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Managing Debris after a Natural Disaster: Evaluation of the Combustion of Storm-Generated Vegetative and C&D Debris in an Air Curtain Burner: Source Emissions Measurement Results

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Abstract

In an effort to expand available options to better manage natural disaster debris in the future, EPA evaluated the combustion of both vegetative debris and construction and demolition (C&D) debris in air curtain burners (ACBs). ACBs can be mobilized to where they're needed as a potential means of reducing the waste volume while minimizing potentially harmful environmental impacts. These tests were conducted in June 2008 by EPA/ORD at the Old Paris Road Landfill in St. Bernard Parish, Louisiana.

Testing was comprised of triplicate tests for each of two main test conditions:

- Evaluation of emissions while burning vegetative debris; and
- Evaluation of emissions from burning a mixture of C&D debris (which did not contain asbestos in sufficient quantities to be categorized as Regulated Asbestos Containing Materials (RACM)) and vegetative debris (used as supplemental fuel to maintain operating temperatures).

The analytes measured in these tests included:

- Asbestos
- Fine PM (less than 2.5 µm)
- Acid gases (HF, HCl, HBr, Cl_2, Br_2)
- Toxic metals (Hg, Pb, As, Cr, Cd, Ni, etc.)
- Polychlorinated dibenzo-*p*-dioxins and furans (PCDD/PCDF)
- Co-planar polychlorinated biphenyls (PCBs)
- Polycyclic aromatic hydrocarbons (PAHs)
- Semivolatile organic compounds (SVOCs)
- Volatile organic compounds (VOCs)
- Visible emissions (opacity).

Analysis of the data suggests that for some of the pollutants (e.g., PM, NO_X), there is little observable difference between ACB operation on vegetative debris or on C&D debris. Emissions from other pollutants (e.g., CO, SO_2, HCl, VOCs) were somewhat higher from combustion of C&D debris than from combustion of vegetative debris. Emissions of some pollutants (e.g., dioxins and furans) were significantly higher from burning C&D debris than from burning vegetative debris.

Disclaimer

U.S. Environmental Protection Agency (EPA), through its Office of Research and Development, performed the work described in this report. Technical support was provided by Research Triangle Institute (RTI) under Contract EP-C-05-060 with ARCADIS as a subcontractor. This document has been subjected to the Agency's review and has been approved for publication. Note that approval does not signify that the contents necessarily reflect the views of the Agency. EPA does not endorse the purchase or sale of any commercial products or services.

Table of Contents

List of Appendices

List of Figures

List of Tables

Acronyms and Abbreviations

ACB	Air Curtain Burner
ACFM	Actual Cubic Feet per Minute
APPCD	Air Pollution Prevention and Control Division
BTU	British Thermal Unit
BV	Bureau Veritas
C&D	Construction and Demolition
CARB	California Air Resource Board
CEM	Continuous Emissions Monitor
CFR	Code of Federal Regulations
DAS	Data Acquisition System
DCMD	Decontamination and Consequence Management Division
DSCM	Dry Standard Cubic Meter
EPA	U.S. Environmental Protection Agency
GC/MS	Gas Chromatography/Mass Spectrometry
ICAP	Inductively Coupled Argon Plasma
ID	Identification, also Induced Draft, also Inner Diameter
ISO	International Organization for Standardization
LCS	Laboratory Control Spike
LCSD	Laboratory Control Spike Duplicate
LLC	Limited Liability Company
MQO	Measurement Quality Objectives
MTBE	Methyl Tertiary Butyl Ether
N/A	Not Available
ND	Non-detect
NDIR	Non Dispersive Infra Red
NHSRC	National Homeland Security Research Center
NIOSH	National Institute for Occupational Safety and Health
NMOC	Non-Methane Organic Compounds
NPT	National Pipe Thread (U.S. standard for tapered threads)
NRMRL	National Risk Management Research Laboratory
ORD	Office of Research and Development
PAH	Polycyclic Aromatic Hydrocarbon
PCB	Polychlorinated Biphenyls
PCDDs/PCDFs	Polychlorinated dibenzo-*p*-dioxins and polychlorinated dibenzofurans
PCM	Phase Contrast Microscopy
PLM	Polarized Light Microscopy
PM	Particulate Matter

PM_{10}	Particulate Matter with an aerodynamic diameter less than or equal to a nominal 10 micrometers
$PM_{2.5}$	Particulate Matter with an aerodynamic diameter less than or equal to a nominal 2.5 micrometers
ppbv	Parts per billion by volume
QA	Quality Assurance
QAPP	Quality Assurance Project Plan
QC	Quality Control
RACM	Regulated Asbestos Containing Material
RPM	Revolutions Per Minute
RPD	Relative Percent Difference
SCFM	Standard Cubic Feet per Minute
SDT	SDT Waste & Debris, LLC
sLm	Standard Liters per Minute
SVOC	Semivolatile Organic Compound
TCLP	Toxicity Characteristic Leaching Procedure
TEF	Toxicity Equivalency Factor
TEM	Transmission Electron Microscopy
TEQ	Toxicity Equivalency Quotient
THC	Total Hydrocarbons
TIC	Tentatively Identified Compound
URG	Unified Recovery Group
UV	Ultraviolet
VOC	Volatile Organic Compound
XAD	Highly absorbent resins used in continuous sampling of organic materials, especially for monitoring of pollutants in gas streams

Acknowledgments

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Executive Summary

In an effort to provide a scientific basis to expand available options to better manage natural disaster debris in the future, EPA evaluated the combustion of both vegetative debris and construction and demolition (C&D) debris in an air curtain burner (ACB). ACBs can be mobilized to where they're needed as a potential means of reducing the waste volume while minimizing potentially harmful environmental impacts. These tests were conducted in June 2008 by EPA/ORD at the Old Paris Road Landfill in St. Bernard Parish, Louisiana.

Testing was comprised of triplicate tests for each of two main test conditions:

- Evaluation of emissions while burning hurricane-derived vegetative debris; and
- Evaluation of emissions from burning a mixture of C&D debris which did not contain asbestos in sufficient quantities to be categorized as Regulated Asbestos Containing Materials (RACM) and hurricane-derived vegetative debris (used as supplemental fuel to maintain operating temperatures).

The analytes measured in these tests included:

- Asbestos
- Fine PM (less than 2.5 μm)
- Acid gases (HF, HCl, HBr, Cl_2, Br_2)
- Toxic metals (Antimony (Sb), Arsenic (As), Barium (Ba), Beryllium (Be), Cadmium (Cd), Chromium (Cr), Cobalt (Co), Lead (Pb), Manganese (Mn), Mercury (Hg), Nickel (Ni), Selenium (Se), Silver (Ag))
- Polychlorinated dibenzo-*p*-dioxins and furans (PCDDs/PCDFs)
- Co-planar polychlorinated biphenyls (PCBs)
- Polycyclic aromatic hydrocarbons (PAHs)
- Semivolatile organic compounds (SVOCs)
- Volatile organic compounds (VOCs)
- Visible emissions (opacity).

These data are intended for use in a separate risk assessment to support decision-making activities regarding disaster debris management. Additional effort is required to relate these results, where possible, to the operational parameters used in the field in execution of the daily burn cycle. Additionally, these data may be used to develop operational guidelines for operators and technical guidelines for local, state, and regional managers in using this technology.

Preliminary analysis of the data suggests that for some of the pollutants (e.g., PM, NO_X), there is little observable difference between ACB operation on vegetative debris or on C&D debris. Emissions of other pollutants (e.g., CO, SO_2, HCl, VOCs) were somewhat higher from combustion of C&D debris than from combustion of vegetative debris. Emission of some pollutants (e.g., dioxins and furans), were significantly higher from burning C&D debris than from burning vegetative debris.

1. Introduction

In the aftermath of the devastation caused by natural disasters such as Hurricane Katrina, federal, state, and local officials are faced with an overwhelming amount of storm-related debris requiring disposal. In addition to vegetative debris including downed trees and limbs, a large number of houses may be damaged beyond repair. In an effort to better deal with these types of situations in the future, EPA is working to develop debris management options that expedite debris removal in a cost-effective and environmentally sound manner. Given the enormous amount of vegetative, building, and demolition debris created by such disasters, coupled with the limited capacity of existing landfills and industrial/commercial incineration facilities capable of handling said waste, combustion in Air Curtain Burners (ACBs) has been proposed as a potential means of reducing the waste volume on site while reducing potentially harmful environmental impacts in emergency response situations that require quickly supplementing conventional waste management methods.

1.1 Objective/Purpose and Intended Use of Project Results

Balancing the needs for efficient and timely disposal of debris with the need to protect both the environment and human health presents a unique challenge. Information shall be gathered on the types and relative quantities of potentially harmful emissions from ACBs burning both land-clearing (vegetative) and construction and demolition (C&D) debris. This information shall be related, where possible, to the operational parameters used in the field in actual execution of the daily burn cycle. Additionally, these data will be used to develop operational guidelines for operators and technical guidelines for local, state, and regional managers who will be using and developing permits for this technology. Note that burning anything but clean wood-type waste in ACBs may subject these units to additional standards which may require development of “official” test procedures for emissions measurements.

To this end, EPA’s Office of Research and Development (ORD), in collaboration with EPA’s Region 6 (located in Dallas, TX), conducted a series of tests of combustion of vegetative debris and construction and demolition (C&D) debris in an ACB. EPA and its contractors conducted measurements of gaseous emissions and combustion ash analysis to provide information on the emissions from ACBs during operation.

This report provides an assessment on the types and relative quantities of source emissions directly from ACBs burning both vegetative and demolition debris. It describes the operational parameters used in the field in actual execution of the daily burn cycle. These data can be used to develop operational guidelines for operators and technical guidelines for local, state, and regional managers who may be using and developing permits for this technology.

1.2 Scope of Project

In June 2008, EPA/ORD conducted a field testing campaign on an ACB that was temporarily deployed at the Old Paris Road Landfill in St. Bernard Parish, Louisiana, for the sole purpose of studying its performance. Testing was comprised of two groupings:

1. Evaluation of emissions from burning hurricane-derived vegetative debris; and

2. Evaluation of emissions from burning a mixture of C&D debris which did not contain asbestos in sufficient quantities to be categorized as Regulated Asbestos Containing Materials (RACM) and hurricane-derived vegetative debris (used as supplemental fuel to maintain operating temperatures).

The key reason for performing testing with vegetative debris as well as C&D debris is to place a comparative perspective on the emissions while burning C&D debris. ACBs are commonly used for vegetative debris combustion, and their use for this application is widely accepted.

In each grouping, a representative portion of the exhaust gas from the combustion process was sub-sampled and routed through ducting to allow stationary sampling at a safe distance for a variety of analytes using codified EPA methods. In addition to emission sampling, there were several stationary air samplers located at regular distances downwind to determine the ambient concentrations of key contaminants downwind from the ACB (the results from this sampling effort are outside the scope of this report and will be reported separately). Estimates of total mass emissions from the entire ACB were calculated using the volume of gas sampled coupled with estimates of the total volume of exhaust gas from the ACB. Emission factors were also generated by determining the mass of contaminant emitted per mass of waste burned. Because of the inherent variability seen in the waste feeds and combustor operation, and the logistical difficulties of accurately measuring some of the operational parameters on an operation of this scale, our ability to accurately estimate potential mass emission rates was limited to order-of-magnitude determinations. In spite of these limitations, however, the emissions measurements reported in this document are believed to be more complete and higher quality than any other available data set reporting on ACB emissions.

1.3 ACB Technology

Figure 1-1 shows a design for a commercially available ACB (Air Burners LLC, 1998-2007). Operated as an above ground installation, or in some instances, installed with the top of the unit at ground level, ACBs are mobile incinerators that utilize the general concept that a high-volume sheet of air is blown at a slight downward angle across the top of, and into, the combustion vessel. The air serves a dual purpose: 1) combustion is enhanced (compared to open burning) through providing a steady supply of forced excess oxygen with turbulent mixing resulting in higher temperatures and more thorough consumption of the solid debris used as fuel; and 2) the injection of the air at a slightly incident angle forms a “curtain” that creates a recirculation zone and serves as a barrier to the emission of particulate matter (PM) (smoke) and forces longer residence times as opposed to conventional open burning (where debris is burned in an open pile with no forced combustion air).

ACBs have been deployed on numerous occasions by the U.S. Forest Service and the U.S. Army Corps of Engineers for the reduction of vegetative waste and in some cases for destruction of animal carcasses. Limited data are available on the emissions from these applications, essentially amounting to just emissions data for carbon monoxide (CO), filterable particulate matter, and opacity. A detailed analysis of available literature on ACB emissions can be found in Miller and Lemieux (Miller and Lemieux, 2007).

Figure 1-1. Photograph of an Air Burners LLC Air Curtain Burner Unit

ACBs are generally used for on-site disposal of vegetative debris such as the debris generated from large scale land clearing or forest management operations. The ACB units burn the combustible material in an enclosed space with an open top, over which a high velocity “curtain” of air is directed to reduce the escape of large particles and to improve air circulation into the burning debris. The combination of high airflow into the combustion zone and recirculation of the combustion products is designed to reduce visible particulate matter (PM) emissions and provide increased gas-phase residence times compared with open pile burning. There are several types of ACB designs. The firebox can be a pit dug into the ground and equipped with a transportable blower and curtain air plenum positioned to blow the curtain air over and down into the pit. These designs are common in applications such as destruction of forest clearing debris because the units are relatively light and can be towed into remote areas with poor roads. A second type of ACB uses a refractory-lined firebox that is entirely above ground. These ACB units are approximately the size of a large waste dumpster and incorporate the air curtain fan on the same skid as the firebox. A third ACB design variant extends the side and back walls of the firebox upward to minimize the impact of wind and may also incorporate provisions for introducing combustion air (underfire air) into the firebox underneath the debris to theoretically improve the airflow through the combustion zone (see Figure 1-2), although field data are not available to assess the performance of this design variant as well as its impact on other pollutants due to potential entrainment of bed material resulting from air blowing up through the bed. This type of unit cannot be transported as an integral unit and can require a week or more to set up and begin operations. It must also be noted that this third design variant is included here only for completeness, -- the manufacturer of the ACB unit tested for this effort does not produce this design variant and data on its performance are not available. Other variants on the design include misters or even secondary combustion chambers. For all of these designs, the operation when burning vegetative debris is fundamentally the same. The initial charge of debris is loaded into the unit and ignited, usually using diesel fuel or kerosene as a starting fluid. Once the debris has ignited, the blower is started and additional debris is loaded into the unit as needed to maintain combustion. The ignition process can generate a temporary puff of black smoke as the diesel fuel ignites, and smoke typically increases for a brief period as subsequent loads of debris are loaded. Generally, no auxiliary fuel is used to maintain good combustion within the unit when burning vegetative debris.

Figure 1-2. ACB with Extended Skirt

1.4 Application of ACB Technology to Demolition Debris

Managing debris from natural disasters presents some unique issues as yet unstudied. One of the more serious problems associated with Hurricane Katrina was the huge number of homes, many of them older homes, built before 1970, that will have to be demolished and disposed of. Many of these homes are likely to contain asbestos and/or lead-based paints, as well as numerous sources of chlorine and metals. We are unaware of any reliable information on the potential emission rates from ACBs burning C&D debris, which may contain a range of contaminants including:

- Asbestos;
- $PM_{2.5}$ (PM with an aerodynamic diameter less than or equal to than 2.5 μm);
- Acid gases -- hydrogen fluoride (HF), hydrogen chloride (HCl), hydrogen bromide (HBr), chlorine (Cl_2), bromine (Br_2);
- Toxic metals (Antimony (Sb), Arsenic (As), Barium (Ba), Beryllium (Be), Cadmium (Cd), Chromium (Cr), Cobalt (Co), Lead (Pb), Manganese (Mn), Mercury (Hg), Nickel (Ni), Selenium (Se), Silver (Ag));
- Polychlorinated dibenzo-*p*-dioxins and furans (PCDDs/PCDFs);
- Co-planar polychlorinated biphenyls (PCBs);
- Polycyclic aromatic hydrocarbons (PAHs);
- Semivolatile organic compounds (SVOCs);

- Volatile organic compounds (VOCs); and
- Visible emissions (opacity);

2. Air Curtain Burner Test Descriptions

2.1 Characteristics of Field Test Site

Figure 2-1 shows the area at the Old Paris Road Landfill in St. Bernard Parish, Louisiana, which was the site of the testing and data gathering. The area is remote from occupied residences (greater than 1000 feet). The numbers refer to locations described in the text following the figure.

Figure 2-1. Aerial Photo of Test Site

The ACB unit used in the tests was an Air Burners Model S-327(Air Burners LLC, 2009) Refractory Lined Air Curtain Burner rated at a throughput of 6 to 10 tons of wood waste while burning approximately 3 gallons per hour of diesel fuel in the onboard generator.

In addition to the source sampling described in this report, additional sampling efforts (outside the scope of this report) were simultaneously occurring on the site to measure pollutant concentrations in the air surrounding the ACB unit. This sampling effort included two concentric sampling rings both centered on the ACB. The two concentric sampling rings are shown in green in Figure 2-1. The inner sampling ring was located between 60 to 75 feet from the ACB. The outer sampling ring was approximately 300 feet from the center of the ACB. Each ring consisted of 18 air sampling stations (measuring PM, dioxins/furans, and asbestos) evenly spaced around the ring.

The ACB unit, centered inside the inner sampling ring shown in Figure 2-1, was oriented roughly east-west lengthwise (refer to Figure 1-1) with the air plenum on the north side. Previous detailed velocity traverse measurements taken on the Air Burners S-327 model (Miller and Lemieux, 2007), showed negligible velocity and gas concentration gradients along the long side of the unit opposite the air inlet plenum. Based on these observations and the desire to minimize damage to the sampling equipment due to the heavy equipment or falling debris, the sampling scoop was placed on the southeast corner of the ACB and the sample extraction ductwork ran south to an induced draft (ID) fan which was approximately 40 feet outside the inner sampling ring. The scoop was positioned flush with the top edge of the ACB, above the air curtain. The duct in which the sampling took place was a section 35 feet in length and six inches in inner diameter roughly centered between the inner sampling ring and the blower. A schematic representation of the extraction system is shown in Figure 2-2.

