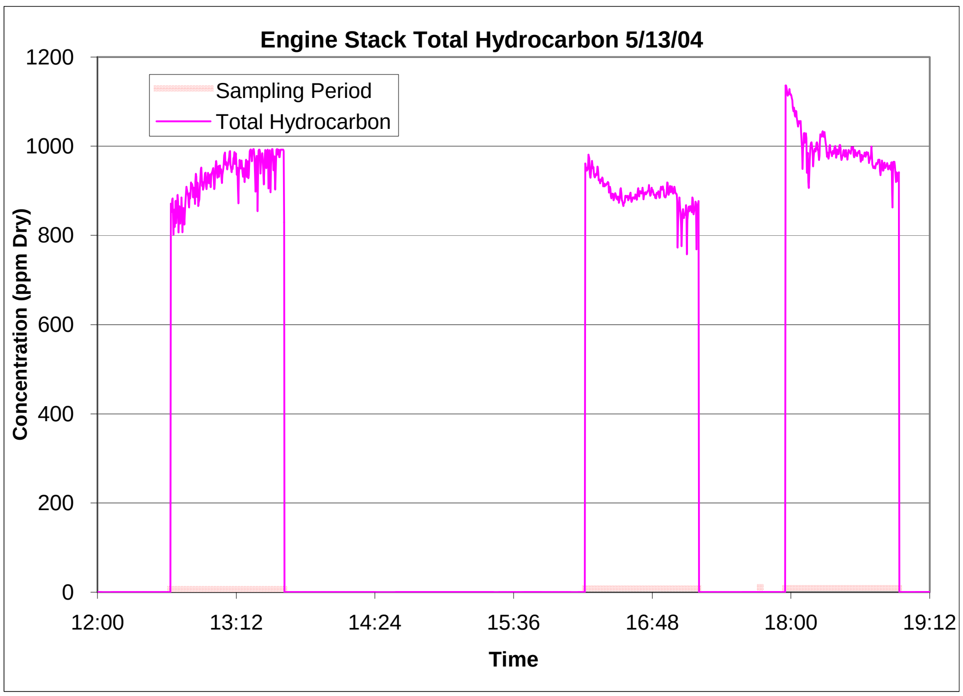



**Figure 4-2. Engine Stack Total Hydrocarbon Concentrations**

**Table 4-11. Engine Stack THC Concentrations**

| | THC (ppmdv as propane) | THC (ppmdv as hexane) |
|---|---|---|
| Run 1 | 934 | 467 |
| Run 2 | 893 | 447 |
| Run 3 | 994 | 497 |
| **Average** | **940** | **470** |

#### *4.2.2.3 Engine Stack Dioxin/Furan (PCDD/PCDFs) Concentrations*

Table 4-12 presents the engine stack PCDD/PCDFs emissions data. In all but one case (12346789-OCDD on Run 1) results were below the detection limits of the analytical method. The detection limits for the individual congeners varied from 0.96 to 12.7 picograms per sample. Table 4-13 presents the same data, but expressed in terms of Toxicity Equivalent (TEQ) emissions. The TEQs are expressed as if the detection limits were the actual laboratory results, i.e., the worst case.

**Table 4-12. Engine Stack Dioxins and Furans Emissions**

| Analyte | C-M23-51304-01 | | | C-M23-51304-02 | | | C-M23-51404-03 | | | Average | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Concentration | Emission Rate | | Concentration | Emission Rate | | Concentration | Emission Rate | | Concentration | Emission Rate | |
| | ($x10^{-3}$ ng/dscm) | ($x10^{-9}$ g/hr) | ($x10^{-12}$ lb/hr) | ($x10^{-3}$ ng/dscm) | ($x10^{-9}$ g/hr) | ($x10^{-12}$ lb/hr) | ($x10^{-3}$ ng/dscm) | ($x10^{-9}$ g/hr) | ($x10^{-12}$ lb/hr) | ($x10^{-3}$ ng/dscm) | ($x10^{-9}$ g/hr) | ($x10^{-12}$ lb/hr) |
| Dioxins | | | | | | | | | | | | |
| 2,3,7,8-TCDD | <0.67 | <2.3 | <5.0 | <0.56 | <1.8 | <4.0 | <0.46 | <1.6 | <3.4 | ND | ND | ND |
| Other TCDD | 4.2 | 14.3 | 31.4 | 12.4 | 40.3 | 89.0 | 8.1 | 27.3 | 60.3 | 8.2 | 27.3 | 60.2 |
| 1,2,3,7,8-PeCDD | <0.39 | <1.3 | <3.0 | <0.56 | <1.8 | <4.0 | <0.94 | <3.2 | <7.1 | ND | ND | ND |
| Other PeCDD | 0 | 0 | 0 | 10.2 | 33.3 | 73.5 | 0 | 0 | 0 | 3.4 | 11.1 | 24.5 |
| 1,2,3,4,7,8-HxCDD | <1.2 | <4.0 | <8.9 | <1.5 | <4.9 | <10.9 | <0.95 | <3.2 | <7.1 | ND | ND | ND |
| 1,2,3,6,7,8-HxCDD | <1.2 | <4.1 | <9.0 | <1.6 | <5.2 | <11.4 | <0.99 | <3.3 | <7.4 | ND | ND | ND |
| 1,2,3,7,8,9-HxCDD | <1.4 | <4.7 | <10.3 | <1.8 | <6.0 | <13.2 | <1.1 | <3.8 | <8.4 | ND | ND | ND |
| Other HxCDD | 0 | 0 | 0 | 3.6 | 11.7 | 25.8 | 0 | 0 | 0 | 1.2 | 3.9 | 8.6 |
| 1,2,3,4,6,7,8-HpCDD | <2.5 | <8.5 | <18.7 | <1.2 | <4.0 | <8.9 | <1.2 | <3.9 | <8.6 | ND | ND | ND |
| Other HpCDD | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1,2,3,4,6,7,8,9-OCDD | 7.6 | 25.9 | 57.1 | <2.7 | <8.9 | <19.6 | <4.0 | <13.5 | <29.9 | 3.7 | 10.1 | 22.3 |
| Total CDD | <19.1 | <65.1 | <144 | <36.2 | <118 | <260 | <17.7 | <59.9 | <132 | ND | ND | ND |
| Furans | | | | | | | | | | | | |
| 2,3,7,8-TCDF | <0.58 | <2.0 | <4.3 | <0.83 | <2.7 | <6.0 | <1.0 | <3.5 | <7.8 | ND | ND | ND |
| Other TCDF | 0 | 0 | 0 | 2.3 | 7.4 | 16.3 | 0 | 0 | 0 | 0.75 | 2.5 | 5.4 |
| 1,2,3,7,8-PeCDF | <1.0 | <3.5 | <7.7 | <0.74 | <2.4 | <5.3 | <0.76 | <2.6 | <5.7 | ND | ND | ND |
| 2,3,4,7,8-PeCDF | <0.94 | <3.2 | <7.0 | <0.70 | <2.3 | <5.0 | <0.68 | <2.3 | <5.1 | ND | ND | ND |
| Other PeCDF | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1,2,3,4,7,8-HxCDF | <0.24 | <0.81 | <1.8 | <0.44 | <1.4 | <3.1 | <0.44 | <1.5 | <3.3 | ND | ND | ND |
| 1,2,3,6,7,8-HxCDF | <0.23 | <0.78 | <1.7 | <0.40 | <1.3 | <2.9 | <0.42 | <1.4 | <3.2 | ND | ND | ND |
| 2,3,4,6,7,8-HxCDF | <0.26 | <0.88 | <1.9 | <0.45 | <1.5 | <3.2 | <0.47 | <1.6 | <3.5 | ND | ND | ND |
| 1,2,3,7,8,9-HxCDF | <0.40 | <1.4 | <3.0 | <0.69 | <2.3 | <5.0 | <0.72 | <2.4 | <5.4 | ND | ND | ND |

| Analyte | C-M23-51304-01 | | | C-M23-51304-02 | | | C-M23-51404-03 | | | Average | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Concentration | Emission Rate | | Concentration | Emission Rate | | Concentration | Emission Rate | | Concentration | Emission Rate | |
| | ($x10^{-3}$ ng/dscm) | ($x10^{-9}$ g/hr) | ($x10^{-12}$ lb/hr) | ($x10^{-3}$ ng/dscm) | ($x10^{-9}$ g/hr) | ($x10^{-12}$ lb/hr) | ($x10^{-3}$ ng/dscm) | ($x10^{-9}$ g/hr) | ($x10^{-12}$ lb/hr) | ($x10^{-3}$ ng/dscm) | ($x10^{-9}$ g/hr) | ($x10^{-12}$ lb/hr) |
| Other HxCDF | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1,2,3,4,6,7,8-HpCDF | <0.37 | <1.3 | <2.8 | <1.2 | <4.1 | <9.0 | <0.52 | <1.8 | <3.9 | ND | ND | ND |
| 1,2,3,4,7,8,9-HpCDF | <0.64 | <2.2 | <4.8 | <0.66 | <2.2 | <4.8 | <0.84 | <2.9 | <6.3 | ND | ND | ND |
| Other HpCDF | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1,2,3,4,6,7,8,9-OCDF | <2.6 | <9.0 | <19.8 | <3.0 | <9.9 | <21.9 | <3.0 | <10.2 | <22.4 | ND | ND | ND |
| Total CDF | <7.3 | <24.9 | <55.0 | <9.2 | <37.4 | <82.4 | <8.9 | <30.2 | <66.5 | ND | ND | ND |
| Total CDD/CDF | <26.4 | <90.0 | <198 | <45.4 | <155 | <343 | <26.6 | <90.1 | <199 | ND | ND | ND |

In computing averages, when all measurements are ND, the average is reported as ND. When one or more measurement is above detection, the ND measurement is treated as 50 percent of the stated MDL. If MDL is not reported, a ND measurement is treated as zero.

“<” denotes the measurement was non-detect. The value following the “<” sign is the detection limit.

**Table 4-13. Engine Stack Dioxins and Furans Toxicity Equivalent Emissions**

| Pollutant | Three-Run Average | | | 1989 Toxicity Equivalency Factor | Toxicity Equivalent Emissions | | |
|---|---|---|---|---|---|---|---|
| | Concentration | Emission Rate | | | Concentration | Emission Rate | |
| | ($x10^{-3}$ ng/dscm) | ($x10^{-9}$ g/hr) | ($x10^{-12}$ lb/hr) | | ($x10^{-3}$ ng/dscm) | ($x10^{-9}$ g/hr) | ($x10^{-12}$ lb/hr) |
| **Dioxins** | | | | | | | |
| 2,3,7,8-TCDD | <0.56 | <1.9 | <4.2 | 1 | <0.56 | <1.9 | <4.2 |
| Other TCDD | 8.2 | 27.3 | 60.2 | --- | NA | NA | NA |
| 1,2,3,7,8-PeCDD | <0.63 | <2.1 | <4.7 | 0.5 | <0.32 | <1.1 | <2.3 |
| Other PeCDD | 3.4 | 11.1 | 24.5 | --- | NA | NA | NA |
| 1,2,3,4,7,8-HxCDD | <1.2 | <4.1 | <9.0 | 0.1 | <0.12 | <0.41 | <0.90 |
| 1,2,3,6,7,8-HxCDD | <1.3 | <4.2 | <9.3 | 0.1 | <0.13 | <0.42 | <0.93 |
| 1,2,3,7,8,9-HxCDD | <1.4 | <4.8 | <10.6 | 0.1 | <0.14 | <0.48 | <1.1 |
| Other HxCDD | 1.2 | 3.9 | 8.6 | --- | NA | NA | NA |
| 1,2,3,4,6,7,8-HpCDD | <1.6 | <5.5 | <12.1 | 0.01 | <0.016 | <0.055 | <0.121 |
| Other HpCDD | 0 | 0 | 0 | --- | NA | NA | |
| 1,2,3,4,6,7,8,9-OCDD | 3.7 | 10.1 | 22.3 | 0.001 | 0.0037 | 0.0101 | 0.0223 |
| **Total CDD** | **24.3** | **81.0** | **178.6** | **---** | **NA** | **NA** | **NA** |
| **Furans** | | | | | | | |
| 2,3,7,8-TCDF | <0.82 | <2.7 | <6.0 | 0.1 | <0.082 | <0.27 | <0.60 |
| Other TCDF | 0.75 | 2.5 | 5.4 | --- | NA | NA | |
| 1,2,3,7,8-PeCDF | <0.84 | <2.8 | <6.2 | 0.05 | <0.042 | <0.14 | <0.31 |
| 2,3,4,7,8-PeCDF | <0.77 | <2.6 | <5.7 | 0.5 | <0.39 | <1.3 | <2.9 |

| **Pollutant** | **Three-Run Average** | | | **1989 Toxicity Equivalency Factor** | **Toxicity Equivalent Emissions** | | |
|---|---|---|---|---|---|---|---|
| | **Concentration** | **Emission Rate** | | | **Concentration** | **Emission Rate** | |
| | **($x10^{-3}$ ng/dscm)** | **($x10^{-9}$ g/hr)** | **($x10^{-12}$ lb/hr)** | | **($x10^{-3}$ ng/dscm)** | **($x10^{-9}$ g/hr)** | **($x10^{-12}$ lb/hr)** |
| Other PeCDF | 0 | 0 | 0 | --- | NA | NA | NA |
| 1,2,3,4,7,8-HxCDF | <0.37 | <1.2 | <2.7 | 0.1 | <0.037 | <0.12 | <0.27 |
| 1,2,3,6,7,8-HxCDF | <0.35 | <1.2 | <2.6 | 0.1 | <0.035 | <0.12 | <0.26 |
| 2,3,4,6,7,8-HxCDF | <0.39 | <1.3 | <2.9 | 0.1 | <0.039 | <0.13 | <0.29 |
| 1,2,3,7,8,9-HxCDF | <0.61 | <2.0 | <4.5 | 0.1 | <0.061 | <0.20 | <0.45 |
| Other HxCDF | 0 | 0 | 0 | --- | NA | NA | NA |
| 1,2,3,4,6,7,8-HpCDF | <0.71 | <2.4 | <5.2 | 0.01 | <0.0071 | <0.024 | <0.052 |
| 1,2,3,4,7,8,9-HpCDF | <0.72 | <2.4 | <5.3 | 0.01 | <0.0072 | <0.024 | <0.053 |
| Other HpCDF | 0 | 0 | 0 | --- | NA | NA | |
| 1,2,3,4,6,7,8,9-OCDF | <2.9 | <9.7 | <21.4 | 0.001 | <0.0029 | <0.0097 | <0.0214 |
| **Total CDF** | **<8.5** | **<30.8** | **<68.0** | **---** | **NA** | **NA** | **NA** |
| **Total CDD/CDF** | **<32.8** | **<112** | **<247** | **---** | **NA** | **NA** | **NA** |

NA – not applicable because no Toxicity Equivalency Factor is available.

“<” denotes the measurement was non-detect. The value following the “<” sign is the detection limit.

#### *4.2.2.4 Engine Stack Polycyclic Aromatic Hydrocarbons (PAHs) Concentrations*

The concentrations of PAHs were obtained by CARB Method 429 analysis (comparable to EPA Method 23). The results are presented in Table 4-14.

#### *4.2.2.5 Hydrogen Chloride (HCl) Concentrations*

Engine stack HCl emissions results are presented in Table 4-15. Since EPA Method 26 (non-isokinetic procedure) was used, stack gas flows from the EPA Method 23 run performed on the same day as the M26 runs (May 14) were used in the mass emissions calculations.

#### *4.2.2.6 Metals Concentrations*

Engine stack metals emissions results are presented in Table 4-16. The metal concentrations were determined by Method 29, and included those for As, Cd, Cr, Pb, Mn, Hg (total), and Ni. Mercury (Hg) concentration (elemental) was separately measured by the LUMEX instrument and those results are also included in Table 4-16.

The "<" symbol denotes that the notated metal was not detected in that sample. The values following the "<" symbol represent the concentrations and emission rates that would have been the case had the metal been found at the method detection limit. Hence the values represent the upper limits of what might be present.

#### *4.2.2.7 Gaseous Concentrations: Carbon Monoxide (CO), Sulfur Dioxide ($SO_2$), and Nitrogen Oxides ($NO_X$)*

Gaseous emissions measured with CEMs include CO, $SO_2$ and $NO_X$. These results are summarized in Table 4-17. The detailed CEM measurement plots are shown in Figures 4-3 through 4-5. Carbon monoxide concentrations averaged 568 ppmdv. Sulfur dioxide was not detected. Nitrogen oxides ranged from 2280 to 3150 ppmdv, averaging at 2730 ppmdv.

### 4.3 Comparison with AP-42 Values

One of the major objectives of the test program is to expand on the database of LFG constituent compounds and their concentrations. If warranted, these data may contribute towards updating the AP-42 default values.

**Table 4-14. Engine Stack Polycyclic Aromatic Hydrocarbons Emissions**

| Analyte | Formula Weight | M23-I-C | | | | M23-II-C | | | | M23-III-C | | | | Average | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Concentration | | Emission Rate | | Concentration | | Emission Rate | | Concentration | | Emission Rate | | Concentration | | Emission Rate | |
| | | ($x10^{-6}$ ppmv) | (ng/dscm) | ($x10^{-6}$ g/hr) | ($x10^{-6}$ lb/hr) | ($x10^{-6}$ ppmv) | (ng/dscm) | ($x10^{-6}$ g/hr) | ($x10^{-6}$ lb/hr) | ($x10^{-6}$ ppmv) | (ng/dscm) | ($x10^{-6}$ g/hr) | ($x10^{-6}$ lb/hr) | ($x10^{-6}$ ppmv) | (ng/dscm) | ($x10^{-6}$ g/hr) | ($x10^{-6}$ lb/hr) |
| Acenaphthene [a] | 154.21 | 101 | 649 | 2500 | 5.4 | 84.5 | 542 | 2000 | 4.4 | 74.1 | 475 | 1800 | 4.0 | 86.6 | 555 | 2100 | 4.6 |
| Acenaphthylene [a] | 152.20 | 270 | 1700 | 6500 | 14.2 | 252 | 1600 | 5800 | 12.8 | 195 | 1230 | 4700 | 10.4 | 239 | 1510 | 5700 | 12.5 |
| Anthracene [a] | 178.23 | 56.8 | 421 | 1600 | 3.5 | 51.2 | 380 | 1400 | 3.1 | 42.8 | 317 | 1200 | 2.7 | 50.3 | 372 | 1400 | 3.1 |
| Benzo(a)anthracene [a] | 228.30 | 7.7 | 73.2 | 278 | 0.612 | 6.5 | 61.4 | 224 | 0.495 | 5.5 | 52.0 | 199 | 0.438 | 6.6 | 62.2 | 233.5 | 0.515 |
| Benzo(a)pyrene [a] | 252.32 | 0.292 | 3.1 | 11.6 | 0.0256 | 0.343 | 3.6 | 13.1 | 0.0290 | 0.248 | 2.6 | 9.9 | 0.0219 | 0.294 | 3.1 | 11.6 | 0.0255 |
| Benzo(b)fluoranthene [a] | 252.32 | 5.6 | 59 | 224 | 0.495 | 3.8 | 40 | 146 | 0.322 | 3.5 | 36.9 | 141 | 0.310 | 4.3 | 45.3 | 170.3 | 0.376 |
| Benzo(g,h,i)perylene [a] | 276.34 | 0.503 | 5.8 | 21.9 | 0.0483 | 0.680 | 7.8 | 28.5 | 0.0629 | 0.416 | 4.8 | 18.2 | 0.0402 | 0.533 | 6.1 | 22.9 | 0.0505 |
| Benzo(k)fluoranthene [a] | 252.32 | 1.4 | 15 | 56.5 | 0.125 | 0.952 | 10.0 | 36.5 | 0.0804 | 0.703 | 7.4 | 28.2 | 0.0621 | 1.0 | 10.8 | 40.4 | 0.0890 |
| Chrysene [a] | 228.29 | 21.4 | 203 | 770 | 1.7 | 16.6 | 158 | 577 | 1.3 | 14.2 | 135 | 513 | 1.1 | 17.4 | 165 | 620.1 | 1.4 |
| Dibenzo(a,h)anthracene [a] | 278.35 | 0.314 | 3.6 | 13.8 | 0.0304 | 0.233 | 2.7 | 9.9 | 0.0217 | 0.202 | 2.3 | 8.9 | 0.0197 | 0.250 | 2.9 | 10.9 | 0.0239 |
| Fluoranthene [a] | 202.26 | 51.5 | 433 | 1600 | 3.6 | 45.1 | 380 | 1400 | 3.1 | 32.1 | 270 | 1000 | 2.3 | 42.9 | 361 | 1400 | 3.0 |
| Fluorene [a] | 166.22 | 127 | 878 | 3300 | 7.3 | 97.1 | 671 | 2500 | 5.4 | 82.8 | 572 | 2200 | 4.8 | 102 | 707 | 2700 | 5.9 |
| Indeno(1,2,3-cd)pyrene [a] | 288.35 | 0.924 | 11.1 | 42.0 | 0.0926 | 0.627 | 7.5 | 27.5 | 0.0605 | 0.538 | 6.5 | 24.6 | 0.0543 | 0.697 | 8.3 | 31.4 | 0.0691 |
| Naphthalene [a] | 128.17 | 7800 | 41400 | 157000 | 346 | 8700 | 46200 | 169000 | 372 | 7800 | 41400 | 158000 | 348 | 8100 | 43000 | 161100 | 355 |
| Phenanthrene [a] | 178.23 | 446 | 3300 | 12500 | 27.6 | 337 | 2500 | 9100 | 20.1 | 300 | 2220 | 8500 | 18.7 | 361 | 2670 | 10000 | 22.1 |
| Pyrene [a] | 202.26 | 41.3 | 347 | 1300 | 2.9 | 32.9 | 277.0 | 1000 | 2.2 | 28.7 | 241 | 920 | 2.0 | 34.3 | 290 | 1100 | 2.4 |
| 2-Methylnaphthalene [a] | 142.20 | 1400 | 8200 | 31000 | 68.3 | 1100 | 6300 | 23200 | 51.1 | 948 | 5600 | 21400 | 47.1 | 1100 | 6700 | 25200 | 55.5 |
| Benzo(e)Pyrene [a] | 252.32 | 4.0 | 42.3 | 160 | 0.354 | 2.5 | 26.2 | 95.8 | 0.211 | 2.3 | 23.9 | 91.1 | 0.200 | 2.9 | 30.8 | 115.8 | 0.255 |
| Perylene [b] | 253.31 | <0.0907 | 951000 | 3.6 | 0.0079 | <0.0952 | 998000 | 3.6 | 0.0080 | <0.0902 | 0.9 | 3.6 | 0.0080 | <0.0920 | 1.0 | 3.6 | 0.0080 |

[a] These analytes were detected in field blank sample. See Table 5-2 for detected concentrations

[b] Recovery of $d_{12}^{-}$ perylene was below acceptable range

**Table 4-15. Engine Stack Hydrogen Chloride (HCl) Emissions**

| | HCl Concentration | | HCl Emission Rate | |
|---|---|---|---|---|
| | (ppmdv) | (mg/m$^3$) | (lb/hr) | (g/hr) |
| Run 1 | 9.1 | 13.8 | 0.103 | 46.6 |
| Run 2 | 12.5 | 19.7 | 0.142 | 64.4 |
| Run 3 | 14.3 | 20.6 | 0.163 | 73.7 |
| **Average** | **12.0** | **18.0** | **0.136** | **61.6** |

**Table 4-16. Engine Stack Metals Emissions**

| Analyte | C-POST-M29-051404-01 | | | C-POST-M29-051404-02 | | | C-POST-M29-051404-03 | | | Average | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Concentration | Emission Rate | | Concentration | Emission Rate | | Concentration | Emission Rate | | Concentration | Emission Rate | |
| | (µg/dscm) | ($x10^{-3}$ g/hr) | ($x10^{-6}$lb/hr) | (µg/dscm) | ($x10^{-3}$ g/hr) | ($x10^{-6}$lb/hr) | (µg/dscm) | ($x10^{-3}$ g/hr) | ($x10^{-6}$lb/hr) | (µg/dscm) | ($x10^{-3}$ g/hr) | ($x10^{-6}$lb/hr) |
| Arsenic | 2.7 | 8.9 | 19.6 | 4.1 | 14 | 30.1 | 2.6 | 8.2 | 18.2 | 3.1 | 10 | 22.6 |
| Cadmium | 0.75 | 2.5 | 5.4 | 0.556 | 1.8 | 4.1 | 0.416 | 1.3 | 2.9 | 0.574 | 1.9 | 4.1 |
| Chromium | 5.2 | 17 | 37.6 | 4.3 | 14 | 31.6 | 3.6 | 12 | 25.6 | 4.4 | 14 | 31.6 |
| Lead | 0.73 | 2.4 | 5.3 | 0.40 | 1.3 | 2.9 | <0.83 | <2.7 | <5.9 | 0.52 | 1.7 | 3.7 |
| Manganese | 3.7 | 12 | 26.5 | 3.6 | 12 | 26.4 | 8.9 | 28 | 62.5 | 5.4 | 17 | 38.5 |
| Nickel [a] | 30.6 | 100 | 220.3 | 12.9 | 43 | 94.4 | 8.9 | 29 | 63.0 | 18 | 57 | 126 |
| Mercury (Total by Method 29) | <2.9 | <10 | <21.2 | <2.9 | <10 | <21.1 | <3.1 | <10 | <22 | ND | ND | ND |
| | RUN 1 | | | RUN 2 | | | RUN 3 | | | Average | | |
| Mercury (Elemental by LUMEX) | 0.147 | 0.457 | 1.0078 | 0.230 | 0.722 | 1.59 | 0.124 | 0.379 | 0.836 | 0.167 | 0.519 | 1.15 |

[a] Two of four calibration verification samples were at 10.6 and 14.0 percent and were above the acceptable range of ±10 percent

**Table 4-17. Engine Stack CO, $SO_2$, $NO_X$ Concentrations**

| | Concentration (ppmdv) | | |
|---|---|---|---|
| | CO | $SO_2$ | $NO_X$ (as NO) |
| Run 1 | 562 | 0 | 2770 |
| Run 2 | 556 | 0 | 3150 |
| Run 3 | 585 | 0 | 2280 |
| Average | 568 | 0 | 2730 |

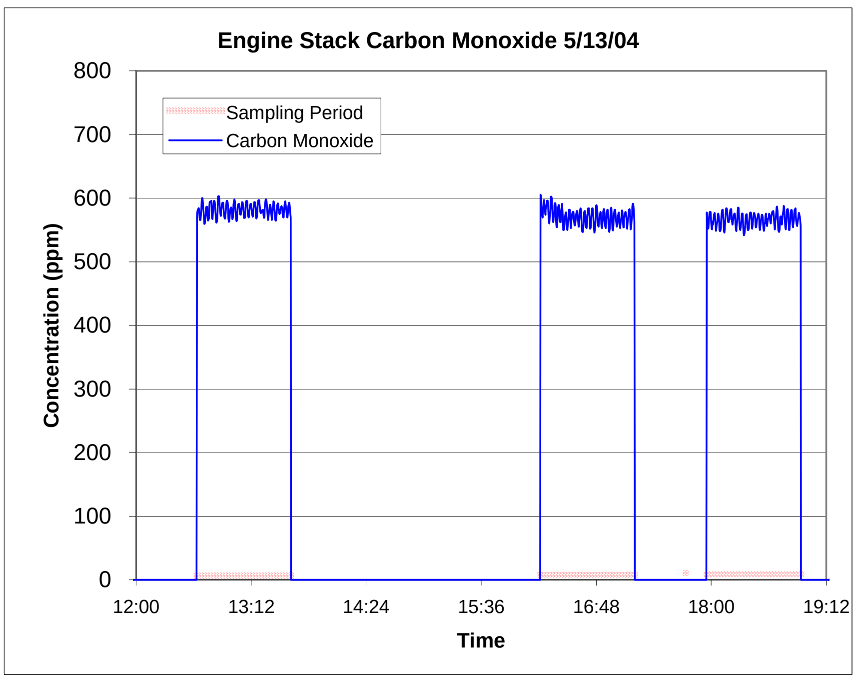
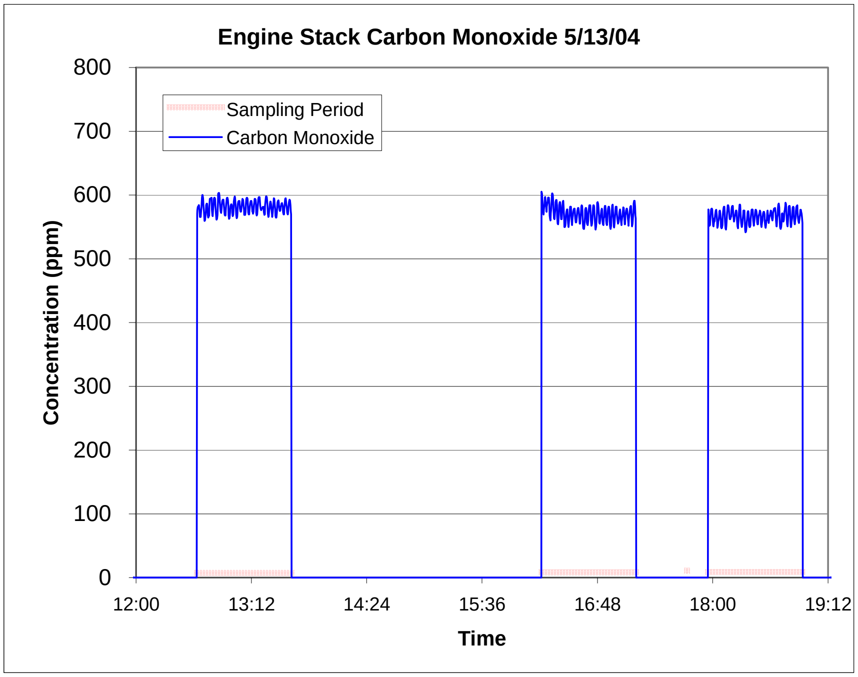



**Figure 4-3. Engine Stack Carbon Monoxide Concentrations**



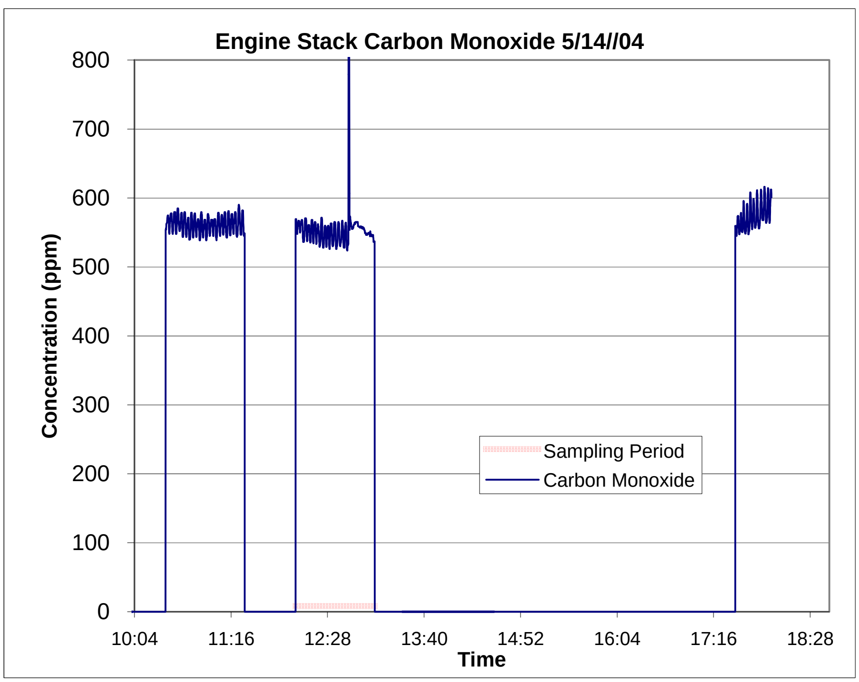




**Figure 4-4. Engine Stack Sulfur Dioxide Concentrations**

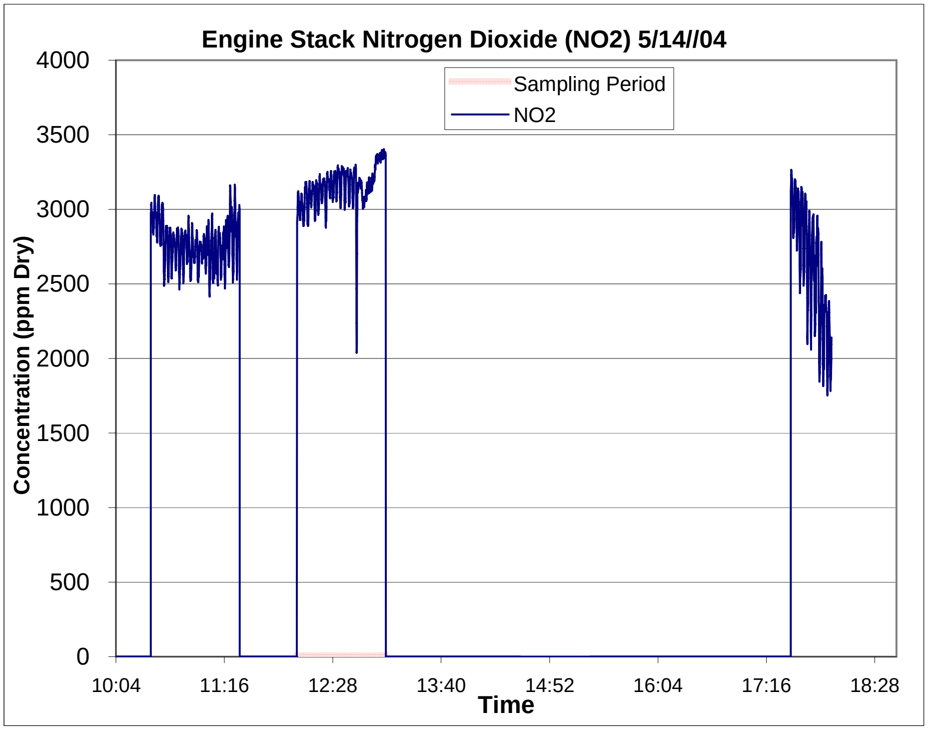



**Figure 4-5. Engine Stack Nitric Oxide Concentrations**

Table 4-18 presents the concentrations of LFG constituents to provide direct comparisons with AP-42 default values. Table 4-19 presents the concentration of other constituents targeted by the various analyses but are not listed in AP-42. An expanded discussion and comparison is included in the overall project report.

**Table 4-18. Comparison of Raw Landfill Gas Constituent Concentrations with AP-42 Values**

| Method | Compound | CAS Number | Formula Wt. | Default Value (ppmv) | Detection Limit (ppmv) | Measured Average (ppmv) | Concentration in Inlet LFG | | Mass Flow Rate in Inlet LFG Stream | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | ($x10^{-9}$ lb/ft$^3$) | (μg/m$^3$) | (mg/hr) | ($x10^{-3}$ lb/hr) |
| M-40 | 1,1,1-Trichloroethane | 71-55-6 | 133.42 | 0.48 | 0.0003 | ND | ND | ND | ND | ND |
| M-40 | 1,1,2,2-Tetrachloroethane | 79-34-5 | 167.85 | 1.11 | 0.0002 | ND | ND | ND | ND | ND |
| M-40 | 1,1-Dichloroethane (Ethylidene Dichloride) | 75-34-3 | 98.96 | 2.35 | 0.0004 | 0.423 | 108 | 1730 | 2060 | 4.5 |
| M-40 | 1,1-Dichloroethene | 75-35-4 | 96.94 | 0.20 | 0.0002 | 0.055 | 13.9 | 222 | 264 | 0.582 |
| M-40 | 1,2-Dichloroethane | 107-06-2 | 98.96 | 0.41 | 0.0003 | 0.037 | 9.5 | 152 | 181 | 0.399 |
| M-40 | 1,2-Dichloropropane | 78-87-5 | 112.98 | 0.18 | 0.0003 | ND | ND | ND | ND | ND |
| M-40 | Isopropyl alcohol (2-Propanol) | 67-63-0 | 60.11 | 50.10 | 0.0002 | 1.28 | 199 | 3190 | 3790 | 8.4 |
| M-40 | Acetone | 67-64-1 | 58.08 | 7.01 | 0.0003 | 11.7 | 1800 | 28200 | 33500 | 73.8 |
| M-40 | Acrylontrile | 107-13-1 | 53.06 | 6.33 | 0.02 | ND | ND | ND | ND | ND |
| M-40 | Bromodichloromethane | 75-27-4 | 163.83 | 3.13 | 0.0002 | ND | ND | ND | ND | ND |
| M-40 | Butane | 106-97-8 | 58.12 | 5.03 | | 37.9 | 5700 | 91200 | 108000 | 239 |
| M-40 | Carbon Disulfide | 75-15-0 | 76.13 | 0.58 | 0.0003 | 0.157 | 30.8 | 494 | 587 | 1.3 |
| No Test | Carbon Monoxide | 630-08-0 | 28.01 | 141 | | NM | NM | NM | NM | NM |
| M-40 | Carbon Tetrachloride | 56-23-5 | 153.84 | 0.004 | 0.0005 | ND | ND | ND | ND | ND |
| No Test | Carbonyl Sulfide (Carbon oxysulfide) | 463-58-1 | 60.07 | 0.49 | | NM | NM | NM | NM | NM |
| M-40 | Chlorobenzene | 108-90-7 | 112.56 | 0.25 | 0.0002 | 0.833 | 242 | 3880 | 4620 | 10.2 |
| M-40 | Chlorodiflouromethane (Freon 22) | 75-45-6 | 86.47 | 1.30 | 0.02 | ND | ND | ND | ND | ND |
| M-40 | Chloroethane (Ethyl Chloride) | 75-00-3 | 64.52 | 1.25 | 0.0002 | 30.4 | 5100 | 81200 | 966000 | 213 |
| M-40 | Chloroform | 67-66-3 | 119.39 | 0.03 | 0.0003 | 0.744 | 230 | 3680 | 4370 | 9.6 |
| M-40 | Chloromethane | 74-87-3 | 50.49 | 1.21 | 0.0001 | 1.26 | 165 | 2640 | 3140 | 6.9 |
| M-40 | 1,4-Dichlorobenzene | 106-46-7 | 147.00 | 0.21 | 0.0003 | 0.328 | 125 | 2000 | 2380 | 5.2 |
| M-40 | 1,3-Dichlorobenzene | 541-73-1 | 147.00 | 0.21 | 0.0002 | 0.394 | 150 | 2400 | 2850 | 6.3 |

| Method | Compound | CAS Number | Formula Wt. | Default Value (ppmv) | Detection Limit (ppmv) | Measured Average (ppmv) | Concentration in Inlet LFG | | Mass Flow Rate in Inlet LFG Stream | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | ($x10^{-9}$ lb/ft$^3$) | (µg/m$^3$) | (mg/hr) | ($x10^{-3}$ lb/hr) |
| M-40 | 1,2-Dichlorobenzene | 95-50-1 | 147.01 | 0.21 | 0.0003 | ND | ND | ND | ND | ND |
| M-40 | Dichlorodifluoromethane (Freon 21) | 75-71-8 | 120.91 | 15.70 | 0.0003 | 1.61 | 501 | 8020 | 9540 | 21.0 |
| M-40 | Dichlorofluoromethane (Freon 12) | 75-43-4 | 102.92 | 2.62 | 0.0003 | ND | ND | ND | ND | ND |
| M-40 | Methylene Chloride (Dichloromethane) | 75-09-2 | 84.94 | 14.30 | 0.0001 | 5.35 | 1200 | 18800 | 22400 | 49.3 |
| No Test | Dimethyl Sulfide (Methyl sulfide) | 75-18-3 | 62.13 | 7.82 | | NM | NM | NM | NM | NM |
| M-40 | Ethane | 74-84-0 | 30.07 | 889 | 1 | 14.3 | 1100 | 17800 | 21200 | 46.8 |
| M-40 | Ethanol | 64-17-5 | 46.08 | 27.20 | 0.0002 | 0.172 | 20.4 | 328 | 390 | 0.859 |
| No Test | Ethyl Mercaptan (Ethanediol) | 75-08-1 | 62.13 | 2.28 | | NM | NM | NM | NM | NM |
| M-40 | Ethylbenzene | 100-41-4 | 106.16 | 4.61 | 0.0003 | 5.89 | 1600 | 25900 | 30800 | 67.9 |
| M-40 | 1,2-Dibromoethane (Ethylene dibromide) | 106-93-4 | 187.88 | 0.001 | 0.0002 | 0.021 | 10.1 | 161 | 192 | 0.422 |
| M-40 | Trichloromonofluoromethane (Fluorotrichloromethane) (F11) | 75-69-4 | 137.38 | 0.76 | 0.0002 | 0.504 | 179 | 2870 | 3410 | 7.5 |
| M-40 | Hexane | 110-54-3 | 86.18 | 6.57 | 0.0003 | 28.4 | 6300 | 101000 | 120000 | 265 |
| M-11 | Hydrogen Sulfide | 7783-06-4 | 34.08 | 35.50 | | 55.5 | 4900 | 78300 | 93100 | 205 |
| Organic mercury | Mercury (Dimethyl) | | 230.66 | Not Listed | 0.05E-06 | 1.6E-06 | 0.000934 | 0.015 | 0.01780 | 0.0000392 |
| LUMEX | Mercury (Elemental) | 7439-97-6 | 200.61 | Not Listed | | 11.8E-06 | 0.0061 | 0.098 | 0.117 | 0.000257 |
| Organic mercury | Mercury (Monomethyl) | | 215.62 | Not Listed | 0.014E-06 | 0.44E-06 | 0.000245 | 0.00393 | 0.00467 | 0.0000103 |
| Organic mercury | Mercury (Total) | | 215.63 | 253.0E-6 | 6E-06 | 51.2E-06 | 0.0285 | 0.46 | 0.54 | 0.00120 |
| M-40 | 2-Butanone (Methyl Ethyl Ketone) | 78-93-3 | 72.10 | 7.09 | 0.0003 | 4.57 | 851 | 13600 | 16200 | 35.7 |

| Method | Compound | CAS Number | Formula Wt. | Default Value (ppmv) | Detection Limit (ppmv) | Measured Average (ppmv) | Concentration in Inlet LFG | | Mass Flow Rate in Inlet LFG Stream | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | ($x10^{-9}$ lb/ft$^3$) | (µg/m$^3$) | (mg/hr) | ($x10^{-3}$ lb/hr) |
| M-40 | 2-Hexanone (Methyl Butyl Ketone) | 591-78-6 | 100.16 | 1.87 | 0.0002 | ND | ND | ND | ND | ND |
| No Test | Methyl Mercaptan (Methanethiol) | 74-93-1 | 48.11 | 2.49 | | NM | NM | NM | NM | NM |
| M-40 | Pentane | 109-66-0 | 72.15 | 3.29 | 1 | 26.6 | 5000 | 79400 | 94400 | 208 |
| M-40 | Tetrachloroethylene (Perchloroethylene) | 127-18-4 | 165.83 | 3.73 | 0.0003 | 1.69 | 726 | 11600 | 13800 | 30.5 |
| M-40 | Propane | 74-98-6 | 44.09 | 11.10 | | 40.0 | 4600 | 73000 | 86800 | 191 |
| M-40 | t-1,2-Dichloroethene | 156-60-5 | 96.94 | 2.84 | 0.0003 | 0.042 | 10.4 | 167 | 199 | 0.439 |
| M-40 | Trichloroethylene (Trichloroethene) | 79-01-6 | 131.38 | 2.82 | 0.0002 | 0.515 | 175 | 2800 | 3330 | 7.4 |
| M-40 | Vinyl Chloride | 75-01-4 | 62.50 | 7.34 | 0.0002 | 0.768 | 124 | 1990 | 2360 | 5.2 |
| M-40 | m/p-Xylene (Dimethyl Benzene) | 1330-20-7 | 106.16 | 12.10 | 0.00065 | 9.21 | 2500 | 40500 | 48100 | 106 |
| M-40 | o-Xylene (Dimethyl Benzene) | 95-47-6 | 106.16 | 12.10 | 0.0003 | 3.66 | 1000 | 16100 | 19200 | 42.2 |
| M-40 | Benzene (Co-disposal) | 71-43-2 | 78.11 | 11.10 | 0.0002 | 1.63 | 328 | 5260 | 6260 | 13.8 |
| M-41 | Benzene (No-disposal or Unknown) | 71-43-2 | 78.11 | 1.91 | 0.0002 | 1.63 | 328 | 5260 | 6260 | 13.8 |
| M-25C | NMOC as Hexane (Co-disposal) | | 86.17 | 2420.00 | | 587 | 1300000 | 20900000 | 24900000 | 54900 |
| M-25C | NMOC as Hexane (No-codispoal or Unknown) | | | 595.00 | | 587 | 1300000 | 20900000 | 24900000 | 54900 |
| M-40 | Toluene (Methyl Benzen) (Co-disposal) | 108-88-3 | 92.13 | 165.00 | 0.0003 | 23.3 | 5600 | 89000 | 106000 | 233 |
| M-40 | Toluene (Methyl Benzene) (No or Unknown) | 108-88-3 | 92.13 | 39.30 | 0.0003 | 23.3 | 5600 | 89000 | 106000 | 233 |

**Table 4-19. Raw Landfill Gas Constituent Concentrations for Compounds without AP-42 Values**

| Method | Compound | CAS Number | Formula Wt. | Detection Limit (ppmv) | Measured Average (ppmv) | Concentration in Inlet LFG | | Mass Flow Rate in Inlet LFG Stream | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | (x10$^{-9}$ lb/ft$^3$) | (µg/m$^3$) | (mg/hr) | (x10$^{-3}$ lb/hr) |
| M-0100 | Acetaldehyde | 75-07-0 | 44.05 | 0.0045 | 0.133 | 15.1 | 242 | 288 | 0.635 |
| M-0100 | Formaldehyde | 50-00-0 | 30.03 | 0.0064 | 0.027 | 2.1 | 34 | 40.4 | 0.0891 |
| M-23 | Dioxins/Furans | | | | NM | NM | NM | NM | NM |
| M-23 | PAHs | | | | NM | NM | NM | NM | NM |
| M-25C | Carbon Dioxide | 124-38-9 | 44.01 | | 462000 | 52600000 | 842000000 | 1000000000 | 2200 |
| M-25C | Methane | 74-82-8 | 16.04 | | 560000 | 23200000 | 372000000 | 442000000 | 975000 |
| M-25C | Oxygen | 7782-44-7 | 32.00 | | 16000 | 1300000 | 21200000 | 25200000 | 55600 |
| M-40 | 1,1,2,3,4,4-Hexachloro-1,3-butadiene | 87-68-3 | 260.76 | 0.0002 | ND | ND | ND | ND | ND |
| M-40 | 1,1,2-Trichloro-1,2,2-trifluoroethane (CFC113) | 76-13-1 | 187.38 | 0.0002 | 0.039 | 19.1 | 305 | 363 | 0.800 |
| M-40 | 1,1,2-Trichloroethane | 79-00-5 | 133.42 | 0.0002 | 0.445 | 154 | 2460 | 2920 | 6.4 |
| M-40 | 1,2,4-Trichlorobenzene | 120-82-1 | 181.46 | 0.0003 | ND | ND | ND | ND | ND |
| M-40 | 1,2,4-Trimethylbenzene | 95-63-6 | 120.19 | 0.0003 | 1.51 | 469 | 7510 | 8930 | 19.7 |
| M-40 | 1,2-Chloro-,1,2,2-Tetrafluoroethane (CFC114) | 76-14-2 | 170.92 | 0.0002 | 0.127 | 56.1 | 899 | 1070 | 2.4 |
| M-40 | 1,3,5-Trimethylbenzene | 108-67-8 | 120.19 | 0.0002 | 0.894 | 278 | 4450 | 5290 | 11.7 |
| M-40 | 1,3-Butadiene (Vinylethylene) | 106-99-0 | 54.09 | 0.0003 | 0.642 | 89.7 | 1440 | 1710 | 3.8 |
| M-40 | 1,4-Dioxane (1,4-Diethylene Dioxide) | 123-91-1 | 88.10 | 0.0002 | 0.007 | 1.5 | 24.3 | 28.9 | 0.0638 |
| M-40 | 1-Ethyl-4-methylbenzene (4-Ethyl Toluene) | 622-96-8 | 120.20 | 0.0002 | 0.894 | 278 | 4450 | 5290 | 11.7 |
| M-40 | 4-Methyl-2-pentanone (MIBK) | 108-10-1 | 100.16 | 0.0002 | 2.17 | 562 | 9000 | 10700 | 23.6 |

| Method | Compound | CAS Number | Formula Wt. | Detection Limit (ppmv) | Measured Average (ppmv) | Concentration in Inlet LFG | | Mass Flow Rate in Inlet LFG Stream | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | ($x10^{-9}$ lb/ft$^3$) | (µg/m$^3$) | (mg/hr) | ($x10^{-3}$ lb/hr) |
| M-40 | Benzyl Chloride (Chloromethyl Benzene) | 100-44-7 | 126.58 | 0.0002 | ND | ND | ND | ND | ND |
| M-40 | Bromomethane (Methyl bromide) | 74-83-9 | 94.95 | 0.0002 | 0.023 | 5.7 | 92 | 109 | 0.241 |
| M-40 | cis-1,2-Dichloroethene | 156-59-2 | 96.94 | 0.0003 | 1.64 | 411 | 6580 | 7820 | 17.2 |
| M-40 | cis-1,3-Dichloropropene | 10061-01-5 | 110.98 | 0.0002 | ND | ND | ND | ND | ND |
| M-40 | Cyclohexane | 110-82-7 | 84.16 | 0.0003 | 3.30 | 718 | 11500 | 13700 | 30.2 |
| M-40 | Dibromochloromethane | 124-48-1 | 208.29 | 0.0002 | 0.009 | 4.7 | 74.8 | 88.9 | 0.196 |
| M-40 | Ethyl Acetate | 141-78-6 | 88.10 | 0.0003 | 1.42 | 323 | 5180 | 6160 | 13.6 |
| M-40 | Heptane | 142-82-5 | 100.20 | 0.0002 | 2.86 | 740 | 11800 | 14100 | 31.1 |
| M-40 | Methyl-t-butyl Ether (MTBE) | 1634-04-4 | 88.15 | 0.0003 | 0.257 | 58.5 | 937 | 1110 | 2.5 |
| M-40 | Styrene (Vinylbenzene) | 100-42-5 | 104.14 | 0.0001 | 1.27 | 340 | 5450 | 6490 | 14.3 |
| M-40 | t-1,3-Dichloropropene | 1006-02-6 | 110.98 | 0.0002 | 0.033 | 9.4 | 150 | 179 | 0.394 |
| M-40 | Tetrahydrofuran (Diethylene Oxide) | 109-99-9 | 72.10 | 0.0004 | 1.17 | 218 | 3500 | 4160 | 9.2 |
| M-40 | Tribromomethane (Bromoform) | 75-25-2 | 252.77 | 0.0003 | 0.016 | 10.3 | 164 | 195 | 0.431 |
| M-40 | Vinyl Acetate | 108-05-4 | 86.09 | 0.0005 | 0.024 | 5.3 | 84 | 100 | 0.221 |

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# 5. Quality Assurance/Quality Control (QA/QC)

This project produced data that qualified to receive the “A” rating with respect to the rating system described in section 4.4.2 of the *Procedures for preparing Emission Factor Documents* (EPA-454/R-95-015). The cited EPA document provides a clear description of the requirements for an “A” data quality rating. Tests were performed by using an EPA reference test method, or when not applicable, a sound methodology. Tests were reported in enough detail for adequate validation and raw data were provided that could be used to duplicate the emission results presented in this report.

Throughout the results sections of this report, notations and footnotes were included to flag data that, for various reasons, did not meet their associated measurement quality objectives.

## 5.1 Assessment of Measurement Quality Objectives

Measurement quality objectives (MQOs) were established for each critical measurement and documented in the *Site-Specific QAPP for the Field Evaluation of Landfill Gas Control Technologies-Landfill C*. The following subsections assess MQOs for each measurement to determine if goals were achieved. When applicable, data validation elements performed on laboratory analytical reports are also included.

### 5.1.1 Continuous Emissions Monitors (CEMs)

Oxygen ($O_2$), $CO/CO_2$, $SO_2$ $NO_X$ and THC were measured in the field using CEMs. The following MQOs were established for CEM measurements for Landfill C:

- Direct calibration bias: ±2 percent
- System bias checks: ±5 percent
- Zero and drift: ±3 percent
- Completeness: >90 percent

Direct calibrations were performed daily, prior to testing, at zero and a minimum of two other concentrations (typically a mid-level concentration and one point towards the end of the instrument range). System bias checks were performed pre-test and post-test. Drift checks were performed daily, post-test. Table 5-1 summarizes these QC checks for all instruments. All MQOs were met for Landfill C and were therefore, 100 percent complete.

**Table 5-1. Continuous Emissions Monitor (CEM) Measurement Quality Objectives (MQO) Summary for Landfill C**

| Instrument and Range | Direct Calibration (±2% criteria) | | | System Bias Checks (±5% criteria) | | | Drift Checks (±3% criteria) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Total # | Bias Range (%) | Percent Complete | Total # | Bias Range (%) | Percent Complete | Total # | Bias Range (%) | Percent Complete |
| Servomex $O_2$ Analyzer (0-21%) | 18 | 0.1-1.5 | 100 | 24 | 0-3.1 | 100 | 12 | 0-0.8 | 100 |
| Cal Analytical $CO_2$ Analyzer (0-20%) | 18 | 0-1.9 | 100 | 24 | 0.1-2.7 | 100 | 12 | 0-1.1 | 100 |
| Cal Analytical CO Analyzer (0-650 ppm) | 24 | 0-1.2 | 100 | 24 | 0-2.6 | 100 | 12 | 0-1.3 | 100 |
| Cal Analytical $SO_2$ Analyzer (0-500 ppm) | 12 | 0.1-7.4 | 92 | 12 | 2.1-4.4 | 100 | 8 | 0-2.5 | 100 |
| TECO THC Analyzer (0-1000 ppm) | NA [a] | NA [a] | NA [a] | 18 | 0.1-2.2 | 100 | 6 | 0-1.9 | 100 |
| TECO $NO_X$ Analyzer (0-4000 ppm) | 9 | 0-1.4 | 100 | 6 | 0.1-4 | 100 | 6 | 0-2.5 | 100 |

[a] The method called for calibration gases to be introduced at a point of the sampling system close to the sampling probe for them to flow through the heated sample line. Calibration gases were not injected directly to the analyzer

#### 5.1.2 Carbonyls (SW-846 Method 8315A)

The following MQOs were established in the QAPP for this method:

- Recovery (formaldehyde): 50-150 percent
- Completeness: >90 percent

Four samples (including one field blank) were submitted from Landfill C for formaldehyde and acetaldehyde determination to Resolution Analytics. Results were reported in RFA#RN990230. The report included information on instrument calibration and internal QC checks. Samples were collected on May 14, 2004 received by the laboratory on May 19, 2004 and analyzed on June 7, 2004, which met the 30 day hold-time limitation. Analytical detection limits were reported as 50 ppb for formaldehyde and 51.7 ppb for acetaldehyde.

The field blank (LDFLC-M0100-051404-FB) did not have detectable levels of either compound. To assess accuracy, an external performance evaluation audit (PEA) sample containing 1.25 ppm formaldehyde and acetaldehyde was analyzed with the sample set. Recovery was 101 percent for both compounds, which met the 50-150 percent MQO established in the QAPP. This spike was analyzed in duplicate with a percent difference (%D) between injections of 4.8 percent. All project samples were injected in duplicate and the %D range for formaldehyde was 0 to 4.5 percent and for acetaldehyde was 0 to 3.6 percent. All MQOs were met for this method for a completeness of 100 percent.

#### 5.1.3 Hydrogen Sulfide ($H_2S$) (EPA Method 11)

The following MQOs were established in the Landfill C QAPP for this method:

- Accuracy: ±5 percent bias
- Completeness: >90 percent

Four samples plus reagent blanks were submitted from Landfill C for $H_2S$ analysis by EPA Method 11 to Oxford Laboratories. The samples were collected on May 14, 2004 submitted on May 27, 2004 and analyzed on June 17, 2004, which exceeded the 30-day hold time established in the QAPP by three days.

One spike and one set of duplicates were also performed by the laboratory as addition QC checks. Spike recoveries were reported as 109 percent, which met the MQO. The duplication of sample LDFLC-PRE-M0011-51304-02 yielded a titration difference of only 0.3 ml. Although the final values were greater than 10 percent difference, this is an acceptable duplicate. The final difference is because of the small titration difference between the sample and the blank.

#### 5.1.4 Dioxins and Furans (PCDD/PCDFs) (EPA Method 23/0011)

The following MQOs were established in the Landfill C QAPP for this method:

- Accuracy: 50-150 percent recovery
- Completeness: >90 percent

Five samples (including field blank and reagent blanks) from Landfill C were submitted for PCDD/PCDF analysis to ALTA Analytical Perspectives. Results were reported in Report #P4173. Detailed information on instrument calibration and laboratory quality assurance (QA)/QC was received with the analytical report. Samples were collected on May 14-15, 2004 received on May 26, 2004, extracted on June 1, 2004 and analyzed on June 11, 2004, which met the 14 day extraction and 30 day analysis hold-time requirements.

The field blank (LDFLC-POST-M23-051304-FB) did not have detectable levels of any dioxin or furan congeners or totals. The laboratory method blank was also clean. Mean recoveries of extraction standards ranged from 78 to 91 percent. Mean recoveries of sampling standards ranged from 95 to 101 percent. All MQOs were met and the achieved completeness for this measurement was 100 percent.

#### 5.1.5 Polycyclic Aromatic Hydrocarbons (PAHs) (CARB 429)

The following MQOs were established in the Landfill C QAPP for this method:

- Accuracy: 50-150 percent recovery
- Completeness: >90 percent

Five samples (including field blank and reagent blanks) from Landfill C were submitted for PAH analysis to ALTA Analytical Perspectives. Results were reported in

Report #P4173. Detailed information on instrument calibration and laboratory QA/QC was received with the analytical report. Samples were collected on May 14-15, 2004, received on May 26, 2004, extracted on June 1, 2004, and analyzed on June 11, 2004, which met the 14 day extraction and 40 day analysis hold-time requirements.

There were reportable concentrations of PAHs detected in the field blank (LDFLC-POST-M23-051304-FB). Table 5-2 presents the amounts of the target analytes found in the blank samples and in the test samples. The amounts of PAHs in the test samples were significantly larger than those in the field blank sample and the method blank sample. Therefore, the presence of detectable quantities of PAHs in the blank samples did not affect the conclusions drawn from PAH analysis.

Recoveries for all extraction standards (ES) ranged from 53 percent to 115 percent with the exception of $d_{12}$-perylene, which was consistently below the acceptable limits. Sampling standards were all within acceptable limits ranging from 85.6 to 107 percent recovery. Because of the low recoveries of $d_{12}$-perylene, the reported concentrations of perylene were noted in the results in Table 4-14.

#### 5.1.6 Non-Methane Organic Compounds (NMOCs) (Method 25C)

The following MQOs were established in the QAPP for Landfill C:

- Accuracy: ±5 percent bias
- Completeness: >90 percent

Four canister samples (including a field blank) were submitted from Landfill C for NMOC analysis by Method 25-C to Triangle Environmental Services. The samples were collected on May 12-14, 2004, submitted on June 3, 2004, and analyzed June 7-22, 2004, which met the 30 day hold time requirements. The laboratory report included information on instrument calibration and internal QC checks.

**Table 5-2. Amounts of Polycyclic Aromatic Hydrocarbons in Blank Samples and Test Samples**

| Analyte | Method Blank First Analysis Amount (ng) | Method Blank Second Analysis Amount (ng) | Amount found in Field Blank (ng) | Average Amount Found in Test Samples (ng) |
|---|---|---|---|---|
| Acenaphthene | 1.14 | 1.2 | 3.74 | 2303 |
| Acenaphthylene | ND | ND | 0.885 | 6260 |
| Anthracene | 1.84 | ND | 3.85 | 1543 |
| Benzo(a)anthracene | ND | ND | 4.55 | 258 |
| Benzo(a)pyrene | ND | ND | 3.89 | 13 |
| Benzo(b)fluoranthene | 1.08 | 1.18 | 22.5 | 188 |
| Benzo(g,h,i)perylene | ND | ND | 6.77 | 25 |
| Benzo(k)fluoranthene | ND | ND | 6.08 | 45 |
| Chrysene | 0.434 | ND | 29.2 | 685 |
| Dibenzo(a,h)anthracene | ND | ND | ND | 12 |
| Fluoranthene | 3.58 | 3.34 | 201 | 1493 |
| Fluorene | 17.5 | 16 | 18.1 | 2933 |
| Indeno(1,2,3-cd)pyrene | ND | ND | 7.56 | 35 |
| Naphthalene | 968 | 768 | 10900 | 178000 |
| Phenanthrene | 13.3 | 11.7 | 113 | 11100 |
| Pyrene | 3.61 | 3.53 | 84.4 | 1200 |
| 2-Methylnaphthalene | 14.6 | 11.9 | 60.5 | 27800 |
| Benzo(e)Pyrene | ND | ND | ND | 128 |
| Perylene | ND | ND | ND | 4 |

The only NMOC detected in the field blank (LDFLC-PRE-M40-051204-FB) was reported at 8 ppm as carbon. Sample concentrations were well above this value. Accuracy for the method was assessed by evaluating results of RF check samples that were run prior to and following sample analysis. Acceptance criteria established by the method is that the RF must be within 20 percent of the RF from initial calibration. All RF checks were within 10 percent of the initial calibration, well within the acceptance criteria. The %D between the pre and post-test checks were less than 1 percent. Samples were run in triplicate and all percent relative standard deviations (RSDs) for samples were <5 percent. The data set was determined valid. The MQOs for accuracy were met and the completeness achieved for this measurement was 100 percent.

#### 5.1.7 Hydrogen Chloride (HCl) (EPA Method 26A)

The following MQOs were established in the QAPP for Landfill C:

- Accuracy: ±10 percent bias
- Completeness: >90 percent

Four samples (including one field blank) were submitted from Landfill C for HCl and chlorine ($Cl_2$) determination to Resolution Analytics. Results were reported in RFA#RN990230. The report included information on instrument calibration and internal QC checks. Samples were collected on May 14, 2004, received on May 19, 2004, and analyzed on June 7, 2004, which met the 4 week hold-time requirement. Analytical detection limits were reported as 2.6 ppm for HCl and 2.5 ppm for $CL_2$.

The field blank (LDFLC-M26-051404-FB) submitted with samples did not have detectable levels of HCL of $Cl_2$. In-house audit samples were analyzed with each respective group of field samples and fell within method criteria of 10 percent of their expected values. A matrix spike was performed on sample LDFLC-051404-3. An 0.8 mls sample was spiked with 0.8 mls of standard (50 ppm for HCl/25 ppm for $Cl_2$) and analyzed in triplicate. The laboratory reported 99 percent recovery of the HCl spike with a 0.4 percent RSD in triplicate injections and 102 percent recovery of the $Cl_2$ spike with a 0.3 percent RSD. This met the MQO of ±10 percent with very good precision. In addition to the matrix spike, an internal QC check was performed after every 10 samples. All samples were measured in triplicate. Calculated bias for internal QC check was <1 percent for all measurements as was the %D between triplicates. All MQOs were met for 100 percent completeness.

#### 5.1.8 Metals (EPA Method 29)

The following MQOs were established in the Landfill C QAPP for this method:

- Accuracy: ±25 percent bias
- Completeness: >90 percent

Four sets of Method 29 Multi-Metals trains (including one field blank) were submitted from Landfill C for As, Cd, Cr, Pb, Mn, Hg, and Ni determination to First Analytical Laboratories. Results were reported in Project #40513. The report included information on instrument calibration and internal QC checks. Samples were collected on May 14, 2004, received on May 19, 2004, and analyzed on May 24-26, 2004, which met the 14 day hold-time requirement. Method detection limits for each of the target metals were reported as follows:

- As = 5.0 µg/L
- Cd = 0.2 µg/L
- Cr = 5.0 µg/L
- Pb = 5.0 µg/L
- Mn = 5.0 µg/L
- Ni = 10 µg/L
- Hg = 0.2 µg/L

Traces of Cd, Cr, Mn, and Ni were found in the blanks, which is not unusual. Some of the back half Mn samples are abnormally high. This is a common problem that can occur in Method 29 if a tiny amount of the potassium permanganate reagent gets into the hydrogen peroxide impingers.

All samples were spiked prior to analysis. The Cd back half spike recovery was poor (56 percent), so the Cd back half analysis was conducted by the method of standard additions to overcome the problem. All of the other spike recoveries were within the acceptable range of 75-125 percent. In addition to spiking the samples, for each metal, internal calibration verification samples (ICVs) and continuing calibration verification samples (CCVs) were performed. ICVs were run at the beginning of each run set and CCVs were run at a frequency of 1 for every 10 samples. The ICVs and CCVs measured values were all <±10 percent for all metals with the exception of Ni. Two of the four CCV measurements for Ni were slightly above the 10 percent acceptance criteria at 10.6 percent and 14.0 percent. This was not considered a major failure and data limitations were not applied. To evaluate precision, all samples were analyzed in duplicate. Whenever the %RSD for duplicate measurements exceeded 20 percent, the sample was re-analyzed. Though CCVs fell slightly outside of range for one metal (Ni), all other metals were within acceptance criteria and data use was not limited, these analyses are considered 100 percent complete. The Ni results were notated in Table 4-16 to reflect the out-of-range CCV check.

#### 5.1.9 Total Mercury (Hg) and Organo-mercury (Hg) (Frontier)

The following MQOs were established in the Landfill C QAPP for this method:

- Recovery: 50-150 percent
- Completeness: >90 percent

For Hg samples, replicates and spikes were incorporated into the sampling scheme. In addition, performance evaluation audit samples were also submitted to Frontier for analysis. Results from the PEA are summarized in Section 5.2.2.2.

Four total Hg samples (including a field blank) were taken at Landfill C. Samples were collected on May 13, 2004, extracted on May 28, 2004, and analyzed on June 3, 2004, which did not meet the 14 day hold-time established in the QAPP. All other QA measures indicated that the analysis of the traps were under good control. All field blanks were consistent with historical values and indicated the detection limit was likely to be at or below the previous estimated value of 50 $ng/m^3$. Spike recoveries were >95 percent and standard deviation between replicates was 1.9 percent, which met MQOs and are 100 percent complete.

Six monomethyl mercury (MMHg) samples (including a field blank) were collected at Landfill C on May 13, 2004. These samples were extracted on May 27, 2004 but analyzed on May 28, 2004 which is one day past the 14 day hold-time. Analysis of these samples was under good control with acceptable distillation spike recoveries and distillation duplicates. All CCV standards had acceptable recoveries. One or the six gas sample was lost because of accidental back flush of the sampling pump by the operator. Spike recoveries were 80-117 percent, which met MQOs. The RSD between replicates was <10 percent. Because of the loss of one sample, MMHg sampling and analysis was 83 percent, which is slightly below the MQO.

Four dimethyl mercury (DMHg) samples (including a field blank) were collected at Landfill C on May 13, 2004. These samples were extracted and analyzed on May 27, 2004, which met the 14 day hold-time. The analysis of samples was well within control, with acceptable recoveries and good linear control standards and second source standard recoveries. One of the triplicate samples taken at Landfill C displayed significantly lower concentrations compared to the other samples, potentially because inadequate purging of the sampling line dead volume. The low value could not statistically be excluded from the site average therefore the RSD for replicates at this site is elevated to 50.4 percent.

The field blank was low indicating that the trap media, handling procedures, and analytical techniques did not contribute to the reported values. Field matrix spike recoveries ranged from 50-93 percent. The DMHg analysis was 100 percent complete.

#### 5.1.10 Volatile Organic Compounds (VOCs) and Methane ($CH_4$) (Method 0040/Method TO-15)

The following MQOs were established in the Landfill C QAPP for this method:

- Accuracy: 50-150 percent recovery
- Completeness: >90 percent

Four SUMMA canisters (including one field blank) were submitted from Landfill C to RTP Laboratories for VOC and $CH_4$ determination by EPA Method TO-15. Results were reported in Project #04-107. Samples were collected on May 13, 2004, received on May 20, 2004, and analyzed on May 25, 2004, which met the 30 day hold-time requirement.

Analysis of the field blank (LDFLC-PRE-M40-51304-FB) resulted in significant levels of several VOC compounds. Table 5-3 list the compounds identified in the field blank that were >1 ppbv. This should be considered when evaluating sample data.

To assess accuracy of the analytical method, a field spike was performed by injecting 2130 ppbv of chlorobenzene into the third canister (LDFLC-PRE-M40-051304-3). Recovery of the field spike was reported at 117 percent. Precision was demonstrated through multiple injection of standards at five concentrations. The RSD between the calculated relative RFs must be <30 percent with allowances that 2 may be >40 percent. The average RSD was 11.3 percent and method criteria were met for all compounds. This met the established MQOs. Valid data was received for all SUMMA canisters submitted; these analyses are considered to be 100 percent complete. The results in Table 4-1 were notated accordingly. Moreover, the measured average sample concentrations of these analytes were many folds the deleted blank concentrations. Therefore, conclusions that may have been drawn from these results are not affected materially.

**Table 5-3. VOCs Identified in Field Blank**

| Compound | Blank Sample Concentration (ppbv) | Test Sample Average Concentration (ppbv) |
|---|---|---|
| Isopropyl alcohol | 2.8 | 1280 |
| Methylene chloride | 9.4 | 5350 |
| Acetone | 13.5 | 11700 |
| Tetrahydrofuran | 35.6 | 1170 |
| 2-butanone | 5.4 | 4570 |
| Heptane | 1.3 | 2860 |
| Toluene | 378 | 23300 |
| MIBK | 21.3 | 2170 |
| Tetrachloroethylene | 37 | 1690 |
| 1,1,2-trichloroethane | 11.4 | 445 |
| Ethylbenzene | 1.5 | 5890 |
| m/p-Xylene | 5.8 | 9200 |
| o-Xylene | 1.5 | 3660 |
| 1,2,4-trimethylbenzene | 1.8 | 1510 |

## 5.2 Audits

### 5.2.1 EPA Technical Systems Audit

EPA/APPCD QA Representative, Robert Wright, conducted an on-site technical systems audit (TSA) of the field evaluations at Landfill C on May 12-13, 2003. The ARCADIS approved QAPP and the associated field sampling manual provided the technical basis for the audit. The ARCADIS QA Officer, Laura Nessley, accompanied the EPA auditor during the TSA. A report of preliminary findings was received on May 19, 2004 and it is included below.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
**NATIONAL RISK MANAGEMENT RESEARCH LABORATORY**
Air Pollution Prevention and Control Division
Research Triangle Park, NC 27711

May 19, 2004

**<u>MEMORANDUM</u>**

**SUBJECT**: Preliminary findings from technical systems audit conducted on May 12-13, 2004 of ARCADIS' field evaluation of landfill gas control technologies at landfill C

**FROM**: Robert S. Wright, Technical Services Branch

**TO**: Susan A. Thorneloe, Atmospheric Protection Branch

I conducted a technical systems audit (TSA) on May 12-13, 2004 of ARCADIS' field evaluation of landfill gas control technologies at Landfill C. This assessment was conducted according to auditing procedures described in *Guidance on Technical Audits and Related Assessments for Environmental Data Operations (EPA QA/G-7)*. ARCADIS' approved quality assurance project plan (QAPP) and its associated field sampling manual provided the technical basis for the TSA. The checklist for the TSA was sent to ARCADIS on May 9, 2004 and was distributed to the project staff prior to the audit. The following are preliminary findings of the audit.

1. In general, I observed that ARCADIS is doing a good job of evaluating landfill gas control technologies at Landfill C. ARCADIS' project staff are well qualified to perform the evaluation and they conducted themselves in a professional manner. They cooperated with me during the TSA and took time out from their busy duties to explain what was happening. They helped to ensure the successful completion of the TSA.

2. In general, the evaluation is being implemented as stated in the QAPP for the project.

3. There were significant disruptions of the testing schedule for reasons beyond ARCADIS' control: the long power loss at Landfill C on May 12; the malfunction of the internal combustion engine on May 12; the higher-than-expected pressure in the engine's exhaust stack on May 13; and inclement weather on May 13. ARCADIS' project staff responded well to these disruptions and modified the planned test matrix and schedule to allow completion of the most important measurements within the available time and funding. Some of these measurements were conducted on May 14.

4. Because some of the measurements were conducted after I had left on May 13 to return to North Carolina, the TSA did not cover all the items on the checklist. Given the general level of expertise and competence displayed by ARCADIS' project staff, I believe that the quality of the measurements that I did not observe is as high as the quality of the measurements that I was able to observe.

5. Sampling for the total mercury and organo-mercury measurements was conducted by Lucas Hawking of Frontier Geosciences, Inc. He approached the sampling in a careful, competent, and professional manner. He followed the standard operating procedures (SOPs) for this sampling.

6. ARCADIS' project staff used both laboratory notebooks and data sheets to record data and observations during the evaluation. In several instances, this information was written in the laboratory notebooks without including the date and the name of the person recording this information. If there is not enough time during sampling activities to follow ARCADIS' procedures for laboratory notebooks, the project staff should add the date and name at the end of the day before they leave the site.

7. The field team leader had copies of equipment calibration certificates in a folder in his possession. However, the certificates of analysis for the gaseous calibration standards were attached to the cylinders under some plastic mesh and the cylinders were attached to the wall behind a table. It was difficult to read the certificates without disrupting the equipment. For future TSAs, ARCADIS may wish to include copies of the certificates of analysis for gaseous calibration standards in the folder to minimize testing disruptions.

8. No check weights were brought into the field to verify that the balance was operating correctly as was described in the QAPP. A crude quality control (QC) check was performed using the weights of known volumes of water and suggested that the balance was operating properly. Upon returning to North Carolina, the APPCD Metrology Laboratory will use NIST-traceable check weights to verify that the balance is operating properly. For future field evaluations, ARCADIS should ensure that check weights are taken with the balance.

9. A gas dilution system was used to calibrate the continuous emission monitors (CEMs) according to EPA Method 205. The ARCADIS CEMs operator had a copy of the September 17, 2003 calibration of this instrument in the APPCD Metrology Laboratory. However, a label containing information about this calibration was not affixed to the gas dilution system as is required by the method. ARCADIS should contact the APPCD Metrology Laboratory to obtain such a label.

A draft findings report for this TSA will be completed in the coming month. It is possible that it may contain additional findings that arise from closer consideration of the audit results, but I do not expect any new findings will address significant problems relating to the project.

Please contact me if you have any questions about the TSA or about this memorandum.

### 5.2.2 Laboratory Audits

Because of the developmental nature of the organo-Hg methods, an internal TSA and PEA were performed by ARCADIS at Frontier Geosciences (Frontier), located in Seattle, Washington.

#### *5.2.2.1 Internal Technical Systems Audit (TSA)*

In an effort to save project funds, a Senior Scientist at the ARCADIS Seattle office was asked to perform the laboratory audit, which would include observation of spiking procedures for MMHg and DMHg media prior to shipment to the field and subsequent analysis of project samples for MMHg, DMHg and total Hg. Ms. Laura Nessley provided Mr. Hicks with checklists to use during the audit. The audits of Frontier's spiking procedures were carried out on April 29, 2003, for MMHg and May 4, 2004, for DMHg and total Hg. Calibration, media spiking techniques, record keeping, and good laboratory practices were the focus of the audit, with special attention paid to the MMHg and DMHg spike preparation for the upcoming field effort. The following Frontier personnel and their associated positions were present for some or all of the audits conducted by ARCADIS.

Some of the primary observations resulting from the first audit included:

- A single source for calibration and spiking was used for MMHg and DMHg. The laboratory had not been able to locate other stable standards for use as an independent source. There were not National Institute of Standards and Technology (NIST)-traceable standards for organo-Hg.

- There were not expiration dates for primary MMHg and MDHg standard materials. The source of the MMHg standard had a 1998 date on the bottle.

- There are not written procedures for spiking of impinger solutions or carbon tubes.

- While work plans state that samples should be kept cold and the organometallic analytes are light sensitive, the analytical standard for MMHg was stored in a clear Teflon bottle on an un-refrigerated shelf across from a large picture window.

- Frontier did not routinely retain an aliquot of spike solution nor spiked traps when sending media to a field project.

The continuation of the earlier audit that focused on matrix spiking and media preparation was performed in late May 2004. This audit concentrated on the analysis of the sampling media sent to Landfill sites C and D, including extraction, analysis, and calibration procedures for MMHg, DMHg, and total Hg. These audits were conducted on three separate days to accommodate Frontier's analysis schedule. On May 27, 2004, the audit focused on MMHg extraction and distillation and DMHg analysis. On May 28, 2004 MMHg analysis and total Hg extraction procedures were audited. On June 3, 2004, the procedures for total Hg analysis were audited.

Significant findings and recommendations resulting from the extraction and analysis portion of the laboratory audit included:

- **Efficiency factor (EF)**. An efficiency factor (EF) based on average results from the analyses of distillation blanks was applied to all MMHg sample results. This practice was not discussed in the narrative portion of the Frontier reports and not mentioned by name in the standard operating procedures (SOPs) provided to ARCADIS. This technique essentially boosts analyte recoveries through a multiplied efficiency factor applied to all MMHg results. The current EF is 89.5 percent, therefore all results were normalized to 100 percent recovery levels. For example, a measured value of 100.0 ng detected in an environmental sample was corrected to 110.5ng after applying the EF. Without a data report disclaimer, this practice misrepresents the results and biases all MMHg results high.

- **Method blank subtraction**. Frontier subtracts the average of the method blanks from each extraction/preparation batch. While scientifically valid, this technique is not acceptable for most EPA-referenced protocols. The laboratory has a responsibility only to report blank concentrations, and it should be the responsibility of the client to adjust environmental sample concentrations through a data evaluation/validation process.

- **MMHg Instrument stability**. The MMHg analysis was performed over a 2-day period because of poor instrument stability and issues associated with efficiency of the ethylating reagent. Initially, two instruments were set up for calibration on May 27$^{th}$. Only one of the instruments showed sufficient sensitivity and stability to continue analysis. Unfortunately, the initial calibration curve did not meet method specifications, so the instrument was recalibrated and environmental samples analyzed while the ARCADIS auditor was present. The following day, the auditor was informed that the sample set did not meet the QAPP requirements because of unexpected lower concentrations in the samples. The samples were successfully reanalyzed the following day after maintenance was performed on the MMHg analysis instrument. Reanalyzing samples is apparently common and sometimes entire sample sets are analyzed more than once. Frontier stated that it is “the nature” of this analysis to have to frequently recalibrate and reanalyze samples. Calibrations should be closely reviewed during data validation.

- **Calibration Curve Forcing:** ARCADIS learned that, in accordance with Frontier policy, all calibration curve origin points were forced through zero. This procedure is not consistent with most EPA-promulgated methods. ARCADIS recommends reprocessing one calibration curve to determine the impact, if any, to the data.

- **Retention Time Marking:** While observing the MMHg analysis, the analyst did not mark the beginning of the analysis charts with a “tick” time marker, which is particularly critical given that identification of MMHg is primarily by retention times or relative retention times. Some of the samples being analyzed had numerous chromatographic peaks including MMHg and other forms of Hg. Based on observation of other laboratory “pods” within Frontier, the marking of the actual start time on the strip chart recorder was not standardized as a procedural practice. Some analysts mark the desorption time on the strip chart recorder and others do not. However, marking of analysis start times should be a requirement of each method in the place of automatic chromatographic data collection (integrators or computer data acquisition) to avoid misidentification of analyte targets. ARCADIS recommends the standardization of marking the start of analysis on strip chart recorders.

- **Digestate Dilution Technique:** The method of bringing the digested total Hg to quantitative volume in a 20 milliliter glass vial was unusual as the technique does not rely on marked, calibrated Class A or B glassware when bringing digested samples to a known quantitative volume. The analyst did not know if the volume of the unmarked vials was recently compared against calibrated glassware, but assumed it was 20 mL. The analyst consistently brought the digested samples to a consistent level that corresponded to the neck of the glass vial. At a minimum, the vials should be calibrated to assure the final volumes are accurate.

- **Sample/Standard Storage:** One refrigerator (“A”) and one freezer (“A”) used to store samples, analytical standards, and frozen ethylating cocktails were not monitored for 3 days prior to the audit (5/25/04). This did not appear to be a systematic problem, but the analyst did not have an explanation. Verification of temperatures in standard and sample storage areas should be checked daily.

- **Calibration Verification:** While discussed in the previous ARCADIS Audit report dated May 17, 2004, this observation is again included because it is critical to the evaluation of the laboratory and the application of these methods to raw LFG monitoring. Frontier uses a single source for calibration and spiking for MMHg and DMHg methods. The laboratory has not been able to locate other acceptable, stable standards, such as NIST-traceable standards. Frontier utilizes Standard Reference Materials and certified standards however, accuracy is only measured for MMHg by comparison to a digested tissue standard and for DMHg by comparison to JSI-1, a material from the JSI Institute in Slovenia. ARCADIS recommends that Frontier make an effort to locate alternate acceptable accuracy standards to verify true concentrations of the main calibration standards.

- **Holding Times:** Holding times are generally not an issue with most analyses Frontier performs, but based on the QAPP, specific holding times to analysis apply to this analysis. This was not documented in the summary report; however the total, MMHg and DMHg analyses were extracted, but not all analyzed within the 14 day holding time assuming May 27$^{th}$ was the 14$^{th}$ day after sampling. Some data qualification might be necessary, depending on the professional judgment of the data validator.

#### *5.2.2.2 Internal Performance Evaluation Audit (PEA)*

Because there is currently not a promulgated method for organo-Hg sampling and analysis, PEA samples were integrated in to the sampling matrix to evaluate accuracy and precision of the methods used by Frontier. ARCADIS subcontracted an independent laboratory to assist in preparation of the PEA samples. The laboratory was Cebam Analytical located in Seattle, Washington. All standards and stock solutions were prepared and verified by a Cebam Analysical analyst.

Two PEA samples were prepared for total Hg. Trap A was spiked with 9.99 ng total Hg by a Cebam analyst. This concentration was verified by Cebam by performing six replicate analyses. Samples were analyzed by Frontier Geosciences as described in the report titled: Determination of Total, Dimethyl, and Monomethyl Hg in raw LFG at Pinconning and Montrose Michigan. Recovery results are presented in Table 5-3. Relative percent difference (RPD) between the duplicate samples was 1.0 percent.

**Table 5-3. Total Mercury PEA Results**

| Sample ID | Total Hg Measured (ng) | Total Hg Spiked (ng) | Recovery (%) |
|---|---|---|---|
| C-052104-01 | 13.60 | 9.99 | 136 |
| C-052104-02 | 13.47 | 9.99 | 135 |

One PEA sample was prepared and analyzed for MMHg. A 2.0 ng/l spiking solution was prepared by transferring a 0.2 ml aliquot of 10 ng/ml standard into a 1-l pre-cleaned glass volumetric flask. The sample was analyzed by Frontier as described in the report titled: Determination of Total, Dimethyl, and Monomethyl Mercury in raw LFG at Pinconning and Montros, Michigan. Recovery results are presented in Table 5-4. Because only one sample was prepared, precision for this analysis could not be evaluated.

**Table 5-4. MMHg PEA Results**

| Sample ID | Total MMHg Measured (ng/L) | Total MMHg Spiked (ng/L) | Recovery (%) |
|---|---|---|---|
| 040513-BR-MHg7 | 2.327 | 2.00 | 117 |

Two PEA samples were prepare and analyzed for DMHg. Trap A and Trap B were spiked with 0.215 ng DMHg for a total concentration of 0.430 ng per train. This concentration was verified by Cebam by analyzing five replicates samples of the standard.

The samples were analyzed by Frontier as described in the report titled: Determination of Total, Dimethyl, and Monomethyl Mercury in raw LFG at Pinconning and Montros, Michigan. Recovery results are presented in Table 5-5. RPD between the duplicate samples was 23 percent.

**Table 5-5. DMHg PEA Results**

| Sample ID | Total MMHg Measured (ng)* | Total MMHg Spiked (ng)* | Recovery (%) |
|---|---|---|---|
| Arcadis DMM Spike #1 | 0.234 | 0.430 | 54.4 |
| Arcadis DMM Spike #2 | 0.295 | 0.430 | 68.6 |

*Trap A and Trap B together

In conclusion, the MQO for recovery for total Hg and organo-Hg samples (as defined in the QAPP) was established at 50 to 150 percent. All PEA samples met this objective. The RPD between duplicate samples was also acceptable. The full text of the TSA and PEA audit reports and completed checklists are included in Appendix S.