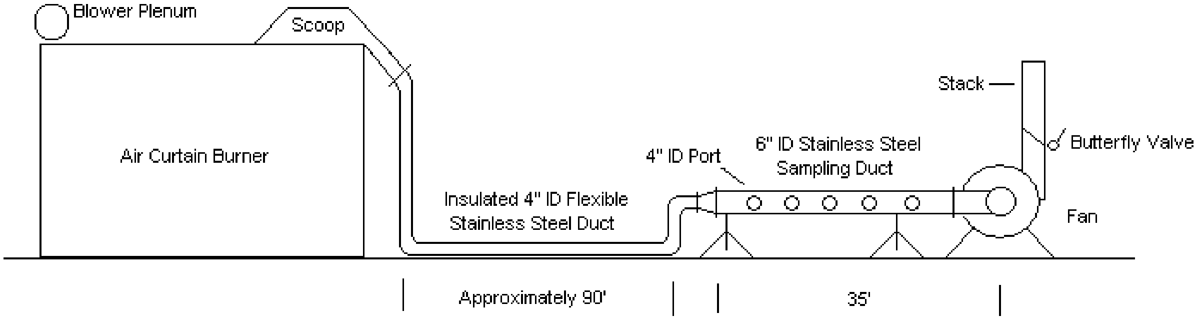


Figure 2-2. Near-isokinetic Scoop and Sample Extraction System.

Ambient air samplers were placed at five additional locations (indicated in Figure 2-1 as red numerals) outside the outer sampling ring. These locations were:

- Location 1. West of the trailers at the United Recyclers Group (URG) Office compound;
- Location 2. Inside the fence on the URG/Parish property west of Paris Road;
- Location 3. West of the motel on Paris Road;
- Location 4. West of SDT Waste & Debris, LLC (landfill operator), Transfer Station; and
- Location 5. West of the URG inspection tower.

The procedures and results from the ambient air samplers are not within the scope of this report and will be published elsewhere.

3. Test Operations

3.1 Sample Locations

The test team utilized five sample locations during the test program: ACB bed temperatures were intermittently obtained by placing sensors and recording devices directly into the bed during operation; ACB combustion level temperatures were recorded during operation by thermocouples placed at intervals through the metal wall and refractory of the device; fuel samples were taken directly from the fuel piles maintained by another contractor; ash samples were extracted from the bed of the ACB after a period of cooling; and all emissions samples were taken from a 6-inch duct connected to a near-isokinetic sampling scoop placed at one corner of the ACB exit. Further discussion of the isokineticity of the scoop during the sampling program can be found in Section 3.2.3. Visible emissions readings were taken by an operator directly observing the ACB exhaust as per EPA Method 9 (U.S. EPA, 1996a).

3.2 Target Analytes

3.2.1 Feed Debris

Samples of the vegetation used for the feed were taken and composited for later analysis. No practical method of compositing the highly heterogeneous C&D debris to accurately represent what was actually combusted was derived so no laboratory analyses of that material were undertaken. The wood fuel was composited into a single wood fuel sample and analyzed by proximate/ultimate analyses for: moisture, volatiles, fixed carbon, ash, sulfur, total carbon, hydrogen, nitrogen, oxygen, chlorine and higher heating value. It must be noted that the vegetative debris used for fuel was recovered as part of the Hurricane Katrina response and had sat in brackish water for an unknown period of time prior to being recovered and brought to the test site. The debris used in the tests therefore was likely representative of much of the vegetative debris recovered during hurricane response activities, where the debris was exposed to salt water for extended periods of time. This uncontrollable variable may have influenced emissions of chlorinated organic compounds including chlorinated benzenes and phenols as well as polychlorinated dibenzo-*p*-dioxins and polychlorinated furans.

3.2.2 ACB Ash

Samples of bulk ash were collected following each of the two phases of testing (vegetative and C&D) on the morning following conclusion of testing. Prior experience indicated that the ash would not cool to ambient temperatures if it remained in the unit overnight, so care was taken in obtaining samples. Multiple samples were taken from randomly selected portions of the ash bed using a metal scoop and placed in a stainless steel container for cooling. The actual number of samples per test condition was determined by ash bed accessibility, and samples were collected from the same locations for each condition to the extent possible. At least one composited sample consisting of sub-samples from several parts of the ACB ash bed (e.g., middle, corner, several depths) was collected for the two fuel types. The composited sample was then sub-sampled and sent to TestAmerica for extraction by the Toxicity Characteristic Leaching Procedure (TCLP) (U.S. EPA, 1992) by SW-846 1311 and for subsequent analyses for the following: RCRA metals by

SW-846 6010B and 7470A, VOCs by SW-846 8260B, SVOCs by SW-846 8270B, organochlorine pesticides and PCBs by SW-846 8081A and 8082, chlorinated herbicides by SW-846 8151A, ignitability by SW-846 1030, reactive cyanide by SW-846 9014, reactive sulfide by SW-846 9034, and pH by SW-846 9045C. Additional sub-samples were provided to Bureau Veritas for evaluation of asbestos content and to Standard Laboratories for proximate/ultimate analyses.

3.2.3 ACB Combustion Gases

The ACB combustion gases were extracted from the ACB exhaust by a near-isokinetic scoop and conveyed by an ID fan to a six-inch diameter duct constructed for the purpose of allowing conventional extractive sampling methodology to be used to sample the gas content (see Figure 2-2). The duct had a number of 1-inch, 3-inch, and 4-inch National Pipe Thread (NPT) sampling ports to provide entry for the sampling probes. Target analytes were: filterable particulate and condensable matter, particle size distribution, $PM_{2.5}$ particulate, asbestos, metals, VOCs, SVOCs, acid gases, dioxins/furans, PCBs, and PAHs. The flexible section of the duct between the scoop and the sampling section was insulated to prevent heat loss. The ID fan outlet pipe was equipped with a butterfly valve, but attempts at fine control proved futile as the temperature of the gas from the scoop varied too widely over a relatively short period of time. We therefore decided to set the valve wide open and leave it at that setting for the duration of the sampling program. With this valve set at wide open, scoop temperature variation during test runs became the sole extraction system operational parameter of great significance for the isokineticity of the extraction scoop.

The entry face of the extraction scoop was 18 inches by 5 inches, with the longer dimension spanning the final 18 inches of the ACB firebox width on the side opposite the blower plenum as shown in Figure 2-2. This 18-inch span along the length of the ACB represents the area where, from earlier flow determinations on an identical burner, essentially all the combustion product gases exit the firebox. With this experience in mind, and the earlier measurement of 15 ft/sec bulk velocity in that 18-inch span, estimated extraction scoop isokinetic variation during the sampling runs was calculated. During the test program, isokinetic variation was between 47.8% and 90.9%, with an average of 65.9%.

3.3 Sampling and Analysis Methods

3.3.1 Feed Debris Sampling Analysis Methods

ACB wood fuel samples were taken daily by technical staff. On June 24 and the morning of the 25th, wood samples were taken hourly and composited for a single laboratory sample representing a single vegetative debris run: i.e., three composited samples were collected. Specific sample collection procedures involved selecting a log from the inner ring that was due for burning and using a claw hammer to remove a handful of thick bacon-strip-size pieces (including bark properly represented) that were temporarily stored in a bucket. At the end of the run, all the hourly samples were representatively sampled to fill a one liter sample jar. These three composited samples were later composited representatively again and submitted for a single proximate/ultimate analysis and chlorine analysis. When received by the lab, the entire sample of bacon-strip-size pieces were air dried, crushed/pulverized to 20 mesh, and riffled to produce a homogenous feed stock for all further analyses. These further analyses utilized a 1-5 gram portion of the whole sample.

No practical method of C&D debris sampling could be developed due to the content and variability of the feed material.

3.3.2 ACB Combustion Gases Sampling and Analysis Methods

3.3.2.1 Continuous Emissions Monitors

Continuous instrumental methods using continuous emissions monitors (CEMs) were employed to measure concentrations of carbon dioxide (CO_2), oxygen (O_2), nitrogen oxides (NO_X), carbon monoxide (CO), sulfur dioxide (SO_2), and THC. These instruments were operated in accordance with EPA Methods 3A (CO_2/O_2) (U.S. EPA, 1989), 7E (NO_X) (U.S. EPA, 1990), 10 (CO) (U.S. EPA, 1996b), 6C (SO_2) (U.S. EPA, 1996c), and 25A (THC) (U.S. EPA, 1996d) as prescribed in the Code of Federal Regulations (CFR), specifically 40 CFR Part 60, Appendices A2, A4, and A7. CEM sampling began prior to test material being fed into the ACB and continued until after extractive sample acquisition was completed.

Effluent gas samples destined for CEM sampling (except the THC monitor) were conditioned to remove water vapor and particulate matter, which are interfering constituents. The sample gas going to the THC monitor was heated and maintained at 250-300 ºF and filtered with glass fiber filters. The THC monitor requires the sample to be hot and condensate-free to operate properly, as some components of THC can be disabled by condensation of water.

Components of the sampling system in contact with the sample gas, including the ducting but excepting the extraction scoop, which was constructed of black iron, were constructed of Type 316 stainless steel or Teflon® to minimize the possibility of surface chemical reactions, which can affect the accuracy of the measurements. The CO_2/O_2, NO_X, SO_2, THC, and CO sample collection and conditioning system consisted of a heated probe and a particulate filter, followed by a moisture-removal trap and an out-of-stack secondary particulate filter. A sample pump (Thomas Model 2107CA 18-TFE) transported the effluent sample through a distribution manifold to the analyzers. The configuration of the sampling system allowed the calibration gases to be injected either directly into the analyzers or through the complete sample collection and conditioning system. Table 3-1 lists the model number and the name and location of the manufacturer of this pump, and summarizes this same information for the remainder of the equipment used during this project.

An Environics Series 4000 Gas Mixer was used to produce calibration gases at the desired concentration. The mixer achieved accurate blending/mixing by using four Tylan Series FC thermal mass flow controllers and an integral Environics computer control system. Based on EPA Method 205 procedures (U.S. EPA, 1996o), the gas mixer blended a high-level EPA protocol 1 calibration gas of known concentration with an inert diluent gas such as nitrogen, thus producing a calibration gas at lower concentration.

The concentration signal outputs from the CEMs were connected to a computer-based data acquisition system (DAS) using software written by ARCADIS. The DAS used a portable computer and a strip chart recorder/analog-to-digital converter. In addition to providing an instantaneous display of analyzer response, the DAS compiled, averaged, and saved analyzer data at a user-set frequency. For the purposes of these tests, the data were logged with a one minute rolling average. The DAS integrated the real-time measurements and provided files and printouts of the averaged emissions over the desired time period. The functioning of the DAS was checked by verifying that its indicated signal levels were in agreement with a calibrated Yokogawa chart recorder.

Table 3-1. Equipment used during the ACB Testing

Item	Model #	Manufacturer	Location
Sample pump	Model 2107CA 18-TFE	Thomas	1419 Illinois Avenue, Sheboygan, WI 53082
Gas mixer	Series 4000	Environics	69 Industrial Park Road East, Tolland, CT 06084
Mass flow controllers	Series FC	Tylan	Company no longer in business
O_2 Analyzer	Model 3300P	Teledyne	16830 Chestnut Street, City of Industry, CA 91748
CO_2 Analyzer	Model ZRH	California Analytical	1312 W. Grove Ave, Orange, CA 92865
SO_2 Analyzer	Model ZRF	California Analytical	1312 W. Grove Ave, Orange, CA 92865
NO_X Analyzer	Model CLD 70S	Eco Physics	3915 Research Park Drive, Suite A-3, Ann Arbor, MI 48108
CO Analyzer	Model ZRH	California Analytical	1312 W. Grove Ave, Orange, CA 92865
THC Analyzer	Model 20S	VIG	4051 East La Palma Ave., Suite C, Anaheim, CA 92807
ACB Thermocouples	K-Type	Omega	One Omega Drive, Stamford, CT 06907
IC for acid gases	LC-10AD/CDD6A	Shimadzu	7102 Riverwood Drive, Columbia, MD 21046
ICAP for metals	Model 3300DV	Perkin-Elmer	940 Winter Street, Waltham, MA 02451
CVAAS for Hg	Model 1100	Perkin-Elmer	940 Winter Street, Waltham, MA 02451
$PM_{2.5}$ cyclone	Model PM2-K	Apex Instruments	125 Quantum Street, Holly Springs, NC 27540
Cascade impactor	Mark III	Andersen	Company no longer in business
PM_{10} cyclone	Model PM10-K	Apex Instruments	125 Quantum Street, Holly Springs, NC 27540
Portable scale	Model L-3040	Vishay SI/Lodec	11400 P.P.G. S.E., Cumberland, MD 21502
TEM for asbestos	Model CM-12	Phillips	5350 NE Dawson Creek Dr., Hillsboro, OR 97124
PCM for asbestos	Model BH-2	Olympus	3500 Corporate Parkway, Center Valley, PA 18034
Data system chart recorder	Model DR-130	Yokogawa	2 Dart Road, Newnan, GA 30265
Asbestos re-deposition filter	47 mm MCE	Pall	600 S. Wagner Rd., Ann Arbor, MI 48103

All pre-test and post-test calibration procedures were performed as outlined in the specific EPA methods. The operating principles of the analyzers are described in the following subsections.

3.3.2.1.1 CO_2/O_2 (EPA Method 3A)

Carbon dioxide and oxygen concentrations were determined by **EPA Method 3A - Determination of Oxygen and Carbon Dioxide Concentrations in Emissions from Stationary Sources (Instrumental Analyzer Procedure)**, as described in 40 CFR Part 60, Appendix A-2 (U.S. EPA, 1989). In Method 3A, a gas sample is continuously extracted from the stack and conveyed to instrumental analyzers for the determination of oxygen and carbon dioxide concentration. Specifically, an electrochemical analyzer (Teledyne Model 3300P) was used for oxygen and a non-dispersive infrared (NDIR) analyzer (California

Analytical Model ZRH) was utilized for carbon dioxide. Results were used in the calculation of sampling duct gas molecular weight.

3.3.2.1.2 SO_2 (EPA Method 6C)

Sulfur dioxide concentration was determined by **EPA Method 6C - Determination of Sulfur Dioxide Emissions from Stationary Sources (Instrumental Analyzer Procedure)**, as described in 40 CFR Part 60, Appendix A-4 (U.S. EPA, 1996c). In Method 6C, a gas sample is continuously extracted from the sampling duct and conveyed to an instrumental analyzer (in this case a California Analytical Model ZRF non-dispersive infrared (NDIR) analyzer) for the determination of sulfur dioxide concentration. Flow data from concurrent EPA Methods 1A (U.S. EPA, 1996n) and 2C (U.S. EPA, 1996m) were used to calculate sulfur dioxide mass emission rates.

3.3.2.1.3 NO_X (EPA Method 7E)

Nitrogen oxides were determined by **EPA Method 7E - Determination of Nitrogen Oxides Emissions from Stationary Sources (Instrumental Analyzer Procedure)**, as described in 40 CFR Part 60, Appendix A-4 (U.S. EPA, 1990). In Method 7E, a gas sample is continuously extracted from the sampling duct and conveyed to an instrumental analyzer (here an Eco Physics Model CLD-70S Chemiluminescence Analyzer) for the determination of nitrogen oxides concentration. Flow data from concurrent EPA Methods 1A (U.S. EPA, 1996n) and 2C (U.S. EPA, 1996m) were used to calculate nitrogen oxides mass emission rates.

3.3.2.1.4 CO (EPA Method 10)

CO emissions were determined by **EPA Method 10 - Determination of Carbon Monoxide Emissions from Stationary Sources**, as described in 40 CFR Part 60, Appendix A-4 (U.S. EPA, 1996b). In Method 10, a gas sample is continuously extracted from the sampling duct and conveyed to an instrumental analyzer (California Analytical Model ZRH NDIR in this case) for the determination of carbon monoxide concentration. Flow data from concurrent EPA Methods 1A (U.S. EPA, 1996n)and 2C (U.S. EPA, 1996m) were used to calculate carbon monoxide mass emission rates.

3.3.2.1.5 THC (EPA Method 25A)

THC emissions were determined by **EPA Method 25A - Determination of Total Gaseous Organic Concentration Using a Flame Ionization Analyzer** as described in 40 CFR Part 60, Appendix A-7 (U.S. EPA, 1996d). Method 25A is applicable over a wide range of THC concentrations, from percent levels down to low ppm levels. The method does not differentiate the species that constitute total hydrocarbons, i.e., methane and non-methane organic compounds (NMOCs) are measured together and reported as one concentration as equivalent propane. Method 25 (U.S. EPA, 1996l) is specifically designed to measure NMOCs. However, Method 25 is not suitable for measuring concentrations less than 50 ppm and was not used.

In Method 25A, a gas sample is extracted from the source through a heated sample line and a glass fiber filter; the gas sample is then introduced to a flame ionization detector (FID). Used here was the VIG Model 20S FID. Results are reported as volume concentration equivalents (ppm by volume) of the calibration gas (propane). The mass emission rate was calculated by the incorporation of results of EPA Methods 1A (U.S.

EPA, 1996n) and 2C (U.S. EPA, 1996m) volumetric flow data along with moisture and molecular weights determined by EPA Methods 3A (U.S. EPA, 1989) and 4 (U.S. EPA, 1995b).

3.3.2.2 Temperature

Temperature in the ACB was determined using two methods. K-type thermocouples were inserted through joints in the refractory lining to allow recording of near-wall temperatures at various points in the ACB. Additionally, bed temperatures were intermittently determined in situ using shielded thermocouple/recorder packages directly in the ACB bed. The ultimate objective of temperature measurement was not to ascertain a “true” temperature; rather the goal was to determine a readily reproducible temperature parameter that can potentially be used by inspectors and operators to monitor ACB performance.

3.3.2.3 Flue Gas Volumetric Flow Rate (EPA Methods 1A and 2C)

Flue gas volumetric flow rates were determined by **EPA Method 1A - Sample and Velocity Traverses for Stationary Sources with Small Stacks or Ducts** and **EPA Method 2C – Determination of Stack Gas Velocity and Volumetric Flow Rate in Small Stacks and Ducts (Standard Pitot Tube)**, as described in 40 CFR Part 60, Appendix A-1 (U.S. EPA, 1996m, U.S. EPA, 1996n). A measurement location in the effluent stream was selected to minimize angular and cyclonic flow. Using Method 1A, the duct cross section was divided into an appropriate number of equal areas and the probe was marked to signify the velocity traverse points. Due to the potential for flow disturbance in small stacks, the sample extraction and flow measurement were performed apart from one another. Sampling ports for extractive samples were located eight equivalent diameters upstream of the velocity sampling ports to allow for the re-establishment of flow stability. Using Method 2C, a traverse for velocity head and sampling duct gas temperature was performed using a standard pitot tube and thermocouple probe to minimize flow disturbance. Sampling duct gas volumetric flow rate was calculated using the resultant data, the sampling duct gas density, and duct cross sectional area. Measurements were performed in conjunction with each test run for filterable/condensable particulate, metals, and dioxins/furans. ACB flow estimates, along with pollutant concentration data from concurrent methods, were used to calculate pollutant mass emission rates.

3.3.2.4 Stack Gas Molecular Weight and Stack Moisture (EPA Methods 3A and 4)

Sampling duct gas molecular weight and diluent concentration were determined by **EPA Method 3A - Determination of Oxygen and Carbon Dioxide Concentrations in Emissions from Stationary Sources (Instrumental Analyzer Procedure)** and **EPA Method 4 - Determination of Moisture Content in Stack Gases**, as described in 40 CFR Part 60, Appendices A-2 and A-3, respectively (U.S. EPA, 1989, U.S. EPA, 1995b). In Method 3A, a gas sample is continuously extracted from the sampling duct and conveyed to instrumental analyzers for the determination of O_2 and CO_2 concentration. Diluent gas concentration and molecular weight are calculated from these results. In Method 4, a gas sample is extracted from the source with moisture being removed and determined gravimetrically and/or volumetrically. Method 4 samples were taken as a part of the EPA Method 5/202 (U.S. EPA, 1996j, U.S. EPA, 1996k), M29 (U.S. EPA, 1996i), and M23 (U.S. EPA, 1995c) samples.

3.3.2.5 Filterable Particulate and Acid Gases

Filterable particulate matter and acid gases (HF, HCl, Cl_2, HBr, and Br_2) were determined according *to* ***EPA Method 5 - Determination of Particulate Emissions from Stationary Sources, and EPA Method 26A - Determination of Hydrogen Halide and Halogen Emissions from Stationary Sources (Isokinetic Method)***, both described in 40 CFR Part 60, Appendix A-3 (U.S. EPA, 1994, U.S. EPA, 1996g, U.S. EPA, 1996k). These two methods were combined into a single sampling train. Using this combined method, a flue gas sample was withdrawn from the sampling duct isokinetically through a heated probe and a pre-weighed, heated, glass fiber filter into an impinger/condenser train containing dilute sulfuric acid and sodium hydroxide solutions which collected the gaseous hydrogen halides and halogens, respectively. The filtered, dried gas was measured with a calibrated dry gas meter and the particulate matter captured in the probe and filter were desiccated and weighed. The hydrogen halides were solubilized in the acidic solution and subsequently formed chloride (Cl^-), bromide (Br^-), and fluoride (F^-) ions. The halogens have a very low solubility in the acidic solution and pass through to the alkaline solution where they are hydrolyzed to form a proton (H^+), the halide ion, and the hypohalous acid (HClO or HBrO). Sodium thiosulfate was added in excess to the alkaline solution to assure reaction with the hypohalous acid to form a second halide ion such that two halide ions are formed for each molecule of halogen gas. The halide ions in the separate solutions were measured by ion chromatography. Emission rates were calculated from these results and the results of concurrent flue gas flow rate measurements using EPA Methods 1A (U.S. EPA, 1996n) and 2C (U.S. EPA, 1996m).

3.3.2.6 Asbestos

No approved method for measuring asbestos in combustion flue gases currently exists. It was initially planned to pull a sample isokinetically from the sampling duct through a 37 mm diameter polycarbonate filter with a 0.4 μm pore size at approximately 15 sLm. In that scenario, it would have been necessary to perform a preliminary test to determine the correct sampling time to load the filters with an amount of sample appropriate to the ultimate asbestos analysis methodology - Transmission Electron Microscopy (TEM) by ISO 10312:1995 Ambient Air-Determinations of Asbestos Fibers - Direct Transfer Transmission Electron Microscopy Method (U.S. EPA, 1987). This microscopic method is capable of identifying the presence and type of asbestos. The preliminary test runs were to be taken for the following durations: one minute, three minutes, five minutes, ten minutes, and thirty minutes. The filters from the preliminary runs were to be subjected to visible examination and phase contrast microscopy (PCM) on site. This technique, National Institute for Occupational Safety and Health (NIOSH) Method 7400 (NIOSH, 1994), is capable of determining if a given filter is properly loaded for TEM analyses. It was hoped that one of the preliminary test run sampling times would be satisfactory for the collection of the actual samples.

However, upon arrival on site and preliminary monitoring of the duct temperature, it was decided that the temperature was too high (as well as widely variable) for the 37 mm polycarbonate filter material. That fact, in addition to the fact that it was decided not to burn RACM during the test program, led to an alteration of the asbestos sampling method. The alteration consisted of simply removing the 37 mm filter from the sampling train and collecting the sample directly into the deionized water in three glass impingers. The samples were extracted isokinetically with what was essentially an EPA Method 5-type sampling train without the filter. Operating parameters were those of Method 5, i. e., extraction rate of ~0.6 cfm, probe/hotbox temperature of ~ 240 °F, impinger volume of 100 mL, impinger temperature of ~35 °F, and a run time of 120 minutes (one was cut short by a thunderstorm). Sample volumes ranged from 47 scf (the shortened run) to 95 scf, sufficient for determination of asbestos. Samples were recovered from the impingers by triple washes of DI water into glass sample jars for shipment to the laboratory. Due to an oversight, field blanks were not collected, but all laboratory method blanks analyzed with these samples did not detect asbestos.

Ash samples were analyzed for asbestos using EPA/600/R-93/116 "Interim Method for the Determination of Asbestos in Bulk Insulation Sample", EPA-600/M4-82-020, December 1982, published as Appendix E to Subpart E of 40CFR763 (U.S. EPA, 1993).

3.3.2.7 Metals

Metals emission rates were determined by the use of **EPA Method 29 - Determination of Metals Emissions from Stationary Sources**, as described in 40 CFR Part 60, Appendix A-8 (U.S. EPA, 1996i). A metered flue gas sample was withdrawn isokinetically from the sampling duct through a heated probe and glass fiber filter into an impinger/condenser train. The impingers contained a mixture of 5 percent nitric/10 percent hydrogen peroxide for metals absorption. Mercury is further absorbed by impingers containing 4 percent potassium permanganate/10 percent sulfuric acid. The filtered, dried, metals-depleted gas was measured with a calibrated dry gas meter. The filter and impinger solutions were digested and analyzed for the target metals by Inductively Coupled Argon Plasma (ICAP) with exception of mercury which was analyzed by cold vapor atomic absorption spectroscopy (CVAAS). Metals emission rates were calculated from the resultant metals concentrations and the results of flue gas volumetric flow rate measurements using concurrent EPA Methods 1A (U.S. EPA, 1996n) and 2C (U.S. EPA, 1996m) measurements.

3.3.2.8 VOCs

Concentrations of VOCs were determined by an adapted version of **EPA Method 0040 – Sampling of Principal Organic Hazardous Constituents from Combustion Sources Using Tedlar Bags**, as described in SW-846, *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods* (U.S. EPA, 1996e). In Method 0040, a representative sample was drawn from a source through a heated sample probe and filter. The sample then passed through a heated 3-way valve into a condenser where the moisture and condensable components were removed from the gas stream and collected in a glass trap. The gas sample was then collected in a canister.

A SUMMA®-passivated canister was substituted for the Tedlar bag. This modification was necessitated by the fact that Tedlar bags are fragile and prone to burst during shipment. SUMMA® canisters, which are routinely used in ambient sampling methods for organics, were an acceptable substitution to solve this problem. VOC mass emission rates were calculated from the resultant constituent VOC concentrations and the results of flue gas volumetric flow rate measurements using concurrent EPA Methods 1A (U.S. EPA, 1996n) and 2C (U.S. EPA, 1996m).

3.3.2.9 Dioxins/Furans

Dioxin/furan emission rates were determined by the use of **EPA Method 23 - Determination of Polychlorinated Dibenzo-*p*-Dioxins and Polychlorinated Dibenzofurans from Stationary Sources**, as described in 40 CFR Part 60, Appendix A-7 (U.S. EPA, 1995c). A metered flue gas sample was withdrawn from the stack isokinetically through a heated probe and Teflon coated, glass fiber filter onto a condenser/XAD-2 packed resin trap for collection of dioxins/furans. The filtered, dried gas flow rate was measured with a calibrated dry gas meter. The XAD resin trap was extracted and analyzed for dioxins/furans by high resolution gas chromatography/mass spectrometry (GC/MS). Dioxin/furan emission rates were calculated from these results and the results of concurrent flue gas flow rate measurements using EPA Methods 1 (U.S. EPA, 1996f) and 2C (U.S. EPA, 1996m). PAHs and PCBs were also determined by use of Method 23 by taking aliquots of the resultant samples and analyzing them for those additional constituents.

3.3.2.10 SVOCs

SVOC emission rates were determined by the use of **EPA Method 0010 – Modified Method 5 Sampling Train** as described in SW-846, *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods* (U.S. EPA, 1986). A metered flue gas sample was isokinetically withdrawn from the sampling duct through a heated probe and Teflon coated, glass fiber filter onto a condenser/XAD-2 packed resin trap for collection of SVOCs. The filtered, dried gas was measured with a calibrated dry gas meter. The XAD resin trap was extracted, split, and analyzed by GC/MS for a variety of SVOCs. Emission rates were calculated from these results and the results of concurrent flue gas flow rate measurements using EPA Methods 1A (U.S. EPA, 1996n) and 2C (U.S. EPA, 1996m).

3.3.2.11 Particle Size Determination

Detailed particle size determinations were made using a modification of **California Air Resource Board (CARB) Method 501** (CARB, 1990). In CARB Method 501, an in-stack PM_{10} (PM smaller than or equal to 10 µm in aerodynamic diameter) particle separation device (a cyclone) was used to determine the concentration of PM_{10} particulate matter. A portion of the sampling duct gas then passed to an Andersen 10-stage cascade particle sizing impactor for further sub-PM_{10} size determination. This procedure yielded PM_{10} concentration (from the PM_{10} cyclone) and a distribution of particle sizes smaller than 10 µm (from the Andersen cascade impactor).

3.3.2.12 $PM_{2.5}$ Particulate

$PM_{2.5}$ particulate determinations were made by a modified version of **EPA Method 201A - Determination of PM_{10} Emissions (Constant Sampling Rate Procedure)** (U.S. EPA, 1996h). In this method, a gas sample was extracted at a constant flow rate through an in-stack sizing device, which separates PM greater than PM_{10}. Variations from isokinetic sampling conditions were maintained within well-defined limits. The particulate mass was determined gravimetrically after removal of uncombined water. The modification employed involved substituting a $PM_{2.5}$ cyclone for the PM_{10} cyclone normally used in this method. The two devices were designed to characterize their respective particulate fractions at the same flow rate, which allowed this modification to be made.

3.3.2.13 Visible Emissions

Visible emissions (opacity) from the ACB were monitored and recorded by the use of **EPA Method 9 – Visual Determination of the Opacity of Emissions from Stationary Sources**, as described in 40 CFR

Part 60, Appendix A-4 (U.S. EPA, 1996a). In this method, the opacity of emissions was determined visually by an EPA certified observer (smoke reader).

3.4 Estimation of ACB Emissions

Some mathematical calculations must be performed in order to convert the concentration measurements in the sampling duct into mass emission rates or emissions per unit mass of feed material. If the assumption is made that the concentrations of the pollutants in the sampling duct are equal to the average concentration of that pollutant leaving the firebox, then:

$$m_i = C_i Q_{total} \tag{1}$$

where m_i is the mass emission rate of pollutant i, C_i is the concentration of pollutant i in on a dry basis, and Q_{total} is the volumetric flow rate of gas leaving the firebox, on a dry basis.

Q_{total} is not a known quantity. The concentration of CO, CO_2 and water vapor are, however, known, and the feed rate and composition are known. Therefore, using material balance calculations, Q_{total} can be estimated using a carbon balance.

Note that Q_{total} inherently contains a contribution due to ambient wind that did not actually pass through the firebox as combustion air. However, this additional dilution does not affect the estimates of mass emission rates or emission factors.

3.4.1 Estimation of Q_{total} using a Carbon Balance

If we assume ideal gas behavior, by the definition of mole fraction,

$$Y_{CO_2} = \frac{n_{C,feed} + n_{C,air} - n_{C,ash} - n_{C,CO} - n_{C,THC}}{\left(\dfrac{PQ_{total}}{RT}\right)} \tag{2}$$

where Y_{CO_2} is the mole fraction of CO_2 in the exhaust gas of the ACB, $n_{C,feed}$ is the molar input rate of carbon in the debris feed, $n_{C,air}$ is the molar input rate of carbon in the air (due to CO_2), $n_{C,ash}$ is the molar generation rate of residual carbon in the ash, $n_{C,CO}$ is the molar emission rate of carbon due to CO in the exhaust gas, and $n_{C,THC}$ is the molar emission rate of carbon due to hydrocarbons (as propane) in the exhaust gas. The molar emission rate of carbon in the particulate matter is neglected for two reasons: 1) carbon is not a measured compound, and 2) the recirculation zones in the ACB serve to increase the burnout of carbon in the flyash to near completeness.

The various molar feed rate terms are calculated using Equations (3) through (7) as follows:

$$n_{C,feed} = \frac{m_{C,feed}}{\overline{M}_C} \tag{3}$$

$$n_{C,air} = \frac{Y_{CO_2,air} P Q_{total}}{RT} \quad (4)$$

$$n_{C,ash} = \frac{m_{C,ash}}{\overline{M}_C} \quad (5)$$

$$n_{C,CO} = \frac{Y_{CO} P Q_{total}}{RT} \quad (6)$$

$$n_{C,THC} = \frac{3Y_{THC} P Q_{total}}{RT(1-Y_{H_2O})} \quad (7)$$

where $m_{C,feed}$ is the mass feed rate of carbon into the ACB due to the debris being burned, $\overline{M}_C$ is the molecular weight of carbon, P and T are the pressure and temperature at standard conditions, R is the ideal gas constant, $Y_{CO_2,air}$ is the mole fraction of CO2 in the ambient air, approximately 314 ppm (http://chemistry.about.com/od/chemistryfaqs/f/aircomposition.htm), $m_{C,ash}$ is the mass generation rate of carbon in the bottom ash, Y_{CO} is the mole fraction of CO in the exhaust gas, Y_{THC} is the mole fraction of hydrocarbons (as propane) in the exhaust gas, and Y_{H_2O} is the mole fraction of water vapor in the exhaust gas (since THC is measured on a wet basis unlike the other fixed combustion gases). Note that Equation (4) is an approximation, because Q_{total} is really the outlet flow rate, not the inlet flow rate. However, due to the large quantities of ambient air contributing to Q_{total}, any errors introduced due to this approximation are negligible.

Substituting these terms for the molar rates in Equation (2) yields Equation (8),

$$Y_{CO_2} = \frac{\frac{m_{C,feed}}{\overline{M}_C} + \frac{Y_{CO_2,air} P Q_{total}}{RT} - \frac{m_{C,ash}}{\overline{M}_C} - \frac{Y_{CO} P Q_{total}}{RT} - \frac{3Y_{THC} P Q_{total}}{RT(1-Y_{H_2O})}}{\left(\frac{P Q_{total}}{RT}\right)} \quad (8)$$

which upon simplification yields Equation (9).

$$Y_{CO_2} = \left(\frac{(m_{C,feed} - m_{C,ash})RT}{\overline{M}_C P Q_{total}}\right) + \left(Y_{CO_2,air} - Y_{CO} - \frac{3Y_{THC}}{(1-Y_{H_2O})}\right) \quad (9)$$

Substituting the mass fractions of carbon in the feed and the ash (as measured by the proximate/ultimate analysis) and solving for Q_{total}, Equation (10) is produced, which can be used to estimate Q_{total} based on a carbon balance,

$$Q_{total} = \frac{(m_{feed} X_{C,feed} - m_{ash} X_{C,ash})RT}{\overline{M}_C \left(Y_{CO_2} - Y_{CO_2,air} + Y_{CO} + \frac{3Y_{THC}}{(1-Y_{H_2O})}\right) P} \quad (10)$$

where m_{feed} is the measured mass feed rate into the ACB, $X_{C,feed}$ is the mass fraction of carbon in the feed, m_{ash} is the ash generation rate, and $X_{C,ash}$ is the mass fraction of carbon in the ash.

Table 3-2 lists the results from estimating Q_{total} using Equation (10). Note that the parameters for the C&D ash were taken from the sample acquired the morning of Day 3 of testing since the last C&D ash sample was acquired much later after the ash had completely burned out.

Table 3-2. Estimation of Total Flow Rate

Run	Feed Rate (lb/hr)	Feed Mass Frac. C	Feed Mass Frac. H_2O	Feed Mass Frac. H	Ash Gen. Rate (lb/hr)	Ash Mass Frac. C	Ash Mass Frac. H	YCO_2 (dry)	YCO_2,air (dry)	YCO (dry)	YTHC (wet)	YH_2O	Qtotal (EQ 10) (dry scfm)
Veg1	9600	0.349	0.27	0.04	1152	0.58	0.010	0.019	0.00031	0.0001	0.00001	0.034	76342
Veg2	9600	0.349	0.27	0.04	1152	0.58	0.010	0.012	0.00031	0.0001	0.00001	0.038	121589
Veg3	13600	0.349	0.27	0.04	1224	0.58	0.010	0.019	0.00031	0.0001	0.00001	0.054	114509
CD1	14800	0.349	0.27	0.04	1332	0.29	0.013	0.008	0.00031	0.0001	0.00001	0.032	327788
CD2	18400	0.349	0.27	0.04	4600	0.29	0.013	0.010	0.00031	0.0002	0.00004	0.070	273234
CD3	9400	0.349	0.27	0.04	2350	0.29	0.013	0.006	0.00031	0.0001	0.00002	0.040	237562

3.4.2 Estimation of Mass Emitted per Unit Mass Feed

The mass emission of a given pollutant per mass of debris fed is calculated using the feed rate and pollutant emission rate from Equation (1), as follows:

$$E_i = \frac{m_i}{m_{feed}} \tag{11}$$

where E_i is the estimated emissions of pollutant i per unit mass of debris burned. This quantity is in units as reported in the EPA's AP-42 database of emission factors (U.S. EPA, 1995a).