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# Field Test Measurements at Five Municipal Solid Waste Landfills with Landfill Gas Control Technology
# Final Report

## Appendix D

## SOURCE TEST REPORT FOR LANDFILL D

## Table of Contents

## Tables

## Figures

## Appendices

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## Acronym List

| | |
|---|---|
| %D | Percent difference |
| AP-42 | Compilation of Air Pollutant Emission Factors |
| APPCD | Air Pollution Prevention Control Division |
| ARCADIS | ARCADIS G&M, Inc. |
| As | Arsenic |
| CCVs | Continuing calibration verification samples |
| Cd | Cadmium |
| CEMS | Continuous emission monitoring system |
| $CH_4$ | Methane |
| $Cl_2$ | Chlorine |
| CO | Carbon monoxide |
| $CO_2$ | Carbon dioxide |
| Cr | Chromium |
| DMHg | Dimethyl mercury |
| EF | Efficiency factor |
| EPA | US Environmental Protection Agency |
| FID | Flame ionization detector |
| Frontier | Frontier Geosciences |
| GC/FID | Gas chromatograph/flame ionization detector |
| HCl | Hydrogen chloride |
| Hg | Mercury |
| $H_2S$ | Hydrogen sulfide |
| ICVs | Internal calibration verification samples |
| LFG | Landfill gas |
| MMHg | Monomethyl mercury |
| Mn | Manganese |
| MQOs | Measurement quality objectives |
| MSW | Municipal solid waste |

# Acronym List

| | |
|---|---|
| $N_2$ | Nitrogen |
| Ni | Nickel |
| NMOCs | Non-methane organic compounds |
| $NO_X$ | Nitrogen oxides |
| $O_2$ | Oxygen |
| PAHs | Polynuclear aromatic hydrocarbons |
| Pb | Lead |
| PEA | Performance evaluation audit |
| QA | Quality Assurance |
| QAPP | Quality Assurance Project Plan |
| QC | Quality control |
| RF | Response factor |
| RPD | Relative percent difference |
| RRF | Relative response factors |
| RSD | Relative standard deviation |
| RTP | Research Triangle Park |
| $SO_2$ | Sulfur dioxide |
| SOPs | Sstandard operating procedures |
| SVOC | Semi-volatile organic compounds |
| TCDD/TCDFs | Dioxins/furans |
| THCs | Total hydrocarbons |
| TSA | Technical systems audit |
| VOCs | Volatile organic compounds |

## 1. Introduction

Large municipal solid waste (MSW) landfills are subject to Clean Air Act regulations because of concerns related to their emissions and their potential adverse effects to human health and the environment. Landfills are listed as a source of air toxics in the Urban Air Toxics Strategy for future evaluation of residual risk. Existing emission factors for landfill gas (LFG) were largely developed using data from the 1980s and early 1990s. A database was developed summarizing data from approximately 1,200 landfills, along with emissions information from literature, test reports prepared by state and local government agencies, and industry. These data were summarized in *Compilation of Air Pollutant Emission Factors (AP-42)*, Chapter 2.4. 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 overall purpose of this testing program was to generate data that could be used to update AP-42 and to include data that reflect current waste management practices.

This report presents the results of a field test conducted at Landfill D, located in a Midwest industrial state. Testing took place on May 15 and 16, 2004. Data from the raw gas volatile organic compounds (VOCs) samples showed that an error had occurred. Collection of samples to replace the defective samples was conducted on September 14, 2004.

The site uses an enclosed flare for destruction of the LFG. A more detailed description of the flare system is presented in Section 2. The specific purpose of the testing program was to determine emissions from the raw pipe and from the flare stack. The pollutants of interest for the raw untreated LFG were VOCs, non-methane organic compounds (NMOCs), hydrogen sulfide ($H_2S$), carbonyls (acetaldehyde, formaldehyde), and mercury (Hg) compounds. The pollutants of interest for the treated LFG, in this case at the enclosed flare stack, were carbon monoxide (CO), nitrogen oxides ($NO_X$), sulfur dioxide ($SO_2$), NMOCs as total hydrocarbons (THCs), hydrogen chloride (HCl), total Hg and metals.

ARCADIS Geraghty & Miller, Inc. (ARCADIS) as contractor to the US Environmental Protection Agency (EPA) Air Pollution Prevention and Control Division (APPCD), performed this work under Work Assignment 0-27 of Onsite Laboratory Support Contract (EP-C-04-023). The testing activities followed the specifications of the approved *Site-Specific Quality Assurance Project Plan for the Field Evaluations of Landfill Gas Control Technologies Landfill* dated October 2003.

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# 2. Landfill Facility Descriptions

Available information indicated that the site began operation in 1991.Based on information provided by the site operator, Landfill D has approximately 2,350,000 tons of waste in place as of August 2004.The waste covered an area of 31 acres. The LFG generated at the landfill were extracted with 21 vertical wells producing a total of 400 cubic feet per minute. The collected LFG was piped to the enclosed flare system for combustion.

## 2.1 Flare Process Description and Operation

A John Zink Model 72 Enclosed Ground Flare Station, rated at maximum LFG input rate of 695 scfm, received and destroyed the collected LFG. Figure 2-1 shows a simplified process schematic of the flare system. A condensate removal system prevented liquids from entering into the flare burners. A flame arrestor prevented flame from propagating from the burner array back into the LFG collection and flow control system. A burner array and an automatic louver system controlled gas and air distribution to achieve proper combustion. The unit could be operated satisfactorily within a 5-to-1 turndown ratio (from 20.9 to 4.0 MMBtu/hr). The system did not have provisions for heat recovery.

According to manufacturer information, the John Zink Enclosed Ground Flare Station was designed for a minimum residence time of 0.7 seconds at 1800 °F to insure thermal destruction of CO and hydrocarbons, with minimal production of $NO_X$. Specific information related to the system's ability to destroy or reduce other potential pollutants was not available.

## 2.2 Sampling Locations

Raw LFG sampling was conducted at the pipe feeding the John Zink enclosed ground flare station and the flare stack as depicted in Figure 2-1.

### 2.2.1 Raw Landfill Gas (LFG) Header Pipe

Raw untreated LFG samples were collected from the header pipe, upstream of any processing units. The pipe was buried underground. Access to the pipe for sampling was achieved by excavating the soil above and around the pipe. Figure 2-2 is a photograph of the LFG inlet pipe. The pipe was 11 inches in inner diameter before it connects to the gas control-and-process system. At the sampling point, four ¼ inch gas

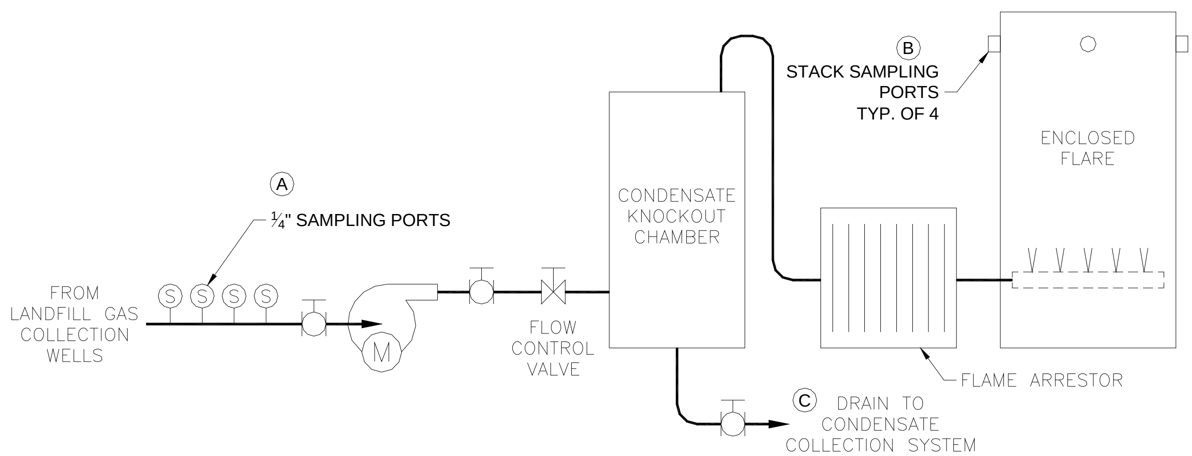


**Figure 2-1. Simplified Flare Process Flow Diagram and Sampling Points**

**Figure 2-2. Raw Landfill Gas Collection Pipe**

taps were installed and gases were withdrawn through these ports to obtain the test samples.

Comparing the physical arrangement of the header pipe with the requirements of standard sampling methodologies indicated that the header configuration rendered isokinetic sampling at the gas collection pipe impossible. Therefore, isokinetic sampling was not attempted at this location. Collected data showed that the particulate loading in the sample was very low, confirming that the effect of not strictly adhering to isokinetic sampling rates was insignificant.

### 2.2.2 Flare Stack

A picture of the flare stack and the arrangement of the sampling ports are shown in Figure 2-3. The flare stack was 72 inches in diameter and had two 4-inch sampling ports installed 90 degrees apart. Figure 2-4 is a schematic of the flare stack and it includes the locations of the sample traverse points. Isokinetic sampling was possible at this location and was followed.

**Figure 2-3. Enclosed Flare Unit Showing Stack Sampling Ports**

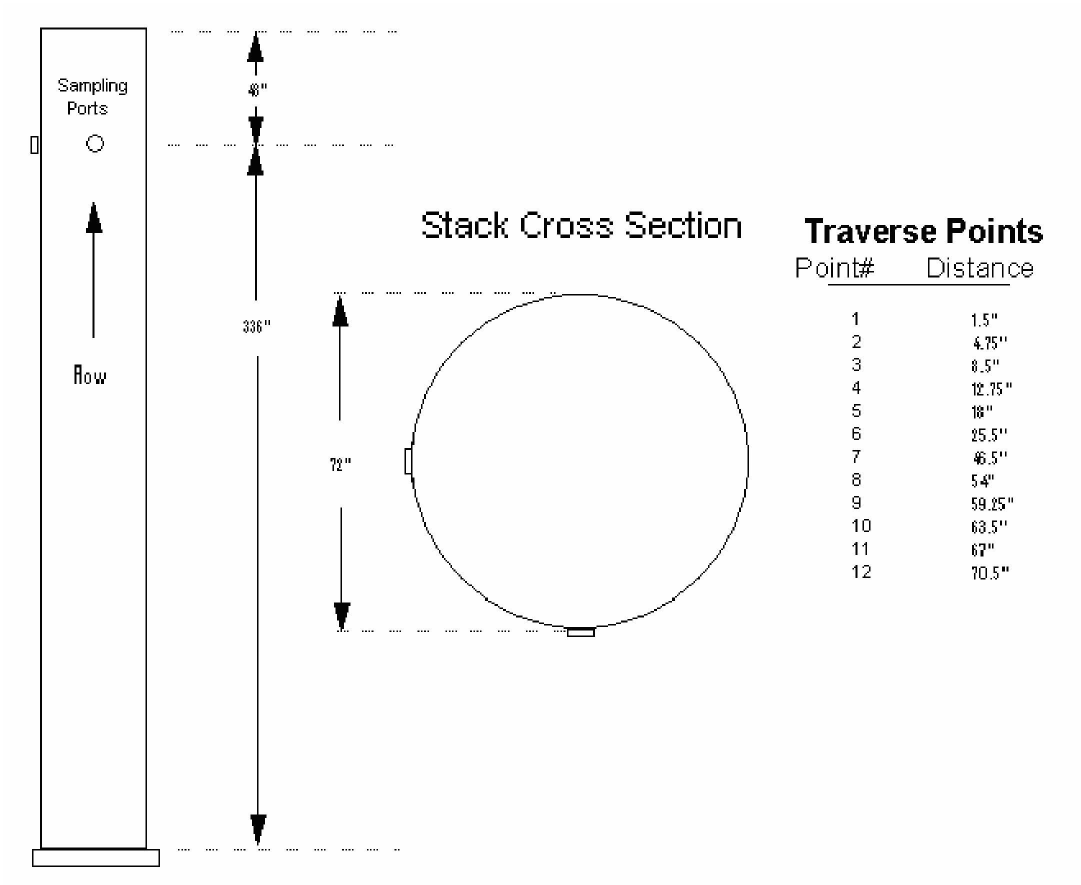


**Figure 2-4.  Flare Stack Dimension and Sampling Traverse Locations**

# 3. Test Operations

As stated previously, the purpose of the sampling program was to determine the concentrations of the target analytes in the raw LFG at the header pipe and emissions from the flare stack.

## 3.1 Test Team

The tests were conducted by a team of seven individuals. The team members and their primary duties are listed in Table 3-1.

**Table 3-1. Test Team Members and Responsibilities**

| Role | Primary Duty |
|---|---|
| Test Engineer | Field Supervisor |
| Test Engineer | CEM operator |
| Test Engineer | Sample train preparation and recovery |
| Test Engineer | Sample train operator at LFG inlet pipe |
| Sampling Technician | Sample train operator at stack |
| Senior Chemist | Mercury measurements |
| Senior Chemist (Frontier Geosciences) | Mercury measurements |

## 3.2 Test Log

### 3.2.1 Planned Test Sample Matrices

The list of target samples to be collected and measurements to be conducted were specified in the Quality Assurance Project Plan (QAPP) Revision 1 dated May 2004. These are reiterated here for completeness. Tables 3-2 lists the target compounds of interest for the raw untreated LFG. Table 3-3 lists the target compounds of interest for the treated gas, collected at the flare stack.

**Table 3-2. Target Analytes for the Raw Landfill Gas**

| Volatile compounds | Volatile compounds (continued) | Carbonyls |
|---|---|---|
| Methane | Ethylene dibromide | Acetaldehyde |
| Ethane | Ethylene dichloride | Formaldehyde |
| Propane | Methyl chloroform | |
| Butane | Methyl isobutyl ketone | **Mercury** |
| Pentane | Methylene chloride | Organo-mercury compounds |
| Hexane | Propylene dichloride | Total |
| Carbonyl sulfide | t-1,2-Dichloroethene | Elemental |
| Chlorodifluoromethane | Tetrachloroethene | |
| Chloromethane | Toluene | **Gases** |
| Dichlorodifluoromethane | Trichlorethylene | Carbon Dioxide |
| Dichlorofluoromethane | Vinyl chloride | Oxygen |
| Ethyl chloride | Vinylidene chloride | |
| Fluorotrichloromethane | Ethanol | |
| 1,3-Butadiene | Methyl ethyl ketone | |
| Acetone | 2-Propanol | |
| Acrylonitrile | 1,4-Dichlorobenzene | |
| Benzene | Ethylbenzene | |
| Bromodichloromethane | Xylenes | |
| Carbon disulfide | | |
| Carbon tetrachloride | | |
| Chlorobenzene | **Non-methane organic compounds** | |
| Chloroform | | |
| Dimethyl sulfide | **Reduced sulfur compounds** | |
| Ethyl mercaptan | Hydrogen sulfide | |

**Table 3-3. Target Analytes for the Flare Stack Outlet Gas Stream**

| **Gases** | **Dioxins/Furans** |
|---|---|
| Oxygen | **Polycyclic aromatic hydrocarbons** |
| Carbon dioxide | |
| Carbon Monoxide | **Mercury** |
| Nitrous Oxides | Total |
| Sulfur Dioxide | |
| Total Hydrocarbons | |
| **Non-methane organic compounds** (as Total Hydrocarbons) | **Metals** |
| | Lead, Arsenic, Cadmium, Chromium, Manganese, Nickel |
| **Hydrogen chloride** | |

### 3.2.2 Raw Landfill Gas (LFG) Pipe (Inlet)

Sample collection took two days to complete. Table 3-4 lists the samples that were collected from the LFG pipe. Figure 3-1 is a photograph of the sampling team in action at this sample location.

### 3.2.3 Flare Stack

Sampling at the flare stack was conducted by accessing the sampling ports with the aid of a scaffold. Figure 3-2 shows the flare and the sampling scaffold platform. Figure 3-3 shows a sampling in place during sample collection on the enclosed flare stack.

**Table 3-4. Raw Landfill Gas Sample Log and Collection Times**

| Sampling Method | Run Number | Analyte(s) | Sample Class | Date | Run Period |
|---|---|---|---|---|---|
| EPA Method 40 (TO-15/25C, 3C) [a] | | | | | |
| | D-Pre-M40-051504-01 | VOCs/NMOCs/$O_2$/$CO_2$,$N_2$ | Test | 05/15/04 | 12:43 - 13:44 |
| | D-Pre-M40-051604-02 | VOCs/NMOCs/$O_2$/$CO_2$,$N_2$ | Test | 05/16/04 | 09:56 - 10:55 |
| | D-Pre-M40-051604-03 | VOCs/NMOCs/$O_2$/$CO_2$,$N_2$ | Test | 05/16/04 | 11:43 - 12:43 |
| | D-Pre-M40-051604-0FB | VOCs/NMOCs/$O_2$/$CO_2$,$N_2$ | Field Blank | 05/16/04 | 14:27 |
| | | | | | |
| | D-Pre-M40-091404-01 | VOCs/NMOCs | Test | 09/14/04 | 10:32 - 11:32 |
| | D-Pre-M40-091404-02 | VOCs/NMOCs | Test | 09/14/04 | 12:08 - 13:08 |
| | D-Pre-M40-091404-03 | VOCs/NMOCs | Test | 09/14/04 | 13:43 - 14:43 |
| | D-Pre-M40-091404-FB | VOCs/NMOCs | Field Blank | 09/14/04 | 15:11 - 15:53 |
| | D-Pre-M40-091404-04 | VOCs/NMOCs | Field Blank | 09/14/04 | 16:05 - 17:05 |
| EPA Method 0100 | | | | | |
| | D-Pre-M0100-051604-01 | Carbonyls | Test | 05/16/04 | 15:25 - 15:57 |
| | D-Pre-M0100-051604-02 | Carbonyls | Test | 05/16/04 | 15:52 - 16:04 |
| | D-Pre-M0100-051604-03 | Carbonyls | Test | 05/16/04 | 16:05 - 16:36 |
| | D-Pre-M0100-051604-0FB | Carbonyls | Field Blank | 05/16/04 | 14:58 |
| EPA Method 11 | | | | | |
| | D-Pre-M0011-051504-01 [b] | $H_2S$ | Test | 05/15/04 | 13:47 - 13:57 |
| | D-Pre-M0011-051604-02 | $H_2S$ | Test | 05/16/04 | 10:42 - 10:53 |
| | D-Pre-M0011-051604-03 | $H_2S$ | Test | 05/16/04 | 11:56 - 12:07 |
| | D-Pre-M0011-051604-04 | $H_2S$ | Test | 05/16/04 | 12:51 - 13:02 |
| | D-Pre-M0011-051604-FB | $H_2S$ | Field Blank | 05/16/04 | 13:40 |
| Lumex Instrument | | | | | |
| | D-Pre-EM-051604-01 | Elemental Hg [c] | Test | 05/16/04 | 09:15 - 09:17 |
| | D-Pre-EM-051604-02 | Elemental Hg [c] | Test | 05/16/04 | 13:10 - 13:12 |
| | D-Pre-EM-051604-03 | Elemental Hg [c] | Test | 05/16/04 | 15:10 - 15:12 |

| Sampling Method | Run Number | Analyte(s) | Sample Class | Date | Run Period |
|---|---|---|---|---|---|
| Frontier | | | | | |
| | 040515-WF-STM1 | Total gaseous Hg | Test | 05/15/04 | 11:51 - 12:37 |
| | 040515-WF-STM2 | Total gaseous Hg | Test | 05/15/04 | 13:10 - 13:50 |
| | 040515-WF-STM4 | Total gaseous Hg | Test | 05/15/04 | 14:32 - 15:22 |
| | 040515-WF-STM3BLK | Total gaseous Hg | Field Blank | 05/15/04 | 14:15 |
| Frontier | | | | | |
| | 040515-WF-MHg5Spike | Monomethyl Hg | Spike | 05/15/04 | 16:10 - 17:04 |
| | 040515-WF-MHg3BLK | Monomethyl Hg | Field Blank | 05/15/04 | 14:15 |
| | 040515-WF-MHg1 | Monomethyl Hg | Test | 05/15/04 | 11:53 - 12:40 |
| | 040515-WF-MHg2 | Monomethyl Hg | Test | 05/15/04 | 13:12 - 13:59 |
| | 040515-WF-MHg4 | Monomethyl Hg | Test | 05/15/04 | 14:33 - 15:22 |
| Frontier | | | | | |
| | 040515-WF-DMHg5Spike | Dimethyl Hg | Spike | 05/15/04 | 17:42 - 17:45 |
| | 040515-WF-DMHg6TripSpk | Dimethyl Hg | Trip Spike | 05/15/04 | 17:55 |
| | 040515-WF-DMHg7 | Dimethyl Hg | Volume Experiment | 05/15/04 | 18:00 - 18:03 |
| | 040515-WF-DMHg8 | Dimethyl Hg | Volume Experiment | 05/15/04 | 18:15 - 18:26 |
| | 040515-WF-DMHg3BLK | Dimethyl Hg | Field Blank | 05/15/04 | 17:15 |
| | 040515-WF-DMHg1 | Dimethyl Hg | Test | 05/15/04 | 16:41 - 16:43 |
| | 040515-WF-DMHg2 | Dimethyl Hg | Test | 05/15/04 | 16:58 - 17:00 |
| | 040515-WF-DMHg4 | Dimethyl Hg | Test | 05/15/04 | 17:29 - 17:31 |

[a] The Method 40 SUMMA canister contents were first analyzed for speciated VOCs, then analyzed for NMOCs by Method 25C

[b] Sampling train back flushed at end of run; run repeated

[c] Represents average of 3 readings, each 30-second in duration

**Figure 3-1. Sampling Operations at the Raw Landfill Gas Pipe Inlet**

**Figure 3-2. Sampling Operations at the Enclosed Flare**

**Figure 3-3. Sampling Train in Place on the Enclosed Flare Stack**

The flare stack was sampled for NMOCs (as THCs), HCl, lead (Pb), arsenic (As), cadmium (Cd), chromium (Cr), manganese (Mn), nickel (Ni) , total Hg, $SO_2$, $NO_X$, CO, carbon dioxide ($CO_2$), and oxygen ($O_2$). Table 3-5 lists the test samples that were collected from the flare stack.

The flare stack cross-section was divided into 24 equal areas according to EPA Method 1. Sampling at the flare stack was conducted at isokinetic conditions. Sample collection times for the Method 26A HCl train and the Method 29 metals train were 60-minutes. Run time for continuous emission monitoring system (CEMS) parameters ($SO_2$, $NO_X$, CO, $O_2$, $CO_2$, and THCs) was 60 minutes.

**Table 3-5. Flare Stack Test Sample Log and Collection Times**

| Sampling Method | Run Number | Analyte(s) | Sample Class | Date | Run Period |
|---|---|---|---|---|---|
| EPA Method 3A (CEM) | | | | | |
| | D-Post-M3A-051604-01 | $O_2$ | Test | 05/16/04 | 10:40 - 11:39 |
| | D-Post-M3A-051604-02 | $O_2$ | Test | 05/16/04 | 12:20 - 13:19 |
| | D-Post-M3A-051604-03 | $O_2$ | Test | 05/16/04 | 14:40 – 15:39 |
| EPA Method 3A (CEM) | | | | | |
| | D-Post-M3A-051604-01 | $CO_2$ | Test | 05/16/04 | 10:40 - 11:39 |
| | D-Post-M3A-051604-02 | $CO_2$ | Test | 05/16/04 | 12:20 - 13:19 |
| | D-Post-M3A-051604-03 | $CO_2$ | Test | 05/16/04 | 14:40 – 15:39 |
| EPA Method 10 (CEM) | | | | | |
| | D-Post-M10-051604-01 | CO | Test | 05/16/04 | 10:40 - 11:39 |
| | D-Post-M10-051604-02 | CO | Test | 05/16/04 | 12:20 - 13:19 |
| | D-Post-M10-051604-03 | CO | Test | 05/16/04 | 14:40 – 15:39 |
| EPA Method 7E (CEM) | | | | | |
| | D-Post-M7E-051604-01 | $NO_X$ | Test | 05/16/04 | 10:40 - 11:39 |
| | D-Post-M7E-051604-02 | $NO_X$ | Test | 05/16/04 | 12:20 - 13:19 |
| | D-Post-M7E-051604-03 | $NO_X$ | Test | 05/16/04 | 14:40 – 15:39 |
| EPA Method 6C (CEM) | | | | | |
| | D-Post-M6C-051604-01 | $SO_2$ | Test | 05/16/04 | 10:40 - 11:39 |
| | D-Post-M6C-051604-02 | $SO_2$ | Test | 05/16/04 | 12:20 - 13:19 |
| | D-Post-M6C-051604-03 | $SO_2$ | Test | 05/16/04 | 14:40 – 15:39 |
| EPA Method 25A (CEM) | | | | | |
| | D-Post-M25A-051604-01 | NMOCs (THC) | Test | 05/16/04 | 10:40 - 11:39 |
| | D-Post-M25A-051604-02 | NMOCs (THC) | Test | 05/16/04 | 12:20 - 13:19 |
| | D-Post-M25A-051604-03 | NMOCs (THC) | Test | 05/16/04 | 14:40 – 15:39 |
| Lumex Instrument | | | | | |
| | D-Post-EM-051604-01 | Elemental Hg [a] | Test | 05/16/04 | 09:15 - 09:17 |
| | D-Post-EM-051604-02 | Elemental Hg [a] | Test | 05/16/04 | 13:10 - 13:12 |
| | D-Post-EM-051604-03 | Elemental Hg [a] | Test | 05/16/04 | 15:10 - 15:12 |

| Sampling Method | Run Number | Analyte(s) | Sample Class | Date | Run Period |
|---|---|---|---|---|---|
| EPA Method 26A | | | | | |
| | D-Post-M26A-051604-01 | HCl | Test | 05/16/04 | 10:35 - 11:38 |
| | D-Post-M26A-051604-02 | HCl | Test | 05/16/04 | 13:03 - 14:05 |
| | D-Post-M26A-051604-03 | HCl | Test | 05/16/04 | 15:00 - 16:02 |
| EPA Method 29 | | | | | |
| | D-Post-M29-051604-01 | Metals | Test | 05/16/04 | 10:34- 11:38 |
| | D-Post-M29-051604-02 | Metals | Test | 05/16/04 | 13:02 - 14:05 |
| | D-Post-M29-051604-03 | Metals | Test | 05/16/04 | 14:59 - 16:04 |

[a] Represents 3 readings, each 30-seconds in duration

## 3.3 Field Test Changes and Deviations from Quality Assurance Project Plan (QAPP) Specifications

### 3.3.1 Variation from Test Methods or Planned Activities

#### *3.3.1.1 Sampling at the Raw Landfill Gas (LFG) Pipe*

There were not variations from test methods or planned activities at the LFG pipe.

#### 3.3.1.2 Raw Landfill Gas (LFG) Condensate Sample

A LFG pipe condensate sample was not specified in the QAPP and was not collected.

#### 3.3.1.3 Raw Landfill Gas (LFG) Flow Rate Measurement

Gas flow as indicated by the John Zink enclosed ground flare station control panel was recorded. The accuracy of the indicated measurement cannot be independently verified because of the inability to measure gas velocity accurately, as discussed in the previous section. The test team was only able to make crude velocity measurements by traversing the pipe using a standard pitot probe. The accuracies of these measurements are uncertain and do not agree closely with the control panel indicted flows which were more stable and likely to be more accurate.

#### 3.3.1.4 Enclosed Flare Stack

There were not variations from test methods or planned activities at the enclosed flare stack.

### 3.3.2 Application of Test Methods

The sampling and, where applicable, analytical methods used in this test program follow those specified in the QAPP. Sampling methods are shown in Table 3-6

### 3.3.3 Test Method Exceptions

Laboratory analytical procedures followed those prescribed by the specified methods, with the following exceptions for the stack flare:

- Non-Methane Organic Compounds (NMOCs) - Method 25A was used instead of the specifically applicable Method 25C. This was necessitated by the low overall VOC concentrations in the flare stack gas (<50 ppm as hexane). Moreover, Method 25C is specifically designed for and applicable to raw LFG. As such, the test method is not applicable to the combustion effluents from the flare stack.

- Polycyclic aromatic hydrocarbons (PAH) were analyzed by CARB Method 429 as opposed to Method 8270. However, these methods are comparable because CARB Method 429 contains procedures for sampling, sample recovery, clean-up, and analysis. Method 8270 is strictly an analytical method. CARB Method 429 is specific to 19 PAHs, the target analytes of this portion of the specified tests. The 19 PAHs are a subset of the more than 200 target analytes listed for Method 8270 for semi-volatile organic compounds (SVOC). Though specific compounds called out for use in instrument performance verifications, internal standard preparation, surrogate standards, and continuing calibration verifications/ calibration checks are slightly different, both methods require them. CARB Method 429 adds another level of quality control (QC) with a required recovery standard. Method performance and acceptance criteria for recoveries are better defined in CARB Method 429 and meet or exceed those stated in Method 8270C. As long as any additional compounds reported by the laboratory using CARB Method 429 are included in the calibration standards and acceptable response factors are demonstrated, using CARB Method 429 is essentially equivalent to using SW-846 Method 8270.

**Table 3-6. Sampling Methods**

| Procedure | Description | Organization Performing Analysis |
|---|---|---|
| EPA Method 1 | Selection of enclosed flare stack traverse points | ARCADIS G&M |
| EPA Method 2 | Determination enclosed flare stack of stack gas velocity and volumetric flow rate | ARCADIS G&M |
| EPA Method 3A | Determination of oxygen ($O_2$) and carbon dioxide ($CO_2$) for enclosed flare stack gas molecular weight calculations | ARCADIS G&M |
| EPA Method 3C | Determination of carbon dioxide ($CO_2$), methane ($CH_4$), nitrogen ($N_2$), and oxygen ($O_2$) in raw LFG | Triangle Environmental Services |
| EPA Method 4 | Determination of enclosed flare stack gas moisture | ARCADIS G&M |
| EPA Method 6C | Determination of enclosed flare stack sulfur dioxide ($SO_2$) | ARCADIS G&M |
| EPA Method 7E | Determination of enclosed flare stack nitrogen oxides ($NO_X$) | ARCADIS G&M |
| EPA Method 10 | Determination of enclosed flare stack carbon monoxide (CO) | ARCADIS G&M |
| EPA Method 11 | Determination of raw LFG hydrogen sulfide ($H_2S$) | Oxford Laboratories |
| EPA Method 25A | Determination of enclosed flare stack gas non-methane organic compounds (NMOCs)(as total hydrocarbons [THCs]) | ARCADIS G&M |
| EPA Method 25C | Determination of raw LFG NMOCs (performed on Method 40 SUMMA canister sample) | Triangle Environmental Services |
| EPA Method 26A | Determination of raw LFG hydrogen chloride (HCl) | Resolution Analytics |
| EPA Method 29 | Determination of enclosed flare stack metals | First Analytical Laboratories |
| EPA Method 40 | Determination of raw LFG volatile organic compounds (VOCs) | Research Triangle Park Laboratories |
| SW-846 Method 0100/TO-11 | Determination of raw LFG carbonyls (formaldehyde, acetaldehyde) | Resolution Analytics |
| LUMEX Instrument | Determination of raw LFG and enclosed flare stack elemental mercury ($Hg^0$) | ARCADIS G&M |
| Frontier Geo. Methods | Determination of raw LFG:<br>Monomethyl mercury<br>Dimethyl mercury<br>Total mercury | Frontier Geosciences |

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# 4. Presentation of Test Results

Testing took place at the Landfill D on May 15 and 16, 2004. Results of the testing are presented in this section. Detailed test results are included in the Appendices. The following subsections provide concise summaries of the test results.

## 4.1 Raw Landfill Gas (LFG) Results

As shown in Figure 2-2, sampling was conducted by extracting samples via the four ¼-inch ports installed in the LFG pipe.

### 4.1.1 Raw Landfill Gas (LFG) Flow Rate and Temperature

#### *4.1.1.1 Direct Measurements*

The facility process system had a flow measurement system, which displays the flow rate on an instrument panel meter. The panel meter read 400 scfm with fluctuations of ±3.5 percent during the testing period.

The small size of the sampling ports precluded the proper measurement of the velocity profile within this pipe. Nonetheless, measurements with a velocity probe returned readings ranging from 376 scfm to 845 scfm. These readings were considered to be less reliable than those indicated by the facility panel meter. Therefore, mass emissions calculations in this report are based on the facility's flow meter readings.

Direct measurement with thermocouples showed the LFG temperature to be 54 °F.

### 4.1.2 Raw Landfill Gas (LFG) Constituents

The concentrations of the constituents of interest in the LFG are presented in Subsections 4.1.2.1 through 4.1.2.5. Following the presentation of the constituent concentrations, Section 4.3 summarizes the data and presents a comparison with the AP-42 values. Section 4.3 also presents the estimated mass flow rates of the constituents at the LFG pipe.

#### *4.1.2.1 Volatile Organic Compounds (VOCs)*

Concentrations of VOCs were obtained collecting summa canister samples using Method 40 procedures. Analysis was performed by Method TO-15, with gas chromatography and mass spectrometry (GC/MS). The alkanes (C2 through C6), being present in much higher concentrations, were analyzed by GC flame ionization detection (FID) on the same summa canister samples.

The data from the testing on May 15 and 16, 2004 were not useable because the results suggested that the samples were not collected properly. The analyte concentrations were extremely low and could not possibly be representative of the raw LFG. Collection of samples to replace the defective samples was repeated on September 14, 2004. Analytical results of the September 14 samples are reported below in Table 4-1.

**Table 4-1. Raw Landfill Gas VOC Concentrations**

| Compound | Unit | MDL | Concentration (ppmv) | | | |
|---|---|---|---|---|---|---|
| | | | Run 1 | Run 2 | Run 3 | Average [a] |
| **By GC/FID** | | | | | | |
| Ethane | ppmv | 1 | 5.9 | 5.5 | 5.4 | 5.6 |
| Propane | ppmv | 1 | 31.5 | 29.5 | 30.5 | 30.5 |
| Butane | ppmv | 1 | ND | ND | ND | ND |
| Pentane | ppmv | 1 | ND | 6.1 | ND | 2.4 |
| Hexane | ppmv | 1 | 3.9 | 3.0 | ND | 2.5 |
| **By TO-15 GC/MS** | | | | | | |
| Dichlorodifluoromethane (Freon 12) [c] | ppbv | 0.3 | 1310 | 1200 | 1190 | 1240 |
| 1,2-Chloro-,1,2,2-Tetrafluoroethane (CFC114) | ppbv | 0.2 | 115 | 116 | 99 | 110 |
| Chloromethane | ppbv | 0.1 | 695 | ND | ND | 232 |
| Vinyl chloride [c] | ppbv | 0.2 | 1240 | 1280 | 1080 | 1200 |
| 1,3-Butadiene ((Vinylethylene) [c] | ppbv | 0.3 | 340 | 347 | 292 | 326 |
| Bromomethane (Methyl Bromide) | ppbv | 0.2 | 8 | ND | ND | 2.8 |
| Chloroethane (Ethyl Chloride) [c] | ppbv | 0.2 | 608 | 608 | 687 | 634 |
| Trichloromonofluoromethane (CFC11) | ppbv | 0.2 | 127 | 118 | 104 | 116 |
| 1,1-Dichloroethene | ppbv | 0.2 | 20 | 23 | 21 | 21 |

| Compound | Unit | MDL | Concentration (ppmv) | | | |
|---|---|---|---|---|---|---|
| | | | Run 1 | Run 2 | Run 3 | Average [a] |
| 1,1,2-Trichloro-1,2,2-trifluoroethane (CFC113) | ppbv | 0.2 | 18 | 19 | 19 | 19 |
| Carbon Disulfide | ppbv | 0.3 | 80 | 110 | 88 | 93 |
| Ethanol [c] | ppbv | 0.2 | 384 | 438 | 359 | 394 |
| Isopropyl Alcohol (2-Propanol) [c] | ppbv | 0.2 | 6920 | 6260 | 6710 | 6630 |
| Methylene chloride (Dichloromethane) [c] | ppbv | 0.1 | 1140 | 1200 | 990 | 1110 |
| Acetone [c] | ppbv | 0.3 | 11900 | 14600 | 12000 | 12800 |
| t-1,2-dichloroethene | ppbv | 0.3 | 60 | 53 | 47 | 53 |
| Hexane [c] | ppbv | 0.3 | 4060 | 4310 | 3570 | 3980 |
| Methyl-t-butyl ether (MTBE) | ppbv | 0.3 | 45 | 46 | 26 | 39 |
| 1,1-Dichloroethane | ppbv | 0.4 | 620 | 575 | 579 | 591 |
| Vinyl Acetate [c] | ppbv | 0.5 | 45 | 50 | 37 | 44 |
| cis-1,2-Dichloroethene [c] | ppbv | 0.3 | 1830 | 1850 | 1650 | 1780 |
| Cyclohexane [c] | ppbv | 0.3 | 2400 | 2320 | 2090 | 2270 |
| Chloroform [c] | ppbv | 0.3 | 430 | 470 | 555 | 485 |
| Ethyl Acetate [c] | ppbv | 0.3 | 4880 | 4760 | 4170 | 4600 |
| Carbon Tetrachloride | ppbv | 0.5 | ND | 114 | ND | 38 |
| Tetrahydrofuran (Diethylene Oxide) [c] | ppbv | 0.4 | 2140 | 2250 | 1800 | 2060 |
| 1,1,1-Trichloroethane | ppbv | 0.3 | ND | ND | ND | ND |
| 2-Butanone (Methyl Ethyl Ketone) [c] | ppbv | 0.3 | 8320 | 8860 | 7040 | 8070 |
| Heptane [c] | ppbv | 0.2 | 3730 | 3730 | 3280 | 3580 |
| Benzene [c] | ppbv | 0.2 | 1220 | 1270 | 1120 | 1200 |
| 1,2-Dichloroethane | ppbv | 0.3 | 23 | 24 | 20 | 22 |

| Compound | Unit | MDL | Concentration (ppmv) | | | |
|---|---|---|---|---|---|---|
| | | | Run 1 | Run 2 | Run 3 | Average [a] |
| Trichloroethylene (Trichloroethene) | ppbv | 0.2 | 422 | 436 | 397 | 418 |
| 1,2-Dichloropropane | ppbv | 0.3 | ND | ND | ND | ND |
| Bromodichloromethane | ppbv | 0.2 | ND | ND | ND | ND |
| 1,4-Dioxane (1,4-Diethylene Dioxide) | ppbv | 0.2 | 0.3 | 23 | 14 | 12 |
| cis-1,3-Dichloropropene | ppbv | 0.2 | 7 | 4 | ND | 4 |
| Toluene (Methyl Benzene) | ppbv | 0.3 | 34000 | 37300 | 19500 | 30300 |
| 4-Methyl-2-pentanone (MIBK) | ppbv | 0.2 | ND | ND | ND | ND |
| t-1,3-Dichloropropene | ppbv | 0.2 | 25 | ND | ND | 8 |
| Tetrachloroethylene (Perchloroethylene) [c] | ppbv | 0.3 | 1030 | 1070 | 963 | 1020 |
| 1,1,2-Trichloroethane [c] | ppbv | 0.2 | ND | ND | ND | ND |
| Dibromochloromethane | ppbv | 0.2 | 11 | 21 | 15 | 16 |
| 1,2-Dibromoethane (Ethylene dibromide) | ppbv | 0.2 | ND | ND | ND | ND |
| 2-Hexanone (Methyl Butyl Ketone) | ppbv | 0.2 | ND | ND | ND | ND |
| Ethylbenzene [c] | ppbv | 0.3 | 8290 | 8620 | 7460 | 8120 |
| Chlorobenzene [c] | ppbv | 0.2 | ND | 62 | ND | 21 |
| m/p-Xylene (Dimethyl Benzene) [c] | ppbv | 0.65 | 13800 | 14700 | 12400 | 13600 |
| o-Xylene (Dimethyl Benzene) [c] | ppbv | 0.3 | 5490 | 5670 | 5060 | 5410 |
| Styrene (Vinylbenzene) [c] | ppbv | 0.1 | 1120 | 1320 | 1090 | 1180 |
| Tribromomethane (Bromoform) | ppbv | 0.3 | ND | 3 | 25 | 9 |
| 1,1,2,2-Tetrachloroethane | ppbv | 0.2 | ND | ND | ND | ND |
| 1-Ethyl-4-methylbenzene (4-Ethyl Toluene) [b, c] | ppbv | 0.2 | 1000 J | 1010 J | 913 J | 976 J |
| 1,3,5-Trimethylbenzene [b, c] | ppbv | 0.2 | 1000 J | 1010 J | 913 J | 976 J |

| Compound | Unit | MDL | Concentration (ppmv) | | | |
|---|---|---|---|---|---|---|
| | | | Run 1 | Run 2 | Run 3 | Average [a] |
| 1,2,4-Trimethylbenzene [c] | ppbv | 0.3 | 2230 | 2290 | 2040 | 2190 |
| 1,4-Dichlorobenzene [c] | ppbv | 0.3 | 707 | 683 | 669 | 686 |
| 1,3-Dichlorobenzene [c] | ppbv | 0.2 | 671 | 647 | 631 | 650 |
| Benzyl Chloride [c] | ppbv | 0.2 | ND | ND | ND | ND |
| 1,2-Dichlorobenzene [c] | ppbv | 0.3 | 33 | 31 | 29 | 31 |
| 1,1,2,3,4,4-Hexachloro-1,3-butadiene | ppbv | 0.2 | ND | ND | ND | ND |
| 1,2,4-Trichlorobenzene | ppbv | 0.3 | ND | ND | ND | ND |
| Acrylonitirile | ppbv | 20 | ND | ND | ND | ND |

ND - Constituent not detected at the stated detection limits

[a] - In computing averages, when all measurements are ND, the average is reported as ND. When one or more measurement is above detection, the ND measurement is treated as 50% of the stated MDL. If MDL is not reported, a ND measurement is treated as zero.

[b] – 1-Ethyl-4-methylbenzene (4-Ethyl Toluene) and 1,3,5-Trimethylbenzene co-eluted from the GC and also have the same quantitation ions, thus making them indistinguishable. Therefore, the reported values represent the combined concentrations of these two compounds.

[c] Analyte detected in blank sample. See table 5-2 for analyte-specific detected levels.

#### *4.1.2.2 Non-methane Organic Compounds (NMOCs)*

Non-methane organic compounds (NMOCs) in the raw LFG were analyzed by Method 25C on the samples collected by Method 40. Table 4-2 shows the concentrations of NMOC, methane ($CH_4$), $CO_2$ and $O_2$ in the LFG. These results were obtained from the samples that were collected during the retest that took place on September 14, 2004.

The analytes, oxygen ($O_2$), carbon dioxide ($CO_2$), and moisture, are not pollutants but are of interest as they are useful indicators of the “quality” of the raw LFG. The concentrations of nitrogen ($N_2$) and $O_2$ are also indicators of the extent of ambient air infiltration into the LFG collection. Method 25C for NMOC determination specifically recommends that these measurements be made to determine potential air infiltration. Therefore, while measurements for methane ($CH_4$), $CO_2$, $O_2$, and $N_2$ by Method 3C were not included in the original QAPP, these measurements were included and performed.

**Table 4-2. Raw Landfill Gas Non-Methane Organic Compound (NMOC) Concentrations**

| | NMOC (as ppmv hexane) | $CH_4$ (% v/v) | | $CO_2$ (% v/v) | | $O_2$ (% v/v) | N2 (% v/v) | Moisture (% v/v) |
|---|---|---|---|---|---|---|---|---|
| | Method 25C | Method 25C | Method 3C | Method 25C | Method 3C | Method 3C | Method 3C | Method 23 |
| Run 1 | 971 | 58.9 | 55.6 | 41.1 | 38.5 | 0.02 | 11.4 | NM |
| Run 2 | 1024 | 57.4 | 54.3 | 40.2 | 37.6 | 0.02 | 12.8 | NM |
| Run 3 | 1024 | 59.5 | 55.5 | 41.7 | 38.3 | 0.01 | 9.5 | NM |
| **Average** | **1006** | **58.6** | **55.1** | **41.0** | **38.1** | **0.02** | **11.2** | **NM** |

NM – not measured because Method 23 sampling train was not run. Data column is included to retain format consistency with reports for Landfills A, B, and C

Concentrations are reported without correction for nitrogen

#### 4.1.2.3 Hydrogen Sulfide ($H_2S$)

Raw landfill gas $H_2S$ concentrations were obtained by collecting and analyzing the samples in accordance with EPA Method 11. These results are presented in Table 4-3.