3.5 Quality Assurance Considerations

This project's main objective was to evaluate emissions from an ACB. This objective puts it into the method development project category, fitting Quality Assurance (QA) Category III. However, this project has high visibility and includes enforcement and regulatory implications, with data that will be used to perform a risk assessment. Therefore, where feasible, QA Category II requirements were adhered to, including an on-site technical systems audit conducted by EPA QA staff. The project utilized the general guidance of EPA's *Quality Assurance Handbook for Air Pollution Measurement System: Volume III – Stationary Source-Specific Methods*. The ultimate decision to permit or prohibit the burning of C&D debris in ACBs is beyond the scope of this project. However, it is important to note that current regulations for solid waste incineration units may not allow this practice due to the stringency of the regulations and the lack of approved testing procedures that could be used to demonstrate compliance with the regulations. The objective of this work was to provide objective and reliable data on the types and relative order of magnitude of emissions from the process.

This pilot project has measured a number of pollutants that are likely to be emitted into the air during the combustion of both vegetative and demolition debris in an ACB. Some of these pollutants are known to cause adverse health effects under certain conditions and durations of exposure. Risk assessment is a tool EPA uses to estimate the likelihood that adverse health effects may occur in people exposed to pollutants present in the environment as a consequence of releases from manmade sources. Risk assessment will be applied here to evaluate the potential human health risk that may be associated with exposures to pollutants emitted from the ACB. The risk assessment process consists of the following four steps:

1. Hazard Identification: the toxicological evaluation of adverse human health effects of a chemical;

2. Dose-response Assessment: the process of characterizing the relationship between the dose of a chemical and the incidence of an adverse health effect in the exposed populations;

3. Exposure Assessment: the process of estimating the ways in which people become exposed to a chemical when the chemical is released into the environment from a source. Exposure assessment involves estimating or measuring the chemical concentrations in the environment as well as estimating the intensity, frequency and durations of human exposures to the chemical; and

4. Risk Characterization (the quantitative expression of the likelihood of an adverse effect occurring in populations exposed to the chemical contaminant).

This report uses the term ‘risk driver’ to describe the identification a pollutant or set of pollutants that constitutes most of the potential human health risk in the context of the pollutant emissions from the ACB and subsequent human exposures. The measurement protocols employed in this project are known to have a relatively high degree of accuracy and precision. How well these measurement protocols translate to ACBs is not well known, however. The ACB does not have a conventional stack, where the concept of stack diameters is meaningful, and there are no validated methodologies to withdraw a representative sample from an ACB. In addition, the representativeness of the conditions tested, including the debris composition and condition, compared to normal daily operation over the lifetime of this or potential future cleanup programs, was unknown and largely unknowable. The composition of the C&D debris is expected to vary substantially with regard to the constituents of greatest concern (lead, mercury, arsenic, and chlorine) and to the parameters of key importance to combustion effectiveness (energy and moisture content). Therefore, although the ACB feed materials and operating conditions were likely to lie within a relatively consistent envelope, the widely varying composition of the debris and transient nature of the feeding operation were expected to lead to substantial variability in emissions.

Currently, visible emissions (i.e., opacity) are the only regulatory criteria specified for the operation of ACBs burning vegetative debris. Opacity is limited to 10% on a 6 minute period (40 CFR Part 62). The critical measurement parameters necessary to adequately evaluate the most important environmental impacts of using ACBs for debris cleanup are as follows:

- Emission rate for Hg, As, and Pb (potential risk drivers);
- Emission rate for CO_2/CO (necessary for estimation of total mass emission rate for other species);
- Emission rate for filterable PM (potential risk driver);
- Emission rate of asbestos (potential risk driver);
- Emission rate of dioxins/furans (potential risk drivers);
- Total sample flow rate (necessary for calculation of total mass emission rate for other species);
- Wall temperature (parameter potentially capable of routine measurement by ACB operators); and
- Visible emissions (i.e., opacity), (the only operating parameter currently used to regulate ACB operation).

For each set of test conditions (i.e., waste feed type), the measured values over all of the individual tests are reported. The measured values, corrected for dilution to a 12 percent CO_2 basis, are also reported. Correction for dilution to a 7% O_2 basis was desirable. However, due to the near-ambient levels of oxygen that were observed in the sampling duct, this calculation would have created large errors in the corrected results. For conventional combustion systems, where O_2 concentrations are in the 7% range and CO_2 concentrations are in the 12% range, the dilution-corrected concentrations are similar. Average values for the dilution-corrected concentrations are also reported, but their ultimate use may not adequately represent long-term emissions given the expected high variability associated with the waste. Subsequent use of these data must be done with the understanding that these tests are limited in scope.

Due to expected variation in the feed/performance of the ACB, triplicate sampling runs (performed successively) will not yield a viable method precision estimate. Concurrent sampling runs are prohibited, in most cases, by a lack of sufficient sampling ports. Performance criteria for precision are therefore limited to two of the methods – M26A for hydrogen halide acid gases and VOCs by modified EPA Method 0040.

4. Test Results

This section presents the test results. Detailed test results can be found in Appendix A, the field data can be found in Appendix B, and the analytical reports themselves can be found in Appendix C. Appendix D contains other supporting documents.

4.1 ACB Feed Material and Operational Overview

4.1.1 Daily Account

4.1.1.1 June 20 – 22, 2008

Five piles of vegetative material were staged near the ACB, referred to as the “inner perimeter”, for loading into the ACB with an excavator. The total weight of this material was 82 tons. This vegetative material consisted primarily of wood from residential trees that had died due to contact with salt water; the wood had been cut at least 2 months prior to the test. Refer to the proximate and ultimate analysis of wood samples (see Section 4.5.1) for further details on this feed stock. The beginning of a given run is defined as the time where sampling was initiated on the series of sampling trains, and the end of the run is defined as the time where sampling was terminated on the series of sampling trains. The ACB unit was in operation prior to the initiation of the run and after termination of the run. A period of operation was maintained prior to the initiation of each run. During the periods between runs, the ACB was allowed to idle at temperature until approximately 20 minutes before the next run. Mass feed estimates are based on average feed rates throughout an entire day of testing.

4.1.1.2 June 24, 2008 (First day of ACB testing, Vegetative Runs (Veg Run) 1 and (Veg Run) 2)

For the first day of testing, three piles of the vegetative material totaling approximately 62 tons were used as the feedstock to the ACB. However, approximately 5 tons of waste vegetative material from these three piles were removed from the inner perimeter, due to their undesirable characteristics (e.g., too large, too sediment- or soil-laden). Therefore, a total of 57 tons was fed to the ACB during the day, which began at 0730 when the ACB was first lit, proceeded through the first run with vegetative debris (Veg Run 1) and ended at 1850, when emissions sampling for Veg Run 2 was completed. This is a time period of 11.3 hours, although the ACB was one-fourth filled with wood, using material from the first 3 piles, prior to being lit at 0730. The emissions sampling for Veg Run 1 began at approximately 0945, and finished at 1345. Veg Run 2 began at 1450, and lasted until 1850. In the interim period between sampling runs, the ACB was still being fed vegetative debris. Material was fed to the ACB using an excavator with a “thumb” attachment, approximately every 15-20 minutes.

In the afternoon on June 24, three additional piles of vegetative material, totaling 31 tons, were brought to the inner perimeter.

4.1.1.3 June 25, 2008, Morning (Veg Run 3)

Based on the total amount of vegetative material that had been brought to the inner perimeter so far (82 + 31 = 113 tons), less the amount fed to the ACB (57 tons), less the waste material removed from the inner perimeter (5 tons), the total amount of vegetative material at the inner perimeter at the start of this day was estimated to be 51 tons. This material was aggregated into 4 piles, with the first pile weighing approximately 21 tons (this was material left over from the previous day, which was brought to the inner perimeter prior to June 23), and the three other piles weighing approximately 10 tons each. At 0710, feeding of vegetative material began (emissions sampling for Veg Run 3 did not begin until 0815), and feeding stopped at 1215, when the emissions sampling for Veg Run 3 stopped. During this approximately 4-hour time period, the first three piles (weighing 41 tons) of vegetative matter were fed to the ACB, except for approximately 5 tons of undesirable vegetative materials from these 3 piles that was removed from the inner perimeter. Therefore, about 36 tons of vegetative material was fed over approximately 5 hours. Additionally, it is estimated that about 10 tons of vegetative material remained in the inner perimeter after Veg Run 3 was completed.

4.1.1.4 June 25, 2008, Afternoon (1st C&D Run 1, House 1)

At about 1330, ACB operation contractors started bringing C&D material from House 1 to the inner perimeter. The debris from House 1 consisted of structural materials as well as the contents of the house, since House 1 was not gutted. The material was roughly segregated based on material type (metals, bricks, furnishings, wood, and sediment) to minimize non-combustible loading in the ACB. The materials were recombined as they were brought into the inner perimeter. At around 1505, the feeding of this debris to the ACB began, with C&D Run 1 commencing at 1520. Over the course of the afternoon, 4 piles of C&D were brought to the inner perimeter, with a total combined weight of 42 tons. Starting at around 1840, another pile of vegetative debris, weighing 11 tons, was brought to the inner perimeter as well. The feeding to the ACB stopped around 1910, except for small pieces of debris that had fallen to ground and were fed manually. C&D Run 1 ended at 1920. Over the course of the afternoon operations (from 1505 to 1910), two of the C&D piles were fed to the ACB, for a combined weight of 21 tons.

For the vegetative material (fed with the C&D as supplemental fuel), it is a bit more difficult to estimate how much was fed to the ACB during this same time period, since the wood piles were moved around the inner perimeter, aggregated, and some wood was separated again because the pieces were too large in diameter to feed, and the operator loading the ACB picked material from different piles to ensure the right size logs were being fed as needed. However, it is estimated that about half of the vegetative material within the perimeter during this run (21 tons were in the perimeter) was fed to the ACB during this time period. To further corroborate this estimate, in a conversation with representatives of Air Burners LLC during this test run, their intention to feed about 10 tons of vegetative material to the ACB during this period was indicated. Thus at the end of the day, 11 tons of vegetative material was estimated to remain in the perimeter.

4.1.1.5 June 26, 2008 Morning (C&D Run 2; House 1)

Based on the above analysis, an estimated 21 tons of C&D was available to start with in the morning. At the beginning of the day, this C&D material began as 2 piles, but the C&D material was eventually combined into one pile by around 1000. C&D Run 2 sampling began at 0900. Starting around 1100, another C&D pile of about 14 tons was brought in, although only a minimal amount of material from this pile was used to feed the ACB during C&D Run 2. At 1200, feeding to the ACB and emissions sampling stopped temporarily, due to rain and lightning from a severe thunderstorm. When the thunderstorm persisted, at 1300, C&D Run 2 at the 3-hour point was terminated due to the continued rain and lightning. At this point, very little remained of the combined 21-ton pile (estimated 2 tons remaining). Therefore, approximately 19 tons of C&D were fed to the ACB in this 3-hour test period (feeding of C&D debris and C&D Run 2 began at around 0900 and stopped at 1200).

A synopsis of the vegetative material balance during this C&D Run 2 follows. After removal of the ash in the ACB, kindling (small logs) was stoked into the ACB from about 0800 to 0830. A small pile of kindling (from all the wood available in the perimeter) had previously been assembled for this purpose, although the mass of this pile is unknown. At 0900 emissions sampling for C&D Run 2 commenced. As with the previous test run, an unknown amount of vegetative debris was fed during this test run, since there were various piles of wood aggregated within the perimeter. However, most of the wood within the perimeter at the start of the day (11 tons) was fed to the ACB, save for the waste material and oversize logs. This waste vegetative material and wood pieces too large to feed were removed from the perimeter, with a total weight removed estimated at 5 tons. Additional wood (6 tons) was brought into the perimeter around 1100 and placed in a separate pile. This wood was used for tamping down the C&D debris in the ACB; only a small portion of this pile was fed to the ACB.

4.1.1.6 June 26, 2008 Afternoon (C&D Run 3; House 2)

Due to concerns over not having sufficient feed material to complete C&D Run 3, the test team decided to use debris from another gutted house (referred to as House 2) to provide emissions data for the burning of C&D debris from a house in which the internal materials and furniture had been removed. However, due to the severe thunderstorm during the early afternoon, this material could not be weighed prior to bringing it to the inner perimeter. The un-weighed House 2 C&D debris was pushed into the inner perimeter using a bulldozer, bypassing the scale, to protect the landfill cap. Feeding to the ACB began at 1530 and ended at 1945; emissions sampling for C&D Run 3 began at 1615 and ended at 1945. The feed material was muddy and wet and fed to the ACB using smaller, more frequent loads.

The C&D from House 2 was amassed in a large pile on the side of the ACB opposite from the C&D from House 1. The piles of C&D from the two houses were separate. The approach for estimating the amount of House 2 C&D material that was fed to the ACB during C&D Run 3 is based on a mass balance for the total House 2 material brought on site. The total weight of House 2 C&D material that remained after the test (weighed by the use of a dump truck during the week of July 7, 2008, when the landfill cap was dry enough to sustain heavy equipment) was 95 tons. The total volume of House 2 C&D remaining on-site after the test was determined to be 201 yds^3 (based on the known dump truck volume and the number of truck loads), thus giving a density of 0.47 tons/yd^3.

Three 80 yd^3 trucks of House 2 C&D material were brought on site on June 26, 2008. Using the density figure determined above, the estimate for the total weight of material brought on site is 3 * 80 yds^3 * 0.47 = 113 tons. Therefore, the estimated amount of House 2 C&D fed to the ACB is 113 – 95 = 18 tons.

Only a small amount of vegetative material was fed to the ACB during C&D Run 3. The approach used for estimating the mass of vegetative material fed to the ACB was to count the number of times the excavator loaded the vegetative material into the ACB throughout the test run, and estimate how full the bucket on the excavator was for each load (it is estimated that the bucket was only one quarter full of material). Using the bucket volume of 2.5 yd^3, and assuming a density of 0.5 tons/yd^3 for wood, the following estimate is made:

6 buckets * 0.25 bucket * 2.5 yd^3/bucket * 0.5 ton/yd^3 = 2 tons

4.1.2 Overall Mass Balance for Vegetative Material

Table 4-1 is a summary of the overall mass balance for vegetative material as described in previous sections, which was used as the sole feedstock for the three vegetative test runs, and as supplemental fuel for the three C&D tests.

Table 4-1. Inner Perimeter Material Balance for Vegetative (Wood) Material in Tons

Date	Test Run	Veg Material Brought in	Fed to ACB	Removed from Perimeter as Waste or Too Big to Feed	Remaining Amount at End of Day or Test Run
June 20 – 22, 2008		82	0	0	82
June 24	Veg Run 1 Veg Run 2	31	57	5	51
June 25 (morning)	Veg Run 3	0	36	5	10
June 25 (afternoon)	C&D Run 1	11	Estimated at 10 tons	0	11
June 26 (morning)	C&D Run 2	6	Estimated at 10 tons	5	2
June 26 (afternoon)	C&D Run 3	0	Estimated at 2 tons	0	0
Total		130	115	15	0

ACB operation contractors reported that 12 tons of vegetative debris remained in the inner perimeter, as determined by weighing dump truck loads during the week of July 7, 2008. This result is in contrast to the mass balance approach discussed above which resulted in an estimate that zero tons of vegetative material would remain. To account for this error, the 12 ton discrepancy was distributed equally between the amount of material brought into the inner perimeter and the amount removed (fed to ACB or removed as waste). The revised vegetative material feed estimates, based on this error distribution, are shown in Table 4-2 below, accounting for the 12 tons of vegetative feed remaining at the end of the test.

Table 4-3 below is a summary of the mass balance for the C&D debris for House 1 only, based on the above discussion.

As with the vegetative material, the actual amount of House 1 C&D material remaining after the test, as reported by ACB operators (weighed afterwards when the landfill cap was dry enough, during the week of July 7, 2008, using a dump truck), was different from the estimated value per the above discussion. The ACB operators determined that 20 tons of material remained, whereas in the mass balance approach described above, 16 tons was estimated to remain. To account for this error, the 4 ton discrepancy was equally distributed, and the revised feed estimates based on this error distribution are shown in Table 4-4.

Based on the revised material feed balance estimates as shown in Tables 4-2 and 4-4, along with the time periods in which these amounts were fed (discussed in the above narrative), the mass feed rates for the vegetative and C&D debris for each test run are summarized in Table 4-5, below. Table 4-5 also contains the total mass fed to the ACB each day, including time periods when emissions tests were not conducted.