**Table 4-3. Raw Landfill Gas Hydrogen Sulfide Concentrations**

| | $H_2S$ Concentration | |
|---|---|---|
| | ($mg/m^3$) | (ppmv) |
| Run 1 | 32.1 | 22.7 |
| Run 2 | 90.2 | 63.9 |
| Run 3 | 186 | 132 |
| **Average** | **103** | **72.7** |

Sample hold times exceeded the 30-day criteria by 2 days

#### 4.1.2.4 Carbonyls

The target carbonyl compounds, formaldehyde and acetaldehyde, were analyzed by SW-846 Method 8315 on samples collected by EPA Method 0100. The analysis results are presented in Table 4-4.

**Table 4-4. Raw Landfill Gas Carbonyls Concentrations**

| | Formaldehyde | | Acetaldehyde | |
|---|---|---|---|---|
| | (µg/m$^3$) | (x10$^{-3}$ ppmv) | (µg/m$^3$) | (x10$^{-3}$ ppmv) |
| MDL | 8.0 | 6.4 | 8.3 | 4.5 |
| Run 1 | 39.0 | 31.5 | 439 | 241 |
| Run 2 | 19.9 | 16.0 | 534 | 293 |
| Run 3 | 16.0 | 12.9 | 72 | 39 |
| **Average** | **25.0** | **20.1** | **348** | **191** |

#### *4.1.2.5 Mercury (Hg)*

Mercury (Hg) can exist in several forms. This test program focused on the elemental, monomethyl, and dimethyl forms of Hg, and total Hg. Elemental Hg was measured with the LUMEX instrument. Organic monomethyl Hg, dimethyl Hg and total Hg were sampled and analyzed using the organic mercury method.

##### 4.1.2.5.1 Total Mercury (Hg) Samples

To collect the total Hg samples, an iodated charcoal trap was used as a sorbent. A backup tube was also 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. A silica gel impinger was used to collect and quantify the water vapor from the stream. A diaphragm air pump was used to pull the sample through the train and collect the sample. A dry gas meter capable of measuring the volume in 10 ml increments was used to monitor and quantify the volume of gas sampled.

Table 4-5 presents the total Hg concentrations in the LFG. They ranged from 723 to 751 ng/m$^3$ with an average of 740 ng/m$^3$.

**Table 4-5. Raw Landfill Gas Total Mercury Concentrations**

| | Total Mercury Concentration | |
|---|---|---|
| | (ng/m$^3$) | (x10$^{-6}$ ppm) |
| MDL | 50 | 6.0 |
| Run 1 | 747 | 89.9 |
| Run 2 | 723 | 87.0 |
| Run 3 | 751 | 90.4 |
| **Average** | **740** | **89.1** |

#### 4.1.2.5.2 Dimethyl Mercury (Hg) Samples

To collect the dimethyl Hg sample, a Carbotrap was used as a sorbent. A backup tube was also present to assess any breakthrough. A third iodated carbon trap was also present to collect any elemental Hg present. The sorbent tube was heated to above the dew point of the gas stream to prevent condensation on the sorbent. A silica gel impinger was used to collect and quantify the water vapor from the stream. A diaphragm air pump was used to pull sample through the train and collect the sample. A dry gas meter capable of measuring the volume in 10 ml increments was used to monitor and quantify the volume of gas sampled.

Table 4-6 presents the dimethyl Hg concentrations in the LFG. These ranged from 49.7 to 53.1 ng/$m^3$ with an average of 51.0 ng/$m^3$.

**Table 4-6. Raw Landfill Gas Dimethyl Mercury Concentrations**

| | Dimethyl Mercury Concentration | |
|---|---|---|
| | **(ng/$m^3$)** | **($x10^{-6}$ ppmv)** |
| MDL | 0.5 | 0.05 |
| Run 1 | 50.3 | 5.3 |
| Run 2 | 49.7 | 5.2 |
| Run 3 | 53.1 | 5.6 |
| **Average** | **51.0** | **5.3** |

#### 4.1.2.5.3 Monomethyl Mercury (Hg) Samples

To collect the sample, a set of three impingers filled with 0.001 M HCl was used to collect the monomethyl Hg. An empty forth impinger was used to knockout 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. A dry gas meter capable of measuring the volume in 10 ml increments was used to monitor and quantify the volume of gas sampled.

As shown in Table 4-7, monomethyl Hg concentrations in the LFG ranged from 2.36 to 2.64 ng/$m^3$ with an average amount of 2.47 ng/$m^3$.

**Table 4-7. Raw Landfill Gas Monomethyl Mercury Concentrations**

| | Monomethyl Mercury Concentration | |
|---|---|---|
| | (ng/m$^3$) | (x10$^{-6}$ ppmv) |
| MDL | 0.13 | 0.014 |
| Run 1 | 2.40 | 0.27 |
| Run 2 | 2.64 | 0.296 |
| Run 3 | 2.36 | 0.264 |
| **Average** | **2.47** | **0.278** |

4.1.2.5.4 Elemental Mercury (Hg)

Elemental Hg was determined by the LUMEX instrument and the results are presented in Table 4-8. The analyzed concentrations ranged from 265 to 290 ng/m$^3$ with an average of 278 ng/m$^3$. each reported run consisted of an instrument reading over a 30-second period.

**Table 4-8. Raw Landfill Gas Elemental Mercury Concentrations**

| | Concentration [a] | | | |
|---|---|---|---|---|
| | Background | | Gas Pipe | |
| | (ng/m$^3$) | (x10$^{-6}$ ppmv) | (ng/m$^3$) | (x10$^{-6}$ ppmv) |
| Run 1 | 0 | 0 | 265 | 31.9 |
| Run 2 | 0 | 0 | 280 | 33.7 |
| Run 3 | 0 | 0 | 290 | 34.9 |
| **Average** | **0** | **0** | **278** | **33.5** |

[a] Average of three readings, each 30-second in duration

### 4.2 Enclosed Flare Stack Results

The enclosed flare stack was sampled for NMOCs (as THCs), HCl, metals (Pb, As, Cd, Cr, Mn, Ni, total Hg), $SO_2$, $NO_X$, CO, $CO_2$, and $O_2$. The stack cross section was divided into 24 equal areas according to EPA Method 1. Sampling run time for HCl and metals was 60 minutes. Run time for CEMS parameters ($SO_2$, $NO_X$, CO, $O_2$, $CO_2$, and THCs) was 60 minutes.

#### 4.2.1 Flare Stack Gas Flow Rate and Temperature

Sampling at the flare stack was conducted at isokinetic conditions. The procedures provided stack gas velocity distribution across the flare stack and reliable measurements of stack gas flow rates. Table 4-9 lists the volumetric flow rates and temperatures at the flare stack measured during the various sampling runs.

**Table 4-9. Flare Stack Gas Operating Conditions Measured During Sampling**

| Run Number | Duration | Average Stack Temp (°F) | Carbon Dioxide (%) | Oxygen (%) | Moisture (%) | Velocity (actual ft/sec) | Vol. Flow Rate (acfm) | Vol. Flow Rate (dscfm) |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |
| D-Post-M26A-051604-01 | 10:35 - 11:38 | 1412 | 6.4 | 13.5 | 10.3 | 18.1 | 30700 | 7830 |
| D-Post-M26A-051604-02 | 13:03 - 14:05 | 1446 | 6.3 | 13.5 | 7.9 | 19.0 | 32200 | 8290 |
| D-Post-M26A-051604-03 | 15:00 - 16:02 | 1446 | 6.4 | 13.5 | 7.9 | 19.0 | 32200 | 8290 |
| | | | | | | | | |
| D-Post-M29-051604-01 | 10:34 - 11:38 | 1430 | 6.4 | 13.5 | 8.3 | 17.9 | 30400 | 7850 |
| D-Post-M29-051604-02 | 13:02 - 14:05 | 1444 | 6.3 | 13.5 | 8.0 | 19.0 | 32200 | 8290 |
| D-Post-M29-051604-03 | 14:59 - 16:04 | 1445 | 6.4 | 13.5 | 8.1 | 18.2 | 30900 | 7930 |
| | | | | | | | | |
| **Average** | | **1437** | **6.4** | **13.5** | **8.4** | **18.5** | **31400** | **8080** |

Flare stack cross-section flow area is 28.27 sq. ft.

#### 4.2.2 Flare Stack Gas Constituents

The concentrations of the constituents of interest in the flare stack are presented in Subsections 4.2.2.1 through 4.2.2.7.

##### *4.2.2.1 Flare Stack Oxygen ($O_2$) and Carbon Dioxide ($CO_2$)*

Oxygen ($O_2$) and $CO_2$ concentrations provide an overall indication of the combustion process. Figure 4-1 shows the $O_2$ and $CO_2$ concentrations measured by the CEMs during the tests. The plotted data do not include the CEM responses to the instrument zeroing and calibration periods. Table 4-10 presents the daily averages of $O_2$ and $CO_2$ concentrations.

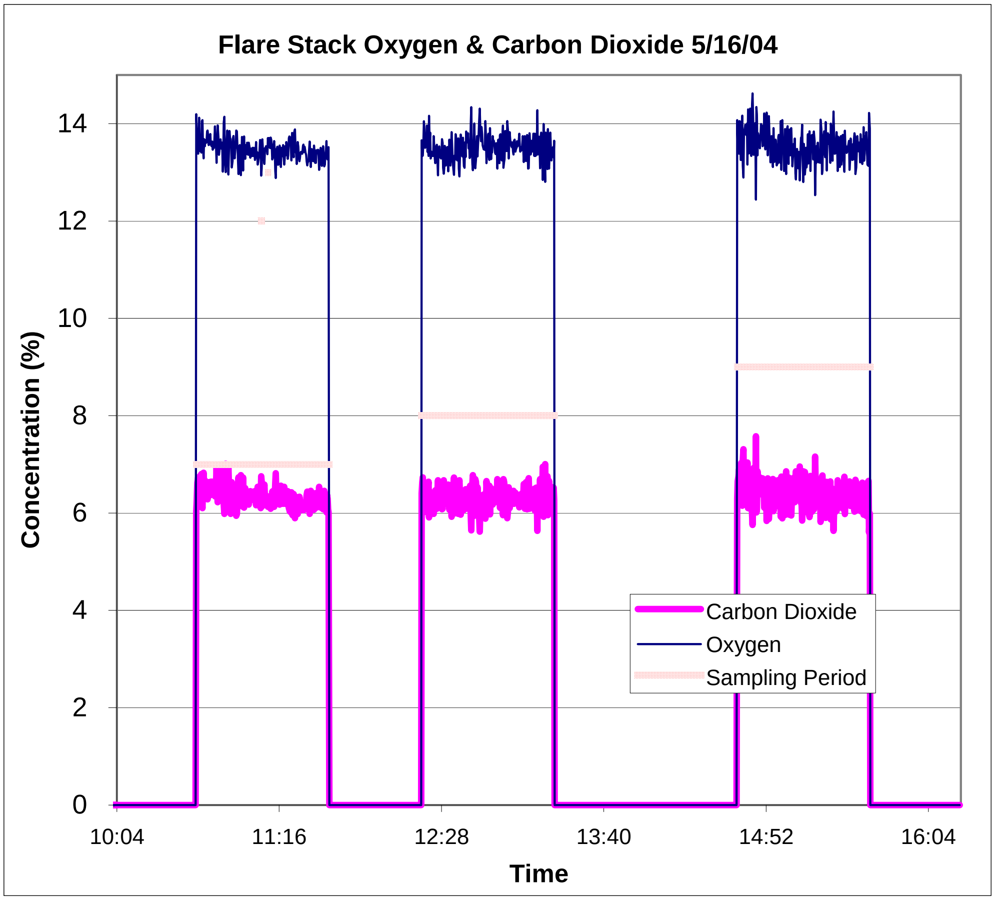


**Figure 4-1. Engine Stack Oxygen and Carbon Dioxide Concentrations**

**Table 4-10. Flare Stack Combustion Products Concentrations**

| | $O_2$ (% v) | $CO_2$ (% v) |
|---|---|---|
| Run 1 | 13.5 | 6.4 |
| Run 2 | 13.5 | 6.3 |
| Run 3 | 13.5 | 6.4 |
| **Average** | **13.5** | **6.4** |

*4.2.2.2 Flare Stack Total Hydrocarbon (THC) Concentrations*

Flare stack THC emissions were measured by EPA Method 25A, which used a CEM. At the flare stack, hydrocarbon (including NMOCs) concentrations were found to be below 50 ppmv. The low concentrations rendered Method 25C, the method designed specifically for NMOC measurement, unsuitable to be applied at this location.

EPA Method 25A was used instead and produced concentrations of all hydrocarbons that respond to flame ionization detector (FID) analysis. The responding hydrocarbons were assumed to be NMOCs. Real-time continuous instrument responses are shown in Figure 4-2. The time-averaged concentrations are presented in Table 4-11. As can be seen, the instantaneous concentrations of total hydrocarbons ranged from 10 to over 175 ppmv, with time-averaged concentration of 17 ppmv as hexane.

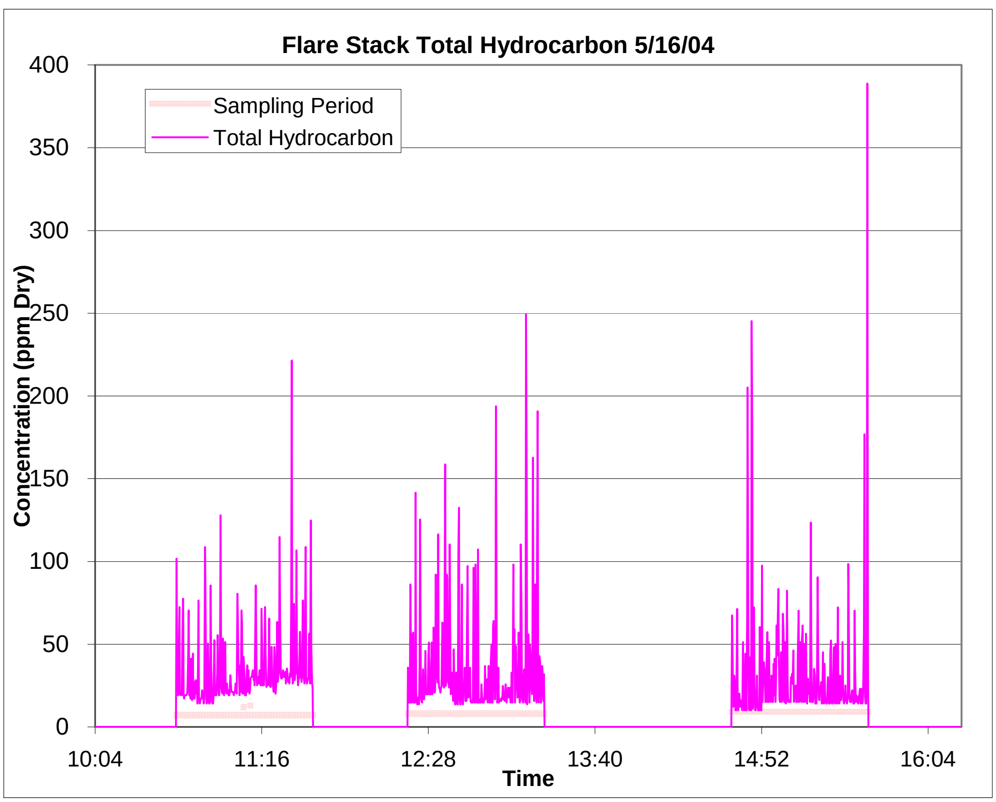


**Figure 4-2. Flare Stack Total Hydrocarbon Concentrations**

**Table 4-11. Flare Stack THC Concentrations**

| | THC (ppmdv as propane) | THC (ppmdv as hexane) |
|---|---|---|
| Run 1 | 35.6 | 17.8 |
| Run 2 | 35.5 | 17.8 |
| Run 3 | 31.3 | 15.7 |
| **Average** | **34.1** | **17.1** |

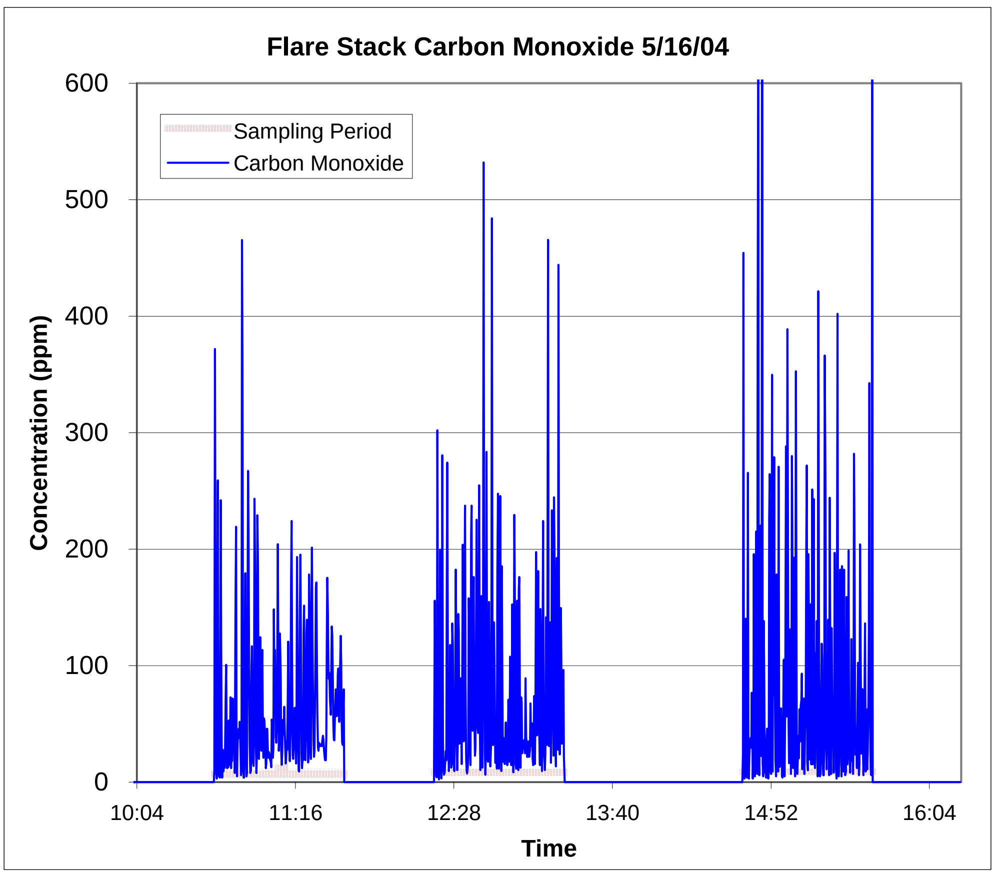


**Figure 4-3. Flare Stack Carbon Monoxide Concentrations**

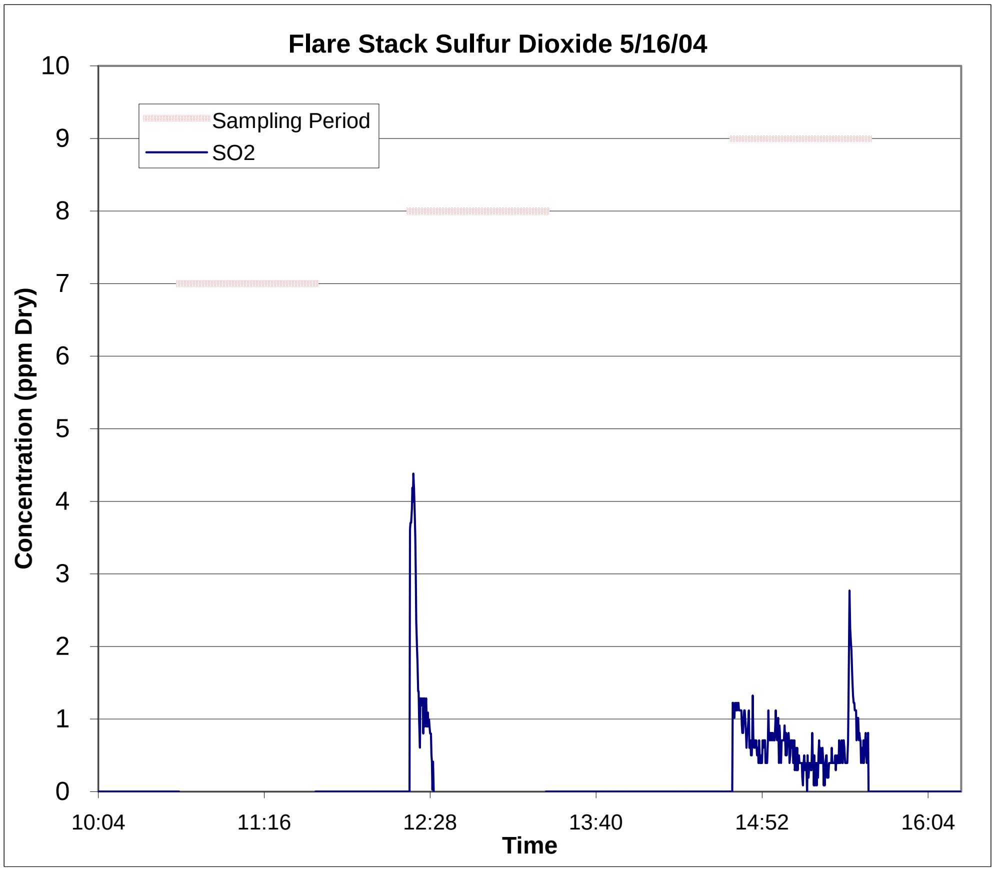


**Figure 4-4.** **Flare Stack Sulfur Dioxide Concentrations**

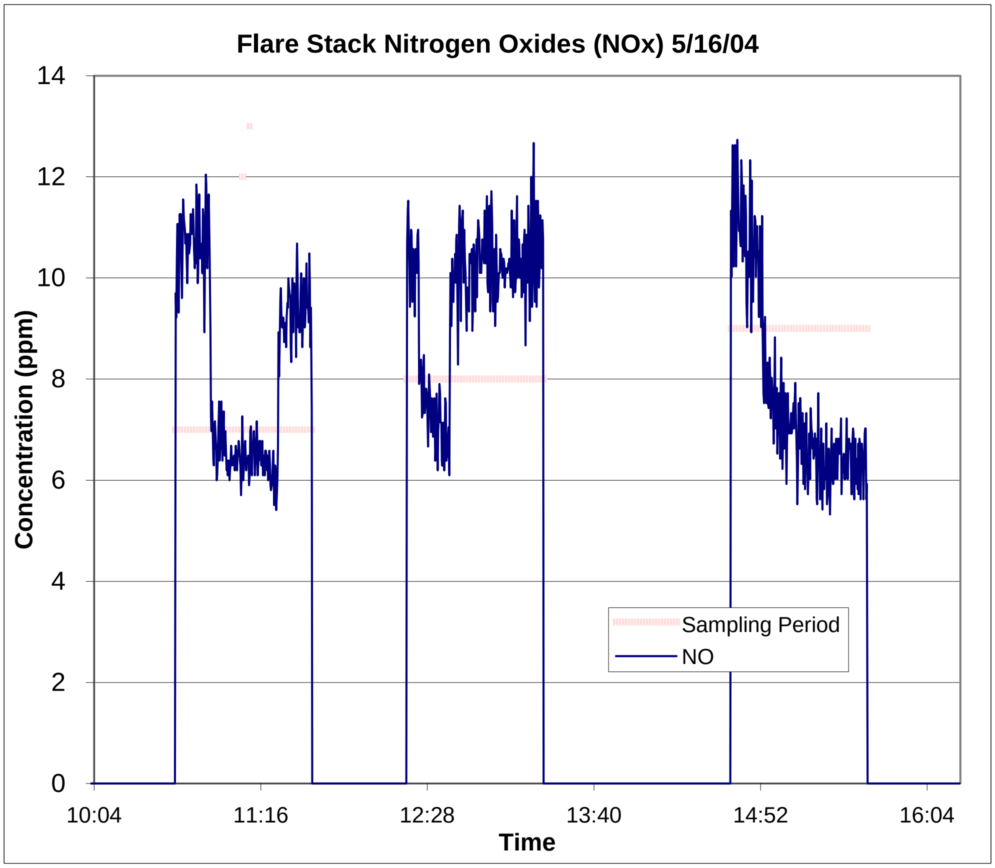


**Figure 4-5. Flare Stack Nitrogen Oxides Concentrations**

*4.2.2.3 Flare Stack Hydrochloride (HCl) Emissions*

Enclosed flare stack HCl emissions results are presented in Table 4-12.

**Table 4-12. Flare Stack Hydrogen Chloride Emissions**

| | HCl Concentration | | HCL Emission Rate | |
|---|---|---|---|---|
| | (ppmdv) | (mg/m$^3$) | (lb/hr) | (g/hr) |
| Run 1 | 1.3 | 2.0 | 0.06 | 27 |
| Run 2 | 1.3 | 2.2 | 0.06 | 27 |
| Run 3 | 1.3 | 2.2 | 0.06 | 27 |
| **Average** | **1.3** | **2.2** | **0.06** | **27** |

#### *4.2.2.4 Flare Stack Metals Emissions*

Flare stack metals emissions results are presented in Table 4-13. The metal concentrations were determined by Method 29, and included those for As, Cd, Cr, Pb, Mn, Hg (total) and Ni. Mercury (Hg) concentration (elemental) was separately measured by the LUMEX instrument and those results are also included in Table 4-16.

The “<” symbol denotes that the notated metal was not detected in that sample. The values following the “<” symbol represent the concentrations and emission rates that would have been the case had the metal been found at the method detection limit. Hence the values represent the upper limits of what might be present.

#### *4.2.2.5 Flare Stack Gaseous Emissions: Carbon Monoxide (CO), Sulfur Dioxide ($SO_2$), and Nitrogen Oxides ($NO_X$)*

Gaseous emissions measured with CEMS include $CO_2$, $SO_2$, $O_2$, and $NO_x$. These results are in Table 4-14. The detailed CEM measurement plots are shown in Figures 4-3 through 4-5.

### 4.3 Comparison with AP-42 Values

One of the major objectives of the test program was to expand on the database of LFG constituent compounds and their concentrations. If warranted, these data may contribute towards updating the AP-42 default values.

Table 4-15 presents the concentrations of LFG constituents to provide direct comparisons with AP-42 default values. Table 4-16 presents the concentration of other constituents targeted by the various analyses but are not listed in AP-42. An expanded discussion and comparison is included in the overall project report.

**Table 4-13. Flare Stack Metals Emissions**

| Analyte | C-POST-M29-051404-01 | | | C-POST-M29-051404-02 | | | C-POST-M29-051404-03 | | | Average | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Concentration | Emission Rate | | Concentration | Emission Rate | | Concentration | Emission Rate | | Concentration | Emission Rate | |
| | (µg/dscm) | (g/hr) | ($x10^{-6}$lb/hr) | (µg/dscm) | (g/hr) | ($x10^{-6}$lb/hr) | (µg/dscm) | (g/hr) | ($x10^{-6}$lb/hr) | (µg/dscm) | (g/hr) | ($x10^{-6}$lb/hr) |
| Arsenic | 5.0 | 0.067 | 150 | 4.4 | 0.063 | 138 | 4.7 | 0.064 | 141 | 4.7 | 0.065 | 142 |
| Cadmium | 0.174 | 0.002 | 5.1 | 0.262 | 0.004 | 8.1 | 0.191 | 0.003 | 5.7 | 0.209 | 0.003 | 6.3 |
| Chromium | 5.1 | 0.068 | 150 | 3.4 | 0.048 | 106 | 3.7 | 0.050 | 111 | 4.1 | 0.055 | 122 |
| Lead | <0.833 | <0.011 | <25 | <0.785 | <0.011 | <24.4 | <0.817 | <0.011 | <24.3 | ND | ND | ND |
| Manganese | 2.2 | 0.030 | 65 | 1.2 | 0.017 | 39 | 20 | 0.273 | 603 | 7.9 | 0.107 | 236 |
| Nickel | 7.0 | 0.094 | 210 | 3.1 | 0.044 | 98 | 4.4 | 0.059 | 129 | 4.8 | 0.065 | 144 |
| Mercury (Total by Method 29) | <2.1 | <0.028 | <61 | <2.5 | <0.035 | <77 | <2.6 | <0.035 | <77 | ND | ND | ND |
| | RUN 1 | | | RUN 2 | | | RUN 3 | | | Average | | |
| Mercury (Elemental by LUMEX) | 0.603 | 0.00821 | 18.1 | 0.886 | 0.0121 | 26.6 | 1.10 | 0.0152 | 33.5 | 0.867 | 0.0118 | 26.1 |

**Table 4-14. Flare Stack CO, $SO_2$, $NO_X$ Concentrations**

| | Concentration (ppmdv) | | |
|---|---|---|---|
| | **CO** | **$SO_2$** | **$NO_X$ (as NO) [a]** |
| Run 1 | 69 | 0 | 8.2 |
| Run 2 | 79 | 0 | 9.7 |
| Run 3 | 92 | 0.7 | 7.7 |
| **Average** | **80** | **0.2** | **8.5** |

[a] One of six drift checks was 3.3 percent and exceeded the ±3 percent criteria

**Table 4-15. Comparison of Raw Landfill Gas Constituent Concentrations with AP-42 Values**

| Method | Compound | CAS Number | Formula Wt. | Default Value (ppmv) | Detection Limit (ppmv) | Measured Average (ppmv) | Concentration in Inlet LFG | | Mass Flow Rate in Inlet LFG Stream | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | (x10-9 lb/ft3) | (µg/m3) | (mg/hr) | (x10-3 lb/hr) |
| M-40 | 1,1,1-Trichloroethane | 71-55-6 | 133.42 | 0.48 | 0.0003 | ND | ND | ND | ND | ND |
| M-40 | 1,1,2,2-Tetrachloroethane | 79-34-5 | 167.85 | 1.11 | 0.0002 | ND | ND | ND | ND | ND |
| M-40 | 1,1-Dichloroethane (Ethylidene Dichloride) | 75-34-3 | 98.96 | 2.35 | 0.0004 | 0.591 | 151 | 2420 | 1650 | 3.6 |
| M-40 | 1,1-Dichloroethene | 75-35-4 | 96.94 | 0.20 | 0.0002 | 0.021 | 5.3 | 85.6 | 58.2 | 0.128 |
| M-40 | 1,2-Dichloroethane | 107-06-2 | 98.96 | 0.41 | 0.0003 | 0.022 | 5.7 | 91.5 | 62.2 | 0.137 |
| M-40 | 1,2-Dichloropropane | 78-87-5 | 112.98 | 0.18 | 0.0003 | ND | ND | ND | ND | ND |
| M-40 | Isopropyl alcohol (2-Propanol) | 67-63-0 | 60.11 | 50.10 | 0.0002 | 6.63 | 1000 | 16500 | 11200 | 24.7 |
| M-40 | Acetone | 67-64-1 | 58.08 | 7.01 | 0.0003 | 12.8 | 1900 | 30800 | 21000 | 46.2 |
| M-40 | Acrylontrile | 107-13-1 | 53.06 | 6.33 | 0.00002 | ND | ND | ND | ND | ND |
| M-40 | Bromodichloromethane | 75-27-4 | 163.83 | 3.13 | 0.0002 | ND | ND | ND | ND | ND |
| M-40 | Butane | 106-97-8 | 58.12 | 5.03 | 1 | ND | ND | ND | ND | ND |
| M-40 | Carbon Disulfide | 75-15-0 | 76.13 | 0.58 | 0.0003 | 0.093 | 18.2 | 292 | 199 | 0.438 |
| No Test | Carbon Monoxide | 630-08-0 | 28.01 | 141 | | NM | NM | NM | NM | NM |
| M-40 | Carbon Tetrachloride | 56-23-5 | 153.84 | 0.004 | 0.0005 | 0.038 | 15.1 | 242 | 165 | 0.363 |
| No Test | Carbonyl Sulfide (Carbon oxysulfide) | 463-58-1 | 60.07 | 0.49 | | NM | NM | NM | NM | NM |
| M-40 | Chlorobenzene | 108-90-7 | 112.56 | 0.25 | 0.0002 | 0.021 | 6.0 | 96 | 66 | 0.15 |
| M-40 | Chlorodiflouromethane (Freon 22) | 75-45-6 | 86.47 | 1.30 | | NM | NM | NM | NM | NM |
| M-40 | Chloroethane (Ethyl Chloride) | 75-00-3 | 64.52 | 1.25 | 0.0002 | 0.63 | 106 | 1700 | 1150 | 2.5 |

| Method | Compound | CAS Number | Formula Wt. | Default Value (ppmv) | Detection Limit (ppmv) | Measured Average (ppmv) | Concentration in Inlet LFG | | Mass Flow Rate in Inlet LFG Stream | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | (x10-9 lb/ft3) | (µg/m3) | (mg/hr) | (x10-3 lb/hr) |
| M-40 | Chloroform | 67-66-3 | 119.39 | 0.03 | 0.0003 | 0.485 | 150 | 2400 | 1630 | 3.6 |
| M-40 | Chloromethane | 74-87-3 | 50.49 | 1.21 | 0.0001 | 0.232 | 30.3 | 485 | 330 | 0.727 |
| M-40 | 1,4-Dichlorobenzene | 106-46-7 | 147.00 | 0.21 | 0.0003 | 0.686 | 261 | 4180 | 2840 | 6.3 |
| M-40 | 1,3-Dichlorobenzene | 541-73-1 | 147.00 | 0.21 | 0.0002 | 0.650 | 247 | 3950 | 2690 | 5.9 |
| M-40 | 1,2-Dichlorobenzene | 95-50-1 | 147.01 | 0.21 | 0.0003 | 0.031 | 11.8 | 189 | 128 | 0.283 |
| M-40 | Dichlorodifluoromethane (Freon 21) | 75-71-8 | 120.91 | 15.70 | 0.0003 | 1.24 | 386 | 6180 | 4200 | 9.3 |
| M-40 | Dichlorofluoromethane (Freon 12) | 75-43-4 | 102.92 | 2.62 | | NM | NM | NM | NM | NM |
| M-40 | Methylene Chloride (Dichloromethane) | 75-09-2 | 84.94 | 14.30 | 0.0001 | 1.11 | 243 | 3900 | 2650 | 5.8 |
| No Test | Dimethyl Sulfide (Methyl sulfide) | 75-18-3 | 62.13 | 7.82 | | NM | NM | NM | NM | NM |
| M-40 | Ethane | 74-84-0 | 30.07 | 889 | 1 | 5.6 | 435 | 6970 | 4740 | 10.4 |
| M-40 | Ethanol | 64-17-5 | 46.08 | 27.20 | 0.0002 | 0.394 | 46.9 | 751 | 511 | 1.1 |
| No Test | Ethyl Mercaptan (Ethanediol) | 75-08-1 | 62.13 | 2.28 | | NM | NM | NM | NM | NM |
| M-40 | Ethylbenzene | 100-41-4 | 106.16 | 4.61 | 0.0003 | 8.12 | 2200 | 35700 | 24300 | 53.5 |
| M-40 | 1,2-Dibromoethane (Ethylene dibromide) | 106-93-4 | 187.88 | 0.001 | 0.0002 | ND | ND | ND | ND | ND |
| M-40 | Trichloromonofluoromethane (Fluorotrichloromethane) (F11) | 75-69-4 | 137.38 | 0.76 | 0.0002 | 0.116 | 41.3 | 662 | 450 | 0.992 |
| M-40 | Hexane | 110-54-3 | 86.18 | 6.57 | 0.0003 | 2.47 | 550 | 8810 | 5990 | 13.2 |
| M-11 | Hydrogen Sulfide | 7783-06-4 | 34.08 | 35.50 | | 72.7 | 6400 | 103000 | 69700 | 154 |

| Method | Compound | CAS Number | Formula Wt. | Default Value (ppmv) | Detection Limit (ppmv) | Measured Average (ppmv) | Concentration in Inlet LFG | | Mass Flow Rate in Inlet LFG Stream | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | (x10-9 lb/ft3) | (µg/m3) | (mg/hr) | (x10-3 lb/hr) |
| Linberg | Mercury (Dimethyl) | | 230.66 | Not Listed | 0.05E-06 | 5.3E-06 | 0.0032 | 0.052 | 0.035 | 0.0000768 |
| LUMEX | Mercury (Elemental) | 7439-97-6 | 200.61 | Not Listed | | 33.5E-06 | 0.0174 | 0.278 | 0.189 | 0.000417 |
| Linberg | Mercury (Monomethyl) | | 215.62 | Not Listed | 0.014E-06 | 278E-06 | 0.154 | 2.47 | 1.68 | 0.0037 |
| Linberg | Mercury (Total) | | 215.63 | 253.0E-6 | 6E-06 | 89.1E-06 | 49.7 | 796 | 541 | 1.19 |
| M-40 | 2-Butanone (Methyl Ethyl Ketone) | 78-93-3 | 72.10 | 7.09 | 0.0003 | 8.07 | 1500 | 24100 | 16400 | 36.1 |
| M-40 | 2-Hexanone (Methyl Butyl Ketone) | 591-78-6 | 100.16 | 1.87 | 0.0002 | ND | ND | ND | ND | ND |
| No Test | Methyl Mercaptan (Methanethiol) | 74-93-1 | 48.11 | 2.49 | | NM | NM | NM | NM | NM |
| M-40 | Pentane | 109-66-0 | 72.15 | 3.29 | 1 | 2.37 | 442 | 7080 | 4820 | 10.6 |
| M-40 | Tetrachloroethylene (Perchloroethylene) | 127-18-4 | 165.83 | 3.73 | 0.0003 | 1.02 | 438 | 7004 | 4760 | 10.5 |
| M-40 | Propane | 74-98-6 | 44.09 | 11.10 | 1 | 30.5 | 3500 | 55700 | 37800 | 83.4 |
| M-40 | t-1,2-Dichloroethene | 156-60-5 | 96.94 | 2.84 | 0.0003 | 0.053 | 13.4 | 214 | 146 | 0.321 |
| M-40 | Trichloroethylene (Trichloroethene) | 79-01-6 | 131.38 | 2.82 | 0.0002 | 0.418 | 142 | 2280 | 1550 | 3.4 |
| M-40 | Vinyl Chloride | 75-01-4 | 62.50 | 7.34 | 0.0002 | 1.20 | 194 | 3100 | 2110 | 4.6 |
| M-40 | m/p-Xylene (Dimethyl Benzene) | 1330-20-7 | 106.16 | 12.10 | 0.00065 | 13.7 | 3800 | 60100 | 40800 | 90.0 |
| M-40 | o-Xylene (Dimethyl Benzene) | 95-47-6 | 106.16 | 12.10 | 0.0003 | 5.41 | 1500 | 23800 | 16100 | 35.6 |

| Method | Compound | CAS Number | Formula Wt. | Default Value (ppmv) | Detection Limit (ppmv) | Measured Average (ppmv) | Concentration in Inlet LFG | | Mass Flow Rate in Inlet LFG Stream | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | (x10-9 lb/ft3) | (µg/m3) | (mg/hr) | (x10-3 lb/hr) |
| M-40 | Benzene (Co-disposal) | 71-43-2 | 78.11 | 11.10 | 0.0002 | 1.20 | 243 | 3890 | 2600 | 5.8 |
| M-40 | Benzene (No-disposal or Unknown) | 71-43-2 | 78.11 | 1.91 | 0.0002 | 1.20 | 243 | 3890 | 2600 | 5.8 |
| M-25C | NMOC as Hexane (Co-disposal) | | 86.17 | 2420.00 | | 668 | 149000 | 2380000 | 1620000 | 3600 |
| M-25C | NMOC as Hexane (No-codispoal or Unknown) | | | 595.00 | | 668 | 149000 | 2380000 | 1620000 | 3600 |
| M-40 | Toluene (Methyl Benzen) (Co-disposal) | 108-88-3 | 92.13 | 165.00 | 0.0003 | 30.3 | 7200 | 116000 | 78500 | 173 |
| M-40 | Toluene (Methyl Benzene) (No or Unknown) | | | 39.30 | 0.0003 | 30.3 | 7200 | 116000 | 78500 | 173 |

**Table 4-16. Raw Landfill Gas Constituent Concentrations for Compounds without AP-42 Default Values**

| Method | Compound | CAS Number | Formula Wt. | Detection Limit (ppmv) | Measured Average (ppmv) | Concentration in Inlet LFG | | Mass Flow Rate in Inlet LFG Stream | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | ($x10^{-9}$ lb/ft$^3$) | (µg/m$^3$) | (mg/hr) | ($x10^{-3}$ lb/hr) |
| M-0100 | Acetaldehyde | 75-07-0 | 44.05 | 0.0045 | 0.191 | 21.7 | 348 | 237 | 0.522 |
| M-0100 | Formaldehyde | 50-00-0 | 30.03 | 0.0064 | 0.020 | 1.6 | 25 | 17 | 0.0375 |
| M-23 | Dioxins/Furans | | | | NM | NM | NM | NM | NM |
| M-23 | PAHs | | | | NM | NM | NM | NM | NM |
| M-25C | Carbon Dioxide | 124-38-9 | 44.01 | | 381333 | 43400000 | 695000000 | 472000000 | 1.0 |
| M-25C | Methane | 74-82-8 | 16.04 | | 551333 | 22900000 | 366000000 | 249000000 | 549000 |
| M-25C | Oxygen | 7782-44-7 | 32.00 | | 16667 | 1400000 | 22100000 | 15000000 | 33100 |
| M-40 | 1,1,2,3,4,4-Hexachloro-1,3-butadiene | 87-68-3 | 260.76 | 0.0002 | ND | ND | ND | ND | ND |
| M-40 | 1,1,2-Trichloro-1,2,2-trifluoroethane (CFC113) | 76-13-1 | 187.38 | 0.0002 | 0.019 | 9.0 | 145 | 98.4 | 0.217 |
| M-40 | 1,1,2-Trichloroethane | 79-00-5 | 133.42 | 0.0002 | ND | ND | ND | ND | ND |
| M-40 | 1,2,4-Trichlorobenzene | 120-82-1 | 181.46 | 0.0003 | ND | ND | ND | ND | ND |
| M-40 | 1,2,4-Trimethylbenzene | 95-63-6 | 120.19 | 0.0003 | 2.187 | 680 | 10900 | 7400 | 16.3 |
| M-40 | 1,2-Chloro-,1,2,2-Tetrafluoroethane (CFC114) | 76-14-2 | 170.92 | 0.0002 | 0.110 | 48.6 | 778 | 529 | 1.2 |
| M-40 | 1,3,5-Trimethylbenzene | 108-67-8 | 120.19 | 0.0002 | 0.976 | 303 | 4860 | 3300 | 7.3 |
| M-40 | 1,3-Butadiene (Vinylethylene) | 106-99-0 | 54.09 | 0.0003 | 0.326 | 45.6 | 731 | 497 | 1.1 |
| M-40 | 1,4-Dioxane (1,4-Diethylene Dioxide) | 123-91-1 | 88.10 | 0.0002 | 0.013 | 3.0 | 48.2 | 32.7 | 0.0721 |
| M-40 | 1-Ethyl-4-methylbenzene (4-Ethyl Toluene) | 622-96-8 | 120.20 | 0.0002 | 0.976 | 303 | 4860 | 3300 | 7.3 |
| M-40 | 4-Methyl-2-pentanone (MIBK) | 108-10-1 | 100.16 | 0.0002 | ND | ND | ND | ND | ND |
| M-40 | Benzyl Chloride (Chloromethyl Benzene) | 100-44-7 | 126.58 | 0.0002 | ND | ND | ND | ND | ND |
| M-40 | Bromomethane (Methyl bromide) | 74-83-9 | 94.95 | 0.0002 | 0.0027 | 0.67 | 11 | 7.3 | 0.0161 |
| M-40 | cis-1,2-Dichloroethene | 156-59-2 | 96.94 | 0.0003 | 1.78 | 446 | 7140 | 4850 | 10.7 |

| Method | Compound | CAS Number | Formula Wt. | Detection Limit (ppmv) | Measured Average (ppmv) | Concentration in Inlet LFG | | Mass Flow Rate in Inlet LFG Stream | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | ($x10^{-9}$ lb/ft$^3$) | (µg/m$^3$) | (mg/hr) | ($x10^{-3}$ lb/hr) |
| M-40 | cis-1,3-Dichloropropene | 10061-01-5 | 110.98 | 0.0002 | 0.0037 | 1.1 | 17 | 12 | 0.026 |
| M-40 | Cyclohexane | 110-82-7 | 84.16 | 0.0003 | 2.268 | 494 | 7910 | 5370 | 11.8 |
| M-40 | Dibromochloromethane | 124-48-1 | 208.29 | 0.0002 | 0.0155 | 8.3 | 134 | 91 | 0.20 |
| M-40 | Ethyl Acetate | 141-78-6 | 88.10 | 0.0003 | 4.60 | 1000 | 16800 | 11400 | 25.2 |
| M-40 | Heptane | 142-82-5 | 100.20 | 0.0002 | 3.58 | 927 | 14900 | 10100 | 22.3 |
| M-40 | Methyl-t-butyl Ether (MTBE) | 1634-04-4 | 88.15 | 0.0003 | 0.039 | 8.9 | 142 | 97 | 0.213 |
| M-40 | Styrene (Vinylbenzene) | 100-42-5 | 104.14 | 0.0001 | 1.177 | 317 | 5070 | 3450 | 7.6 |
| M-40 | t-1,3-Dichloropropene | 1006-02-6 | 110.98 | 0.0002 | 0.0084 | 2.4 | 39 | 26.2 | 0.058 |
| M-40 | Tetrahydrofuran (Diethylene Oxide) | 109-99-9 | 72.10 | 0.0004 | 2.06 | 385 | 6160 | 4190 | 9.2 |
| M-40 | Tribromomethane (Bromoform) | 75-25-2 | 252.77 | 0.0003 | 0.0094 | 6.1 | 98 | 67 | 0.147 |
| M-40 | Vinyl Acetate | 108-05-4 | 86.09 | 0.0005 | 0.044 | 9.8 | 157 | 107 | 0.235 |

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# 5. Quality Assurance/Quality Control (QA/QC)

This project produced data that qualified to receive the "A" rating with respect to the rating system described in section 4.4.2 of the *Procedures for preparing Emission Factor Documents* (EPA-454/R-95-015). The cited EPA document provides a clear description of the requirements for an "A" data quality rating. Tests were performed by using an EPA reference test method, or when not applicable, a sound methodology. Tests were reported in enough detail for adequate validation and raw data were provided that could be used to duplicate the emission results presented in this report.

Throughout the results sections of this report, notations and footnotes were included to flag data that, for various reasons, did not meet their associated measurement quality objectives.

## 5.1 Assessment of Measurement Quality Objectives

Measurement quality objectives (MQOs) were established for each critical measurement and documented in the *Site-Specific QAPP for the Field Evaluation of Landfill Gas Control Technologies-Landfill D*. The following subsections assess MQOs for each measurement to determine if goals were achieved. When applicable, data validation elements performed on laboratory analytical reports are also included.

### 5.1.1 Continuous Emissions Monitors (CEMs)

Oxygen ($O_2$), $CO/CO_2$, $SO_2$ $NO_x$ and THC were measured in the field using CEMs. The following MQOs were established for CEM measurements for Landfill D:

- Direct calibration bias: ±2 percent
- System bias checks: ±5 percent
- Zero and drift: ±3 percent
- Completeness: >90 percent

Direct calibrations were performed daily, prior to testing, at zero, and a minimum of two other concentrations (typically a mid-level concentration and one point towards the end of the instrument range). System bias checks were performed pre-test and post-test. Drift checks were performed daily, post-test. Table 5-1 summarizes these QC checks for all instruments. All MQOs were met for all CEM measurements except the TECO THC monitor drift checks. One of the six measurements fell slightly outside of the ±3.0 percent acceptance criteria at 3.3 percent, which dropped completeness to 83 percent, below the 90 percent MQO. This was not considered a major failure. Limitation on data use was not necessary. Nonetheless, the results in Table 4-14 were notated to reflect this deviation.

**Table 5-1. CEM MQO Summary for Landfill D**

| Instrument and Range | Direct Calibration (±2% criteria) | | | System Bias Checks (±5% criteria) | | | Drift Checks (±3% criteria) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Total # | Bias Range | Complete % | Total # | Bias Range | Complete % | Total # | Bias Range | Complete % |
| Servomex $O_2$ Analyzer (0-21%) | 9 | 0.1-0.5% | 100 | 12 | 0-1.1.2% | 100 | 6 | 0.3-0.7% | 100 |
| Cal Analytical $CO_2$ Analyzer (0-20%) | 9 | 0-2.0% | 100 | 12 | 0.2-1.3% | 100 | 6 | 0.1-0.6% | 100 |
| Cal Analytical CO Analyzer (0-650 ppm) | 12 | 0.2-0.6% | 100 | 12 | 0-1.4% | 100 | 6 | 0-1.8% | 100 |
| Cal Analytical $SO_2$ Analyzer (0-500 ppm) | 9 | 0-0.7% | 100 | 12 | 0.1-4.3% | 100 | 6 | 0-2.1% | 100 |
| TECO THC Analyzer (0-1000 ppm) | NA [a] | NA [a] | NA [a] | 18 | 0.2-1.5% | 100 | 6 | 0-1.8% | 100 |
| TECO $NO_X$ Analyzer (0-4000 ppm) | 9 | 0.3-1.3% | 100 | 12 | 0.2-3.2% | 100 | 6 | 0-3.3 | 83 [b] |

[a] The method called for calibration gases to be introduced at a point of the sampling system close to the sampling probe for them to flow through the heated sample line. Calibration gases were not injected directly to the analyzer

[b] One of the six measurements was above acceptance criteria.

### 5.1.2 Carbonyls (SW-846 Method 8315A)

The following MQOs were established in the QAPP for this method:

- Recovery (formaldehyde): 50-150 percent
- Completeness: >90 percent

Four samples (including one field blank) were submitted from Landfill D for formaldehyde and acetaldehyde determination to Resolution Analytics. Results were reported in RFA#RN990230. The report included information on instrument calibration and internal QC checks. Samples collected on May 16, 2004 were received by the laboratory on May 19, 2004 and analyzed on June 7, 2004. That met the 30-day hold-time limitation. Analytical detection limits were reported as 50 ppb for formaldehyde and 51.7 ppb for acetaldehyde in the extract. The extract volume was 5 ml. Therefore, the detectable quantities for formaldehyde and acetaldehyde were 250 ng and 258 ng, respectively. Based on a sample gas volume of about 31 liters (at standard condition), the corresponding MDLS for formaldehyde and acetaldehyde were 6.4 ppbv and 4.5 ppbv, respectively.

The field blank (LDFLD-M0100-051604-FB) did not have detectable levels of either compound. To assess accuracy, an external performance evaluation audit sample containing 1.25 ppm formaldehyde and acetaldehyde was analyzed with the sample set. Recovery was 101 percent for both compounds, which meets the 50-150 percent MQO established in the QAPP. This spike was analyzed in duplicate with a percent difference (%D) between injections of 4.8 percent. All project samples were injected in duplicate and the %D range for formaldehyde was 0 to 4.5 percent and for acetaldehyde was 0 to 3.6 percent. All MQOs were met for this method for a completeness of 100 percent.

#### 5.1.3 Hydrogen Sulfide ($H_2S$) (EPA Method 11)

The following MQOs were established in the Landfill D QAPP for this method:

- Accuracy: ±5 percent bias
- Completeness: >90 percent

Five samples (including a field blank) plus reagent blanks were submitted to Oxford Laboratories for $H_2S$ analysis by EPA Method 11, as part of the Landfill D field test effort. The samples were collected on May 15, 2004, submitted on May 27, 2004, and were analyzed on June 17, 2004, which exceeded the 30-day hold time criteria established in the QAPP by 2 days. The potential adverse effect of hold-time having been exceeded on the results is unkown. The test results in Table 4-3 were notated accordingly.

The field blank submitted did not have quantifiable concentrations of $H_2S$. One spike and one set of duplicates were also performed by the laboratory as additional QC checks. Spike recoveries were reported as 109 percent, which meets MQO. The duplication of sample LDFLC-PRE-M0011-51304-02 yielded a titration difference of only 0.3 ml. Although the computed sample concentration values showed greater than 10 percent difference, this was an acceptable duplicate. The final difference was because of the small titration difference between the sample and the blank.

#### 5.1.4 Dioxins and Furans (PCDD/PCDFs) (EPA Method 23/0011)

The specification to conducting testing for these compounds was incorrectly retained in the Site-Specific QAPP for Landfill D. The high gas temperatures (>1400 °F) at the sampling location near the flare stack exit rendered the presence of dioxins and furans (PCDD/PCDFs) improbable. Extensive research data showed that formation of PCDD/PCDFs is favored within the temperature window between 500 and 700 °F. The flare system did not provide for the gases to be cooled to these temperatures before the gases were emitted into the atmosphere.

Furthermore, PCDD/PCDF test results showed that these targets were mostly non-detectable. The cost of this measurement, which would most likely return non-detect results, was not justified. Hence, consistent with the intent of this test program, PCDD/PCDF samples were not collected from Landfill D.

#### 5.1.5 Polycyclic Aromatic Hydrocarbons (PAH) (EPA Method 23/0011)

Polycyclic aromatic hydrocarbon (PAH) samples were not collected for the same reason stated in Section 5.1.4.

#### 5.1.6 Non-Methane Organic Compounds (NMOC) (Method 25C)

The following MQOs were established in the QAPP for Landfill D:

- Accuracy: ±5 percent bias
- Completeness: >90 percent

Four canister samples (including a field blank) were submitted from to Triangle Environmental Services for NMOC analysis by Method 25-C. The samples were collected on May 16, 2004, submitted on June 3, 2004, and analyzed June 7-22, 2004, which met the 30 day hold time requirements. The laboratory report included information on instrument calibration and internal QC checks.

Non-methane organic compounds (NMOCs) in the field blank (LDFLD-PRE-M40-051604-FB) were below detection limit. Accuracy for the method was assessed by evaluating results of response factor (RF) check samples that were run prior to and following sample analysis. Acceptance criteria established by the method is that the RF must be within 20 percent of the RF from initial calibration. All RF checks were within 10 percent of the initial calibration, well within the acceptance criteria. The %D between the pre and post-test checks were less than 1 percent. Samples were run in triplicate and all percent relative standard deviation (RSD) for samples were <5 percent.

The data set was determined valid but there was a problem with the samples from the Landfill D site. All three of the gas pipe samples had nitrogen ($N_2$) and $O_2$ concentrations that exceeded the Method 25C criteria of 20 percent for $N_2$ and 5 percent for $O_2$. The NMOC data for these samples could not be used. Since three of the four samples could not be used, the completeness MQO for this measurement was 25 percent and did not meet the objective set in the QAPP.

#### 5.1.7 Hydrogen Chloride (HCl) (EPA Method 26A)

The following MQOs were established in the QAPP for Landfill D:

- Accuracy: ±10 percent bias
- Completeness: >90 percent

Four samples (including one field blank) were submitted from Landfill D for HCl and chlorine ($Cl_2$) determination to Resolution Analytics. Results were reported in RFA#RN990230. The report included information on instrument calibration and internal QC checks. Samples were collected on May 16, 2004, received by the laboratory on May 19, 2004, and analyzed on June 7, 2004, which met the 4 week hold-time requirement. Analytical detection limits were reported as 2.6 ppm for HCl and 2.5 ppm for $Cl_2$.

The field blank (LDFLD-M26-051604-FB), submitted with samples, did not contain detectable levels of HCl or $Cl_2$. In-house audit samples were analyzed with each respective group of field samples and fell within method criteria of 10 percent of their expected values. A matrix spike was performed on sample LDFLC-051404-3. An 0.8 ml sample was spiked with 0.8 ml of standard (50 ppm for HCl/25 ppm for $Cl_2$) and analyzed in triplicate. The laboratory reported 99 percent recovery of the HCl spike with a 0.4 percent RSD in triplicate injections, and 102 percent recovery of the $Cl_2$ spike with a 0.3 percent RSD. This met the MQO of ±10 percent with very good precision. In addition to the matrix spike, an internal QC check was performed after every 10 samples. All samples were measured in triplicate. Calculated bias for internal QC check was <1 percent for all measurements as was the %D between triplicates. All MQOs were met for 100 percent completeness.

#### 5.1.8 Metals (EPA Method 29)

The following MQOs were established in the Landfill D QAPP for this method:

- Accuracy: ±25 percent bias
- Completeness: >90 percent

Four sets of Method 29 Multi-Metals trains (including one field blank) were submitted from Landfill D for As, Cd, Cr, Pb, Mn, Hg, and Ni determination to First Analytical Laboratories. Results were reported in Project #40513. The report included information on instrument calibration and internal QC checks. Samples were collected on May 16, 2004, received by the laboratory on May 19, 2004, and analyzed on May 24-26, 2004, which met the 14 day hold-time requirement. Method detection limits for each of the target metals were reported as follows:

- As = 5.0 µg/L
- Cd = 0.2 µg/L
- Cr = 5.0 µg/L
- Pb = 5.0 µg/L
- Mn = 5.0 µg/L
- Ni = 10 µg/L
- Hg = 0.2 µg/L

Traces of Cd, Cr, Mn, and Ni were found in the blanks, which is not unusual. Some of the back half Mn samples are abnormally high. This is a common problem which can occur in Method 29 if a tiny amount of the potassium permanganate reagent gets in to the hydrogen peroxide impingers.

All samples were spiked prior to analysis. The Cd back half spike recovery was poor (56 percent), so the Cd back half analysis was conducted by the method of standard additions to overcome the problem. All of the other spike recoveries were within the acceptable range of 75-125 percent. In addition to spiking the samples, for each metal, internal calibration verification samples (ICVs) and continuing calibration verification samples (CCVs) were performed. ICVs were run at the beginning of each run set and CCVs were run at a frequency of one for every 10 samples. The ICV and CCV measured values were all <±10 percent for all metals with the exception of Ni. Two of the four CCV measurements for Ni were slightly above the 10 percent acceptance criteria at 10.6 percent and 14.0 percent. This was not considered a major failure and data limitations were not applied. To evaluate precision, all samples were analyzed in duplicate. Whenever %RSD for duplicate measurements exceeded 20 percent, the sample was re-analyzed.

#### 5.1.9 Organo-Mercury (Hg) and Total Mercury (Hg) (Frontier)

The following MQOs were established in the Landfill D QAPP for this method:

- Recovery: 50-150 percent
- Completeness: >90 percent

For Hg samples, replicates and spikes were incorporated into the sampling scheme. In addition, performance evaluation audit samples were also submitted to Frontier for analysis. Results from the performance evaluation audit (PEA) are summarized in Section 5.2.2.2.

Four total Hg samples (including a field blank) were taken at Landfill D. Samples were collected on May 15, 2004, extracted on May 28, 2004, and analyzed on June 3, 2004. That analysis schedule exceeded the 14-day hold-time specified in the QAPP. All other quality assurance measures indicated that the analysis of the traps were under good control. All field blanks were consistent with historical values and indicated the detection limit was likely to be at or below the previous estimated value of 50ng/$m^3$.

Spike recoveries were >95 percent and standard deviation between replicates was 169 percent, which met MQOs and were 100 percent complete.

Five monomethyl mercury (MMHg) samples (including a field blank) were collected at Landfill D on May 15, 2004. These samples were extracted on May 27, 2004 and analyzed on May 28, 2004 which meets the 14-day hold-time. Analysis of these samples was under good control with acceptable distillation spike recoveries and distillation duplicates. All CCV standards had acceptable recoveries. Spike recoveries were 80-117 percent, which meets MQOs. The RSD between replicates was <10 percent. For Landfill D, this analysis was 100 percent complete.

Six dimethyl mercury (DMHg) samples (including a field blank) were collected at Landfill D on May 15, 2004. These samples were extracted and analyzed on May 27, 2004, which met the 14-day hold-time. The analysis of samples was well within control, with acceptable recoveries as well as good linear control standards and second-source standard recoveries. Spike recovery for Landfill D samples was 78-80 percent and RSD between replicate samples was 3.6 percent. This meets MQOs established in the QAPP and DMHg analysis was therefore 100 percent complete.

The field blank was low indicating that the trap media, handling procedures, and analytical techniques did not contribute to the reported values. Field matrix spike recoveries ranged from 50-93 percent. The DMHg analysis was 100 percent complete.

#### 5.1.10 Volatile Organic Compound (VOCs) and Methane ($CH_4$) (Method TO-15)

The following MQOs were established in the Landfill D QAPP for this method:

- Accuracy: 50-150 percent recovery
- Completeness: >90 percent

Five SUMMA canisters (including field blanks) were submitted from Landfill D to Research Triangle Park (RTP) Laboratories for VOC and $CH_4$ determination by EPA Method TO-15. Results were reported in Project #04-162. Samples were collected on September 14, 2004 and analyzed on October 4, 2004, which met the 30 day hold-time requirement.

Analysis of the field blank (LDFLD-091404-M40-FB) resulted in significant levels of several VOC compounds. Table 5-2 lists the compounds identified in the field blank that were >1 ppbv. This should be considered when evaluating sample data. Accuracy was assessed using results of a 10 ppbv laboratory control sample containing all target compounds. For all but one compound, recoveries ranged from 75-135 percent, which met the established acceptance criteria of 50-150 percent. The recovery reported for m/p-xylene was 250 percent. Results for this compound should be flagged as estimated, “J”. Precision was demonstrated through multiple injections of standards at five concentration levels. The RSD between the calculated relative response factors (RRF) must be <30 percent with allowances that two may be >40 percent. The average RSD was 11.8 percent and method criteria were met for all compounds except cyclohexane with an RSD of 41.2 percent and heptane with an RSD of 57.4 percent. Results for these compounds should be flagged as estimated, “J”. Valid data was received for all SUMMA canisters submitted; these analyses are considered to be 100 percent complete.

**Table 5-2. VOCs Identified in Field Blank**

| Compound | Concentration in Field Blank Sample (ppbv) | Average Concentration in Samples (ppbv) |
|---|---|---|
| Dichlordifluoromethane | 11.95 | 1240 |
| Vinyl Chloride | 10.67 | 1200 |
| 1,3-butadiene | 2.15 | 326 |
| Chloroethane | 4.36 | 634 |
| Ethanol | 18.71 | 394 |
| Isopropyl alcohol | 96.84 | 6630 |
| Methylene chloride | 16.02 | 1110 |
| Acetone | 108.43 | 12800 |
| Hexane | 25.47 | 3980 |
| Vinyl acetate | 25.3 | 44 |
| Cis-1,2-dichloroethene | 10.8 | 1780 |
| Cyclohexane | 11.03 J | 2270 |
| Chloroform | 4.45 | 485 |
| Ethyl acetate | 23.81 | 4600 |
| Tetrahydrafuran | 47.64 | 2060 |
| 2-butanone | 114.14 | 8070 |
| Heptane | 36.44 J | 3580 |
| Benzene | 8.97 | 1200 |
| Trichloroethylene | 4.76 | 418 |
| Toluene | 696.78 | 30300 |

| Compound | Concentration in Field Blank Sample (ppbv) | Average Concentration in Samples (ppbv) |
|---|---|---|
| Tetrachloroethylene | 17.55 | 1020 |
| 1,1,2-trichloroethane | 3.36 | ND |
| Ethylbenzene | 121.54 | 8120 |
| Chlorobenzene | 2.49 | 21 |
| m/p-xylene | 289.79 J | 13600 |
| o-xylene | 87.66 | 5410 |
| Styrene | 18.21 | 1180 |
| 1-ethyl-4-methylbenzene | 22.38 | 976 |
| 1,3,5-trimethylbenzene | 22.38 | 976 |
| 1,2,4-trimethylbenzene | 66.83 | 2190 |
| 1,4-dichlorobenzene | 40.03 | 686 |
| 1,3-dichlorobenzene | 38.27 | 650 |
| Benzyl chloride | 7.05 | ND |
| 1,2-dichlorobenzene | 1.46 | 31 |

J – Value is categorized as an estimate per EPA QA/G-8 guidance

### 5.2 Audits

This project was designated as QA Category II effort. Hence, audits were required. The internal and external audits performed for this project are described in the following subsections.

#### 5.2.1 EPA Technical Systems Audit

EPA audits were not performed at the Landfill D site. EPA/APPCD Quality Assurance (QA) Representative, Robert Wright, conducted an on-site technical systems audit (TSA) of the field evaluations at Landfill C on May 12-13, 2003. The approved Site-Specific QAPP and the associated field sampling manual provided the technical basis for the audit. The ARCADIS QA Officer, Laura Nessley, accompanied the EPA auditor during the TSA. A report of preliminary findings was received on May 19, 2004 and it was included in the Landfill C report.

### 5.2.2 Laboratory Audits

Because of the developmental nature of the organo-Hg methods, an internal TSA and PEA were performed by ARCADIS at Frontier Geosciences (Frontier) facilities in Seattle, Washington.

#### *5.2.2.1 Internal Technical Systems Audit (TSA)*

In an effort to save project funds by minimizing expenses associated with staff travel, Mr. John Hicks, a Senior Scientist at the ARCADIS Seattle Office, was assigned to perform the laboratory audit. The laboratory audit included observation of spiking procedures for MMHg and DMHg media prior to shipment to the field, and subsequent analysis of project samples for MMHg, DMHg and total Hg. Ms. Laura Nessley provided Mr. Hicks with checklists to use during the audits.

The audits of Frontier's spiking procedures took place on April 29, 2003 for MMHg and May 4, 2004 for DMHg and total Hg. Calibration, media spiking techniques, record keeping and good laboratory practices were the focus of the audit, with special attention paid to the MMHg and DMHg spike preparation for the upcoming field effort. The following Frontier personnel were present for some or all of the audits conducted by ARCADIS:

- Lucas Hawkins Research Associate/Field Sampling/Analyst
- Amber Stewart Total Mercury Laboratory Supervisor
- Melissa Oheara MMHg preparation and distillation
- Cindy Moulder MMHg analysis
- Matt Gomes Total Hg extractions
- Melinda Cowen Senior Laboratory Analyst for total Hg

Some of the primary observations resulting from the first audit included:

- A single source for calibration and spiking was used for MMHg and DMHg. The laboratory had not been able to locate other stable standards for use as an independent source. There were not NIST-traceable standards for organo-Hg.

- Expiration dates for primary MMHg and DMHg standard materials were not available. The MMHg standard bottle had a label dated 1998.

- Written procedures for spiking of impinger solutions or carbon tubes were not evident.

- While work plans state that samples should be kept cold and the organometallic analytes are light sensitive, the analytical standard for MMHg was stored in a clear Teflon bottle on an un-refrigerated shelf across from a large picture window.

- Frontier did not routinely retain an aliquot of spike solution or spiked traps when sending media to a field project.

The continuation of the earlier audit that focused on matrix spiking and media preparation was performed in late May 2004. This audit concentrated on the analysis of the sampling media sent to Landfill site D, including extraction, analysis and calibration procedures for MMHg, DMHg, and total Hg. These audits were conducted on three separate days to accommodate Frontier's analysis schedule. On May 27, 2004, the audit focused on MMHg extraction and distillation as well as DMHg analysis. On May 28, 2004 MMHg analysis and total Hg extraction procedures were audited. On June 3, 2004, the procedures for total Hg analysis were audited.

Significant findings and recommendations resulting from the extraction and analysis portion of the laboratory audit included:

- **Efficiency factor (EF)**: An efficiency factor (EF) based on average results from the analyses of distillation blanks was applied to all MMHg sample results. This practice was not discussed in the narrative portion of the Frontier reports and not mentioned by name in the standard operating procedures (SOPs) provided to ARCADIS. This technique essentially boosted analyte recoveries through a multiplied efficiency factor applied to all MMHg results. The current EF is 89.5 percent, therefore all results were normalized to 100 percent recovery levels. For example, a measured value of 100.0 ng detected in an environmental sample was corrected to 110.5 ng after applying the EF. Without a data report disclaimer, this practice misrepresents the results and biases all MMHg results high.

- **Method blank subtraction**: Frontier subtracts the average of the method blanks from each extraction/preparation batch. While scientifically valid, this technique is not acceptable for most EPA-referenced protocols. The laboratory has a responsibility only to report blank concentrations; adjusting environmental sample concentrations through a data evaluation/validation process is the client's responsibility.

- **MMHg Instrument stability**: Monomethyl Hg (MMHg) analysis was performed over a 2-day period because of poor instrument stability and issues associated with efficiency of the ethylating reagent. Initially, two instruments were set up for calibration on May 27. Only one of the instruments showed sufficient sensitivity and stability to continue analysis. Unfortunately, the initial calibration curve did not meet method specifications, so the instrument was recalibrated and environmental samples analyzed while the ARCADIS auditor was present. The following day, the auditor was informed that the sample set did not meet the QAPP requirements because of unexpected lower concentrations in the samples. The samples were successfully reanalyzed the following day after maintenance was performed on the MMHg analysis instrument. Reanalyzing samples is apparently common and sometimes entire sample sets are reanalyzed more than once. Ms. Moulder stated that it is "the nature" of this analysis to have to frequently recalibrate and reanalyze samples. Calibrations should be closely reviewed during data validation.

- **Calibration Curve Forcing**. ARCADIS learned that, in accordance with Frontier policy, all calibration curve origin points are forced through zero. ARCADIS notes that this procedure is not consistent with most EPA-promulgated methods. ARCADIS recommends reprocessing one calibration curve to determine the impact, if any, to the data.

- **Retention Time Marking**: While observing the MMHg analysis, the analyst did not mark the beginning of the analysis charts with a "tick" time marker, which was particularly critical given that identification of MMHg is primarily determined by retention times or relative retention times. Some of the samples being analyzed had numerous chromatographic peaks including MMHg and other forms of Hg. Based on observation of other laboratory "pods" within Frontier, the marking of the actual start time on the strip chart recorder was not standardized as a procedural practice. Some analysts mark the desorption time on the strip chart recorder and others do not. However, marking of analysis start times should be a requirement of each method in the place of automatic chromatographic data collection (integrators or computer data acquisition) to avoid misidentification of analyte targets. ARCADIS recommends the standardization of marking the start of analysis on strip chart recorders.

- **Digestate Dilution Technique**: The method of bringing the digested total Hg to quantitative volume in a 20 milliliter glass vial was unusual as the technique does not rely on marked, calibrated Class A or B glassware when bringing digested samples to a known quantitative volume. The analyst did not know if the volume of the unmarked vials was recently compared against calibrated glassware, but assumed it was 20 mL. The analyst consistently brought the digested samples to a consistent level that corresponded to the neck of the glass vial. At a minimum, the vials should be calibrated to assure the final volumes are accurate.

- **Sample/Standard Storage**: The temperatures of one refrigerator ("A") and one freezer ("A") used to store samples, analytical standards, and frozen ethylating cocktails were not monitored for three days prior to the audit (5/25/04). This did not appear to be a systematic problem, but the analyst did not have an explanation. Verification of temperatures in standard and sample storage areas should be checked daily.

- **Calibration Verification**: While discussed in the previous ARCADIS Audit report dated May 17, 2004, this observation was again included because it is critical to the evaluation of the laboratory and the application of these methods to LFG monitoring. Frontier uses a single source for calibration and spiking for MMHg and DMHg methods. The laboratory has not been able to locate other acceptable, stable standards, such as NIST-traceable standards. Frontier utilizes Standard Reference Materials and certified standards. However, accuracy was only measured for MMHg by comparison to a digested tissue standard and for DMHg by comparison to JSI-1, a material from the JSI Institute in Slovenia. ARCADIS recommends that Frontier make an effort to locate alternate acceptable accuracy standards to verify true concentrations of the main calibration standards.

- **Holding Times**: Holding times were generally not an issue with most analyses Frontier performs, but based on the QAPP, specific holding times to analysis apply to this analysis. This was not documented in the summary report. However the Total, MMHg and DMHg analyses were extracted, but not all analyzed within the 14 day holding time assuming May 27 was the 14$^{th}$ day after sampling. Some data qualification might be necessary, depending on the professional judgment of the data validator.

### 5.2.3 Internal Performance Evaluation Audits (PEA)

Because there is not a currently promulgated method for organo-Hg sampling and analysis, PEA samples were integrated in to the sampling matrix to evaluate accuracy and precision of the methods used by Frontier. ARCADIS subcontracted an independent laboratory to assist in preparation of the PEA samples. The laboratory was Cebam Analytical located in Seattle, Washington. All standards and stock solutions were prepared and verified by a Cebam Analytical analyst.

Two PEA samples were prepared for total Hg. Trap A was spiked with 9.99 ng THg by a Cebam analyst. This concentration was verified by Cebam by performing six replicate analyses. Samples were analyzed by Frontier Geosciences as described in the report titled *Determination of Total, Dimethyl, and Monomethyl Mercury in Raw Landfill Gas at Pinconning and Montrose Michigan*. Recovery results are presented in Table 5-3. Relative percent difference (RPD) between the duplicate samples was 1.0 percent.

**Table 5-3. Total Mercury PEA Results**

| Sample ID | Total Hg Measured (ng) | Total Hg Spiked (ng) | Recovery (%) |
|---|---|---|---|
| C-052104-01 | 13.60 | 9.99 | 136 |
| C-052104-02 | 13.47 | 9.99 | 135 |

One PEA sample was prepared and analyzed for MMHg. A 2.0 ng/L spiking solution was prepared by transferring a 0.2 mL aliquot of 10 ng/mL standard into a 1L pre-cleaned glass volumetric flask. The sample was analyzed by Frontier Geosciences as described in the report titled *Determination of Total, Dimethyl, and Monomethyl Mercury in Raw Landfill Gas at Pinconning and Montros, Michigan*. Recovery results are presented in Table 5-4. Because only one sample was prepared, precision for this analysis could not be evaluated.

**Table 5-4. MMHg PEA Results**

| Sample ID | Total MMHg Measured (ng/L) | Total MMHg Spiked (ng/L) | Recovery (%) |
|---|---|---|---|
| 040513-BR-MHg7 | 2.327 | 2.00 | 117 |

Two PEA samples were prepare and analyzed for DMHg. Trap A and Trap B were spiked with 0.215 ng DMHg for a total concentration of 0.430 ng per train. This concentration was verified by Cebam by analyzing five replicates samples of the standard.

The samples were analyzed by Frontier Geosciences as described in the report titled *Determination of Total, Dimethyl, and Monomethyl Mercury in Raw Landfill Gas at Pinconning and Montros, Michigan*. Recovery results are presented in Table 5-5. The RPD between the duplicate samples was 23 percent.

**Table 5-5. DMHg PEA Results**

| Sample ID | Total MMHg Measured (ng)* | Total MMHg Spiked (ng)* | Recovery (%) |
|---|---|---|---|
| ARCADIS DMM Spike #1 | 0.234 | 0.430 | 54.4 |
| ARCADIS DMM Spike #2 | 0.295 | 0.430 | 68.6 |

*Trap A and Trap B together

In conclusion, the MQO for recovery for total Hg and organo-Hg samples (as defined in the QAPP) was established at 50-150 percent. All PEA samples met this objective. The RPD between duplicate samples was also acceptable. The full text of the TSA and PEA audit reports and completed checklists are included in Appendix S.

EPA/600/R-07/043

# Field Test Measurements at Five Municipal Solid Waste Landfills with Landfill Gas Control Technology Final Report

## Appendix E

## SOURCE TEST REPORT FOR LANDFILL E

# Table of Contents

## Tables

## Figures

## Appendices

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## Acronym List

| | |
|---|---|
| %D | Percent drift |
| AP-42 | Compilation of Air Pollutant Emission Factors |
| APPCD | Air Pollution Prevention Control Division |
| ARCADIS | ARCADIS G&M, Inc. |
| As | Arsenic |
| AS | Alternative standard |
| CCVs | Continuing calibration verification samples |
| Cd | Cadmium |
| CEMS | Continuous emission monitoring system |
| $CH_4$ | Methane |
| $Cl_2$ | Chlorine |
| CO | Carbon monoxide |
| $CO_2$ | Carbon dioxide |
| Cr | Chromium |
| DMHg | Dimethyl mercury |
| EPA | US Environmental Protection Agency |
| ES | Extraction standard |
| FID | Flame ionization detector |
| GC/FID | Gas chromatograph/flame ionization detector |
| GC/MS | Gas chromatograph/mass spectrometer |
| HCl | Hydrogen chloride |
| Hg | Mercury |
| $H_2S$ | Hydrogen sulfide |
| ICVs | Internal calibration verification samples |
| LFG | Landfill gas |
| MDLs | Method detection levels |
| MMHg | Monomethyl mercury |
| Mn | Manganese |

## Acronym List

| | |
|---|---|
| MQOs | Measurement quality objectives |
| MSW | Municipal solid waste |
| $N_2$ | Nitrogen |
| Ni | Nickel |
| NMOCs | Non-methane organic compounds |
| $NO_X$ | Nitrogen oxides |
| $O_2$ | Oxygen |
| PAHs | Polynuclear aromatic hydrocarbons |
| Pb | Lead |
| QA | Quality Assurance |
| QAPP | Quality Assurance Project Plan |
| QC | Quality control |
| RF | Response factor |
| RPD | Relative percent difference |
| RRF | Relative response factors |
| RSD | Relative standard deviation |
| RTP | Research Triangle Park |
| $SO_2$ | Sulfur dioxide |
| SS | Sampling standards |
| TCDD/TCDFs | Dioxins/furans |
| THCs | Total hydrocarbons |
| TICs | Tentatively identified compounds |
| VOCs | Volatile organic compounds |

## 1. Introduction

Large municipal solid waste (MSW) landfills are subject to Clean Air Act regulations because of emissions that can contribute to environmental and health concerns. Landfills are listed as a source of air toxics in the Urban Air Toxics Strategy for future evaluation of residual risk. Existing emission factors for landfill gas (LFG) were largely developed using data from the 1980s and early 1990s. A database was developed summarizing data from approximately 1,200 landfills, along with emissions information from literature, and from test reports prepared by state and local government agencies and industry. These data were summarized in *Compilation of Air Pollutant Emission Factors (AP-42)*, Chapter 2.4. Requirements for landfill gas control for new and existing MSW landfills are 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 overall purpose of this testing program was to generate data that could be used to update AP-42 and to include data that reflect current waste management operating practices. Emission factors are used in determining applicability to Clean Air Act regulations, developing emission inventories, and for evaluating potential health concerns associated with LFG emissions.

This report presents the results of a field test conducted at Landfill E, located in a Midwest state. Testing took place on June 22 and 23, 2005.

The site uses a boiler for destruction of the LFG. A more detailed description of the boiler is presented in Section 2. The specific purpose of the testing program was to determine the gas quality of raw LFG (sampling the header pipe prior to gas cleaning) and the emissions of the boiler stack. The pollutants of interest for the raw untreated landfill gas were volatile organic compounds (VOCs), non-methane organic compounds (NMOCs), hydrogen sulfide ($H_2S$), carbonyls (acetaldehyde and formaldehyde), and mercury (Hg) compounds. The pollutants of interest for the treated LFG, in this case at the boiler stack, were carbon monoxide (CO), nitrogen oxides ($NO_X$), sulfur dioxide ($SO_2$), NMOCs as total hydrocarbons (THCs), hydrogen chloride (HCl), total Hg, dioxins/furans (PCDD/PCDFs), polycyclic aromatics hydrocarbons (PAHs), and metals.

ARCADIS G&M, Inc. (ARCADIS), as contractor to the US Environmental Protection Agency's (EPA) Air Pollution Prevention and Control Division (APPCD), performed this work under Work Assignment 1-27 of Onsite Laboratory Support Contract (EP-C-

04-023). The testing activities followed the specifications of the approved "*Site-Specific Quality Assurance Project Plan for the Field Evaluations of Landfill Gas Control Technologies Landfill E*" dated May 2005.

## 2. Landfill E Facility Descriptions

Available information indicates that Landfill E began operation in 1971. As of June 2005, the landfill had 14,500,000 metric tons of waste in place over an area of 240 acres. The LFG extraction rate was 4,800 standard cubic feet per minute. The landfill had 320 vertical wells that feed into a main header pipe. The raw LFG was filtered, de-watered, and compressed prior to being piped for use either off-site or on-site. The different uses of LFG at this site are identified in Table 2-1. Demand and seasonal factors largely determine the use pattern; maximum and minimum rates. The base-load steam boiler at Customer A's facility was tested in this program.

**Table 2-1. Devices Utilizing Landfill E LFG**

| LFG End User | Devices | LFG Utilization Rate (scfm) |
|---|---|---|
| Customer A | Base-load Steam Boiler | 500 - 3400 |
| Customer A | Gas Turbine Generator | 1300 -1700 |
| Customer B | Greenhouse Hot Water Boiler | 100 - 500 |
| Customer C | Asphalt Plant Kiln Burner | 500 -1400 |
| On-site | IC Engine/Micro Turbine Generators | 200 |
| On-site | Four Candlestick Flares | 600 per flare |
| On-site | Candlestick Flare | 2825 |

### 2.1 Boiler Process Description and Operation

The tested boiler was a Combustion Engineering Model 33-7KT-10, A-Type Package Boiler, rated at 80,000 pounds-per-hour of 250 psi steam. The boiler was fueled by the collected LFG and produced base-load steam for Customer A's industrial facility. The boiler was located on Customer A's property, approximately 3 miles from Landfill E. Figure 2-1 shows a simplified process schematic of the LFG-boiler system. Information related to the boiler's ability to destroy potential pollutants was not available.

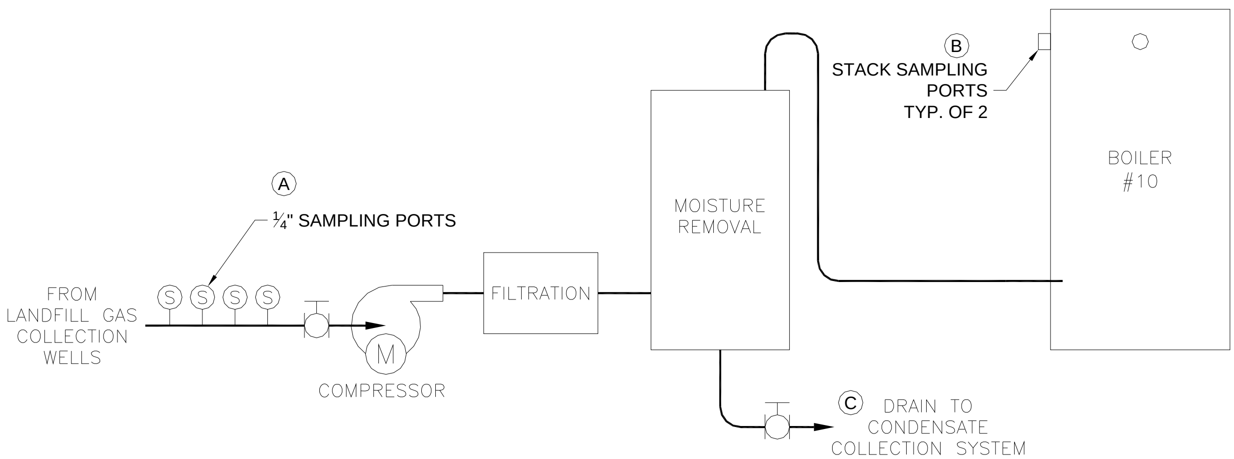


**Figure 2-1. Simplified Landfill E LFG Boiler Process Flow Diagram**

### 2.2 Source Sampling Locations

Raw LFG samples were collected at the landfill gas pipe (location labeled "A"). Samples of treated gas were collected at the boiler stack (location labeled "B"), as depicted in Figure 2-1.

#### 2.2.1 Landfill Gas (LFG) Header Pipe

Raw untreated LFG samples were collected from the header pipe, as it emerged from the ground, upstream of processing units. Figure 2-2 is a photograph of the raw LFG header pipe before it passes into the gas control-and-process system. The pipe is 16 inches in inner diameter. At the sampling point, four ¼-inch gas taps were installed. Through these ports, gases were withdrawn to obtain the test samples.

Isokinetic sampling and accurate velocity measurement requires the measurement point to have at least eight pipe diameter of straight pipe upstream and two pipe diameter of disturbance-free pipe downstream. The header pipe at Landfill E did not meet this requirement. Therefore, isokinetic sampling was not attempted at this location. Furthermore, the short pipes between the upstream and downstream bends precluded accurate measurement of the volumetric flow rate of the raw LFG.

**Figure 2-2. Raw Landfill Gas Collection Pipe**

### 2.2.2 Boiler Stack

A picture of the boiler stack is shown in Figure 2-3. The picture shows the arrangement of the sampling ports. The boiler stack was 76.5 inches in diameter and had two 6-inch sampling ports installed 90 degrees apart. Figure 2-4 illustrates the cross-sectional dimensions of the boiler stack and includes the locations of the sample traverse points. Isokinetic sampling was possible at this location and was followed.

**Figure 2-3. Boiler Stack**

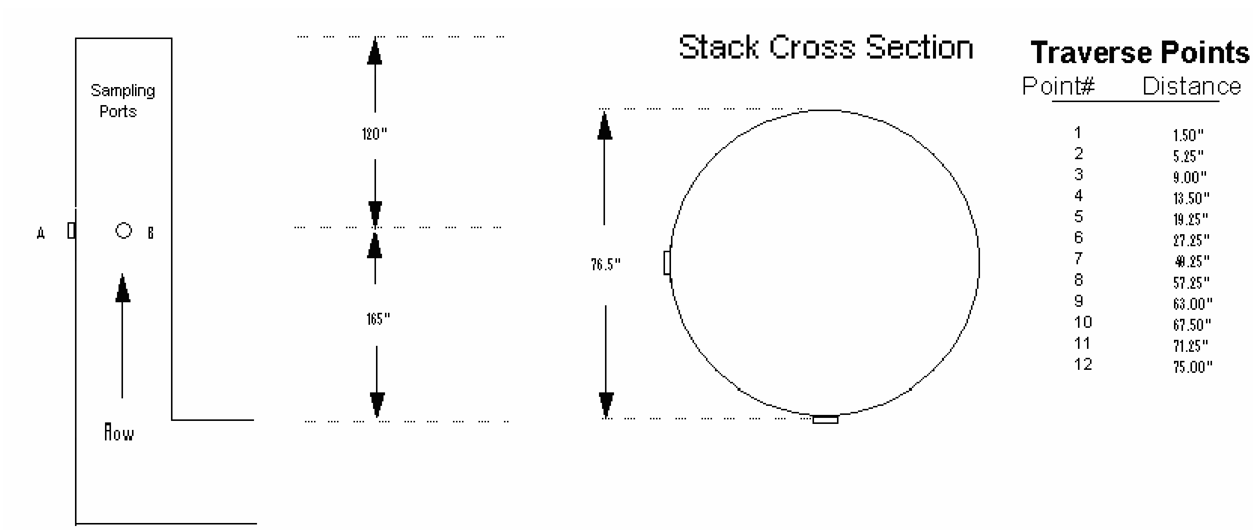


**Figure 2-4. Boiler Stack Dimension and Sampling Traverse Locations**

# 3. Test Operations

As stated previously, the purpose of the sampling program was to determine the quality of raw LFG and emissions from the boiler stack.