Table 4-2. Revised Inner Perimeter Material Balance for Vegetative (Wood) Material in Tons

Date	Test Run	Material Brought in	Material Fed to ACB	Material Removed from Perimeter as Waste or Too Big to Feed	Material Remaining at End of Day or Test Run
June 20 – 22, 2008		86	0	0	86
June 24	Veg Run 1 Veg Run 2	32	54	5	59
June 25 (morning)	Veg Run 3	0	34	5	20
June 25 (afternoon)	C&D Run 1	12	9.5	0	22.5
June 26 (morning)	C&D Run 2	6	9.5	5	14
June 26 (afternoon)	C&D Run 3	0	2	0	12
Total		136	109	15	12

Table 4-3. Inner Perimeter Material Balance for House 1 C&D Debris Material in Tons

Date	Test Run	Material Brought In	Material Fed to ACB	Material Removed from Perimeter as Waste	Material Remaining at End of Day or Test Run
June 25 (afternoon)	C&D Run 1	42	21	0	21
June 26 (morning)	C&D Run 2	14	19	0	16

Table 4-4. Revised Inner Perimeter Material Balance for House 1 C&D Debris Material in Tons

Date	Test Run	Material Brought In	Material Fed to ACB	Material Removed from Perimeter as Waste	Material Remaining at End of Day or Test Run
June 25 (afternoon)	C&D Run 1	43.5	20	0	23.5
June 26 (morning)	C&D Run 2	14.5	18	0	20

Table 4-5. Summary of Feed Rates (tons/hour) for Each Test Run

Date	Test Run	Vegetative Feed Rate	C&D Feed Rate	Total Mass Fed during Day (tons)
June 24	Veg Run1 Veg Run 2	4.8	0	54
June 25 (morning)	Veg Run 3	6.8	0	
June 25 (afternoon)	C&D Run 1 (House 1)	2.4	5	64
June 26 (morning)	C&D Run 2 (House 1)	3.2	6	
June 26 (afternoon)	C&D Run 3 (House 2)	0.5	4.2	48

4.1.2.1 Ash Production

Around 0600 on June 25, ash (still hot; see Figure 4-1) from the previous day was removed from the ACB and placed in a 40 yd^3 roll-off container. The weight and volume were 2.5 tons and 5 yd^3, respectively, giving a density of 0.5 tons/yd^3. Roughly 12 inches of ash was left in the ACB to facilitate the ignition of the new vegetative material for the testing that day. With firebox dimensions of 27 feet 2 inches long by 8 feet 5 inches wide by 8 feet 1inch high, the remaining ash volume was 8.5 yd^3, or 4 tons. The total ash produced on June 24 was thus 6.5 tons, 12 percent of the total material fed that day (54 tons).

At 0600 on June 26, ash from the previous day's burn was removed from the ACB. The weight and volume were 6 tons and 14 yds^3, giving a density of 0.43 tons/yd^3. As on the previous day, roughly 12 inches of ash was left in the ACB to provide residual heat to facilitate the ignition of the new material for the testing that day. However, since 12 inches of ash was in the burner to start with, the amount of ash that was removed was approximately the same as the amount of ash that was produced on June 25. The ash produced was thus approximately 9 percent of the total material fed that day (63.5 tons).

On June 27 in the morning, all of the ash was removed from the ACB and placed in a roll-off container. of Ash at a volume of 24 yds^3 (18.9 tons) was removed (density of 0.79 tons/yd^3). Since there had been 12 inches of ash in the ACB at the start of the testing the previous day, this amount of ash (8.5 yd^3, which equals 6.7 tons based on the above density) is subtracted from the above figure. Therefore, 12.2 tons of ash was produced on June 26, 25 percent of the total material (47.5 tons) fed that day.

Note all the ash weights and volumes described above were determined during the week of July 7, 2008, after the test had been completed. The ash from each previous day's test was placed in separate 40 yd^3 roll-off containers. The ash weight was determined as the difference between the weight of the roll-off container when filled with ash and when empty.

Figure 4-1. Removal of Ash from the ACB the Morning Following a Day of Testing

4.1.3 Debris Weighing Procedure

The materials placed in the inner perimeter (also waste material removed from the inner perimeter) that were fed to the ACB during the three vegetative test runs and C&D test runs 1-2 was weighed with an axle scale (LODEC L3040 Portable Axle Scale, electronic load cell, 50 ton capacity, calibrated 6/4/2008) (see Figure 4-2). Two front-end loaders were used to move and weigh this material. The weight of each front-end loader, whether empty (tare) or loaded, was determined as the combined weight of each axle reading. The material mass was determined as the difference between the tare and loaded weight. Figure 4-3 is a photograph of the front axle being weighed when loaded with vegetative material. The readout for each axle weight, and the calculated weight of each load, was manually recorded in a notebook. The loads were then tallied for each material pile.

Figure 4-2. Axle scale

Figure 4-3. Loaded Front Axle Being Weighed

The ash and feed material remaining after the test were weighed with roll-off containers and dump trucks, respectively.

4.1.4 Other Process Operation Notes

The following additional noteworthy items related to the ACB operation during the test are meant to supplement the other discussions (e.g., feed, ash, burner air flow, etc.) in this section of the report.

4.1.4.1 June 24, 2008

0730: With ACB filled with vegetative matter, diesel fuel was sprayed onto the material and lit using a propane torch.

0930: The first load of C&D material was brought to the site; workers began separating non-combustible materials such as bricks, aluminum, shingles, etc.

1345: A railroad tie was inadvertently fed to the ACB.

1815: Water was sprayed on C&D piles for dust suppression.

4.1.4.2 June 25, 2008

0645: Ash sample taken

1035: Wood sample taken; another taken at 1145.

1430: Replaced thermocouple located at ACB sample scoop.

1450: Started raining lightly – sampling continued.

1515: The thermocouple at the sample scoop was lost again when the loader bucket hooked the thermocouple wire.

1650: Due to a change in wind direction, feeding of ACB was suspended for about 5 minutes, although emissions sampling continued.

1900: A roll of carpet (approximately 10 feet long by 1 foot in diameter) was fed to the ACB.

4.1.4.3 June 26, 2008

0650: Ash sample taken while there was still enough ash from the C&D material.

0745: Another thermocouple was installed on the sample scoop.

0945: C&D material from house 2 arrived on site.

1200: Sampling and feeding stopped due to rain and lightning, which lasted until ~ 1500. After the rain stopped, operations continued and C&D Run 3 proceeded.

4.1.5 Combustion Air Fan Speed and ACB Exhaust Airflow

Although the monitoring of the ACB blower fan speed was not included in the QA project plan (QAPP) the ACB blower fan speed was manually recorded. Blower fan speed could be used as an indication of combustion air flow and potentially exhaust air flow, since actual ACB exhaust gas velocity or flow was not measured during the test. (Refer to Section 3.4 for the discussion of exhaust gas flow estimation methods.) However, velocity profile measurements were made on the same ACB model burning vegetative material during a previous scoping test conducted in 2005 (Miller and Lemieux, 2007).

Air Burners personnel operated the ACB during the test, including periodic adjustment of the fan speed and providing direction to the equipment operator about what, how often, and where to place the feed to optimize combustion. The following text summarizes information provided by Air Burners personnel regarding the planned and actual operation of the diesel engine (which rotates the fan), the fan itself, and the combustion air flows during the test.

- At typical operations, the burner combustion air flow rate is approximately 9,000 SCFM.

- The maximum fuel usage for the engine is about 3.2 gallons per hour, but more typically runs at 2.9 gallons per hour at 2000 RPM fan speed. The engine is exhausted near the intake for the combustion air flow.

- Air Burners personnel indicated that during the feeding of C&D material, the fan speed would be lowered to 1800 RPM. However, vegetative material would be fed alternately with the C&D, and when this situation occurred, the fan speed would be raised to 2000 – 2200 RPM.

- In e-mails following the test, Air Burners personnel reported that, in general, during the test they were running at 2100 RPM for the vegetative burns and at 2000 RPM for the C&D test runs. They did run at lower RPM ranges for short periods of time during startup, but otherwise they were operating at either 2100 or 2000 RPM settings the majority of the time.

A few actual fan speed readings were taken during the test program; the times they were taken and other related information are shown in Table 4-6 below.

Table 4-6. Burner Fan Speed Readings and Notes on Fan Operation

Date	Test Run	Time	Fan speed (RPM)	Notes
6/24/08	Veg Run 1	1205	2400	
		1300		Blower fan off due to technical malfunction
		1320		Blower fan back on
6/25/08	Veg Run 3	0845	2200	
6/26/08	C&D Run 2	0920	2000	

The ACB combustion air flows, as a function of fan speed and as reported by Air Burners personnel, are listed below:

- 2400 RPM = 10,200 SCFM
- 2100 RPM = 8800 SCFM
- 1800 RPM = 7600 SCFM

4.2 Test Periods

Table 4-7 shows the start and stop times of the various runs.

Table 4-7. Run Start and Stop Times

Run	Date	Start Time	Stop Time
Veg Run 1	June 24, 2008	945	1345
Veg Run 2	June 24, 2008	1532	1847
Veg Run 3	June 25, 2008	900	1220
C&D Run 1	June 25, 2008	1520	1920
C&D Run 2	June 26, 2008	900	1215
C&D Run 3	June 26, 2008	1615	1945

Times of collection for all temperature and CEM data were adjusted to local (Central Daylight) time.

Figures 4-4 through 4-9 are Gantt charts detailing the timing of the burns and sampling runs.

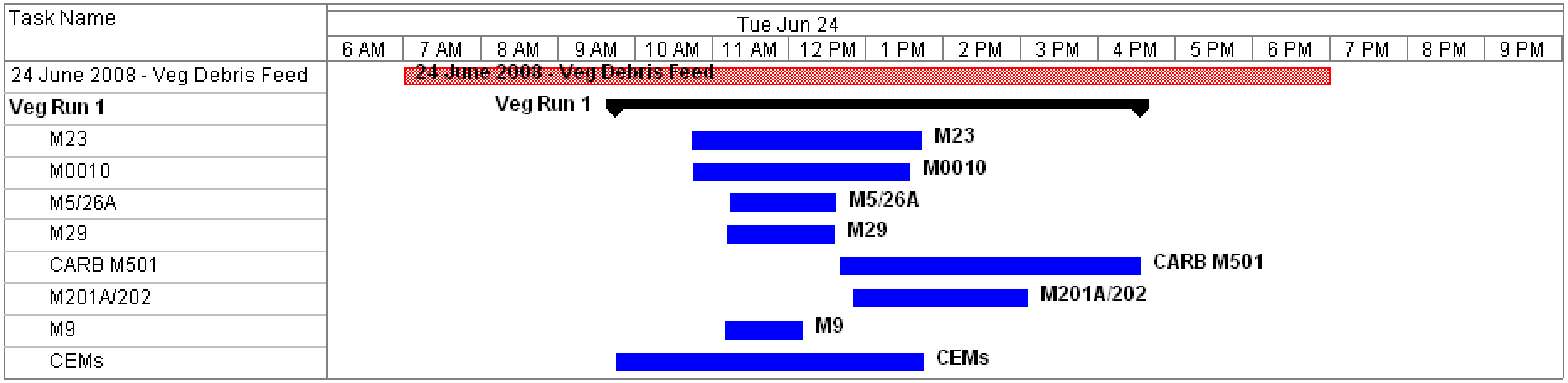


Figure 4-4. Veg Run 1 Activity Timeline

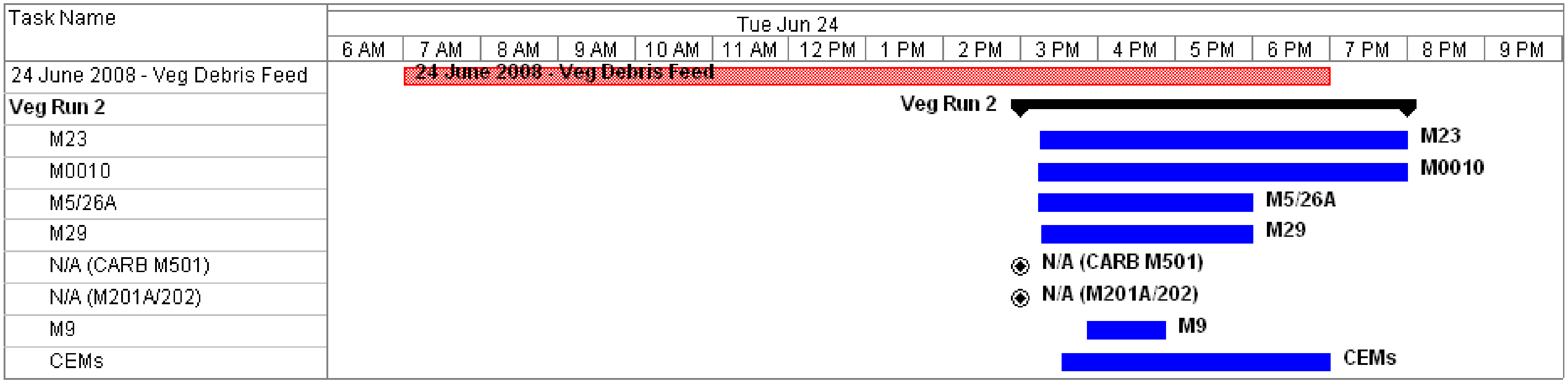


Figure 4-5. Veg Run 2 Activity Timeline

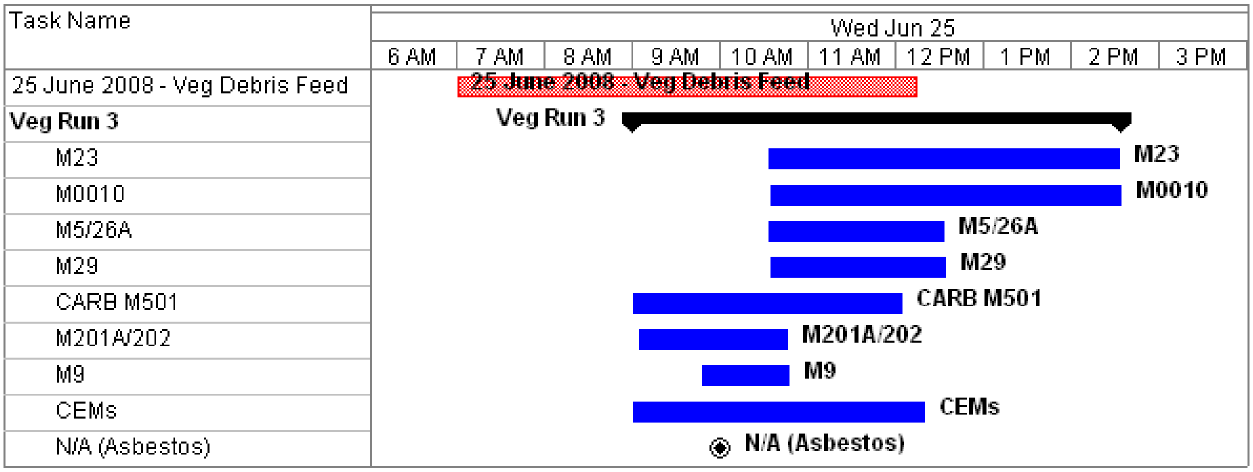


Figure 4-6. Veg Run 3 Activity Timeline

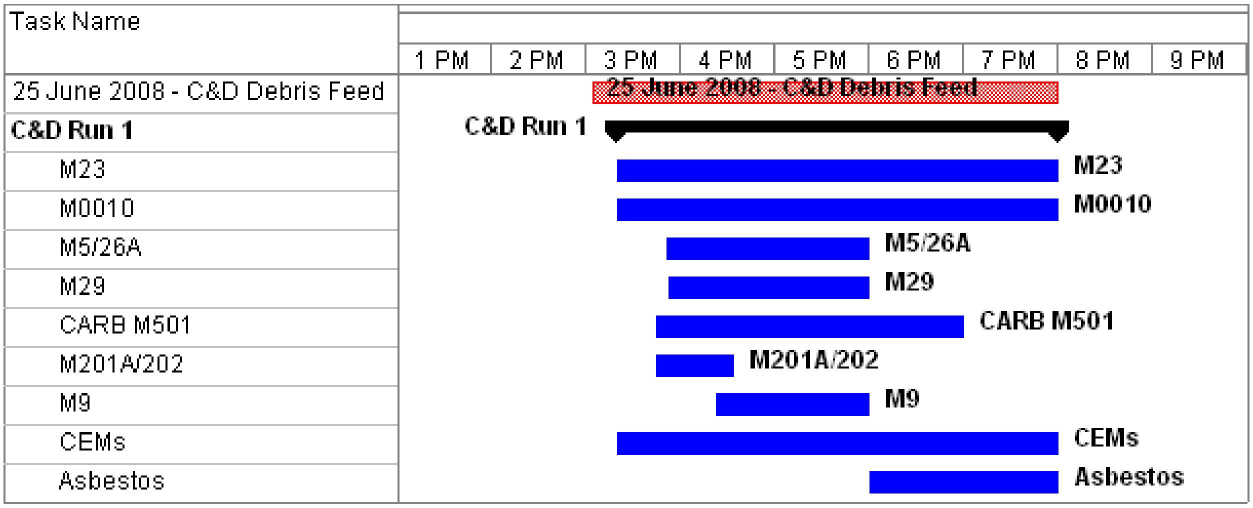


Figure 4-7. C&D Run 1 Activity Timeline

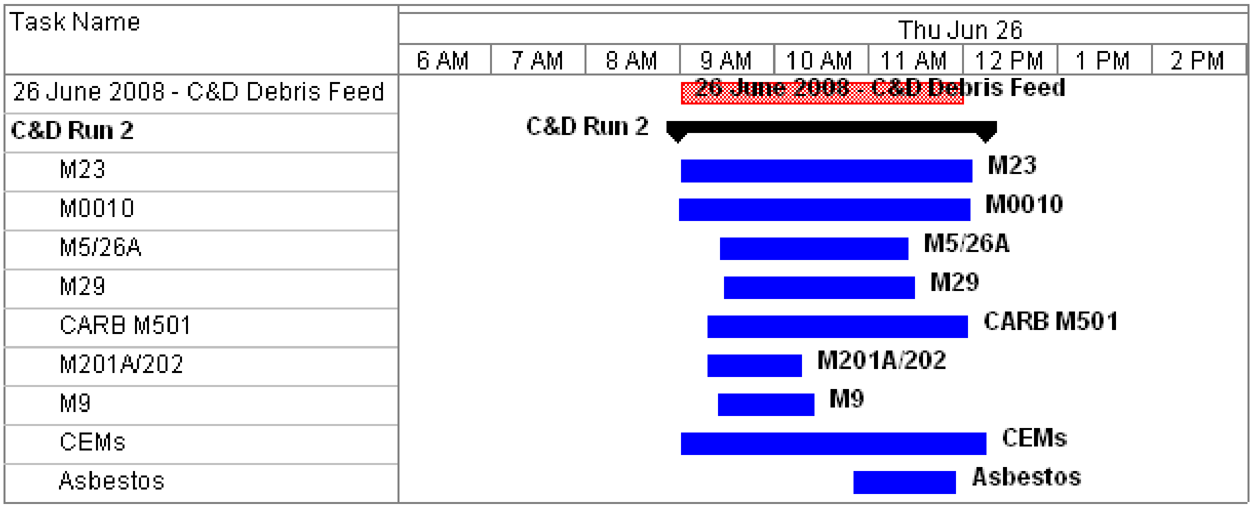


Figure 4-8. C&D Run 2 Activity Timeline

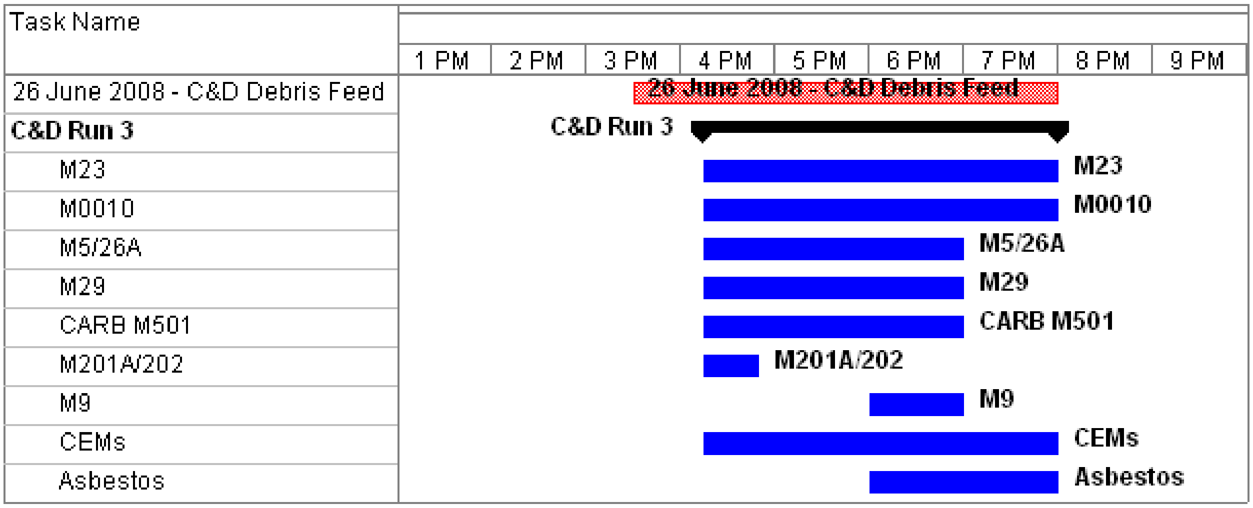


Figure 4-9. C&D Run 3 Activity Timeline

4.3 CEMs

Table 4-8 shows the average of the raw concentrations determined by CEMs over the nominal test durations. All CEM measurements were on a dry basis except THC.

Table 4-8. Raw CEM Concentrations for Air Curtain Burner Tests

Run	O_2 (%)	CO_2 (%)	CO (ppm)	NO_X (ppm)	SO_2 (ppm)	THC (ppm)
Veg Run 1	19	1.9	56	18	5.3	9.3
Veg Run 2	20	1.2	72	13	2.1	8.9
Veg Run 3	19	1.9	119	24	0.7	10
C&D Run 1	20	0.8	72	13	6.5	12
C&D Run 2	20	1.0	150	13	29	39
C&D Run 3	21	0.6	99	6.4	5.6	22

In order to compare "apples to apples" when examining both the replicate runs and the different test conditions, it is important to account for the effect of ambient dilution air (drawn in by the sampling scoop, or entrained into the unit itself) on the measurements. Normal U.S. regulatory reporting for incinerators typically mandates correcting emissions data to 7 percent oxygen. However, the formula for calculating the corrected emissions is susceptible to very large errors when the oxygen concentrations in the samples approach ambient levels, as was the case for these data. So for the purposes of this analysis, the CEM data have been corrected to 12 percent CO_2, which is the method used in the Canadian regulations. Correcting emissions based on CO_2 does not introduce significant errors when sampling at near ambient oxygen concentrations. Note that for most conventional combustion systems, correcting to 7 percent O_2 and 12 percent CO_2 yields similar results. Note also that when calculating mass emissions rates or emission factors (see Section 5), the raw pollutant concentrations are used, so the method of correcting for dilution does not affect the numbers that will eventually be used as the source term in any risk assessment activities.

Looking at the CO_2 data in particular, and the O_2 data to a lesser extent, and comparing the results from Day 1 (which was a calm day) and Days 2 and 3 (which were much windier days), it is readily apparent that the ambient wind speed and wind direction played a role in how much effluent gas was pulled into the sampling scoop. However, as explained below, this external influence appears not to have adversely impacted the measurements. Detailed meteorological data on the wind speed and ambient conditions will be published in a separate report along with the air monitoring data.

Table 4-9 shows the average of the CO, NO_X, SO_2, and THC, corrected to 12 percent CO_2. Again note that all CEM measurements are on a dry basis, with the exception of THC. SO_2 concentrations on Veg Run 3 and C&D Run 1 may have been slightly affected by an out-of-specification post-test bias check on June 25. This situation was corrected for the following day's testing.

Table 4-9. CEM Concentrations Corrected to 12 Percent CO_2

Run	CO (ppm)	NO_X (ppm)	SO_2 (ppm)	THC (ppm)
Veg Run 1	364	118	34	60
Veg Run 2	701	126	20	87
Veg Run 3	754	151	4	64
C&D Run 1	1122	203	101	193
C&D Run 2	1824	153	347	470
C&D Run 3	1876	121	107	412

Plots of the dilution-corrected CEM data are shown in Figures 4-10 through 4-13. The following discussion applies to the data as corrected to 12 percent CO_2.

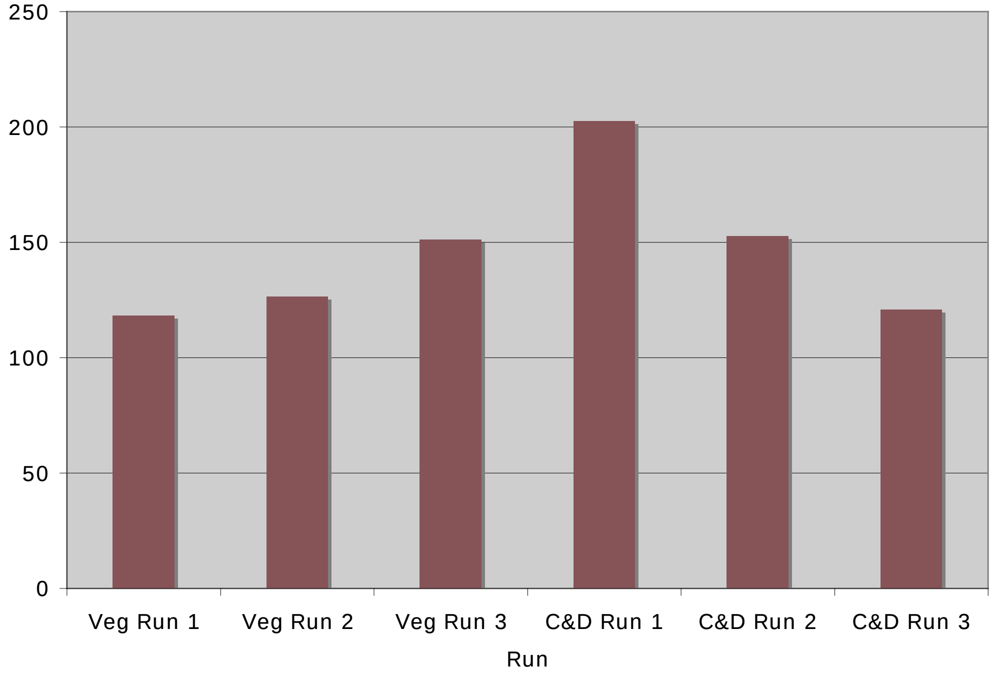


Figure 4-10. NO_X Concentrations Corrected to 12 Percent CO_2

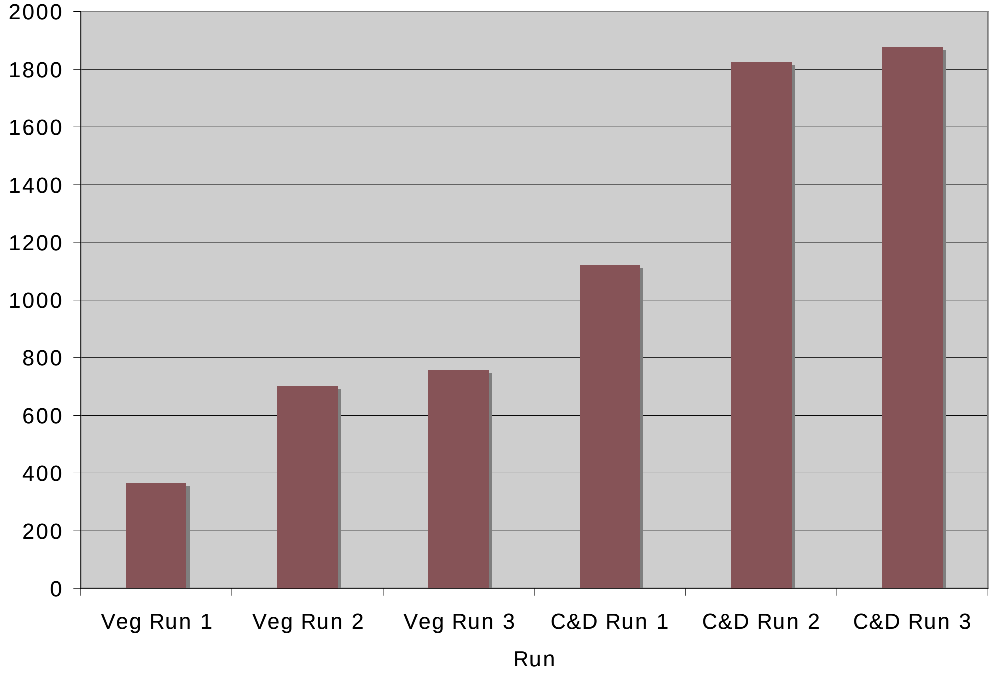


Figure 4-11. CO Concentrations Corrected to 12 Percent CO_2

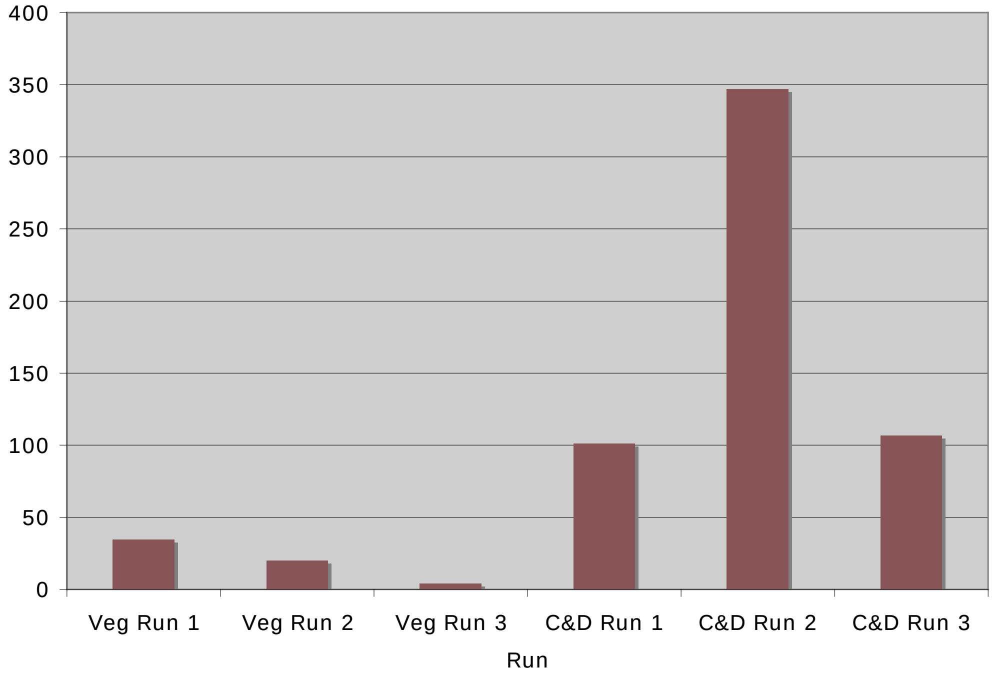


Figure 4-12. SO_2 Concentrations Corrected to 12 Percent CO_2

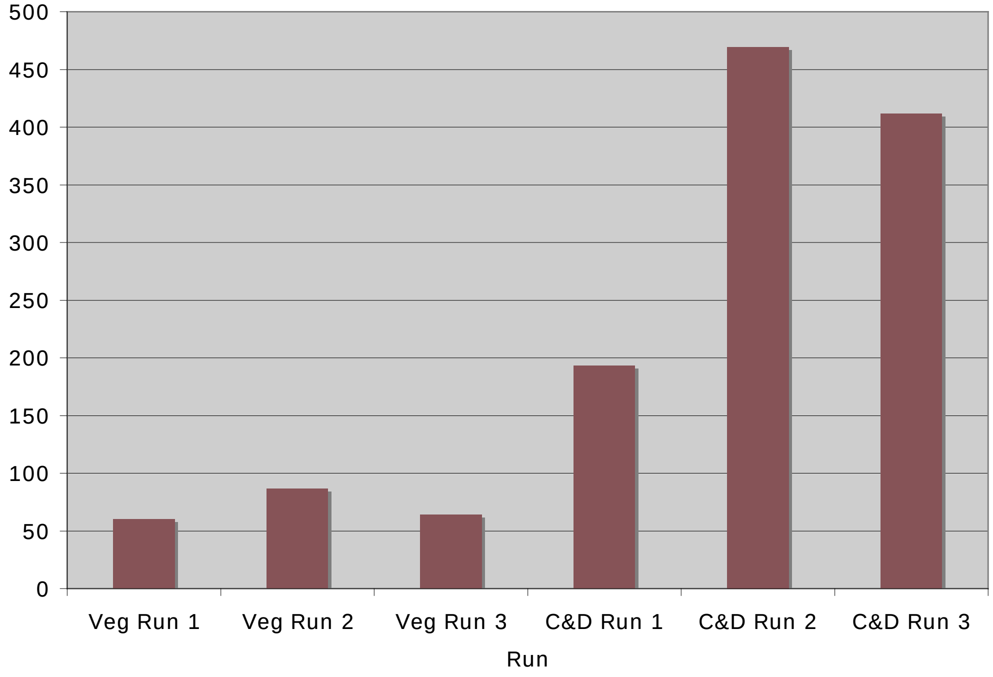


Figure 4-13. THC Concentration Corrected to 12 Percent CO_2

To examine the CEM data, it makes sense to examine the NO_X data first, since the NO_x data will give an initial assessment of how well the sampling scoop worked across varying ambient conditions. Since the feed materials both for the vegetative debris and for the C&D debris contain little fuel nitrogen (and what fuel nitrogen is present is not expected to be significantly different between the two feedstocks – see Table 4-10), the majority of the NO_X emissions should be due to thermal NO_X, mostly a function of the firebox temperature. Since the firebox temperature generally ranged from 1300 to 1800 °F across all tests, as long as the sampling was generally consistent in spite of ambient conditions (e.g., wind speed, wind direction), then NO_X should not vary significantly across all test conditions.

If we examine Figure 4-10, NO_X measurements showed relatively little variation among test conditions and among replicate runs (when compared with other continuously monitored gases). This consistency in the NO_X measurements suggests that the ambient wind conditions, although affecting the relative amount of dilution air entering the scoop, did not impact the overall measurements after accounting for dilution.

Therefore, once dilution is considered, observed differences both among test conditions and within test conditions are likely to be real and not artifacts due to changes in wind speed and wind direction.

CO concentrations (Figure 4-11) were fairly consistent within test conditions. The CO emissions from the C&D material are approximately a factor of 3 higher than the CO emissions from the vegetative debris.

SO_2 concentrations are shown in Figure 4-12. In general, SO_2 concentrations from the vegetative debris were very low, on the order of 50 ppm, and there was not a significant degree of variation from run to run.

The C&D debris showed somewhat higher SO_2 emissions, and much greater variability among runs, with nearly an order of magnitude variation between the lowest and highest observed measurements. SO_2 emissions on C&D Run 2 were significantly higher than all other runs. It is likely that something in the feed throughout that run contributed to higher SO_2 emissions. Analysis of the video record of the burns will be done in the future to attempt to explain this observation.

THC measurements, shown in Figure 4-13, somewhat paralleled the observations seen with the CO and SO_2 measurements, with C&D Run 2 being high relative to C&D Run 1. Since THC is a measure of incomplete combustion, it would be expected to track more closely with CO than SO_2. As in the SO_2 measurements, the THCs from the vegetative debris did not vary significantly, yet there was a factor of 5 difference between the lowest and highest THC measurements with the C&D debris.

Appendix A, Test Results, contains the raw CEM measurements plotted versus time. Looking at those plots shows that the increased SO_2 and THC emissions observed during C&D Run 2 persisted throughout the test and were not an isolated transient that unduly influenced the average concentration.

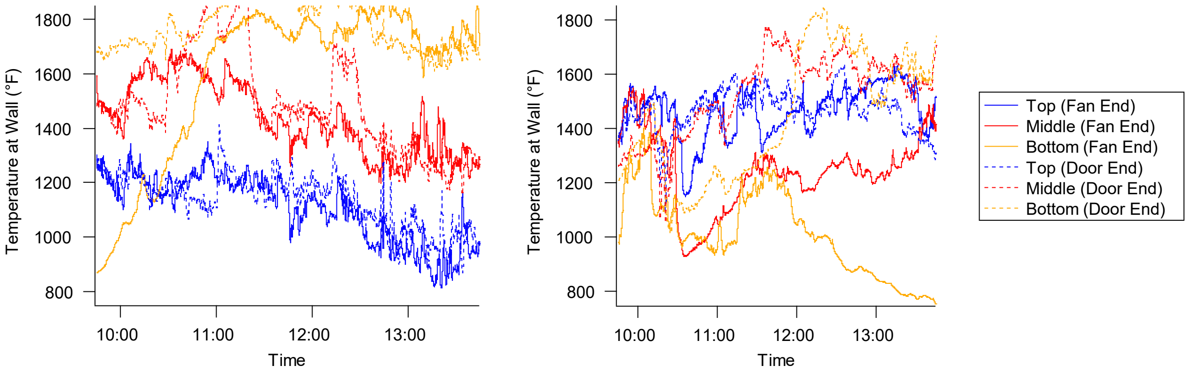
4.4 ACB Temperatures

4.4.1 Time-Resolved Wall Temperatures

Figure 4-14 shows the locations of the thermocouples mounted on the walls of the ACB. The tips of the thermocouples protruded approximately ½ inch into the firebox. A set of thermocouples was installed on the side with the air inlet plenum and directly opposite, on the side without the air inlet plenum.