## 3.1 Test Team

The tests were conducted by a team of seven individuals. The team members and their primary duties are listed in Table 3-1.

**Table 3-1. Test Team Members and Responsibilities**

| Role | Primary Duty |
|---|---|
| Test Engineer | Field Supervisor |
| Chemical Technician | Sample train preparation and recovery |
| Test Engineer | Sample train operator at raw LFG inlet pipe |
| Sampling Technician | Sample train operator at stack |
| Sampling Technician | Sample train operator at stack |
| CEMS Technician | CEMS operations |
| Senior Chemist (Frontier Geosciences) | Mercury measurements |

## 3.2 Test Log

### 3.2.1 Planned Test Sample Matrices

The list of target samples to be collected and measurements to be taken are specified in the Quality Assurance Project Plan (QAPP) dated June 2005. These are reiterated here for completeness. Table 3-2 lists the target compounds of interest for the raw untreated LFG, collected at the raw LFG pipe. Table 3-3 lists the target compounds of interest for the treated gas, at the boiler stack.

**Table 3-2. Target Analytes for the Raw Landfill Gas Stream**

| Volatile compounds | Volatile compounds (continued) | Carbonyls |
|---|---|---|
| Methane | Ethylene dibromide | Acetaldehyde |
| Ethane | Ethylene dichloride | Formaldehyde |
| Propane | Methyl chloroform | |
| Butane | Methyl isobutyl ketone | **Mercury** |
| Pentane | Methylene chloride | Organo-mercury compounds |
| Hexane | Propylene dichloride | Total |
| Carbonyl sulfide | t-1,2-Dichloroethene | Elemental |
| Chlorodifluoromethane | Tetrachloroethene | |
| Chloromethane | Toluene | **Gases** |
| Dichlorodifluoromethane | Trichlorethylene | Carbon dioxide |
| Dichlorofluoromethane | Vinyl chloride | Oxygen |
| Ethyl chloride | Vinylidene chloride | |
| Fluorotrichloromethane | Ethanol | |
| 1,3-Butadiene | Methyl ethyl ketone | |
| Acetone | 2-Propanol | |
| Acrylonitrile | 1,4-Dichlorobenzene | |
| Benzene | Ethylbenzene | |
| Bromodichloromethane | Xylenes | |
| Carbon disulfide | | |
| Carbon tetrachloride | | |
| Chlorobenzene | **Non-methane organic compounds** | |
| Chloroform | | |
| Dimethyl sulfide | **Reduced sulfur compounds** | |
| Ethyl mercaptan | Hydrogen sulfide | |

**Table 3-3. Target Analytes for the Boiler Stack Outlet Gas Stream**

| Gases | Mercury |
|---|---|
| Oxygen | Total |
| Carbon dioxide | |
| Carbon monoxide | **Metals** |
| Nitrogen oxide | Lead, arsenic, cadmium, chromium, manganese, nickel |
| Sulfur dioxide | |
| **Total hydrocarbons** | **Dioxins/Furans** |
| **Non-methane organic compounds** (as THCs) | |
| | **Polycyclic aromatic hydrocarbons** |
| **Hydrogen chloride** | |

3.2.2 Landfill Gas (LFG) Pipe (Inlet)

Figure 3-1 is a photograph of sampling operations taking place at the raw LFG header pipe. Collection of raw LFG samples took two days to complete. Table 3-4 lists the samples that were collected from the raw LFG pipe.

**Figure 3-1. Sampling Operations at the Raw Landfill Gas Header Pipe**

**Table 3-4. Landfill E Raw LFG Sample Log and Collection Times**

| Sampling Method | Run Number | Analyte(s) | Sample Class | Date | Run Period |
|---|---|---|---|---|---|
| EPA Method 40 (TO-15, 25C 3C) | | | | | |
| | E-Pre-M40-062205-01 | VOCs/NMOCs/$O_2$/$CO_2$,$N_2$ | Test | 06/22/05 | 08:03 - 09:03 |
| | E-Pre-M40-062205-02 | VOCs/NMOCs/$O_2$/$CO_2$,$N_2$ | Test | 06/22/05 | 10:25 - 11:25 |
| | E-Pre-M40-062205-03 | VOCs/NMOCs/$O_2$/$CO_2$,$N_2$ | Test | 06/22/05 | 12:24 - 13:24 |
| | E-Pre-M40-062205-04 | VOCs/NMOCs/$O_2$/$CO_2$,$N_2$ | Test | 06/22/05 | 14:20 - 15:20 |
| | E-Pre-M40-062305-B | VOCs/NMOCs/$O_2$/$CO_2$,$N_2$ | Field Blank | 06/23/05 | 08:28 – 09:28 |
| EPA Method 0100 | | | | | |
| | E-Pre-M0100-062205-01 | Carbonyls | Test | 06/22/05 | 09:11 – 09:41 |
| | E-Pre-M0100-062205-02 | Carbonyls | Test | 06/22/05 | 11:39 – 12:09 |
| | E-Pre-M0100-062205-03 | Carbonyls | Test | 06/22/05 | 13:28 – 13:58 |
| | E-Pre-M0100-062205-B | Carbonyls | Field Blank | 06/22/05 | 14:01 |
| EPA Method 11 | | | | | |
| | E-Pre-M0011-062205-01 | $H_2S$ | Test | 06/22/05 | 15:32 - 15:42 |
| | E-Pre-M0011-062205-02 | $H_2S$ | Test | 06/22/05 | 16:31 - 16:41 |
| | E-Pre-M0011-062205-03 | $H_2S$ | Test | 06/22/05 | 17:21 - 17:31 |
| | E-Pre-M0011-062205-B | $H_2S$ | Reagent Blank | 06/22/05 | - |
| Lumex Instrument | | | | | |
| | E-Pre-EM-062305-01 | Elemental Hg [a] | Test | 06/23/05 | ~09:50 |
| | E-Pre-EM-062305-02 | Elemental Hg [a] | Test | 06/23/05 | ~09:55 |
| | E-Pre-EM-062305-03 | Elemental Hg [a] | Test | 06/23/05 | ~10:00 |
| Frontier | | | | | |
| | 062205-Site E-STM1 | Total gaseous Hg | Test | 06/22/05 | 13:39 - 14:39 |
| | 062205-Site E-STM2 | Total gaseous Hg | Test | 06/22/05 | 14:53 - 15:54 |
| | 062205-Site E-STM3 | Total gaseous Hg | Test | 06/22/05 | 17:00 - 18:01 |
| | 062205-Site E-STMBLK | Total gaseous Hg | Field Blank | 06/22/05 | 18:09 |
| Frontier | | | | | |
| | 062305-Site E-MMHg1 | Monomethyl Hg | Test | 06/23/05 | 08:34 - 09:34 |
| | 062305-Site E-MMHg2 | Monomethyl Hg | Test | 06/23/05 | 10:29 – 11:29 |
| | 062305-Site E-MMHg3 | Monomethyl Hg | Test | 06/23/05 | 11:59 - 12:59 |

| Sampling Method | Run Number | Analyte(s) | Sample Class | Date | Run Period |
|---|---|---|---|---|---|
| | 062305-Site E-MMHgBLK | Monomethyl Hg | Field Blank | 06/23/05 | 13:28 |
| | 062305-Site E-MMHgSPK | Monomethyl Hg | Spike | 06/23/05 | 13:53 - 14:53 |
| Frontier | | | | | |
| | 062205-Site E-DMHg1 | Dimethyl Hg | Test | 06/22/05 | 13:10 - 13:15 |
| | 062205-Site E-DMHg2 | Dimethyl Hg | Test | 06/22/05 | 13:55 - 14:01 |
| | 062205-Site E-DMHg3 | Dimethyl Hg | Test | 06/22/05 | 15:00 - 15:08 |
| | 062205-Site E-DMHgBLK | Dimethyl Hg | Field Blank | 06/22/05 | 18:00 |
| | 062205-Site E-DMSPK | Dimethyl Hg | Spike | 06/22/05 | 15:28 - 15:34 |
| Geochimica | | | | | |
| | 062205-Site-E-DMHg-blk | Dimethyl Hg | Field Blank | 06/22/05 | -- |
| | 062205-Site-E-DMHg-1 | Dimethyl Hg | Test | 06/22/05 | 13:10 - 13:15 |
| | 062205-Site-E-DMHg-2 | Dimethyl Hg | Test | 06/22/05 | 13:55 - 14:01 |
| | 062205-Site-E-DMHg-3 | Dimethyl Hg | Test | 06/22/05 | 15:00 - 15:07 |
| | 062205-Site-E-DMHg-spk | Dimethyl Hg | Spike | 06/22/05 | 15:28 - 15:34 |
| Geochimica | | | | | |
| | 062205-Site-E-STM-1 | Total gaseous Hg | Test | 06/22/05 | 13:39 - 14:39 |
| | 062205-Site-E-STM-blk | Total gaseous Hg | Field Blank | 06/22/05 | 18:09 |
| | 062205-Site-E-STM-4 | Total gaseous Hg | Test | 06/22/05 | 17:00 - 18:01 |
| | 062205-Site-E-STM-2 | Total gaseous Hg | Test | 06/22/05 | 14:53 - 15:54 |
| Geochimica | | | | | |
| | 062305-Site-E-MMHg-spk | Monomethyl Hg | Spike | 06/23/05 | 13:53 -14:53 |
| | 062305-Site-E-MMHg-1 | Monomethyl Hg | Test | 06/23/05 | 08:34 - 09:34 |
| | 062305-Site-E-MMHg-2 | Monomethyl Hg | Test | 06/23/05 | 10:29 - 11:29 |
| | 062305-Site-E-MMHg-3 | Monomethyl Hg | Test | 06/23/05 | 11:59 - 12:59 |
| | 062305-Site-E-MMHg-blk | Monomethyl Hg | Field Blank | 06/23/05 | 13:28 |

[a] Represents 3 readings, each ~60-seconds in duration

#### 3.2.3 Boiler Stack

The boiler stack gases were sampled for measurement of NMOCs (as THCs), HCl, metals (lead [Pb], arsenic [As], cadmium [Cd], chromium [Cr], manganese [Mn], nickel [Ni]), PCDD/PCDFs, PAHs, total Hg, $SO_2$, $NO_X$, CO, carbon dioxide ($CO_2$), and oxygen ($O_2$). Sampling of the boiler stack gases was conducted by inserting sampling probes into the stack pipe and withdrawing the gases with the various sampling trains. The boiler stack cross-section was divided into 24 equal areas according to EPA Method 1. The sample probe was placed in each of these 24 areas to extract equal amounts of gas sample from each area. Sampling at the boiler stack was conducted at isokinetic conditions.

Accessing the sampling ports required the aid of scaffold platforms. Figure 3-2 shows the stack and the sampling scaffold platforms. Figure 3-3 shows a sampling train in place during sample collection at the boiler stack.

**Figure 3-2. Sampling Operations at the Boiler Stack**

**Figure 3-3. Sampling Train at the Boiler Stack**

Sample run times for the Method 26A HCl trains and the Method 29 metals trains were 120-minutes. Runs times for the Method 23 PCDD/PCDF and PAH trains were 240 minutes. Run times for continuous emission monitoring system (CEMS) parameters ($SO_2$, $NO_X$, CO, $O_2$, $CO_2$, and THCs) varied and were timed to coincide with the collection periods of the other samples. Table 3-5 lists the sample collections times and samples collected from the boiler stack

**Table 3-5. Boiler Stack Test Sample Log and Collection Times**

| Sampling Method | Run Number | Analyte(s) | Sample Class | Date | Run Period |
|---|---|---|---|---|---|
| EPA Method 3A (CEM) | | | | | |
| | E-Post-M3A-062205-01 | $O_2$ | Test | 06/22/05 | 10:42 - 15:53 |
| | E-Post-M3A-062205-02 | $O_2$ | Test | 06/22/05 | 16:50 - 19:43 |
| | E-Post-M3A-062305-03 | $O_2$ | Test | 06/23/05 | 08:33 – 13:26 |
| | E-Post-M3A-062305-04 | $O_2$ | Test | 06/23/05 | 14:38 - 16:12 |
| EPA Method 3A (CEM) | | | | | |
| | E-Post-M3A-062205-01 | $CO_2$ | Test | 06/22/05 | 10:42 - 15:53 |
| | E-Post-M3A-062205-02 | $CO_2$ | Test | 06/22/05 | 16:50 - 19:43 |
| | E-Post-M3A-062305-03 | $CO_2$ | Test | 06/23/05 | 08:33 – 13:26 |
| | E-Post-M3A-062305-04 | $CO_2$ | Test | 06/23/05 | 14:38 - 16:12 |
| EPA Method 10 (CEM) | | | | | |
| | E-Post-M10-062205-01 | CO | Test | 06/22/05 | 10:42 - 15:53 |
| | E-Post-M10-062205-02 | CO | Test | 06/22/05 | 16:50 - 19:43 |
| | E-Post-M10-062305-03 | CO | Test | 06/23/05 | 08:33 – 13:26 |
| | E-Post-M10-062305-04 | CO | Test | 06/23/05 | 14:38 - 16:12 |
| EPA Method 7E (CEM) | | | | | |
| | E-Post-M7E-062205-01 | $NO_X$ | Test | 06/22/05 | 10:42 - 15:53 |
| | E-Post-M7E-062205-02 | $NO_X$ | Test | 06/22/05 | 16:50 - 19:43 |
| | E-Post-M7E-062305-03 | $NO_X$ | Test | 06/23/05 | 08:33 – 13:26 |
| | E-Post-M7E-062305-04 | $NO_X$ | Test | 06/23/05 | 14:38 - 16:12 |
| EPA Method 6C (CEM) | | | | | |
| | E-Post-M6C-062205-01 | $SO_2$ | Test | 06/22/05 | 10:42 - 15:53 |
| | E-Post-M6C-062205-02 | $SO_2$ | Test | 06/22/05 | 16:50 - 19:43 |
| | E-Post-M6C-062305-03 | $SO_2$ | Test | 06/23/05 | 08:33 – 13:26 |
| | E-Post-M6C-062305-04 | $SO_2$ | Test | 06/23/05 | 14:38 - 16:12 |
| EPA Method 25A (CEM) | | | | | |
| | E-Post-M25A-062205-01 | NMOCs (THC) | Test | 06/22/05 | 10:42 - 15:53 |
| | E-Post-M25A-062205-02 | NMOCs (THC) | Test | 06/22/05 | 16:50 - 19:43 |
| | E-Post-M25A-062305-03 | NMOCs (THC) | Test | 06/23/05 | 08:33 – 13:26 |
| | E-Post-M25A-062305-04 | NMOCs (THC) | Test | 06/23/05 | 14:38 - 16:12 |
| Lumex Instrument | | | | | |
| | E-Post-EM-062205-01 | Elemental Hg [a] | Test | 06/23/05 | ~16:30 |
| | E-Post-EM-062205-02 | Elemental Hg [a] | Test | 06/23/05 | ~16:35 |

| Sampling Method | Run Number | Analyte(s) | Sample Class | Date | Run Period |
|---|---|---|---|---|---|
| | E-Post-EM-062305-03 | Elemental Hg [a] | Test | 06/23/05 | ~16:40 |
| | E-Post-EM-062305-04 | Elemental Hg [a] | Test | 06/23/05 | ~16:45 |
| | E-Post-EM-062305-05 | Elemental Hg [a] | Test | 06/23/05 | ~16:50 |
| EPA Method 26A | | | | | |
| | E-Post-M26A-062205-01 | HCl | Test | 06/22/05 | 17:18 - 19:42 |
| | E-Post-M26A-062305-02 | HCl | Test | 06/23/05 | 08:47 - 10:50 |
| | E-Post-M26A-062305-03 | HCl | Test | 06/23/05 | 14:09 - 16:12 |
| EPA Method 23 | | | | | |
| | E-Post-M23-062205-01 | PCDD/PCDFs, PAHs | Test | 06/22/05 | 11:41 - 16:02 |
| | E-Post-M23-062205-02 | PCDD/PCDFs, PAHs | Test | 06/22/05 | 11:43 - 15:58 |
| | E-Post-M23-062305-03 | PCDD/PCDFs, PAHs | Test | 06/23/05 | 08:52 - 12:56 |
| EPA Method 29 | | | | | |
| | E-Post-M29-062205-01 | Metals | Test | 06/22/05 | 17:21 - 19:45 |
| | E-Post-M29-062305-02 | Metals | Test | 06/23/05 | 11:27 - 13:31 |
| | E-Post-M29-062305-03 | Metals | Test | 06/23/05 | 14:06 - 16:19 |

[a] Represents three readings, each ~60-seconds in duration

## 3.3 Field Test Changes and Deviations from Quality Assurance Project Plan (QAPP) Specifications

### 3.3.1 Variation from Test Methods or Planned Activities

#### *3.3.1.1 Sampling at the Landfill Gas (LFG) Inlet Pipe*

There were not variations from test methods or planned activities at the raw LFG pipe.

#### *3.3.1.2 Raw Landfill Gas (LFG) Inlet Pipe Condensate Sample*

Raw LFG pipe condensate sample was not planned and was not collected.

#### *3.3.1.3 Raw Landfill Gas (LFG) Flow Rate Measurement*

A control panel at the landfill displays real-time raw LFG flow rates. The accuracy of the indicated measurement will need to be verified by the facility operator based on instrument calibration and certification records. Moreover, the accuracy of the flow rate measurement cannot be verified as part of this program because of the tightly configured geometry of the raw LFG pipe which precluded accurate gas velocity measurements. Within these physical limitations, the test team nonetheless made approximate velocity measurements by traversing the pipe using a standard pitot probe. The accuracies of these measurements are unknown and the measurements should be viewed with caution.

##### *3.3.1.4 Boiler Stack*

There were not variations from test methods or planned activities at the boiler stack.

#### 3.3.2 Application of Test Methods

The sampling and, where applicable, analytical methods used in this test program follow those specified in the QAPP.

#### 3.3.3 Test Method Exceptions

Laboratory analytical procedures followed those prescribed by the specified methods, with the following exceptions:

<u>Raw LFG at Inlet</u>

- Carbonyls were analyzed by Method TO-11 SW-846 Method 8315. Method TO-11 and 8315 close resemble each other.

- Landfill gas NMOCs were analyzed by the gas chromatograph/mass spectrometer (GC/MS) Method as described in EPA Publication EPA/600-R-98/16.

- For LFG inlet samples, VOCs and methane ($CH_4$) were analyzed by EPA Method TO-15.

<u>Boiler Stack</u>

- Non-Methane Organic Compounds (NMOCs) - Method 25A was used instead of the specifically applicable Method 25C. This was necessitated by the low analyte concentration which rendered Method 25C inappropriate for the intended measurement.

**Table 3-6. Test Methods and Performing Organizations**

| Procedure | Description | Performing Organization |
|---|---|---|
| EPA Method 1 | Selection of boiler stack traverse points | ARCADIS G&M |
| EPA Method 2 | Determination boiler stack gas velocity and volumetric flow rate | ARCADIS G&M |
| EPA Method 3A | Determination of oxygen ($O_2$) and carbon dioxide ($CO_2$) for boiler stack gas molecular weight calculations | ARCADIS G&M |
| EPA Method 3C | Determination of carbon dioxide ($CO_2$), methane ($CH_4$), nitrogen ($N_2$), and oxygen ($O_2$) in raw LFG | Triangle Environmental Services |
| EPA Method 4 | Determination of boiler stack gas moisture | ARCADIS G&M |
| EPA Method 6C | Determination of boiler stack sulfur dioxide ($SO_2$) | ARCADIS G&M |
| EPA Method 7E | Determination of boiler stack nitrogen oxides ($NO_X$) | ARCADIS G&M |
| EPA Method 10 | Determination of boiler stack carbon monoxide (CO) | ARCADIS G&M |
| EPA Method 11 | Determination of raw LFG hydrogen sulfide ($H_2S$) | Enthalpy Analytical |
| EPA Method 23 | Determination of boiler stack:<br>Dioxins/furans by Method 8290<br>Polycyclic aromatic hydrocarbons (PAHs) by Method 8270 | ALTA Analytical Perspectives |
| EPA Method 25A | Determination of boiler stack gas non-methane organic compounds (NMOCs) (as total hydrocarbons [THCs]) when total organic concentration is less than the 50 ppm Method 25C applicability threshold | ARCADIS G&M |
| EPA Method 25C | Determination of raw LFG NMOCs | Triangle Environmental Services |
| EPA Method 26A | Determination of boiler stack hydrogen chloride (HCl) | Resolution Analytics |
| EPA Method 29 | Determination of boiler stack metals | First Analytical Laboratories |
| EPA Method 40 | Determination of raw LFG volatile organic compounds (VOCs) | Research Triangle Park Laboratories |
| SW-846 Method 0100/TO-11 | Determination of raw LFG carbonyls (formaldehyde and acetaldehyde) | Resolution Analytics |
| LUMEX instrument | Determination of raw LFG and boiler stack elemental mercury ($Hg^0$) | ARCADIS G&M |
| Organic mercury methods | Determination of raw LFG:<br>Monomethyl mercury<br>Dimethyl mercury<br>Total mercury. | Frontier Geosciences |

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# 4. Presentation of Test Results

Results of the testing are presented in this section. Detailed test results are included in the Appendices. The following subsections provide concise summaries of the test results.

Section 4.1 and its subsections present the test results obtained from the raw LFG measurements (at location “A”, see Figure 2-1). The concentrations of the constituents of interest in the raw LFG are presented in Sections 4.1.2.1 through 4.1.2.5.

Section 4.2 and its subsections present the test results related to the boiler and the boiler stack (at location “B”, see Figure 2-1).

Section 4.3 summarizes the data and presents a comparison with the AP-42 default values.

## 4.1 Raw Landfill Gas (LFG) Measurements

As shown in Figure 2-2, sampling was conducted by extracting samples via the four ¼-inch ports installed in the raw LFG pipe.

### 4.1.1 Raw Landfill Gas (LFG) Flow Rate and Temperature

#### *4.1.1.1 Direct Measurements*

The estimated mass flow rates of the constituents in the raw LFG pipe were calculated based on the flow rate indicated by the facility’s flowmeter display. This approach was selected because:

- The pitot probe readings were subject to large errors because of the not fully developed velocity profile inside the tightly configured LFG pipe.
- The facility flowmeter readings were likely accurate because the indicated readings were probably the basis on which financial arrangements between the landfill owner and its customers were made and settled.

During these tests, the panel meter displayed flow rates ranging from 4335 to 4340 scfm. This was the total LFG flow going to all users, not just to the tested boiler.

Measurement of the velocity profile within the raw LFG pipe using a velocity probe returned readings of approximately 3856 scfm.

A direct measurement with a thermocouple showed the raw LFG temperature to be 71°F.

### 4.1.2 Raw Landfill Gas (LFG) Constituent Analytes

#### *4.1.2.1 Volatile Organic Compounds (VOCs)*

Concentrations of VOCs were obtained by collecting summa canister samples using Method 40 procedures. Analysis was performed by Method TO-15, with gas chromatography and mass spectrometry (GC/MS). The alkanes (C2 through C6), being present in much higher concentrations, were analyzed by GC flame ionization detection (FID) on the same summa canister samples.

Table 4-1 lists the results of these analyses. Tentatively identified compounds (TICs) can be seen in the Research Triangle Park (RTP) Laboratory reports in Appendix A.

**Table 4-1. Raw Landfill Gas VOC Concentrations**

| Compound | Unit | MDL | Concentration | | | |
|---|---|---|---|---|---|---|
| | | | Run 1 | Run 2 | Run 3 | Average [a] |
| **Analyzed by GC/FID** | | | | | | |
| Ethane | ppmv | 1 | 13.0 | 13.6 | 14.0 | 14.0 |
| Propane | ppmv | 1 | 13.6 | 12.6 | 12.8 | 13.0 |
| Butane | ppmv | 1 | 3.7 | 3.4 | ND | 3.6 |
| Pentane | ppmv | 1 | 2.9 | ND | ND | 1.0 |
| Hexane | ppmv | 1 | ND | ND | ND | ND |
| **Analyzed by TO-15 GC/MS** | | | | | | |
| Dichlorodifluoromethane (Freon 12) | ppbv | 0.3 | 248 | 206 | 242 | 232 |
| 1,2-Chloro-1,1,2,2-tetrafluoroethane | ppbv | 0.2 | ND | 23.7 | 22.2 | 15.3 |
| Chloromethane | ppbv | 0.1 | ND | ND | ND | ND |
| Vinyl chloride | ppbv | 0.2 | ND | 190 | ND | 63 |
| 1,3-Butadiene ((Vinylethylene) | ppbv | 0.3 | ND | ND | ND | ND |

| Compound | Unit | MDL | Concentration | | | |
|---|---|---|---|---|---|---|
| | | | **Run 1** | **Run 2** | **Run 3** | **Average** [a] |
| Bromomethane (Methyl Bromide) | ppbv | 0.2 | ND | ND | ND | ND |
| Chloroethane (Ethyl Chloride) | ppbv | 0.2 | ND | ND | ND | ND |
| Trichloromonofluoromethane (CFC11) | ppbv | 0.2 | 24.4 | ND | ND | 8.1 |
| 1,1-Dichloroethene | ppbv | 0.2 | ND | ND | ND | ND |
| 1,1,2-Trichloro-1,2,2-trifluoroethane (CFC113) | ppbv | 0.2 | ND | ND | ND | ND |
| Ethanol [d] | ppbv | 0.2 | ND J | ND J | ND J | ND J |
| Carbon Disulfide | ppbv | 0.2 | 1020 | ND | ND | 339 |
| Isopropyl Alcohol (2-Propanol) [e] | ppbv | 0.2 | 5030 J | 1110 J | 944 J | 2360 J |
| Methylene chloride (Dichloromethane) | ppbv | 0.1 | 3720 | 3020 | 2400 | 3050 |
| Acetone | ppbv | 0.3 | 21800 | 12900 | 11900 | 15500 |
| t-1,2-dichloroethene | ppbv | 0.3 | ND | ND | ND | ND |
| Hexane [f] | ppbv | 0.3 | 655 J | 534 J | 601 J | 597 J |
| Methyl-t-butyl ether (MTBE) | ppbv | 0.3 | ND | ND | ND | ND |
| 1,1-Dichloroethane | ppbv | 0.3 | ND | ND | ND | ND |
| Vinyl Acetate | ppbv | 0.5 | 110 | 120 | 102 | 111 |
| cis-1,2-Dichloroethene | ppbv | 0.3 | 180 | 134 | 175 | 163 |
| Cyclohexane | ppbv | 0.3 | ND | ND | ND | ND |
| Chloroform | ppbv | 0.3 | ND | ND | ND | ND |
| Ethyl Acetate | ppbv | 0.3 | ND | ND | ND | ND |
| Tetrahydrofuran (Diethylene Oxide) | ppbv | 0.4 | 1090 | 692 | 832 | 870 |
| 1,1,1-Trichloroethane | ppbv | 0.3 | ND | ND | ND | ND |
| Carbon Tetrachloride | ppbv | 0.5 | ND | ND | ND | ND |
| 2-Butanone (Methyl Ethyl Ketone) | ppbv | 0.3 | 3270 | 1920 | 2290 | 2490 |
| Heptane [b] | ppbv | 0.2 | 380 | 282 | 332 | 331 |
| Benzene | ppbv | 0.2 | 998 | 764 | 900 | 887 |
| 1,2-Dichloroethane | ppbv | 0.3 | ND | ND | ND | ND |

| Compound | Unit | MDL | Concentration | | | |
|---|---|---|---|---|---|---|
| | | | Run 1 | Run 2 | Run 3 | Average [a] |
| Trichloroethylene (Trichloroethene) | ppbv | 0.2 | 110 | 73.7 | 98.3 | 93.9 |
| 1,2-Dichloropropane | ppbv | 0.3 | ND | ND | ND | ND |
| Bromodichloromethane | ppbv | 0.2 | ND | ND | ND | ND |
| 1,4-Dioxane (1,4-Diethylene Dioxide) | ppbv | 0.2 | ND | ND | ND | ND |
| cis-1,3-Dichloropropene | ppbv | 0.2 | ND | ND | ND | ND |
| Toluene (Methyl Benzene) | ppbv | 0.3 | 8780 | 6860 | 8220 | 7950 |
| 4-Methyl-2-pentanone (MIBK) | ppbv | 0.2 | ND | ND | ND | ND |
| t-1,3-Dichloropropene | ppbv | 0.2 | ND | ND | ND | ND |
| Tetrachloroethylene (Perchloroethylene) | ppbv | 0.3 | 128 | 125 | 122 | 125 |
| 1,1,2-Trichloroethane | ppbv | 0.2 | ND | ND | ND | ND |
| Dibromochloromethane | ppbv | 0.2 | ND | ND | ND | ND |
| 1,2-Dibromoethane (Ethylene dibromide) | ppbv | 0.2 | ND | ND | ND | ND |
| 2-Hexanone (Methyl Butyl Ketone) | ppbv | 0.2 | ND | ND | ND | ND |
| Ethylbenzene | ppbv | 0.3 | ND | ND | ND | ND |
| Chlorobenzene | ppbv | 0.2 | 132 | 139 | 134 | 135 |
| m/p-Xylene (Dimethyl Benzene) [g] | ppbv | 0.65 | 9670 J | 7830 J | 9500 J | 9000 J |
| o-Xylene (Dimethyl Benzene) | ppbv | 0.3 | 3460 | 2670 | 3180 | 3100 |
| Styrene (Vinylbenzene) | ppbv | 0.1 | 491 | 314 | 455 | 420 |
| Tribromomethane (Bromoform) | ppbv | 0.3 | ND | ND | ND | ND |
| 1,1,2,2-Tetrachloroethane | ppbv | 0.2 | ND | ND | ND | ND |
| 1-Ethyl-4-methylbenzene (4-Ethyl Toluene) [c] | ppbv | 0.2 | 2540 | 2250 | 2750 | 2510 |
| 1,3,5-Trimethylbenzene | ppbv | 0.2 | 1040 | 919 | 1150 | 1040 |
| 1,2,4-Trimethylbenzene | ppbv | 0.3 | 2740 | 2390 | 2800 | 2640 |
| 1,3-Dichlorobenzene | ppbv | 0.2 | ND | ND | ND | ND |
| 1,4-Dichlorobenzene | ppbv | 0.3 | ND | ND | ND | ND |

| Compound | Unit | MDL | Concentration | | | |
|---|---|---|---|---|---|---|
| | | | Run 1 | Run 2 | Run 3 | Average [a] |
| Benzyl Chloride | ppbv | 0.2 | ND | ND | ND | ND |
| 1,2-Dichlorobenzene | ppbv | 0.3 | ND | ND | ND | ND |
| 1,1,2,3,4,4-Hexachloro-1,3-butadiene | ppbv | 0.2 | ND | ND | ND | ND |
| 1,2,4-Trichlorobenzene | ppbv | 0.3 | ND | ND | ND | ND |
| Chlorodiflouromethane (Freon 22) | ppbv | 20 | ND | ND | ND | ND |
| Acrylonitrile | ppbv | 20 | ND | ND | ND | ND |

ND - Constituent not found at detection stated method detection limit

[a] Average - equals ND if all three measurements are ND. Otherwise, ND contribution to the average is equal to 50 percent of the analyte MDL

[b] Field blank reported heptane at 32.1 ppbv

[c] Field blank reported 1-ethyl-4-methylbenzene at 161 ppbv

[d] Ethanol spike recovery was 2 – 4 percent

[e] Isopropyl alcohol relative standard deviation (RSD) was 56.3 percent

[f] Hexane RSD was 40.7 percent

[g] m/p-Xylene spike recovery was 230 percent

#### *4.1.2.2 Non-methane Organic Compounds (NMOCs)*

Non-methane organic compounds (NMOCs) in the raw LFG were analyzed by Triangle Environmental Services in accordance with Method 25C, performed on the samples collected with Method 40. Table 4-2 presents the NMOC concentrations in the LFG.

This table also includes concentrations of $CH_4$, $CO_2$, and $O_2$, which were obtained by Method 3C.The analytes, oxygen ($O_2$), carbon dioxide ($CO_2$), and moisture, are not pollutants but are of interest as they are useful indicators of the “quality” of the raw LFG. The concentrations of nitrogen ($N_2$) and $O_2$ are also indicators of the extent of ambient air infiltration into the LFG collection. Method 25C for NMOC determination specifically recommends that these measurements be made to determine potential air infiltration. Therefore, while measurements for methane ($CH_4$), $CO_2$, $O_2$, and $N_2$ by Method 3C were not included in the original QAPP, these measurements were included and performed.

**Table 4-2. Raw LFG Non-Methane Organic Compound (NMOC)**

| | NMOC (ppmv as Hexane) | $CH_4$ (% v/v) | | $CO_2$ (% v/v) | | $O_2$ (%v/v) | $N_2$ (% v/v) | Moisture (% v/v) |
|---|---|---|---|---|---|---|---|---|
| | Method 25C [a] | Method 25C [a] | Method 3C | Method 25C [a] | Method 3C | Method 3C | Method 3C | Method 23 |
| Run 1 | 288 | 50.9 | 51.7 | 36.3 | 31.9 | 2.1 | 11.9 | NM |
| Run 2 | 218 | 46.7 | 46.8 | 33.3 | 30.2 | 3.4 | 16.4 | NM |
| Run 3 | 194 | 50.8 | 49.9 | 36.3 | 31.9 | 2.2 | 12.4 | NM |
| **Average** | **233** | **49.5** | **49.5** | **35.3** | **31.3** | **2.6** | **13.6** | **NM** |

NM – not measured because Method 23 sampling train was not run. Data column is included to retain format consistency with other reports.

Concentrations are reported without correction for nitrogen.

[a] Method 25C samples hold time were up to 42 days. Method specifies 30 days hold time.

Non-methane organic compounds ranged from 194 to 288 ppmv as hexane. The major components in the LFG consisted of methane at an average concentration of 49.5 percent. Carbon dioxide ranged from approximately 30 to 36 percent. Oxygen was present at about 2 to 6 percent. Nitrogen concentrations averaged at 13.6 percent.

#### *4.1.2.3 Hydrogen Sulfide ($H_2S$)*

Raw LFG $H_2S$ concentrations were obtained by collecting and analyzing the samples in accordance with EPA Method 11. The laboratory analysis reports and the concentration calculation worksheet are included in Appendix G. Table 4-3 presents the concentrations of $H_2S$ in the raw LFG.

**Table 4-3. Raw LFG Hydrogen Sulfide Concentrations**

| | $H_2S$ Concentration | |
|---|---|---|
| | ($mg/m^3$) | (ppmv) |
| Run 1 | 519 J | 366 J |
| Run 2 | 438 J | 309 J |
| Run 3 | 413 J | 291 J |
| **Average** | **458 J** | **322 J** |

J – Estimated per EPA QA/G-8 guidance. Spike sample was not prepared. Spike recovery data were not available.

#### *4.1.2.4 Carbonyls*

The target carbonyl compounds, formaldehyde and acetaldehyde, were analyzed by SW-846 Method 8315 on samples collected by EPA Method 0100. The analysis reports, prepared by Resolution Analytics, are included as Appendix D. Calculation worksheets to convert the laboratory results to carbonyl concentrations in the raw LFG are presented as well. Table 4-4 below presents the concentrations of formaldehyde and acetaldehyde in the raw LFG.

**Table 4-4. Raw LFG Carbonyls Concentrations**

| | **Formaldehyde** | | **Acetaldehyde** | |
|---|---|---|---|---|
| | **(μg/m$^3$ )** | **(x10$^{-3}$ ppmv)** | **(μg/m$^3$ )** | **(x10$^{-3}$ ppmv)** |
| MDL | 2.9 | 2.3 | 3.8 | 2.1 |
| Run 1 | 11.8 | 9.6 | 27.9 | 15.3 |
| Run 2 | 8.9 | 7.2 | 151 | 82.8 |
| Run 3 | 8.1 | 6.5 | 98.1 | 53.8 |
| **Average** | **9.6** | **7.8** | **92.4** | **50.6** |

#### *4.1.2.5 Mercury (Hg)*

Mercury (Hg) can exist in several forms. This test program focused on measuring the concentrations of the elemental, monomethyl, and dimethyl forms of Hg and the total Hg concentrations in the raw LFG. Total Hg, monomethyl Hg and dimethyl Hg were sampled and analyzed using the organic mercury method. Elemental Hg was measured with the LUMEX instrument.

Result tables that have data from both Frontier and Geochimica laboratories for the same run signifies that the samples were collected simultaneously by these two groups.

##### 4.1.2.5.1 Total Mercury (Hg)

To collect the total Hg samples, an iodated charcoal trap was used as a sorbent. A backup tube was also 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. A silica gel impinger was used to collect and quantify the water vapor from the stream. A diaphragm air pump was used to pull sample through the train and collect the sample. A dry gas meter with 10 ml resolution was used to quantify the volume of gas sampled.

Duplicate samples were collected simultaneously. One set was sent to Frontier Geosciences and the second set was sent to Studio Geochimica. The two laboratories performed the analysis independently. Their results provide a means of assessing the precision of the analytical method. Frontier Geosciences' results are included as Appendix E-1 and Studio Geochimica's results are included as Appendix E-2.

Table 4-5 presents the total Hg concentrations in the raw LFG. Total Hg concentrations ranged from 1330 to 1650 ng/m$^3$. The average of all six measurements is 1460 ng/m$^3$. The deviation from the overall mean of the six measurements ranged from 0.05 percent to 12.5 percent of the mean value.

**Table 4-5. Raw LFG Total Mercury Concentrations**

| | **Total Mercury Concentration** | | | |
|---|---|---|---|---|
| | **(ng/m$^3$)** | | **(x10$^{-6}$ ppmv)** | |
| | **Frontier [a]** | **Geochimica** | **Frontier [a]** | **Geochimica** |
| MDL | 50 | 9 | 6 | 1 |
| Run 1 | 1460 | 1400 | 164 | 156 |
| Run 2 | 1330 | 1410 | 149 | 158 |
| Run 3 | 1520 | NR | 170 | NR |
| Run 4 | NR | 1650 | NR | 184 |
| **Average** | **1430** | **1490** | **161** | **166** |

NR – No sampling while the other laboratory group was collecting sample.

[a] Sample hold times were 30 days. Specified hold time was 14 days.

4.1.2.5.2 Dimethyl Mercury (Hg) Samples:

A Carbotrap was used as sorbent to collect samples for dimethyl Hg analysis. A backup trap was present to detect and assess breakthrough, if any. A third iodated carbon trap was present to collect elemental Hg if any is present. The sorbent tube was heated and maintained at temperatures above the dew point of the gas stream to prevent condensation on the sorbent. A silica gel impinger was used to collect and quantify the water vapor in the sampled gas. A diaphragm air pump was used to pull sample through the sampling train. A dry gas meter with 10 ml resolution was used to quantify the volume of gas sampled.

As in the measurement for total Hg, duplicate samples were collected simultaneously. One set was sent to Frontier Geosciences and the second set was sent to Studio

Geochimica. The two laboratories performed the analysis independently. Their results provide a means of assessing the precision of the analytical method. Frontier Geosciences' report of their results is included as Appendix E-1 and Studio Geochimica's report of their results is included as Appendix E-2.

Table 4-6 presents the dimethyl Hg concentrations in the raw LFG. Dimethyl Hg concentrations ranged from 17.4 to 99.8 ng/m$^3$. The average of the six measurements was 52.5 ng/m$^3$. Spike recoveries for the dimethyl Hg traps averaged at 98.3 percent.

**Table 4-6. Raw LFG Dimethyl Mercury Concentrations**

| | Dimethyl Mercury Concentration | | | |
|---|---|---|---|---|
| | (ng/m$^3$) | | (x10$^{-6}$ ppmv) | |
| | Frontier | Geochimica | Frontier | Geochimica |
| MDL | 0.5 | 0.4 | 0.05 | 0.04 |
| Run 1 | NR | 17.4 | NR | 1.82 |
| Run 2 | 73.6 | NR | 7.71 | NR |
| Run 3 | 27.1 | 33.4 | 2.84 | 3.50 |
| Run 4 | 63.8 | 99.8 | 6.68 | 10.5 |
| **Average** | **54.8** | **50.2** | **5.74** | **5.26** |

NR – No sampling while the other laboratory group was collecting sample.

#### 4.1.2.5.3 Monomethyl Mercury (Hg) Samples

A sampling train, consisting of three impingers each filled with 0.001 M HCl, was used to collect samples for monomethyl Hg analysis. An empty forth impinger was used to knockout any impinger solution and prevent carryover to the pump and metering system. A diaphragm air pump was used to pull sample through the train and collect the sample. A dry gas meter with 10 ml resolution was used to the volume of gas sampled.

As in the measurement for total Hg and dimethyl Hg, duplicate samples were collected simultaneously. One set was sent to Frontier Geosciences and the second set was sent to Studio Geochemica. The two laboratories performed the analysis independently. Their results provide a means of assessing the precision of the analytical method. Frontier Geosciences' results are included as Appendix E-1 and Studio Geochimica's results are included as Appendix E-2.

As shown in Table 4-7, monomethyl Hg concentrations in the raw LFG ranged from 3.4 to 8.2 ng/m$^3$ with an mean of the six measurements of 5.4 ng/m$^3$. Spike recovery for the monomethyl Hg sample was 89.7 percent.

**Table 4-7. Raw LFG Monomethyl Mercury Concentrations**

| | Monomethyl Mercury Concentration | | | |
|---|---|---|---|---|
| | (ng/m$^3$) | | (x10$^{-6}$ ppmv) | |
| | Frontier | Geochimica | Frontier | Geochimica |
| MDL | 0.13 | 1.4 | 0.014 | 0.15 |
| Run 1 | 3.4 | 6.2 | 0.38 | 0.69 |
| Run 2 | 4.6 | 4.6 | 0.52 | 0.52 |
| Run 3 | 5.6 | 8.2 | 0.63 | 0.92 |
| **Average** | **4.5** | **6.3** | **0.50** | **0.71** |

4.1.2.5.4 Elemental Mercury (Hg)

Elemental Hg was determined by the LUMEX instrument. The measurement records are included as Appendix F and the results are presented in Table 4-8.