Figure 4-14. Location of Thermocouple Probes on ACB Walls

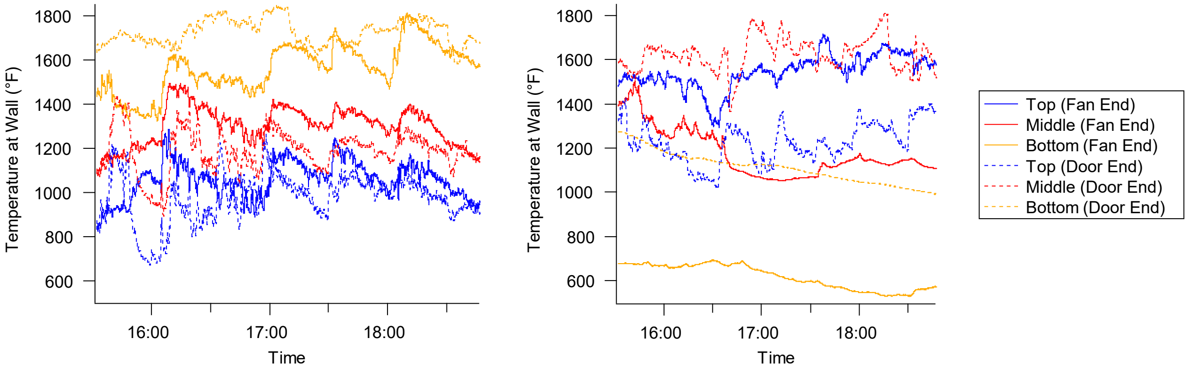
Figures 4-15 through 4-19 show the time-resolved temperatures measured by the thermocouples mounted on the walls of the ACB. Temperature data were not available for C&D Run 3. The yellow traces represent the thermocouples mounted at the two lowest locations. These particular thermocouples start out in the freeboard, and as the runs progress, become covered with the ash at the bottom of the ACB. Note that the traces have fewer transient fluctuations once the thermocouples are buried in the ash. The temperatures on the side with the plenum tend to be somewhat lower than the temperatures on the corresponding thermocouples on the opposite side. This observation suggests that the cool air being introduced through the plenum tends to cool the ACB on the side on which the air is introduced. In general, observed temperatures from the C&D burns were lower than temperatures observed from the vegetative debris burns.



SIDE OPPOSITE PLENUM

PLENUM SIDE

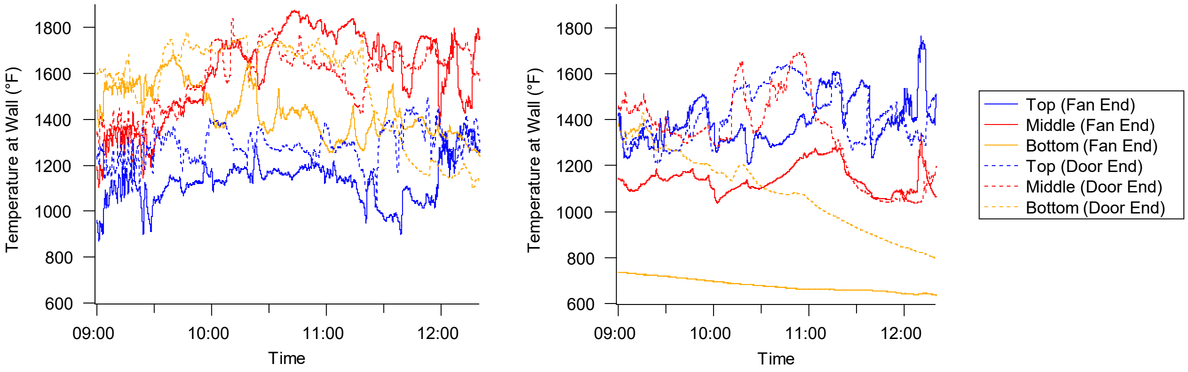
Figure 4-15. Wall Temperatures from Veg Run 1



SIDE OPPOSITE PLENUM

PLENUM SIDE

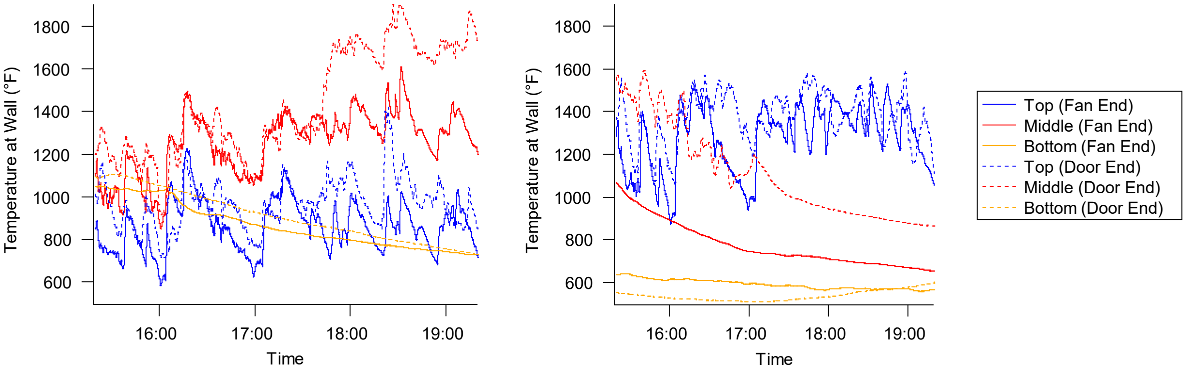
Figure 4-16. Wall Temperatures from Veg Run 2



SIDE OPPOSITE PLENUM

PLENUM SIDE

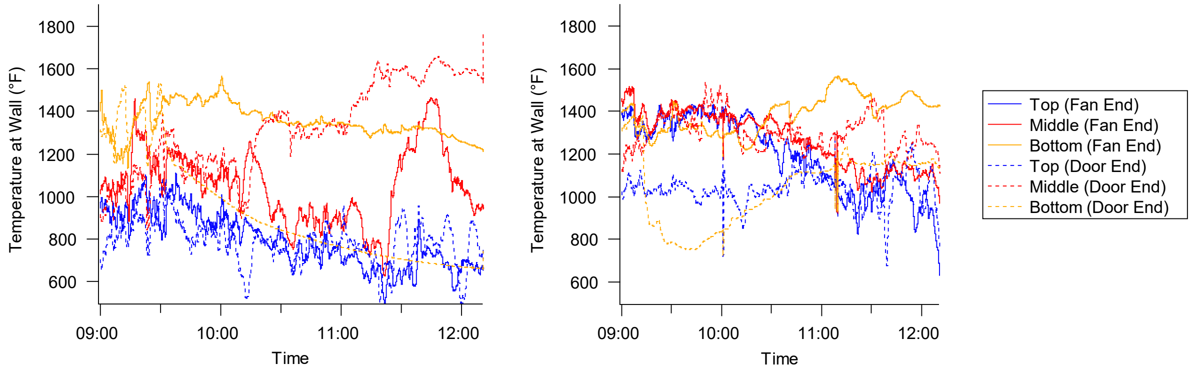
Figure 4-17. Wall Temperatures from Veg Run 3



SIDE OPPOSITE PLENUM

PLENUM SIDE

Figure 4-18. Wall Temperatures from C&D Run 1



SIDE OPPOSITE PLENUM

PLENUM SIDE

Figure 4-19. Wall Temperatures from C&D Run 2

4.4.2 Average Wall Temperatures

Taking the average temperatures at each of the thermocouple locations over the duration of each of the runs yields the temperature distributions shown in Figures 4-20 through 4-24. The average temperatures on the plenum side appear to be generally lower than the temperatures on the side opposite the plenum. Noting that Veg Run 1 was started with no ash in the firebox, and Veg Run 3 and C&D Run 2 were both started after most of the ash was removed. As the ACB fills with ash, the average temperatures are apparently lower.

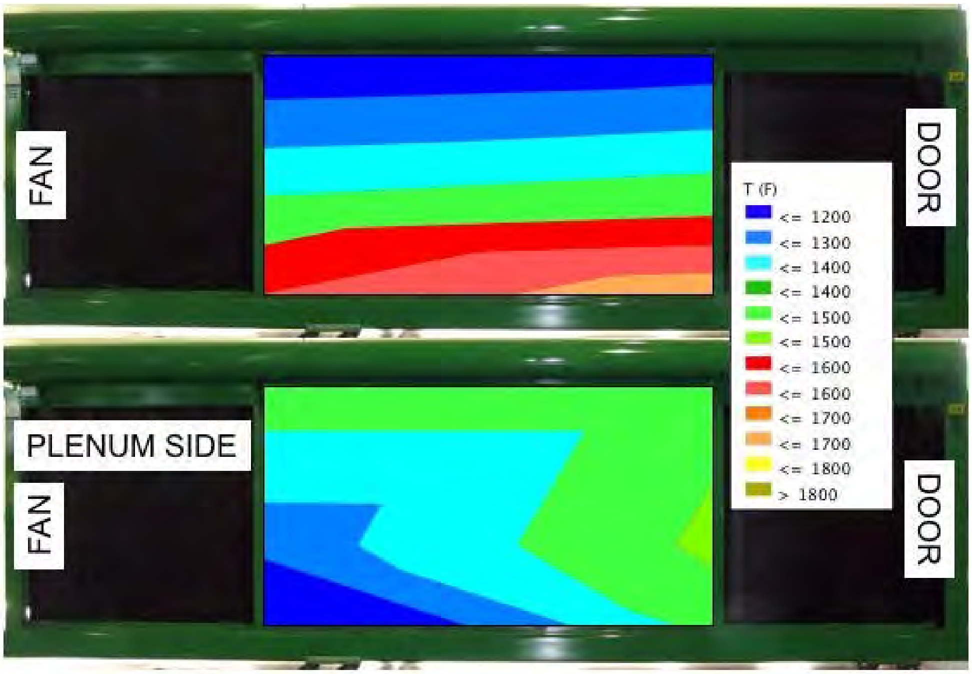


Figure 4-20. Average Wall Temperatures from Veg Run 1

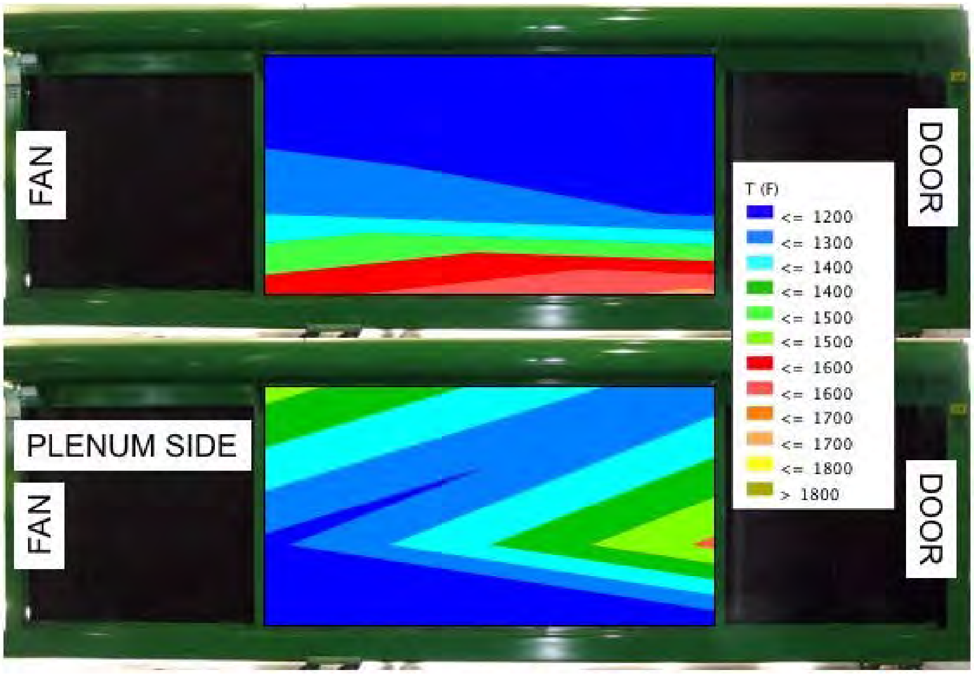


Figure 4-21. Average Wall Temperatures from Veg Run 2

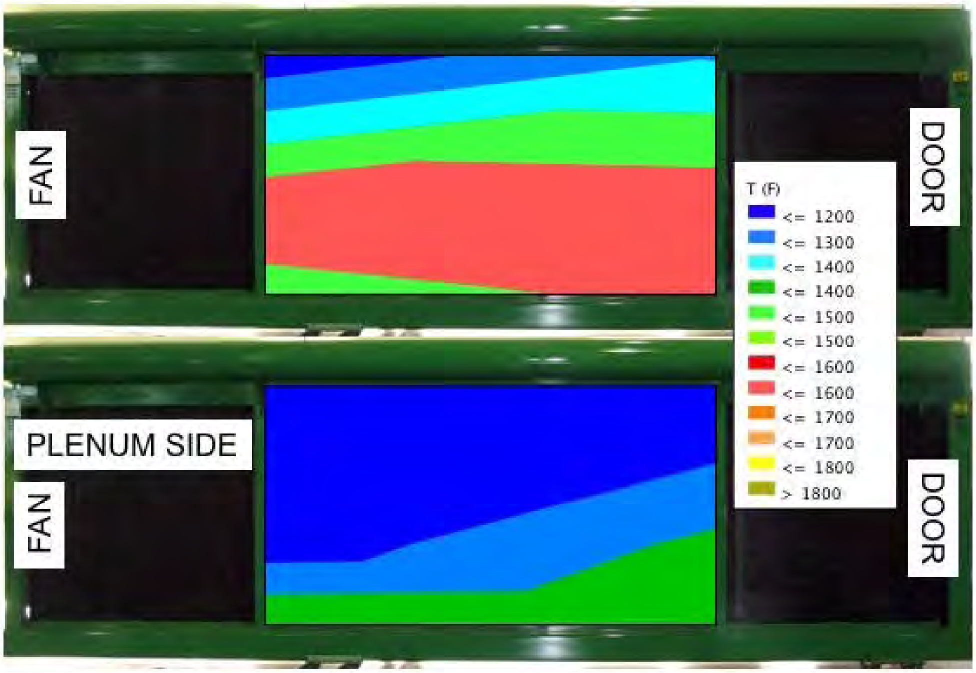


Figure 4-22. Average Wall Temperatures from Veg Run 3

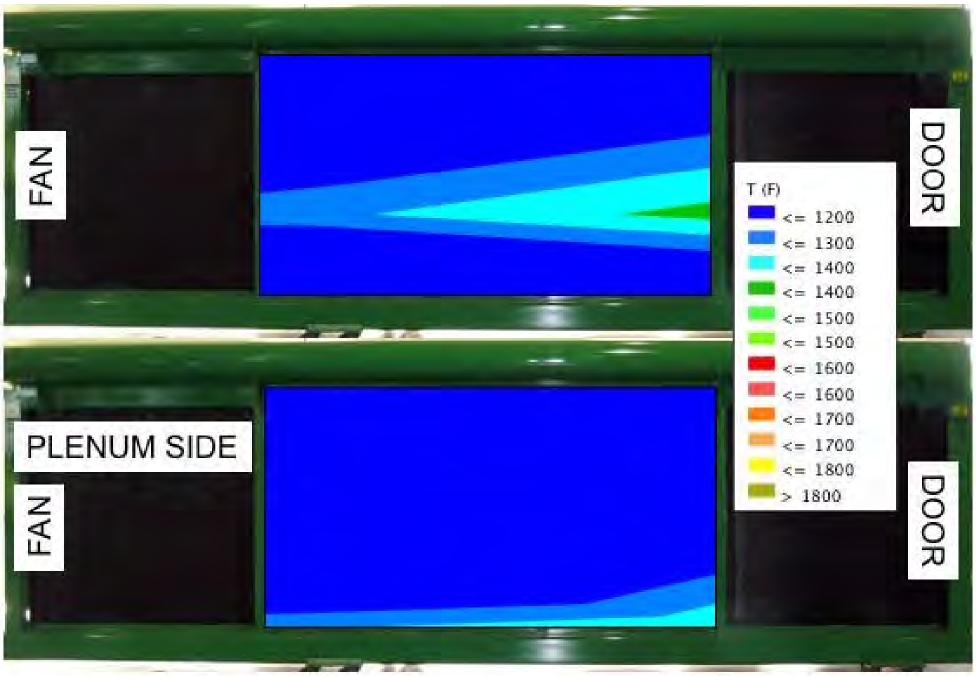


Figure 4-23. Average Wall Temperatures from C&D Run 1

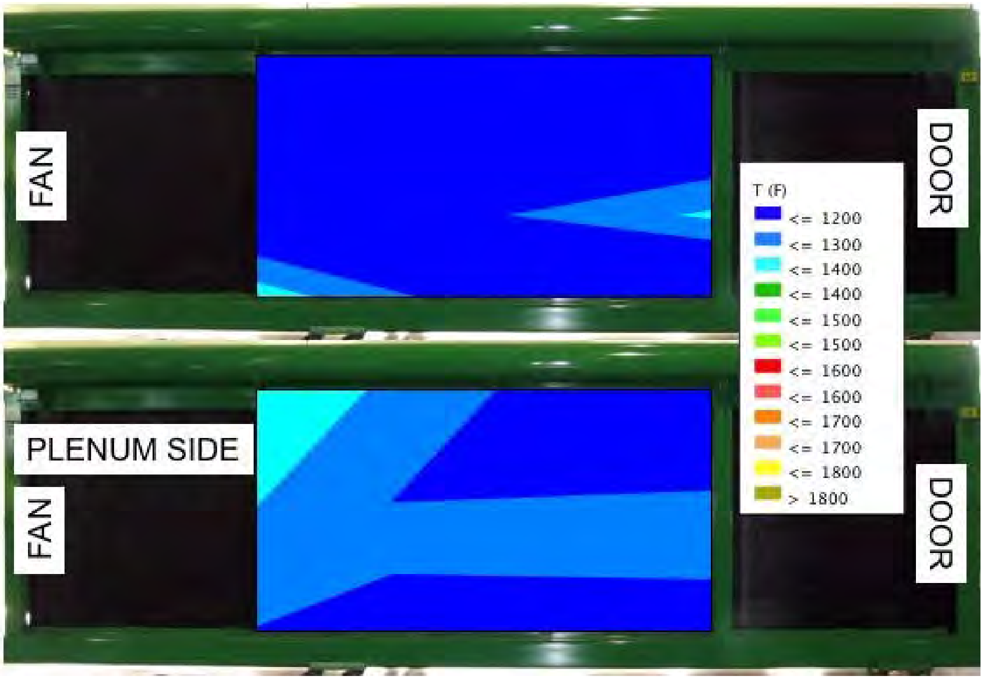


Figure 4-24. Average Wall Temperatures from C&D Run 2

4.4.3 Sampling Scoop Temperature

The time-resolved temperatures from the thermocouple at the inlet to the sampling scoop are shown in Figures 4-25 to 4-27. The scoop thermocouple was highly susceptible to damage due to radiative heat transfer from the burning bed and physical contact with the feed material and heavy equipment. Because of these factors, valid scoop data were only acquired from Veg Runs 1 and 2 and C&D Run 2. In general, inlet temperatures to the sampling scoop were in the 600 to 800 °F range. Because the temperatures at the top set of wall thermocouples inside the firebox were typically in the 1300-1500 °F range, it is readily apparent that a significant amount of dilution air is being introduced into the gas stream being sampled, either through air being entrained into the ACB or from dilution due to wind blowing across the top of the unit.