The LFG sample was collected from a pressurized port downstream of the compressor, as the LUMEX instrument was unable to draw a sample from the vacuum portion of the LFG header pipe.

**Table 4-8. Raw LFG Elemental Mercury Concentrations**

| | Elemental Mercury Concentration [a] | | | |
|---|---|---|---|---|
| | Background | | Raw LFG | |
| | (ng/m$^3$) | (x10$^{-6}$ ppmv) | (ng/m$^3$) | (x10$^{-6}$ ppmv) |
| Run 1 | 13 | 1.6 | 437 | 52.6 |
| Run 2 | 9 | 1.1 | 445 | 53.6 |
| Run 3 | 33 | 4.0 | 438 | 52.7 |
| Average | 18 | 2.2 | 440 | 53.0 |

[a] Reported value is the average of three readings, each about 60-second in duration

### 4.2 Boiler Stack Results

During the tests, the boiler ran under nominally unchanged conditions. The boiler operating conditions are shown in Tables 4-9a and 4-9b for a 2-day test period. The reported data were recorded from the boiler process control system monitor.

**Table 4-9a. Boiler Operating Condition on June 22, 2005 as indicated by Boiler Control System**

| Time | Steam Production Rate (lb/hr) | LFG Flow Rate (scfm) | Stack $O_2$ (% v/v) | Stack Temperature (°F) | % Load | Total Cumulative Heat Content (MMBtu) |
|---|---|---|---|---|---|---|
| **06/22/05** | | | | | | |
| 12:14 | 76,800 | 2,433 | 6.88 | 492 | 41.0 | Not recorded [a] |
| 12:52 | 75,609 | 2,348 | 7.27 | 489 | 41.0 | Not recorded [a] |
| 13:25 | 75,375 | 2,344 | 7.29 | 489 | 41.0 | 34,096 |
| 13:58 | 75,554 | 2,331 | 7.26 | 489 | 41.0 | 34,133 |
| 14:38 | 75,211 | 2,340 | 7.28 | 489 | 41.0 | 34,182 |
| 15:12 | 74,881 | 2,342 | 7.30 | 489 | 41.0 | 34,225 |
| 15:45 | 76,510 | 2,384 | 7.11 | 490 | 41.0 | 34,267 |
| 17:20 | 80,313 | 2,514 | 6.59 | 494 | 41.0 | 34,393 |
| 17:52 | 79,516 | 2,494 | 6.61 | 494 | 41.0 | 34,435 |
| 18:42 | 79,557 | 2,498 | 6.70 | 494 | 41.0 | 34,502 |
| 19:23 | 80,512 | 2,500 | 6.75 | 494 | 41.0 | 34,556 |
| 19:46 | 81,034 | 2,500 | 6.76 | 494 | 41.0 | 34,587 |

**Event Notes:**

| | |
|---|---|
| 11:41 | Start M23 Run 1 |
| 11:43 | Start M23 Run 2 |
| 15:55 | Finished M23 Runs 1 and 2 |
| 17:18 | Start M29 Run 1 and M26A Run 1 |
| 19:45 | Finished M29 Run 1 and M26A Run 1 |

[a] Reading was missed and not recorded during startup

**Table 4-9b. Boiler Operating Condition on June 23, 2005 as indicated by Boiler Control System**

| Time | Steam Production Rate (lb/hr) | LFG Flow Rate (scfm) | Stack O2 (% v/v) | Stack Temperature (°F) | % Load | Total Cumulative Heat Content (MMBtu) |
|---|---|---|---|---|---|---|
| **6/23/05** | | | | | | |
| 8:48 | 87,303 | 2,745 | 5.58 | 498 | 41.0 | 34,885 |
| 9:20 | 88,470 | 2,741 | 5.60 | 498 | 41.0 | 34,932 |
| 9:52 | 87,104 | 2,731 | 5.52 | 499 | 41.0 | 34,979 |
| 10:23 | 88,100 | 2,742 | 5.53 | 498 | 41.0 | 35,025 |
| 11:10 | 69,470 | 2,134 | 5.40 | 466 | 41.0 | 35,085 |
| 11:42 | 88,759 | 2,779 | 5.29 | 497 | 41.0 | 35,126 |
| 12:29 | 71,159 | 2,277 | 7.30 | 484 | 40.0 | 35,187 |
| 13:06 | 71,448 | 2,273 | 7.33 | 484 | 40.0 | 35,231 |
| 13:33 | 72,612 | 2,281 | 7.27 | 484 | 40.0 | 35,264 |
| 14:08 | 71,516 | 2,269 | 7.25 | 485 | 40.0 | 35,306 |
| 14:34 | 71,372 | 2,285 | 7.25 | 484 | 40.0 | 35,337 |
| 15:07 | 71,180 | 2,271 | 7.27 | 484 | 40.0 | 35,377 |
| 15:37 | 74,071 | 2,362 | 6.78 | 486 | 40.0 | 35,415 |
| 16:12 | 74,043 | 2,365 | 6.73 | 486 | 40.0 | 35,458 |

**Event Notes:**

| | |
|---|---|
| 8:47 | Start M23 Run 3 and M26A Run 2 |
| 10:50 | Finished M26A Run 2 |
| 11:00 | Load dropped due to gas pressure problem. Will be back up to condition in 45 minutes. |
| 11:27 | Start M29 Run 2 |
| 12:05 | Same pressure problem as at 11:00 will recover slowly. |
| 12:56 | Finished M23 Run 3 |
| 13:30 | Finished M29 Run 2 |
| 14:06 | Start M29 Run 3 and M26A Run 3 |
| 16:11 | Finished M29 Run 3 and M26A Run 3 |

The boiler stack was sampled for NMOCs (as THCs), HCl, Pb, As, Cd, Cr, Mn, Ni, total Hg, PCDD/PCDFs, PAHs, $SO_2$, $NO_X$, CO, $CO_2$, and $O_2$. The stack cross section was divided into 24 equal areas according to EPA Method 1. Sampling run time for HCl and metals was 120 minutes. Run time for PCDD/PCDFs and PAHs was 240 minute. Run time for CEMS parameters ($SO_2$, $NO_X$, CO, $O_2$, $CO_2$, and THCs) varied.

#### 4.2.1 Boiler Stack Gas Flow Rate and Temperature

Samples from the boiler stack were collected under isokinetic conditions. As an integral part of the procedure, the sampling operation measured stack gas velocity distribution across the boiler stack and hence provided reliable measurements of stack gas flow rates. Table 4-10 lists the volumetric flow rates and temperatures at the boiler stack measured during the various sampling runs.

**Table 4-10. Boiler Stack Gas Conditions Measured during Sampling**

| Run Number | Duration | Average Stack Temp (°F) | Carbon Dioxide (%) | Oxygen (%) | Moisture (%) | Velocity (actual ft/sec) | Vol. Flow Rate (acfm) | Vol. Flow Rate (dscfm) |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |
| E-Post-M26A-062205-01 | 06/22/05, 17:18 - 19:42 | 484 | 12.2 | 7.9 | 12.4 | 30.0 | 57,494 | 28,116 |
| E-Post-M26A-062305-02 | 06/23/05, 08:47 - 10:50 | 488 | 12.2 | 7.2 | 14.1 | 31.3 | 59,925 | 28,629 |
| E-Post-M26A-062305-03 | 06/23/05, 14:09 - 16:12 | 470 | 12.5 | 7.2 | 11.6 | 31.7 | 60,633 | 30,397 |
| | | | | | | | | |
| E-Post-M29-062205-01 | 06/22/05, 17:21 - 19:45 | 475 | 12.1 | 7.9 | 13.1 | 30.0 | 57,447 | 28,134 |
| E-Post-M29-062305-02 | 06/23/05, 11:27 - 13:31 | 479 | 12.5 | 7.2 | 13.1 | 31.3 | 59,912 | 29,244 |
| E-Post-M29-062305-03 | 06/23/05, 14:06 - 16:19 | 476 | 12.5 | 7.2 | 13.1 | 32.2 | 61,660 | 30,192 |
| | | | | | | | | |
| E-Post-M23-062205-01 | 06/22/05, 11:41 - 16:02 | 479 | 12.1 | 7.9 | 11.8 | 30.3 | 58,017 | 28,710 |
| E-Post-M23-062205-02 | 06/22/05, 11:43 - 15:58 | 481 | 12.1 | 7.9 | 11.9 | 29.6 | 56,725 | 27,986 |
| E-Post-M23-062305-03 | 06/23/05, 08:52 - 12:56 | 476 | 12.5 | 7.2 | 12.7 | 28.5 | 54,488 | 26,819 |
| | | | | | | | | |
| | **Average** | **479** | **12.3** | **7.5** | **12.6** | **30.5** | **58,478** | **28,692** |

Boiler stack cross-section flow area is 31.92 sq. ft.

### 4.2.2 Boiler Stack Oxygen and Carbon Dioxide

Oxygen ($O_2$) and $CO_2$ concentrations provide an overall indication of the combustion process. Figure 4-1 shows the $O_2$ and $CO_2$ concentrations measured by the CEMs during the two days of testing. Table 4-11 presents the run averages of $O_2$ and $CO_2$ concentrations.

**Table 4-11. Boiler Stack Oxygen and Carbon Dioxide Concentrations**

| | $O_2$ (% v) | $CO_2$ (% v) |
|---|---|---|
| Run 1 | 8.2 | 11.8 |
| Run 2 | 7.4 | 12.1 |
| Run 3 | 7.2 | 12.9 |
| Run 4 | 7.4 | 12.8 |
| **Average** | **7.5** | **12.3** |

### 4.2.3 Boiler Stack Total Hydrocarbon (THC)

With consideration focused on data relevant to AP-42, NMOC is the analyte of interest at the boiler stack. Measurement of hydrocarbon concentrations EPA Method 25A, which included NMOCs, showed that THC concentrations to be below 50 ppmv. These low concentrations rendered Method 25C, the method designed specifically for NMOC measurement, unsuitable to be applied at this sample location. Hence, Method 25A became the practical method of choice.

Method 25A used a CEM and produced measurements of concentration of all hydrocarbons that respond to flame ionization detector (FID) analysis. Real-time continuous instrument responses are shown in Figure 4-2. The time-averaged concentrations are presented in Table 4-12.

A conservative approach can be taken to assume all hydrocarbons to be NMOCs. However, this interpretation will bias the NMOC concentration results high. As shown by the measurements, the concentrations of THC were low throughout the tests. Hence, concentrations of NMOC were also low at the boiler stack.

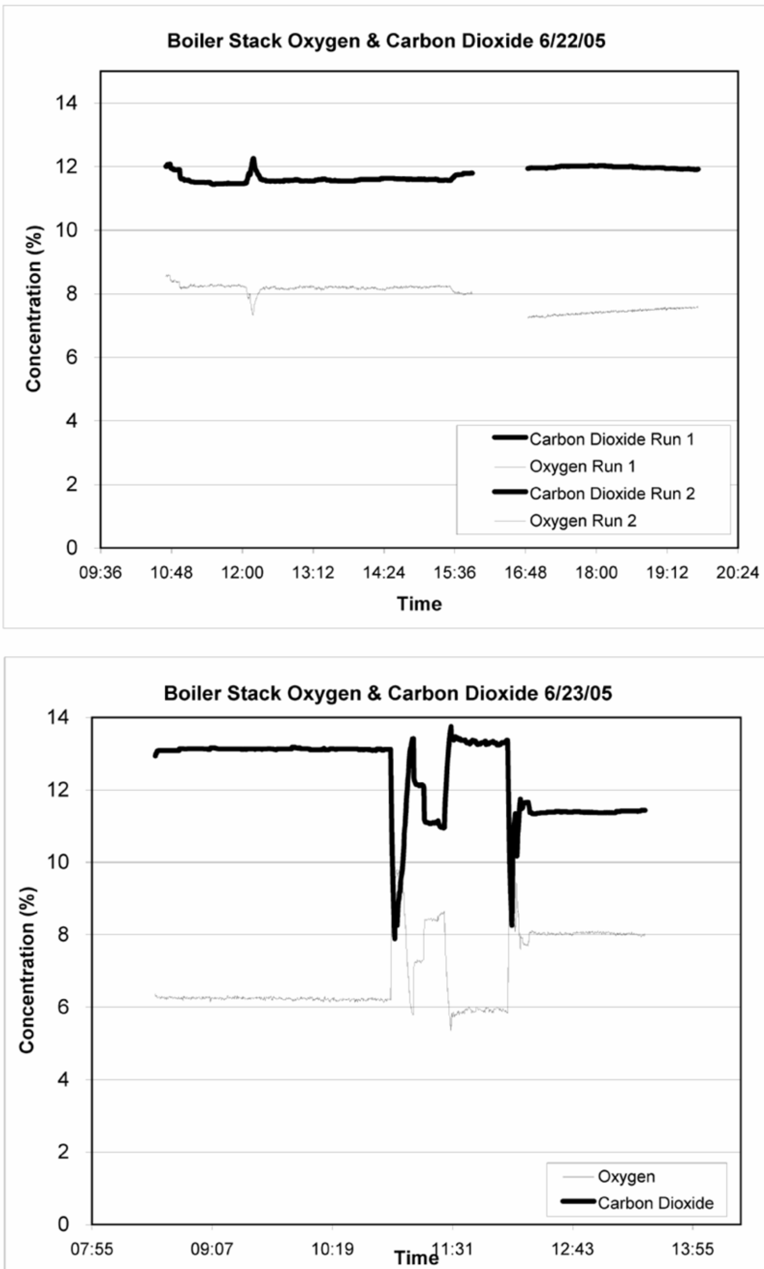



**Figure 4-1. Boiler Stack Oxygen and Carbon Dioxide Concentrations**

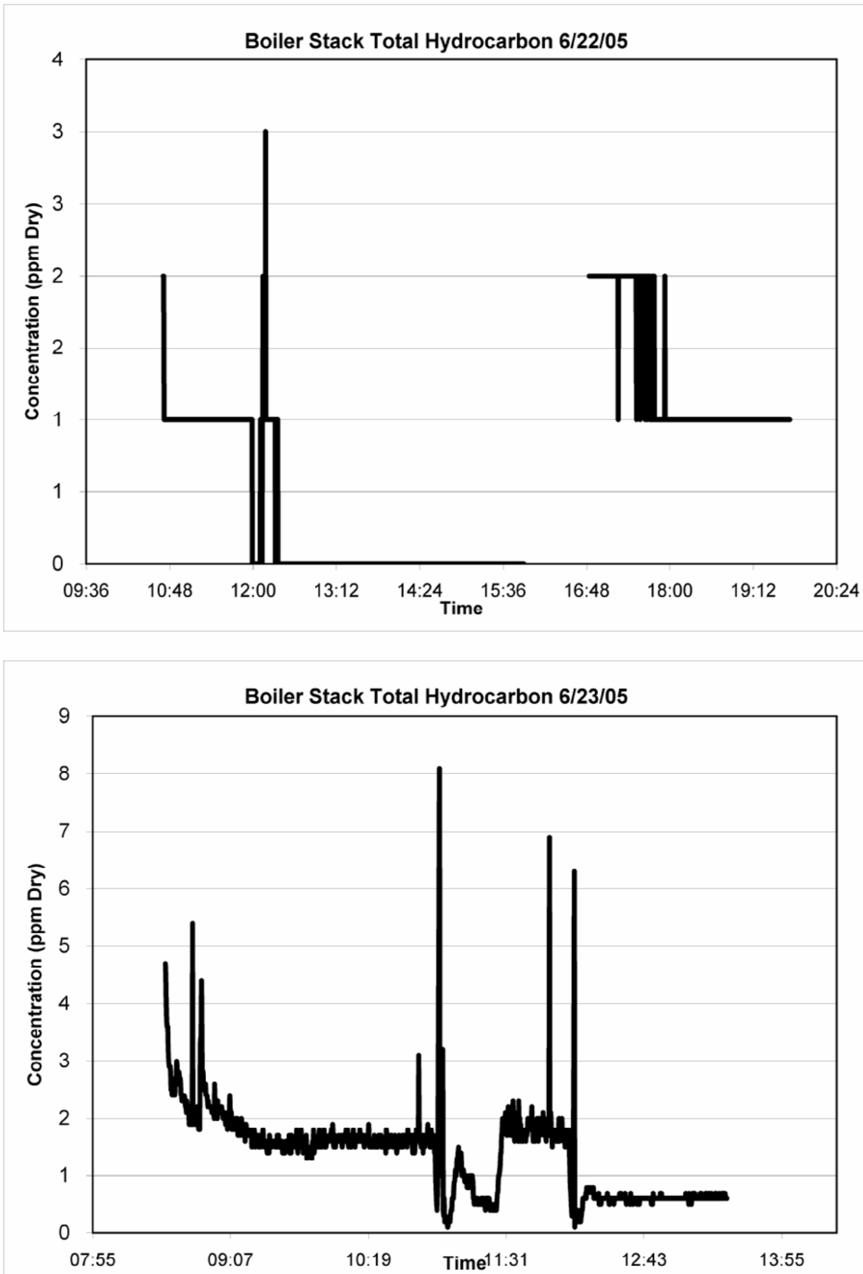



**Figure 4-2. Boiler Stack Total Hydrocarbon Concentration**

**Table 4-12. Boiler Stack Total Hydrocarbon Concentration**

| | Total Hydrocarbon | |
|---|---|---|
| | (ppmdv as propane) | (ppmdv as hexane) |
| Run 1 | ND | ND |
| Run 2 | 1 | 0.5 |
| Run 3 | 1 | 0.5 |
| Run 4 | 1 | 0.5 |
| **Average** | **1** | **0.4** |

#### 4.2.4 Boiler Stack Dioxin/Furan (PCDD/PCDFs)

Three EPA Method 23 sampling runs were performed. Table 4-13 presents the boiler stack PCDD/PCDF emissions data. Table 4-14 presents the same data, but expressed in terms of Toxicity Equivalent emissions.

The data showed that detectable levels of PCDD/PCDFs were found in concentrations ranging from the single digit to several tens of picogram per standard cubic meter of the exhaust gas.

#### 4.2.5 Boiler Stack Polycyclic Aromatic Hydrocarbon (PAH) Emissions

The concentrations of PAH were also obtained by Method 23. The results are presented in Table 4-15. The concentrations of PAHs in the boiler stack ranged from 10 ng/dscm of acenaphthylene to 1400 ng/dscm of fluoranthene.

**Table 4-13. Boiler Stack Dioxins and Furans**

| Analyte | E-062205-M23-1 | | | E-062205-M23-2 | | | E-062305-M23-3 | | | Average | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Concentration | Emission Rate | | Concentration | Emission Rate | | Concentration | Emission Rate | | Concentration | Emission Rate | |
| | ($x10^{-3}$ ng/dscm) | ($x10^{-9}$ g/hr) | ($x10^{-12}$ lb/hr) | ($x10^{-3}$ ng/dscm) | ($x10^{-9}$ g/hr) | ($x10^{-12}$ lb/hr) | ($x10^{-3}$ ng/dscm) | ($x10^{-9}$ g/hr) | ($x10^{-12}$ lb/hr) | ($x10^{-3}$ ng/dscm) | ($x10^{-9}$ g/hr) | ($x10^{-12}$ lb/hr) |
| <u>Dioxins</u> | | | | | | | | | | | | |
| 2,3,7,8-TCDD | 1.1 | 54.4 | 120 | 1.3 | 62.9 | 139 | <0.685 | <31.2 | <68.8 | 0.926 | 44.3 | 97.6 |
| Other TCDD | 78.1 | 3800 | 8400 | 71.1 | 3400 | 7500 | 77.4 | 3500 | 7800 | 75.5 | 3600 | 7900 |
| 1,2,3,7,8-PeCDD | <3.1 | <152 | <335 | 5.2 | 249 | 550 | <2.3 | <103 | <228 | 2.6 | 126 | 277 |
| Other PeCDD | 82.1 | 4000 | 8800 | 89.5 | 4300 | 9400 | 58.2 | 2700 | 5800 | 76.6 | 3600 | 8000 |
| 1,2,3,4,7,8-HxCDD | 3.3 | 162 | 356 | 4.2 | 200 | 441 | 2.5 | 114 | 252 | 3.3 | 159 | 350 |
| 1,2,3,6,7,8-HxCDD | 6.0 | 291 | 642 | 7.6 | 360 | 794 | 5.1 | 230 | 508 | 6.2 | 294 | 648 |
| 1,2,3,7,8,9-HxCDD | 4.2 | 207 | 456 | 5.7 | 271 | 598 | 3.5 | 159 | 351 | 4.5 | 212 | 468 |
| Other HxCDD | 71.8 | 3500 | 7700 | 82.5 | 3900 | 8700 | 59.0 | 2700 | 5900 | 71.1 | 3400 | 7400 |
| 1,2,3,4,6,7,8-HpCDD | 27.7 | 1400 | 3000 | 31.9 | 1500 | 3300 | 24.3 | 1100 | 2400 | 28.0 | 1300 | 2900 |
| Other HpCDD | 27.6 | 1300 | 3000 | 34.0 | 1600 | 3600 | 23.7 | 1100 | 2400 | 28.5 | 1300 | 3000 |
| 1,2,3,4,6,7,8,9-OCDD | 39.5 | 1900 | 4200 | 55.8 | 2700 | 5900 | 35.5 | 1600 | 3600 | 43.6 | 2100 | 4600 |
| Total CDD | 345 | 16800 | 37100 | 389 | 18500 | 40800 | 292 | 13300 | 29400 | 341 | 16200 | 35600 |
| <u>Furans</u> | | | | | | | | | | | | |
| 2,3,7,8-TCDF | 6.2 | 302 | 666 | 7.6 | 360 | 794 | 3.7 | 171 | 376 | 5.8 | 278 | 612 |
| Other TCDF | 198 | 9600 | 21200 | 215 | 10200 | 22600 | 114 | 5200 | 11500 | 176 | 8400 | 18400 |
| 1,2,3,7,8-PeCDF | 9.4 | 457 | 1000 | 12.1 | 578 | 1300 | 6.0 | 271 | 598 | 9.2 | 435 | 960 |
| 2,3,4,7,8-PeCDF | 13.0 | 635 | 1400 | 17.6 | 837 | 1800 | 7.9 | 359 | 791 | 12.8 | 610 | 1300 |
| Other PeCDF | 127 | 6200 | 13600 | 160 | 7600 | 16800 | 69.4 | 3200 | 7000 | 119 | 5700 | 12500 |
| 1,2,3,4,7,8-HxCDF | 11.1 | 541 | 1200 | 16.7 | 796 | 1800 | 7.4 | 338 | 746 | 11.8 | 559 | 1200 |
| 1,2,3,6,7,8-HxCDF | 11.7 | 569 | 1300 | 15.3 | 729 | 1600 | 7.8 | 356 | 785 | 11.6 | 551 | 1200 |
| 2,3,4,6,7,8-HxCDF | 12.0 | 585 | 1300 | 15.8 | 750 | 1700 | 7.6 | 347 | 765 | 11.8 | 560 | 1200 |
| 1,2,3,7,8,9-HxCDF | 2.8 | 139 | 307 | 4.5 | 216 | 476 | 1.9 | 89 | 196 | 3.1 | 148 | 326 |

| Analyte | E-062205-M23-1 | | | E-062205-M23-2 | | | E-062305-M23-3 | | | Average | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Concentration | Emission Rate | | Concentration | Emission Rate | | Concentration | Emission Rate | | Concentration | Emission Rate | |
| | ($x10^{-3}$ ng/dscm) | ($x10^{-9}$ g/hr) | ($x10^{-12}$ lb/hr) | ($x10^{-3}$ ng/dscm) | ($x10^{-9}$ g/hr) | ($x10^{-12}$ lb/hr) | ($x10^{-3}$ ng/dscm) | ($x10^{-9}$ g/hr) | ($x10^{-12}$ lb/hr) | ($x10^{-3}$ ng/dscm) | ($x10^{-9}$ g/hr) | ($x10^{-12}$ lb/hr) |
| Other HxCDF | 57.8 | 2800 | 6200 | 84.4 | 4000 | 8800 | 36.0 | 1600 | 3600 | 59.4 | 2800 | 6200 |
| 1,2,3,4,6,7,8-HpCDF | 28.3 | 1400 | 3000 | 38.9 | 1900 | 4100 | 21.7 | 987 | 2200 | 29.6 | 1400 | 3100 |
| 1,2,3,4,7,8,9-HpCDF | 3.8 | 187 | 412 | 5.0 | 239 | 527 | 2.4 | 111 | 244 | 3.8 | 179 | 395 |
| Other HpCDF | 10.2 | 498 | 1100 | 15.5 | 738 | 1600 | 6.8 | 309 | 682 | 10.8 | 515 | 1100 |
| 1,2,3,4,6,7,8,9-OCDF | 11.0 | 538 | 1200 | 12.9 | 615 | 1400 | 9.3 | 423 | 932 | 11.1 | 526 | 1200 |
| Total CDF | 304 | 24500 | 53900 | 407 | 29600 | 65200 | 188 | 13800 | 30400 | 300 | 22600 | 49900 |
| Total CDD/CDF | 648 | 41300 | 91000 | 796 | 48100 | 106000 | 480 | 27100 | 59800 | 640 | 38800 | 85500 |

"<" denotes the measurement was non-detect. The value following the "<" sign is the detection limit.

**Table 4-14. Boiler Stack Dioxins and Furans Toxicity Equivalent Emissions**

| Pollutant | Concentration | Emission Rate | | 1989 Toxicity Equivalency Factor | Concentration | Emission Rate | |
|---|---|---|---|---|---|---|---|
| | ($x10^{-3}$ ng/dscm) | ($x10^{-9}$ g/hr) | ($x10^{-12}$ lb/hr) | | ($x10^{-3}$ ng/dscm) | ($x10^{-9}$ g/hr) | ($x10^{-12}$ lb/hr) |
| **Dioxins** | | | | | | | |
| 2,3,7,8-TCDD | 0.926 | 44.3 | 97.6 | 1 | 0.926 | 44.3 | 97.6 |
| Other TCDD | 75.5 | 3600 | 7900 | --- | NA | NA | NA |
| 1,2,3,7,8-PeCDD | 2.6 | 126 | 277 | 0.5 | 1.3 | 63 | 139 |
| Other PeCDD | 76.6 | 3600 | 8000 | --- | NA | NA | NA |
| 1,2,3,4,7,8-HxCDD | 3.3 | 159 | 350 | 0.1 | 0.33 | 15.9 | 35 |
| 1,2,3,6,7,8-HxCDD | 6.2 | 294 | 648 | 0.1 | 0.62 | 29.4 | 64.8 |
| 1,2,3,7,8,9-HxCDD | 4.5 | 212 | 468 | 0.1 | 0.45 | 21.2 | 46.8 |
| Other HxCDD | 71.1 | 3400 | 7400 | --- | NA | NA | NA |
| 1,2,3,4,6,7,8-HpCDD | 28.0 | 1300 | 2900 | 0.01 | 0.28 | 13.2 | 29 |
| Other HpCDD | 28.5 | 1300 | 3000 | --- | NA | NA | NA |
| 1,2,3,4,6,7,8,9-OCDD | 43.6 | 2100 | 4600 | 0.001 | 0.0436 | 2.1 | 4.6 |
| **Total CDD** | **341** | **16200** | **35600** | **---** | **4.0** | **189** | **417** |
| **Furans** | | | | | | | |
| 2,3,7,8-TCDF | 5.8 | 278 | 612 | 0.1 | 0.58 | 27.8 | 61.2 |
| Other TCDF | 0.0084 | 8400 | 18400 | --- | NA | NA | NA |
| 1,2,3,7,8-PeCDF | 9.2 | 435 | 960 | 0.05 | 0.46 | 21.8 | 48.0 |
| 2,3,4,7,8-PeCDF | 12.8 | 610 | 1300 | 0.5 | 6.4 | 305 | 673 |
| Other PeCDF | 119 | 5700 | 12500 | --- | NA | NA | NA |

| Pollutant | Concentration | Emission Rate | | 1989 Toxicity Equivalency Factor | Concentration | Emission Rate | |
|---|---|---|---|---|---|---|---|
| | ($x10^{-3}$ ng/dscm) | ($x10^{-9}$ g/hr) | ($x10^{-12}$ lb/hr) | | ($x10^{-3}$ ng/dscm) | ($x10^{-9}$ g/hr) | ($x10^{-12}$ lb/hr) |
| 1,2,3,4,7,8-HxCDF | 11.8 | 559 | 1230 | 0.1 | 1.2 | 55.9 | 123 |
| 1,2,3,6,7,8-HxCDF | 11.6 | 551 | 1220 | 0.1 | 1.2 | 55.1 | 122 |
| 2,3,4,6,7,8-HxCDF | 11.8 | 560 | 1240 | 0.1 | 1.2 | 56.0 | 124 |
| 1,2,3,7,8,9-HxCDF | 3.1 | 148 | 326 | 0.1 | 0.31 | 14.8 | 32.6 |
| Other HxCDF | 59.4 | 2800 | 6200 | --- | NA | NA | NA |
| 1,2,3,4,6,7,8-HpCDF | 29.6 | 1400 | 3100 | 0.01 | 0.296 | 14.1 | 31.0 |
| 1,2,3,4,7,8,9-HpCDF | 3.8 | 179 | 395 | 0.01 | 0.038 | 1.8 | 3.9 |
| Other HpCDF | 10.8 | 515 | 1100 | --- | NA | NA | NA |
| 1,2,3,4,6,7,8,9-OCDF | 11.1 | 526 | 1200 | 0.001 | 0.0111 | 0.526 | 1.2 |
| **Total CDF** | **300** | **22600** | **49900** | **---** | **11.6** | **553** | **1200** |
| **Total CDD/CDF** | **640** | **38800** | **85500** | **---** | **15.6** | **742** | **1600** |

NA – Not applicable because no Toxicity Equivalent Factor is available

“<” denotes the measurement was non-detect. The value following the “<” sign is the detection limit.

**Table 4-15. Boiler Stack Polycyclic Aromatic Hydrocarbons (PAHs) Emissions**

| Analyte | Formula Weight | E-062205-M23-1 | | | | E-062205-M23-2 | | | | E-062305-M23-3 | | | | Average | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Concentration | | Emission Rate | | Concentration | | Emission Rate | | Concentration | | Emission Rate | | Concentration | | Emission Rate | |
| | | ($x10^{-6}$ ppmv) | (ng/dscm) | ($x10^{-6}$ g/hr) | ($x10^{-6}$ lb/hr) | ($x10^{-6}$ ppmv) | (ng/dscm) | ($x10^{-6}$ g/hr) | ($x10^{-6}$ lb/hr) | ($x10^{-6}$ ppmv) | (ng/dscm) | ($x10^{-6}$ g/hr) | ($x10^{-6}$ lb/hr) | ($x10^{-6}$ ppmv) | (ng/dscm) | ($x10^{-6}$ g/hr) | ($x10^{-6}$ lb/hr) |
| Acenaphthene | 154.21 | 10.3 | 66.3 | 3200 | 7.1 | 10.2 | 65.6 | 3100 | 6.9 | 2.5 | 16.0 | 728 | 1.6 | 7.7 | 49.3 | 2400 | 5.2 |
| Acenaphthylene | 152.20 | 1.8 | 11.1 | 543 | 1.2 | 2.5 | 15.8 | 750 | 1.7 | 0.587 | 3.7 | 169 | 0.373 | 1.6 | 10.2 | 487 | 1.1 |
| Anthracene | 178.23 | 5.5 | 40.6 | 2000 | 4.4 | 6.7 | 50.0 | 2400 | 5.2 | 1.4 | 10.0 | 458 | 1.0 | 4.5 | 33.6 | 1600 | 3.5 |
| Benzo(a)anthracene | 228.30 | 41.9 | 398 | 19400 | 42.8 | 37.2 | 353 | 16800 | 37.0 | 16.3 | 154. | 7000 | 15.5 | 31.8 | 302 | 14400 | 31.7 |
| Benzo(a)pyrene | 252.32 | 29.1 | 305 | 14900 | 32.8 | 36.3 | 380 | 18100 | 39.9 | 1.1 | 11.9 | 541 | 1.2 | 22.2 | 233 | 11200 | 24.6 |
| Benzo(b)fluoranthene | 252.32 | 81.0 | 850 | 41500 | 91.4 | 70.5 | 739 | 35100 | 77.5 | 36.9 | 387 | 17600 | 38.9 | 62.8 | 659 | 31400 | 69.3 |
| Benzo(g,h,i)perylene | 276.34 | 34.9 | 401 | 19500 | 43.1 | 28.3 | 325 | 15500 | 34.1 | 1.5 | 17.4 | 795 | 1.8 | 21.6 | 248 | 11900 | 26.3 |
| Benzo(k)fluoranthene | 252.32 | 30.5 | 320 | 15600 | 34.4 | 25.7 | 270 | 12800 | 28.3 | 12.5 | 132 | 6000 | 13.2 | 22.9 | 240 | 11500 | 25.3 |
| Chrysene | 228.29 | 69.2 | 657 | 32000 | 70.7 | 59.5 | 564 | 26800 | 59.2 | 33.0 | 313 | 14300 | 31.5 | 53.9 | 512 | 24400 | 53.8 |
| Dibenzo(a,h)anthracene | 278.35 | 7.3 | 84.4 | 41000 | 9.1 | 6.1 | 70.5 | 3400 | 7.4 | 3.0 | 34.9 | 1600 | 3.5 | 5.5 | 63.3 | 3000 | 6.7 |
| Fluoranthene | 202.26 | 213 | 1800 | 87300 | 192 | 190 | 1600 | 76100 | 168 | 84.1 | 707 | 32200 | 71.0 | 162 | 1400 | 65200 | 144 |
| Fluorene | 166.22 | 11.4 | 78.7 | 3800 | 8.5 | 12.1 | 83.4 | 4000 | 8.7 | 8.9 | 61.4 | 2800 | 6.2 | 10.8 | 74.5 | 3500 | 7.8 |
| Indeno(1,2,3-cd)pyrene | 288.35 | 33.4 | 401 | 19500 | 43.1 | 27.9 | 334 | 15900 | 35.0 | 8.0 | 95.7 | 4400 | 9.6 | 23.1 | 277 | 13300 | 29.2 |

| Analyte | Formula Weight | E-062205-M23-1 | | | | E-062205-M23-2 | | | | E-062305-M23-3 | | | | Average | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Concentration | | Emission Rate | | Concentration | | Emission Rate | | Concentration | | Emission Rate | | Concentration | | Emission Rate | |
| | | ($x10^{-6}$ ppmv) | (ng/dscm) | ($x10^{-6}$ g/hr) | ($x10^{-6}$ lb/hr) | ($x10^{-6}$ ppmv) | (ng/dscm) | ($x10^{-6}$ g/hr) | ($x10^{-6}$ lb/hr) | ($x10^{-6}$ ppmv) | (ng/dscm) | ($x10^{-6}$ g/hr) | ($x10^{-6}$ lb/hr) | ($x10^{-6}$ ppmv) | (ng/dscm) | ($x10^{-6}$ g/hr) | ($x10^{-6}$ lb/hr) |
| Naphthalene | 128.17 | 183 | 974 | 47500 | 105 | 175 | 932 | 44300 | 97.7 | 84.1 | 448 | 20400 | 45.0 | 147 | 785 | 37400 | 82.5 |
| Phenanthrene | 178.23 | 174 | 1300 | 62800 | 139 | 242 | 1800 | 85300 | 188 | 74.3 | 550 | 25100 | 55.3 | 163 | 1200 | 57700 | 127 |
| Pyrene | 202.26 | 131 | 1100 | 53700 | 118 | 128 | 1100 | 51300 | 113 | 37.6 | 316 | 14400 | 31.7 | 99.0 | 832 | 39800 | 87.8 |
| 2-Methylnaphthalene | 142.20 | 136 | 804 | 39200 | 86.5 | 170 | 1000 | 47800 | 106 | 23.5 | 139 | 6300 | 14.0 | 110 | 650 | 31100 | 68.6 |
| Benzo(e)Pyrene | 252.32 | 45.3 | 475 | 23200 | 51.1 | 39.5 | 414 | 19700 | 43.4 | 16.6 | 174 | 7900 | 17.5 | 33.8 | 355 | 16900 | 37.3 |
| Perylene | 253.31 | 3.6 | 37.7 | 1800 | 4.1 | 7.7 | 81.3 | 3900 | 8.5 | 0.176 | 1.8 | 84.1 | 0.186 | 3.8 | 40.3 | 1900 | 4.3 |

#### 4.2.6 Hydrogen Chloride (HCl) Emissions

Boiler stack HCl emissions results are presented in Table 4-16. The concentrations were low, averaging at 1.4 ppmdv.

**Table 4-16. Boiler Stack Hydrogen Chloride Measurement Results**

| | Concentration | | Emission | |
|---|---|---|---|---|
| | (ppmdv) | ($x10^3$ µg/m$^3$) | (lb/hr) | (g/hr) |
| Run 1 | 1.6 | 2.4 | 0.26 | 120 |
| Run 2 | 1.3 | 2.0 | 0.21 | 95 |
| Run 3 | 1.3 | 2.0 | 0.22 | 99 |
| **Average** | **1.4** | **2.1** | **0.23** | **100** |

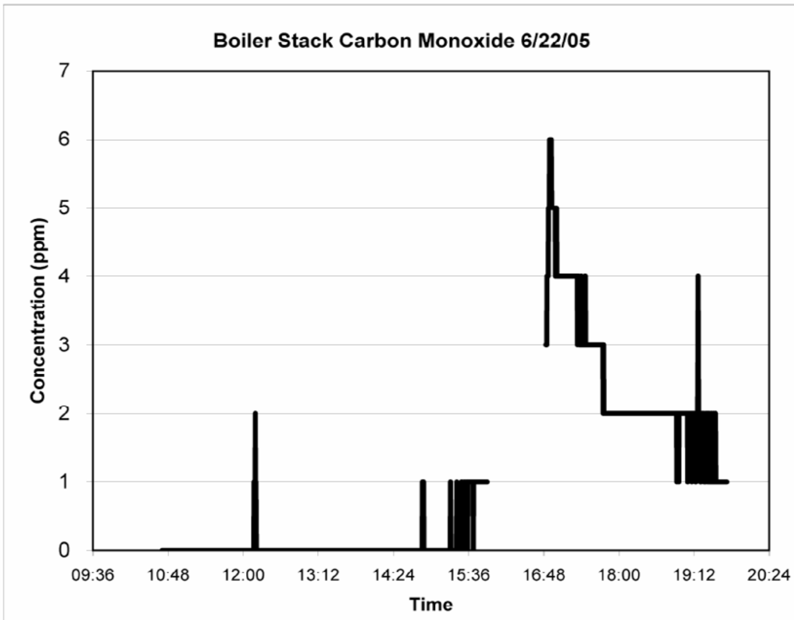
#### 4.2.7 Metals Emissions

Concentrations Toxic heavy metals in the engine stack gases were measured by Method 29. Manganese was determined by inductively coupled plasma – mass spectroscopy (ICP-MS). Arsenic (As), Cd, Cr, Pb, and Ni were determined by graphite furnace atomic absorption spectroscopy (GFAAS). Mercury was determined by cold vapor (CV) AA and was not detected in any of the samples. Boiler stack metals emissions results are presented in Table 4-17.

Mercury (Hg) concentration (elemental) was separately measured by the LUMEX instrument and those results are also included in Table 4-17.

#### 4.2.8 Gaseous Emissions: Carbon Monoxide (CO), Sulfur Dioxide ($SO_2$), and Nitrogen Oxides ($NO_X$)

Gaseous emissions measured with CEMs include CO, $SO_2$ and $NO_X$. These results are in Table 4-18. Figures 4-3 through 4-5 show the real-time concentrations of CO, $SO_2$, and $NO_X$, respectively.



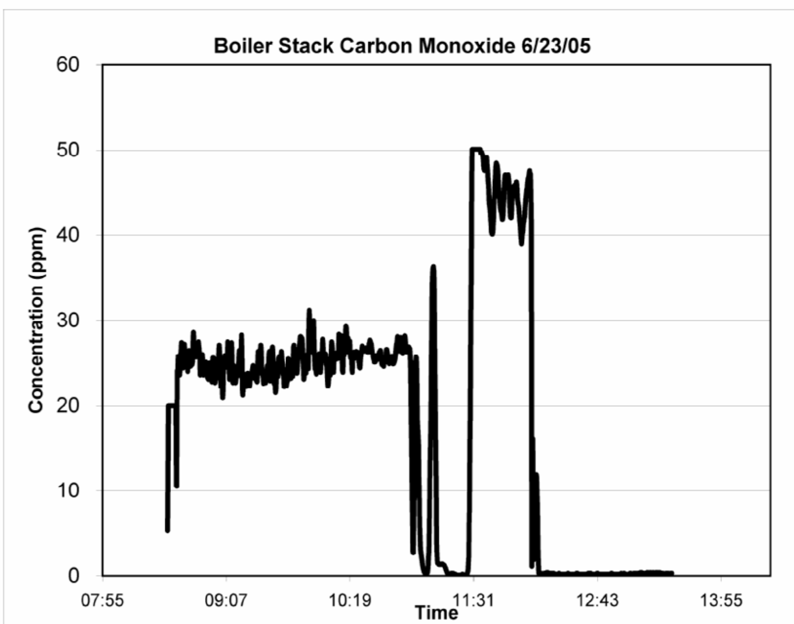
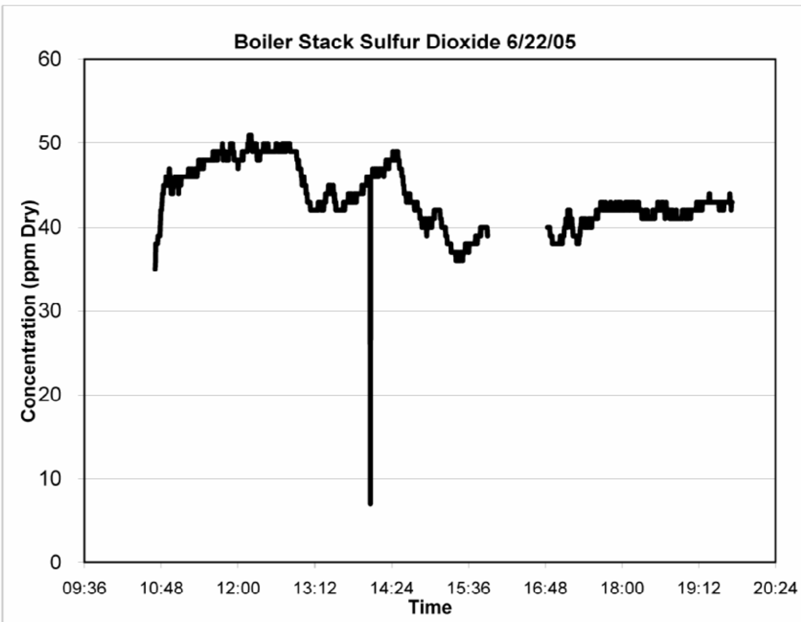




**Figure 4-3. Boiler Stack Carbon Monoxide Concentration**



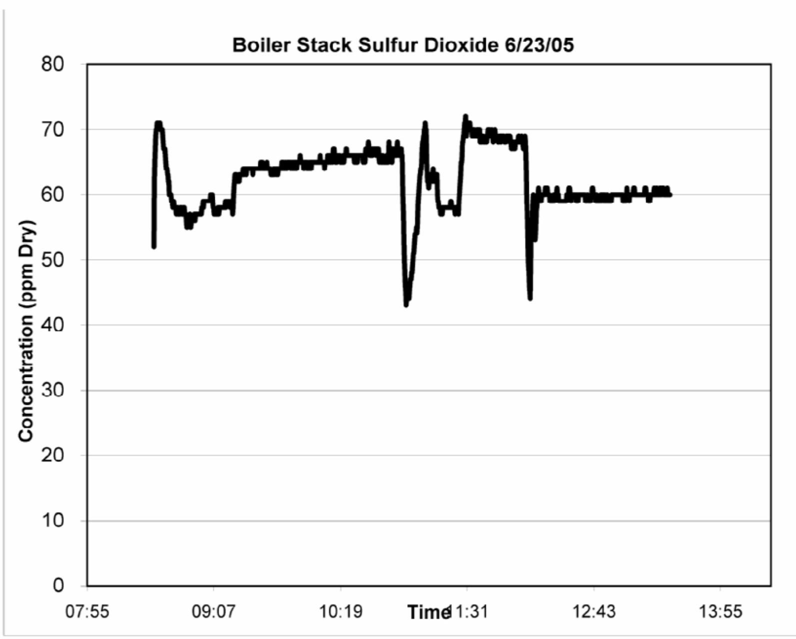




**Figure 4-4. Boiler Stack Sulfur Dioxide Concentration**

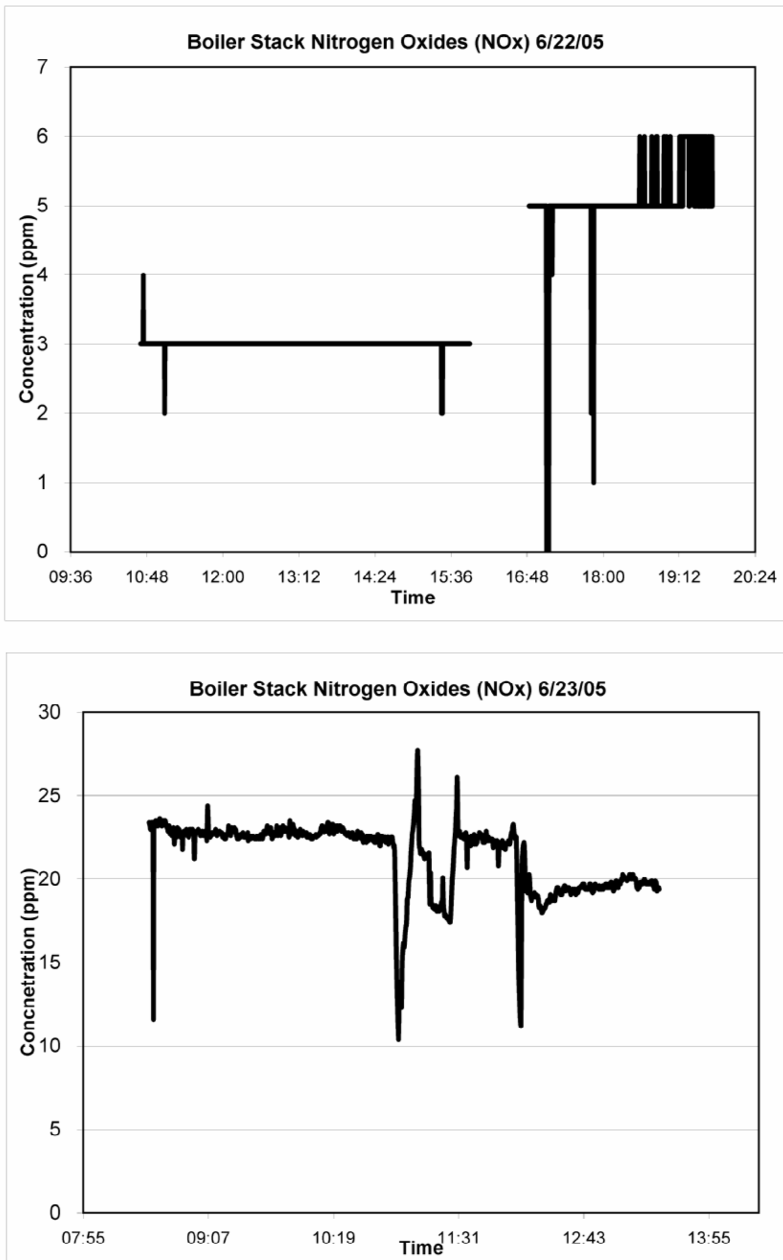



**Figure 4-5.** **Boiler Stack Nitrogen Oxides Concentration**

**Table 4-17. Boiler Stack Metals Emissions**

| Analyte | E-062205-M29-1 | | | E-062305-M29-2 | | | E-062305-M29-3 | | | Average | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Concentration | Emission Rate | | Concentration | Emission Rate | | Concentration | Emission Rate | | Concentration | Emission Rate | |
| | (µg/dscm) | ($x10^{-3}$ g/hr) | ($x10^{-6}$lb/hr) | (µg/dscm) | ($x10^{-3}$ g/hr) | ($x10^{-6}$lb/hr) | (µg/dscm) | ($x10^{-3}$ g/hr) | ($x10^{-6}$lb/hr) | (µg/dscm) | ($x10^{-3}$ g/hr) | ($x10^{-6}$lb/hr) |
| Arsenic | 1.8 | 87 | 190 | 2.6 | 130 | 260 | 2.4 | 120 | 240 | 2.3 | 110 | 221 |
| Cadmium | 1.1 | 52 | 120 | 1.5 | 74 | 160 | 1.1 | 57 | 130 | 1.2 | 61 | 135 |
| Chromium | 3.0 | 140 | 320 | 4.3 | 210 | 470 | 24 | 1200 | 2700 | 10 | 530 | 1200 |
| Lead | 7.2 | 340 | 760 | 4.2 | 210 | 460 | 6.4 | 330 | 730 | 6.0 | 300 | 649 |
| Manganese | 4.4 | 210 | 460 | 3.6 | 180 | 390 | 4.1 | 210 | 460 | 4.0 | 200 | 439 |
| Nickel | 5.3 | 250 | 560 | 10.9 | 540 | 1200 | 120 | 6400 | 14100 | 47 | 2400 | 5300 |
| Mercury (Total by Method 29) | 0.46 | 22 | 49 | 0.46 | 23 | 51 | ND | ND | ND | 0.46 | 23 | 50 |
| | RUN 1 | | | RUN 2 | | | RUN 3 | | | Average | | |
| Mercury (Elemental by LUMEX) | .057 | 2.7 | 6.0 | 0.033 | 1.6 | 3.6 | 0.042 | 2.1 | 4.7 | 0.044 | 2.2 | 4.8 |

**Table 4-18. Boiler Stack CO, $SO_2$, $NO_X$ Concentrations**

| | Concentration (ppmdv) | | |
|---|---|---|---|
| | CO | $SO_2$ | $NO_X$ (as NO) |
| Run 1 | 0 | 45 | 3 |
| Run 2 | 2 | 41 | 5 |
| Run 3 | 18 | 66 | 21 |
| Run 4 | 14 | 68 | 21 |
| **Average** | **9** | **55** | **13** |

### 4.3 Comparison with AP-42 Default Values

One of the major objectives of the test program is to expand on the database of LFG constituent compounds and their concentrations. If warranted, these data may contribute towards updating the AP-42 default values. Table 4-19 presents the concentrations of LFG constituents to provide direct comparisons with AP-42 default values. Table 4-20 presents the concentration of other constituents targeted by the various analyses but not listed in AP-42. An expanded discussion and comparison is included in the overall project summary report.

**Table 4-19. Comparison of Raw Landfill Gas Constituent Concentrations with AP-42 Default Values**

| Method | Compound | CAS Number | Formula Wt. | Default Value (ppmv) | Detection Limit (ppmv) | Measured Average (ppmv) | Concentration in Inlet LFG | | Mass Flow Rate in Inlet LFG Stream | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | ($x10^{-9}$ lb/ft$^3$) | (µg/m$^3$) | (mg/hr) | ($x10^{-3}$ lb/hr) |
| M-40 | 1,1,1-Trichloroethane | 71-55-6 | 133.42 | 0.48 | 0.0003 | ND | ND | ND | ND | ND |
| M-40 | 1,1,2,2-Tetrachloroethane | 79-34-5 | 167.85 | 1.11 | 0.0002 | ND | ND | ND | ND | ND |
| M-40 | 1,1-Dichloroethane (Ethylidene Dichloride) | 75-34-3 | 98.96 | 2.35 | 0.0003 | ND | ND | ND | ND | ND |
| M-40 | 1,1-Dichloroethene | 75-35-4 | 96.94 | 0.20 | 0.0002 | ND | ND | ND | ND | ND |
| M-40 | 1,2-Dichloroethane | 107-06-2 | 98.96 | 0.41 | 0.0003 | ND | ND | ND | ND | ND |
| M-40 | 1,2-Dichloropropane | 78-87-5 | 112.98 | 0.18 | 0.0003 | ND | ND | ND | ND | ND |
| M-40 | Isopropyl alcohol (2-Propanol) | 67-63-0 | 60.11 | 50.10 | 0.0002 | 2.36 | 367 | 5870 | 43300 | 95.5 |
| M-40 | Acetone | 67-64-1 | 58.08 | 7.01 | 0.0003 | 15.5 | 2300 | 37300 | 275000 | 606 |
| M-40 | Acrylontrile | 107-13-1 | 53.06 | 6.33 | 0.02 | ND | ND | ND | ND | ND |
| M-40 | Bromodichloromethane | 75-27-4 | 163.83 | 3.13 | 0.0002 | ND | ND | ND | ND | ND |
| M-40 | Butane | 106-97-8 | 58.12 | 5.03 | 1 | 2.53 | 380 | 6090 | 44900 | 99.0 |
| M-40 | Carbon Disulfide | 75-15-0 | 76.13 | 0.58 | 0.0002 | 0.34 | 66.9 | 1070 | 7900 | 17.4 |
| No Test | Carbon Monoxide | 630-08-0 | 28.01 | 141 | NM | NM | NM | NM | NM | NM |
| M-40 | Carbon Tetrachloride | 56-23-5 | 153.84 | 0.004 | 0.0005 | ND | ND | ND | ND | ND |
| No Test | Carbonyl Sulfide (Carbon oxysulfide) | 463-58-1 | 60.07 | 0.49 | NM | NM | NM | NM | NM | NM |
| M-40 | Chlorobenzene | 108-90-7 | 112.56 | 0.25 | 0.0002 | 0.135 | 39.3 | 629 | 4640 | 10.2 |
| M-40 | Chlorodiflouromethane (Freon 22) | 75-45-6 | 86.47 | 1.30 | 0.02 | ND | ND | ND | ND | ND |
| M-40 | Chloroethane (Ethyl Chloride) | 75-00-3 | 64.52 | 1.25 | 0.0002 | ND | ND | ND | ND | ND |
| M-40 | Chloroform | 67-66-3 | 119.39 | 0.03 | 0.0003 | ND | ND | ND | ND | ND |
| M-40 | Chloromethane | 74-87-3 | 50.49 | 1.21 | 0.0001 | ND | ND | ND | ND | ND |
| M-40 | 1,4-Dichlorobenzene | 106-46-7 | 147.00 | 0.21 | 0.0003 | ND | ND | ND | ND | ND |

| Method | Compound | CAS Number | Formula Wt. | Default Value (ppmv) | Detection Limit (ppmv) | Measured Average (ppmv) | Concentration in Inlet LFG | | Mass Flow Rate in Inlet LFG Stream | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | ($x10^{-9}$ lb/ft$^3$) | (µg/m$^3$) | (mg/hr) | ($x10^{-3}$ lb/hr) |
| M-40 | 1,3-Dichlorobenzene | 541-73-1 | 147.00 | 0.21 | 0.0002 | ND | ND | ND | ND | ND |
| M-40 | 1,2-Dichlorobenzene | 95-50-1 | 147.01 | 0.21 | 0.0003 | ND | ND | ND | ND | ND |
| M-40 | Dichlorodifluoromethane (Freon 12) | 75-71-8 | 120.91 | 15.70 | NM | NM | NM | NM | NM | NM |
| M-40 | Dichlorofluoromethane (Freon 12) | 75-43-4 | 102.92 | 2.62 | 0.0003 | 0.232 | 61.7 | 989 | 7290 | 16.1 |
| M-40 | Methylene Chloride (Dichloromethane) | 75-09-2 | 84.94 | 14.30 | 0.0001 | 3.05 | 670 | 10700 | 79100 | 174 |
| No Test | Dimethyl Sulfide (Methyl sulfide) | 75-18-3 | 62.13 | 7.82 | NM | NM | NM | NM | NM | NM |
| M-40 | Ethane | 74-84-0 | 30.07 | 889 | 1 | 13.5 | 1000 | 16800 | 124000 | 273 |
| M-40 | Ethanol | 64-17-5 | 46.08 | 27.20 | 0.0002 | ND | ND | ND | ND | ND |
| No Test | Ethyl Mercaptan (Ethanediol) | 75-08-1 | 62.13 | 2.28 | NM | NM | NM | NM | NM | NM |
| M-40 | Ethylbenzene | 100-41-4 | 106.16 | 4.61 | 0.0003 | 15.5 | 4300 | 68100 | 502000 | 1100 |
| M-40 | 1,2-Dibromoethane (Ethylene dibromide) | 106-93-4 | 187.88 | 0.001 | 0.0002 | ND | ND | ND | ND | ND |
| M-40 | Trichloromonofluoromethane (Fluorotrichloromethane) (F11) | 75-69-4 | 137.38 | 0.76 | 0.0002 | 0.00820 | 2.9 | 47 | 344 | 0.758 |
| M-40 | Hexane | 110-54-3 | 86.18 | 6.57 | 0.0003 | 0.597 | 133 | 2130 | 15700 | 34.6 |
| M-11 | Hydrogen Sulfide | 7783-06-4 | 34.08 | 35.50 | NR | 322 | 28400 | 454000 | 3350000 | 7400 |
| Organic mercury | Mercury (Dimethyl) | | 230.66 | Not Listed | 0.05E-06 | 5.5E-06 | 0.0033 | 0.0526 | 0.388 | 0.000856 |
| LUMEX | Mercury (Elemental) | 7439-97-6 | 200.61 | Not Listed | NR | 53.E-06 | 0.0275 | 0.440 | 3.25 | 0.0072 |
| Organic mercury | Mercury (Monomethyl) | | 215.62 | Not Listed | 0.014E-06 | 0.61E-06 | 0.0003400 | 0.00545 | 0.0402 | 0.0000885 |
| Organic mercury | Mercury (Total) | | 215.63 | 253.0E-6 | 6E-06 | 163.E-06 | 0.0909 | 1.46 | 10.7 | 0.0000237 |

| Method | Compound | CAS Number | Formula Wt. | Default Value (ppmv) | Detection Limit (ppmv) | Measured Average (ppmv) | Concentration in Inlet LFG | | Mass Flow Rate in Inlet LFG Stream | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | ($x10^{-9}$ lb/ft$^3$) | (µg/m$^3$) | (mg/hr) | ($x10^{-3}$ lb/hr) |
| M-40 | 2-Butanone (Methyl Ethyl Ketone) | 78-93-3 | 72.10 | 7.09 | 0.0003 | 2.49 | 464 | 7430 | 54800 | 121 |
| M-40 | 2-Hexanone (Methyl Butyl Ketone) | 591-78-6 | 100.16 | 1.87 | 0.0002 | ND | ND | ND | ND | ND |
| No Test | Methyl Mercaptan (Methanethiol) | 74-93-1 | 48.11 | 2.49 | NM | NM | NM | NM | NM | NM |
| M-40 | Pentane | 109-66-0 | 72.15 | 3.29 | 1 | 1.30 | 242 | 3880 | 28600 | 63.1 |
| M-40 | Tetrachloroethylene (Perchloroethylene) | 127-18-4 | 165.83 | 3.73 | 0.0003 | 0.125 | 53.6 | 858 | 6330 | 14.0 |
| M-40 | Propane | 74-98-6 | 44.09 | 11.10 | 1 | 13.0 | 1500 | 23700 | 175000 | 386 |
| M-40 | t-1,2-Dichloroethene | 156-60-5 | 96.94 | 2.84 | 0.0003 | ND | ND | ND | ND | ND |
| M-40 | Trichloroethylene (Trichloroethene) | 79-01-6 | 131.38 | 2.82 | 0.0002 | 0.0940 | 31.9 | 511 | 3770 | 8.3 |
| M-40 | Vinyl Chloride | 75-01-4 | 62.50 | 7.34 | 0.0002 | 0.0634 | 10.2 | 164 | 1210 | 2.7 |
| M-40 | m/p-Xylene (Dimethyl Benzene) | 1330-20-7 | 106.16 | 12.10 | 0.00065 | 9.00 | 2500 | 39600 | 292000 | 643 |
| M-40 | o-Xylene (Dimethyl Benzene) | 95-47-6 | 106.16 | 12.10 | 0.0003 | 3.10 | 851 | 13600 | 100000 | 222 |
| M-40 | Benzene (Co-disposal) | 71-43-2 | 78.11 | 11.10 | 0.0002 | 0.887 | 179 | 2870 | 21100 | 46.6 |
| M-40 | Benzene (No-disposal or Unknown) | 71-43-2 | 78.11 | 1.91 | 0.0002 | 0.887 | 179 | 2870 | 21100 | 46.6 |
| M-25C | NMOC as Hexane (Co-disposal) | | 86.17 | 2420.00 | NR | 233 | 51900 | 831000 | 6130000 | 13500 |
| M-25C | NMOC as Hexane (No-codispoal or Unknown) | | | 595.00 | NR | 233 | 51900 | 831000 | 6130000 | 13500 |
| M-40 | Toluene (Methyl Benzen) (Co-disposal) | 108-88-3 | 92.13 | 165.00 | 0.0003 | 7.95 | 1900 | 30300 | 224000 | 493 |
| M-40 | Toluene (Methyl Benzene) (No or Unknown) | | | 39.30 | 0.0003 | 7.95 | 1900 | 30300 | 224000 | 493 |

**Table 4-20. Raw Landfill Gas Constituent Concentrations for Compounds without AP-42 Default Values**

| Method | Compound | CAS Number | Formula Wt. | Detection Limit (ppmv) | Measured Average (ppmv) | Concentration in Inlet LFG | | Mass Flow Rate in Inlet LFG Stream | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | ($x10^{-9}$ lb/$ft^3$) | (µg/$m^3$) | (mg/hr) | ($x10^{-3}$ lb/hr) |
| M-0100 | Acetaldehyde | 75-07-0 | 44.05 | 0.021 | 0.0503 | 5.7 | 91.7 | 677 | 1.5 |
| M-0100 | Formaldehyde | 50-00-0 | 30.03 | 0.016 | 0.00767 | 0.595 | 9.54 | 70.3 | 0.155 |
| M-25C | Carbon Dioxide | 124-38-9 | 44.01 | NR | 353000 | 40200000 | 643000000 | 4740000000 | 10500000 |
| M-25C | Methane | 74-82-8 | 16.04 | NR | 495000 | 20500000 | 329000000 | 2420000000 | 5300000 |
| M-25C | Oxygen | 7782-44-7 | 32.00 | NR | 25700 | 2100000 | 34100000 | 251000000 | 554000 |
| M-40 | 1,1,2,3,4,4-Hexachloro-1,3-butadiene | 87-68-3 | 260.76 | 0.0002 | ND | ND | ND | ND | ND |
| M-40 | 1,1,2-Trichloro-1,2,2-trifluoroethane (CFC113) | 76-13-1 | 187.38 | 0.0002 | ND | ND | ND | ND | ND |
| M-40 | 1,1,2-Trichloroethane | 79-00-5 | 133.42 | 0.0002 | ND | ND | ND | ND | ND |
| M-40 | 1,2,4-Trichlorobenzene | 120-82-1 | 181.46 | 0.0003 | ND | ND | ND | ND | ND |
| M-40 | 1,2,4-Trimethylbenzene | 95-63-6 | 120.19 | 0.0003 | 2.64 | 820 | 13100 | 96900 | 214 |
| M-40 | 1,2-Chloro-,1,2,2-Tetrafluoroethane (CFC114) | 76-14-2 | 170.92 | 0.0002 | 0.0153 | 6.8 | 108 | 799 | 1.8 |
| M-40 | 1,3,5-Trimethylbenzene | 108-67-8 | 120.19 | 0.0002 | 1.04 | 323 | 5180 | 38200 | 84.1 |
| M-40 | 1,3-Butadiene (Vinylethylene) | 106-99-0 | 54.09 | 0.0003 | ND | ND | ND | ND | ND |
| M-40 | 1,4-Dioxane (1,4-Diethylene Dioxide) | 123-91-1 | 88.10 | 0.0002 | ND | ND | ND | ND | ND |
| M-40 | 1-Ethyl-4-methylbenzene (4-Ethyl Toluene) | 622-96-8 | 120.20 | 0.0002 | 2.51 | 780 | 12500 | 92100 | 203 |
| M-40 | 4-Methyl-2-pentanone (MIBK) | 108-10-1 | 100.16 | 0.0002 | ND | ND | ND | ND | ND |
| M-40 | Benzyl Chloride (Chloromethyl Benzene) | 100-44-7 | 126.58 | 0.0002 | ND | ND | ND | ND | ND |
| M-40 | Bromomethane (Methyl bromide) | 74-83-9 | 94.95 | 0.0002 | ND | ND | ND | ND | ND |
| M-40 | cis-1,2-Dichloroethene | 156-59-2 | 96.94 | 0.0003 | 0.163 | 40.8 | 654 | 4820 | 10.6 |
| M-40 | cis-1,3-Dichloropropene | 10061-01-5 | 110.98 | 0.0002 | ND | ND | ND | ND | ND |
| M-40 | Cyclohexane | 110-82-7 | 84.16 | 0.0003 | ND | ND | ND | ND | ND |

| Method | Compound | CAS Number | Formula Wt. | Detection Limit (ppmv) | Measured Average (ppmv) | Concentration in Inlet LFG | | Mass Flow Rate in Inlet LFG Stream | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | ($x10^{-9}$ lb/ft$^3$) | (µg/m$^3$) | (mg/hr) | ($x10^{-3}$ lb/hr) |
| M-40 | Dibromochloromethane | 124-48-1 | 208.29 | 0.0002 | ND | ND | ND | ND | ND |
| M-40 | Ethyl Acetate | 141-78-6 | 88.10 | 0.0003 | ND | ND | ND | ND | ND |
| M-40 | Heptane | 142-82-5 | 100.20 | 0.0002 | 0.331 | 85.7 | 1370 | 10100 | 22.3 |
| M-40 | Methyl-t-butyl Ether (MTBE) | 1634-04-4 | 88.15 | 0.0003 | ND | ND | ND | ND | ND |
| M-40 | Styrene (Vinylbenzene) | 100-42-5 | 104.14 | 0.0001 | 0.420 | 113 | 1810 | 13400 | 29.4 |
| M-40 | t-1,3-Dichloropropene | 1006-02-6 | 110.98 | 0.0002 | ND | ND | ND | ND | ND |
| M-40 | Tetrahydrofuran (Diethylene Oxide) | 109-99-9 | 72.10 | 0.0004 | 0.871 | 162 | 2600 | 19200 | 42.3 |
| M-40 | Tribromomethane (Bromoform) | 75-25-2 | 252.77 | 0.0003 | ND | ND | ND | ND | ND |
| M-40 | Vinyl Acetate | 108-05-4 | 86.09 | 0.0005 | 0.111 | 24.7 | 396 | 2920 | 6.4 |

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# 5. Quality Assurance/Quality Control

This project produced data that qualified to receive the “A” rating with respect to the rating system described in section 4.4.2 of the *Procedures for preparing Emission Factor Documents* (EPA-454/R-95-015). The cited EPA document provides a clear description of the requirements for an “A” data quality rating. Tests were performed by using an EPA reference test method, or when not applicable, a sound methodology. Tests were reported in enough detail for adequate validation and raw data were provided that could be used to duplicate the emission results presented in this report.

Throughout the results sections of this report, notations and footnotes were included to flag data that, for various reasons, did not meet their associated measurement quality objectives.

## 5.1 Assessment of Measurement Quality Objectives

Measurement quality objectives (MQOs) were established for each critical measurement and documented in the *Site-Specific QAPP for the Field Evaluation of Landfill Gas Control Technologies-Landfill E*. The following subsections assess MQOs for each measurement to determine if goals were achieved. When applicable, data validation elements performed on laboratory analytical reports are also included.

### 5.1.1 Continuous Emissions Monitors (CEMs)

Combustion produce gases $O_2$, $CO/CO_2$, $SO_2$, $NO_X$ and THC were measured in the field using CEMs. The following MQOs were established for CEM measurements for Landfill E:

- Direct calibration bias: ±2 percent
- System bias checks: ±5 percent
- Zero and drift: ±3 percent
- Completeness: >90 percent

Direct calibrations were performed daily, prior to testing, with certified calibration gases at zero and a minimum of two other concentrations (typically a mid-level concentration and one point towards the full-scale end of the instrument range). System bias checks were performed pre-test and post-test. Drift checks were performed daily, post-test. Table 5-1 summarizes these quality control (QC) checks for all instruments. All MQOs were met for all CEM measurements

**Table 5-1. CEM MQO Summary for Landfill E**

| Instrument and Range | Direct Calibration (±2% criteria) | | | System Bias Checks (±5% criteria) | | | Drift Checks (±3% criteria) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Total (#) | Bias Range (%) | Complete (%) | Total (#) | Bias Range (%) | Complete (%) | Total (#) | Bias Range (%) | Complete (%) |
| Servomex $O_2$ Analyzer (0-21%) | 8 | 0.1 – 0.3 | 100 | 8 | 0.3 – 1.0 | 100 | 8 | 0.05 – 1.0 | 100 |
| Cal Analytical $CO_2$ Analyzer (0-20%) | 8 | 0.0 – 0.6 | 100 | 8 | 0.1 – 1.1 | 100 | 8 | 0.0 – 1.2 | 100 |
| Cal Analytical CO Analyzer (0-650 ppm) | 12 | 0.0 – 1.2 | 100 | 8 | 0.0 -2.0 | 100 | 8 | 0.0 – 1.4 | 100 |
| Cal Analytical $SO_2$ Analyzer (0-500 ppm) | 8 | 0.0 – 1.4 | 100 | 8 | 0.0 – 2.2 | 100 | 8 | 0.0 – 2.2 | 100 |
| TECO THC Analyzer (0-1000 ppm) | NA [a] | NA [a] | NA [a] | 12 | 0.0 -0.4 | 100 | 8 | 0.0 – 1.0 | 100 |
| TECO $NO_X$ Analyzer (0-4000 ppm) | 8 | 0.0 – 0.2 | 100 | 8 | 0.0 – 0.8 | 100 | 8 | 0.0 – 0.5 | 100 |

[a] The method called for calibration gases to be introduced at a point of the sampling system close to the sampling probe for them to flow through the heated sample line. Calibration gases were not injected directly to the analyzer

### 5.1.2 Carbonyls (Method TO-11)

The following MQOs were established in the QAPP for this method:

- Recovery (formaldehyde): 50-150 percent
- Completeness: >90 percent

Four samples (including three raw LFG samples and one field blank) were submitted to Resolution Analytics for formaldehyde and acetaldehyde determination. Results were reported in RFA# 90231. The report included information on instrument calibration and internal QC checks. Samples collected on June 22, 2005 were received by the laboratory on July 5, 2005 and analyzed on July 12, 2005. That met the 30-day hold-time limitation. Analytical detection limits were reported as 15.9 ppb for formaldehyde and 20.9 ppb for acetaldehyde in the liquid extract.

The extract value was 5 ml. Hence, the detection limit amounts were 79.5 ng and 104.5 ng, respectively. The sample gas volume was about 27 standard liters. Therefore, the gas phase MDL for formaldehyde and acetaldehyde were 2.3 ppbv and 2.1 ppbv, respectively.

The field blank did not have detectable levels of either compound. To assess accuracy, an external performance evaluation audit sample containing 2.0 ppm formaldehyde and acetaldehyde was analyzed with the sample set. Recovery was 95.2 percent for formaldehyde and 99.8 percent for acetaldehyde, which met the 50-150 percent MQO. All project samples were injected in duplicate and the percent drift (%D) range for formaldehyde was 3.1 to 22.8 percent and for acetaldehyde was 0.2 to 4.4 percent. All MQOs were met for this method for a completeness of 100 percent.

#### 5.1.3 Hydrogen Sulfide ($H_2S$) (EPA Method 11)

The following MQOs were established in the Landfill E QAPP for this method:

- Accuracy: ±5 percent bias
- Completeness: >90 percent

Four samples (including a reagent blank) plus two laboratory in-house reagent blanks were submitted to Enthalpy Analytical Inc. for $H_2S$ analysis by EPA Method 11. The samples were collected on June 22, 2005, submitted to the laboratory on June 30, 2005, and the results report was dated July 15, 2005. Therefore the analysis met the 30-day hold time criteria.

The field blank submitted did not have quantifiable concentrations of $H_2S$. No field spike or laboratory spike was performed. While Method 11 does not require sample spike recovery in its procedure, the QAPP specified one spike sample to be analyzed. The three test samples produced results of similar concentrations. The analysis was 75 percent complete. The lack of demonstrated satisfactory spike recovery data warrants the data to be flagged as estimated and notated with a “J”.

#### 5.1.4 Dioxins and Furans (PCDD/PCDFs) (EPA Method 23/0011)

The following MQOs were established in the QAPP for this method:

- Recovery: 50-150 percent
- Completeness: >90 percent

Four sample sets (including one set of reagent blank and sample train rinsates) were submitted to ALTA Analytical Perspectives for PCDD/PCDFs analysis. The samples were collected on June 23, 2005, delivered to the laboratory on July 1, 2005, and analyzed on July 14, 2005. That met the 14-day hold-time for extraction and 40-day hold time for analysis.

The field blank did not have detectable levels of either compound. Detection limits for the various congeners were in the single-digit pictogram level. To assess accuracy, each sample train was spiked with standard Method 23 spiking compounds and analysis of the samples yielded extraction standard (ES) recovery from 77 to 90 percent,. Recovery of sampling standards ranged from 96 to 103 percent. These recoveries are well within the 50-150 percent MQO. All MQOs were met for this method for a completeness of 100 percent.

#### 5.1.5 Polycyclic Aromatic Hydrocarbons (PAHs) (EPA Method 23/0011)

The following MQOs were established in the QAPP for this method:

- Recovery: 50-150 percent
- Completeness: >90 percent

Four samples (including one reagent blank) were submitted to ALTA Analytical Perspectives for PAH analysis. The report included information on instrument calibration and internal QC checks. Samples collected on June 23, 2005 were received by the laboratory on July 1, 2005 and analyzed on July 15, 2005. That met the 14-day hold-time for extraction and 40-day hold time for analysis.

Table 5-2 shows the amounts of detectable target analytes in the reagent blank and the average amounts of the respective target analytes that were found in the test samples. The analysis yielded detectable but low levels of the target compounds, in the range of less than 1 ng for acenaphthylene to 385 ng for naphthalene. In contrast, the test samples showed PAH levels that were significantly higher than those found in the reagent blank. Therefore, the presence of detectable analytes in the reagent blank did not change the conclusions that can be drawn from the test sample concentration measurements,

Recovery of ES ranged from 90 to 105 percent. Recovery of sampling standards (SS), $d_{10}$-fluorene was 109 percent, and 111 percent for $d_{14}$-terphenyl. Recovery of the alternative standard (AS) $d_{10}$-anthracene was 100 percent. These recoveries were well within the 50 to 150 percent MQO. Hence, all MQOs were met for this method for a completeness of 100 percent.

**Table 5-2. Polycyclic Aromatic Hydrocarbon Reagent Blank Target Analyte Concentrations**

| Analyte | Amount found in RR062305 – Reagent Blank (ng) | Average Amount found in Test Samples (ng) |
|---|---|---|
| Naphthalene | 385 | 2610 |
| 2-Methylnaphthalene | 12.0 | 2170 |
| Acenaphthylene | 0.423 | 33.9 |
| Acenaphthene | 1.54 | 165 |
| Fluorene | 94.4 | 246 |
| Phenanthrene | 16.3 | 4010 |
| Anthracene | 2.06 | 112 |
| Fluoranthene | 15.1 | 4550 |
| Pyrene | 14.5 | 2780 |
| Benzo(a)Anthracene | 3.20 | 1000 |
| Chrysene | 4.54 | 1700 |
| Benzo(b)Fluoranthene | 6.80 | 2190 |
| Benzo(k)Fluoranthene | 2.37 | 800 |
| Benzo(e)Pyrene | 3.73 | 1180 |
| Benzo(a)Pyrene | 3.22 | 780 |
| Perylene | 0.396 | 134 |
| Indeno(1,2,3-cd)Pyrene | 3.27 | 926 |
| Dibenzo(a,h)Anthracene | <4 | 211 |
| Benzo(ghi)Perylene | 3.43 | 835 |

#### 5.1.6 Non-Methane Organic Compounds (NMOCs) (Method 25C)

The following MQOs were established in the QAPP for Landfill E:

- Recovery: 50 to 150 percent
- Completeness: >90 percent

Five canister samples (including a field blank) were submitted from Landfill E for NMOC analysis by Method 25-C to Triangle Environmental Services. The samples were collected on June 22, 2005, submitted on July 22, 2005, and analyzed July 27 – August 4, 2005. Therefore the analysis did not meet the 30 day hold time requirements. The apparent delay in sample delivery was partly attributed to the fact that the same canisters had to be analyzed by RTP Laboratory for volatile organics first. The impact of exceeding the prescribed 30-day hold time by up to 12 days is unknown.

The laboratory report included information on instrument calibration and internal QC checks.

The only NMOC detected in the field blank was at 3 ppmv as hexane. Accuracy for the method was assessed by evaluating results of response factor (RF) check samples that were run prior to and following sample analysis. Acceptance criteria established by the method is that the RF must be within 20 percent of the RF from initial calibration. All RF checks were within 10 percent of the initial calibration, well within the acceptance criteria. The %D between the pre and post-test checks were less than 2 percent. Samples were run in triplicate and all percent relative standard deviations (RSDs) for samples were less than 1.5 percent.

There was a problem with Sample #4 in that this sample contained nitrogen ($N_2$) and $O_2$ concentrations that exceeded the Method 25C criteria of 20 percent for $N_2$ and 5 percent for $O_2$. Therefore, the NMOC concentration value for Sample #4 could not be used. With data from three of the four samples being usable, and the QAPP specified that three test samples were to be analyzed, the completeness MQO for this measurement was 100 percent and met the objective set in the QAPP. The problem with Sample #4 notwithstanding, the data set was valid.

#### 5.1.7 Hydrogen Chloride (HCl) (EPA Method 26A)

The following MQOs were established in the QAPP for Landfill E:

- Accuracy: ±10 percent bias
- Completeness: >90 percent

Four samples (including one field blank) were submitted to Resolution Analytics for HCl and chlorine ($Cl_2$) determination. The results were reported in RFA# 990231. The report included information on instrument calibration and internal QC checks. Samples were collected on June 22, 2005, received by the laboratory on July 5, 2005, and analyzed on July 4, 2005, which met the 4 week hold-time requirement. Analytical detection limits were reported as 0.188 ppm for both HCl and $Cl_2$.

The field blank did not contain detectable levels of HCl or $Cl_2$. In-house audit samples were analyzed with each respective group of field samples and the measured concentrations fell within method criteria of 10 percent of their expected values.

A matrix spike was performed on Sample #3 (RR062305-3). A 0.75 ml of sample was spiked with 0.75 ml of standard (5 ppm HCl) and analyzed in duplicate. A 1.1 ml of sample was spiked with 0.5 ml of standard (20 ppm $Cl_2$) and analyzed in duplicate. The laboratory reported 98.7 percent recovery of the HCl spike with a 0.8 percent deviation in duplicate injections; and 96.9 percent recovery of the $Cl_2$ spike with a 0.91 percent deviation. This meets the MQO of ±10 percent with very good precision. Calculated bias for internal QC check was less than 2.2 percent. All MQOs were met for 100 percent completeness.

#### 5.1.8 Metals (EPA Method 29)

The following MQOs were established in the Landfill E QAPP for this method:

- Accuracy: ±25 percent bias
- Completeness: >90 percent

Four sets of Method 29 Multi-Metals trains (including one field blank) were submitted to First Analytical Laboratories for As, Cd, Cr, Pb, Mn, Hg, and Ni determination.

Results were reported in Project #50627. The report included information on instrument calibration and internal QC checks. Samples were collected on June 22, 2005, received by the laboratory on June 28, 2005, and analyzed on July 5, 2005, which met the 14 day hold-time requirement. Method detection limits for each of the target metals were reported as follows:

- As = 7.0 µg/L
- Cd = 0.2 µg/L
- Cr = 5.0 µg/L
- Pb = 5.0 µg/L
- Mn = 10 µg/L
- Ni = 10 µg/L
- Hg = 0.2 µg/L

Traces of Cd, Cr, Mn and Ni were found in the blanks, which is not unusual. Some of the back half Mn samples were abnormally high. This is a common problem which can occur in Method 29 if a tiny amount of the potassium permanganate reagent gets in to the hydrogen peroxide impingers.

All samples were spiked prior to analysis. Spike recoveries ranged from 75 to 108 percent and were within the acceptable range of 75-125 percent. In addition to spiking the samples, for each metal, internal calibration verification samples (ICVs) and continuing calibration verification samples (CCVs) were performed. ICVs were run at the beginning of each run set and CCVs were run at a frequency of one for every ten samples. ICV and CCV measured values were all less than ±10 percent for all metals with the exception of Ni which had a CCV of +12.2 percent. This was not considered a major failure and data limitations were not applied. Therefore, the MQO for this measurement was 100 percent and met the objective set in the QAPP.

#### 5.1.9 Organo-Mercury (Hg) and Total Mercury (Hg) (Frontier and Geochimica)

The following MQOs were established in the Landfill E QAPP for this method:

- Recovery: 50-150 percent
- Completeness: >90 percent

Mercury (Hg) analysis was performed separately by Frontier Geosciences and Studio Geochimica.

#### *5.1.9.1 Frontier Geosciences*

Four total Hg samples (including a field blank) were taken at Landfill E. Samples were collected on June 22, 2005 and analyzed on July 22, 2005. That analysis schedule exceeded the 14-day hold-time specified in the QAPP. All other quality assurance measures indicated that the analysis of the traps were under good control. All field blanks were consistent with historical values and indicated the detection limit was likely to be at or below the previous estimated value of 50 ng/m$^3$. Spike recoveries were 106.5 to 108.1 percent and relative percent difference (RPD) between replicates was 4 percent, which meets MQOs and are 100 percent complete.

Five monomethyl mercury (MMHg) samples (including a field blank and a field spike) were collected on June 23, 2005. These samples were analyzed on July 14, 2005 which exceeded the 14-day hold-time. Analysis of these samples was under good control with acceptable distillation spike recoveries and distillation duplicates. All CCV standards had acceptable recoveries. Spike recovery was 101 percent, which meets MQOs. RSD between replicates was less than10 percent. Monomethyl mercury (MMHg) analysis was 100 percent complete.

Seven dimethyl mercury (DMHg) samples (including a field blank and two trip spikes) were collected on June 22, 2005. These samples were analyzed on July 7 to 14, 2005 and did not meet the 14-day hold-time. The analysis of samples was well within control, with acceptable recoveries as well as good linear control standards and second-source standard recoveries. Spike recovery for these samples was 78 to 80 percent and RSD between replicate samples was 2.5 percent. This meets MQOs established in the QAPP and DMHg analysis was therefore 100 percent complete.

The field blank was low indicating that the trap media, handling procedures, and analytical techniques do not contribute to the reported values. Field matrix spike recoveries ranged from 67 to 93 percent. The DMHg analysis was 100 percent complete.

#### *5.1.9.2 Studio Geochimica*

Four total Hg samples (including a field blank) were taken at Landfill E. Samples were collected on June 22, 2005, received at the laboratory on July 1, 2005 and analyzed on July 2, 2005. This analysis schedule met the 14-day hold-time specified in the QAPP. All other quality assurance (QA) measures indicated that the analysis of the traps were under good control. All field blank concentrations were low and the detection limit is estimated at 10 ng/$m^3$. Spike recovery was 100.2 and RPD between replicates was 0.7 percent. These analyses meet the MQOs and are 100 percent complete.

Five MMHg samples (including a field blank and a field spike) were collected on June 23, 2005. These samples were analyzed on July 2, 2005. The analysis met the 14-day hold-time requirement. Spike recovery was 98.7 percent, which met MQOs. The RSD between replicates was 2.2 percent. The MMHg analysis was 100 percent complete.

Five DMHg samples (including a field blank and a field spike) were collected on June 22, 2005. These samples were extracted and analyzed on July 2, 2005, which meets the 14-day hold-time requirement. Spike recovery was 89.6 percent and RSD. This meets MQOs the established in the QAPP and DMHg analysis is therefore 100 percent complete.

### 5.1.10 Volatile Organic Compounds (VOCs) and Methane ($CH_4$) (Method TO-15)

The following MQOs were established in the Landfill E QAPP for this method:

- Accuracy: 50-150 percent recovery
- Completeness: >90 percent

Five SUMMA canisters (including one field blank) were submitted from Landfill E to RTP Laboratories for VOC and $CH_4$ determination by EPA Method TO-15. Results were reported in Project #05-072. Samples were collected on June 22 and 23, 2005 and analysis was completed by July 13, 2005, which met the 30 day hold-time requirement.

Analysis of the field blank found 32.1 ppbv of heptane and 161 ppbv of 1-ethyl-4-methylbenzene. Other target analytes were not found at method detection levels (MDLs) in the range of 0.1 to 0.65 ppbv.

Accuracy was assessed using results of a 10 ppbv laboratory control sample containing all target compounds. For all but two compounds, recoveries ranged from 60-150 percent, which met the established acceptance criteria of 50-150 percent. The recovery reported for ethanol was 2.4 percent, and 230 percent for m/p-xylene. Results for these two compounds should be flagged as estimated, “J”.

Sample 062205-04 was spiked with 200 ppbv of chlorobenzene prior to dilution with helium and analysis. The recovery of chlorobenzene was 89.5 percent.

Precision was demonstrated through multiple injections of standards at five concentration levels. The RSD between the calculated relative response factors (RRF) must be less than 30 percent with allowances that two may be greater than 40 percent. The average RSD was 13.8 percent and method criteria were met for all compounds except isopropyl alcohol with an RSD of 56.3 percent and hexane with an RSD of 40.7 percent. Results for these compounds should be flagged as estimated, “J”. Valid data was received for all SUMMA canisters submitted; these analyses are considered to be 100 percent complete.

### 5.2 Audits

This project was designated as QA Category II effort. Hence, audits were required. The internal and external audits performed for this project were completed earlier and their findings were included in the Landfill D report of this project.

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