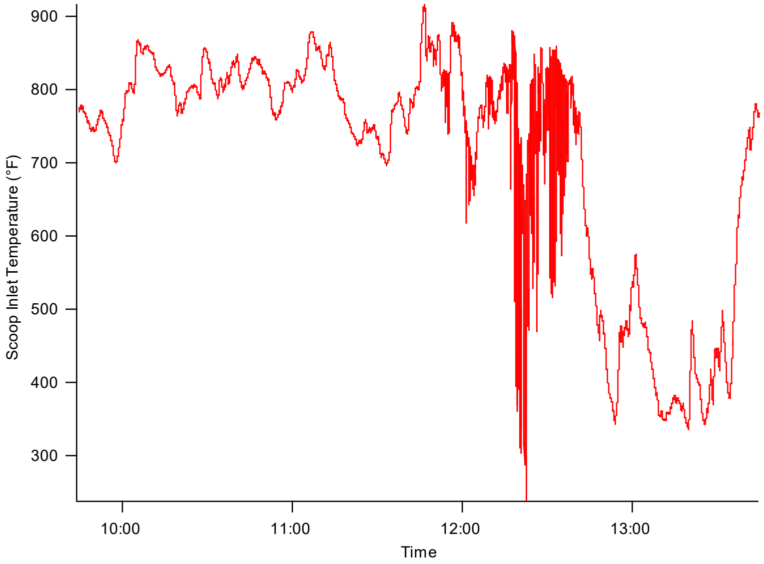


Figure 4-25. Sampling Scoop Inlet Temperature from Veg Run 1

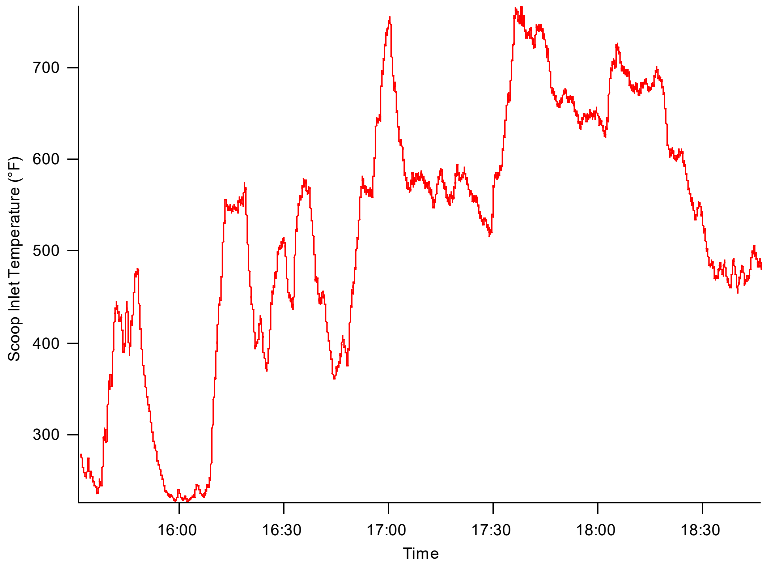


Figure 4-26. Sampling Scoop Inlet Temperature from Veg Run 2

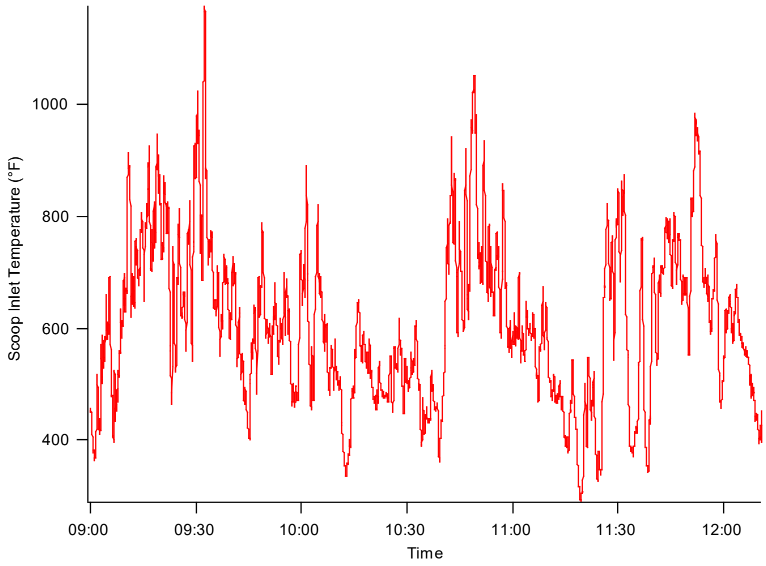


Figure 4-27. Sampling Scoop Inlet Temperature from C&D Run 2

4.4.4 ACB Bed Temperatures

Figures 4-28 through 4-35 show the results from temperature measurements of the ACB bed made using a prototype device that was placed in the bed of burning material and then generally removed 30 – 60 minutes later. The device is an in-house manufactured metal box 8 inches on a side with a protruding thermocouple. The box is heavily insulated to protect the interior electronics (thermocouple data logger) from the incinerator environment. The electronics embedded within the box record the temperature signals from the thermocouple and voltage from the battery, which can later be recovered.

A number of these *in-situ* measurement devices were thrown into the ACB during the three days of tests, but for various reasons, only the data shown here were available. In some cases, only a portion of the recovered data was usable. For example, even with the insulating material, the electronics within the box become heated and this heating of the electronics may lower the voltage of the battery. If the battery voltage drops below a certain level, the temperature readings at that point become questionable. Therefore, the data presented below represent only the temperature data considered valid, and the temperature data which were judged to have been collected with inadequate battery voltage have been removed from these charts.

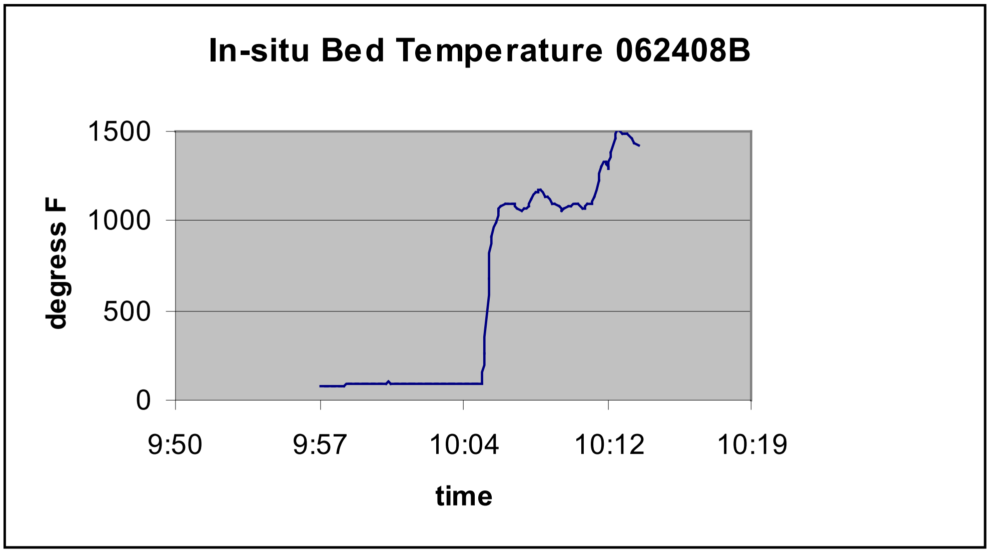


Figure 4-28. ACB Bed Temperature Taken during the Morning of June 24, 2008 (Veg Run 1).

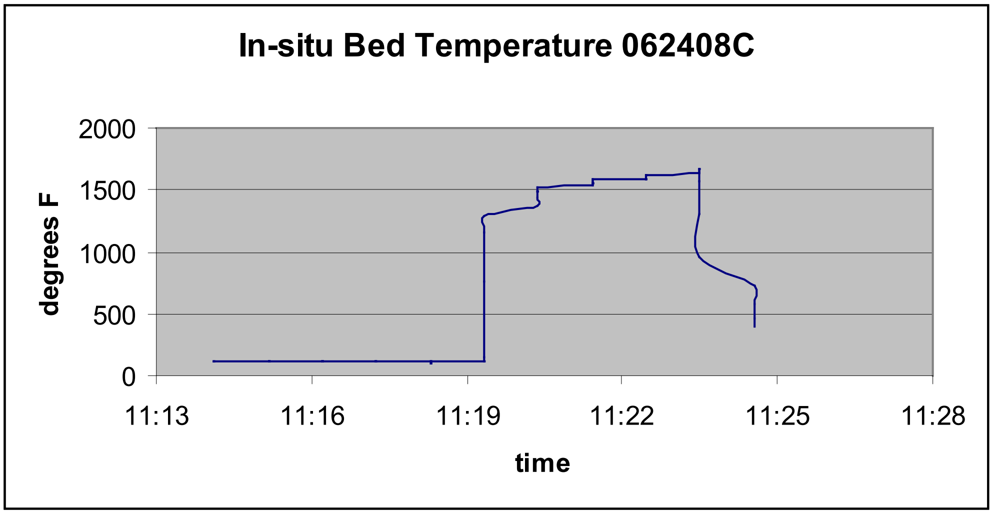


Figure 4-29. ACB Bed Temperature Taken during the Morning of June 24, 2008 (Veg Run 1).

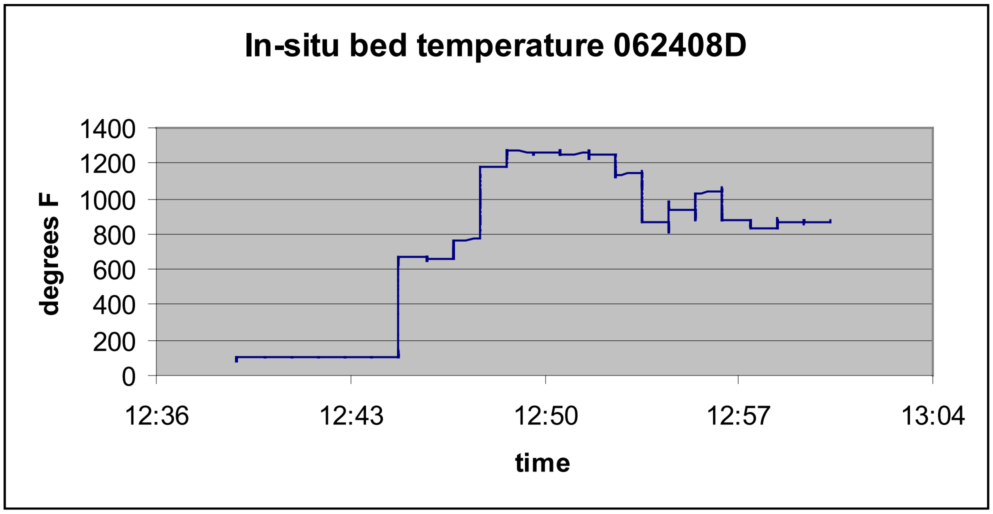


Figure 4-30. ACB Bed Temperature Taken during the Afternoon of June 24, 2008 (Veg Run 2).

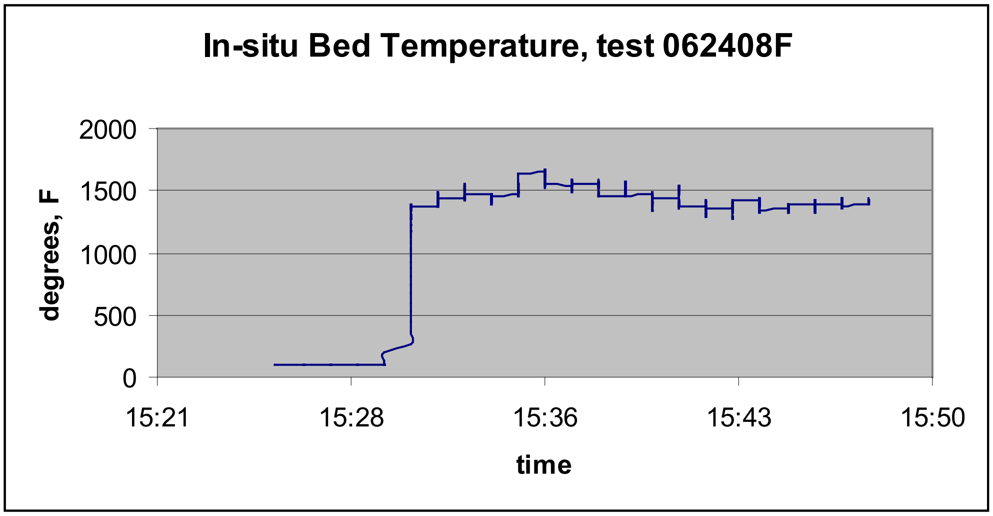


Figure 4-31. ACB Bed Temperature Taken during the Afternoon of June 24, 2008 (Veg Run 2).

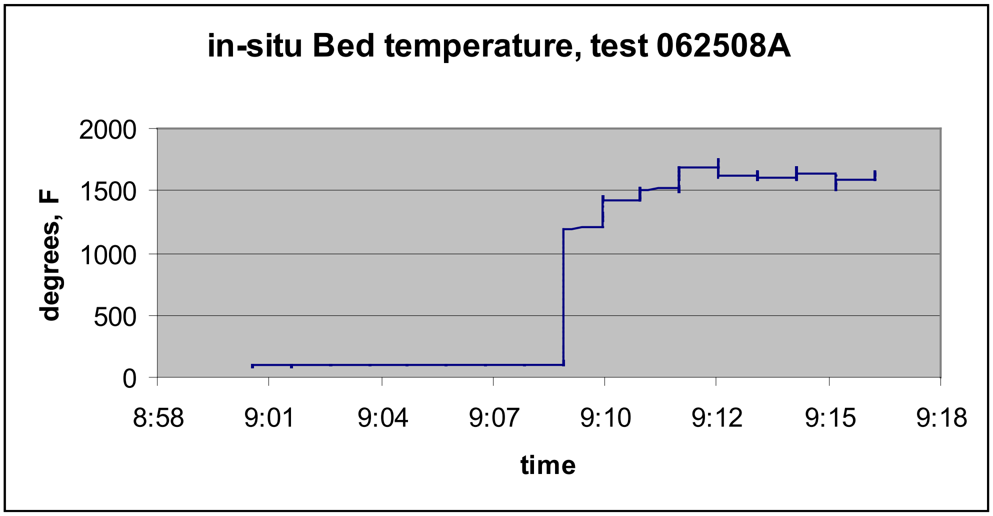


Figure 4-32. ACB Bed Temperature Taken during the Morning of June 25, 2008 (Veg Run 3).

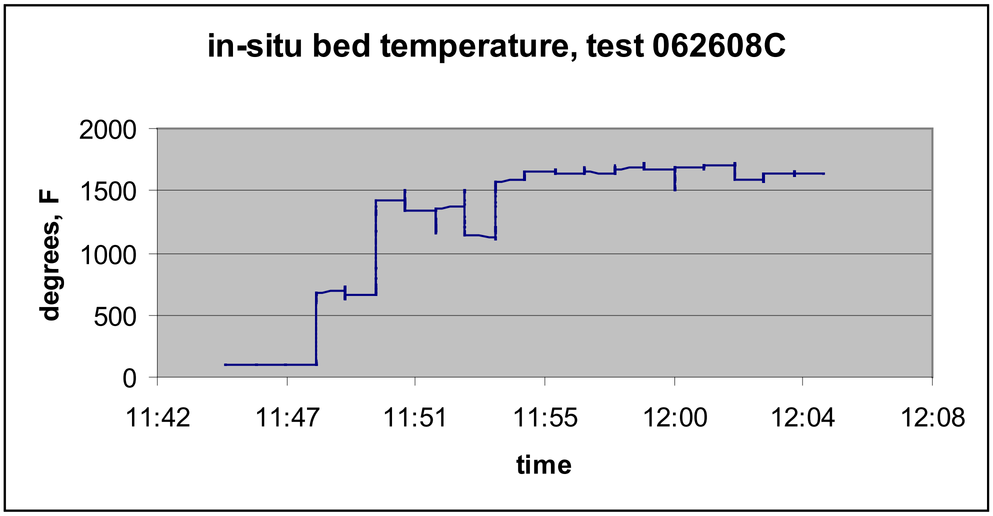


Figure 4-33. ACB Bed Temperature Taken during the Morning of June 26, 2008 (C&D Run 2).

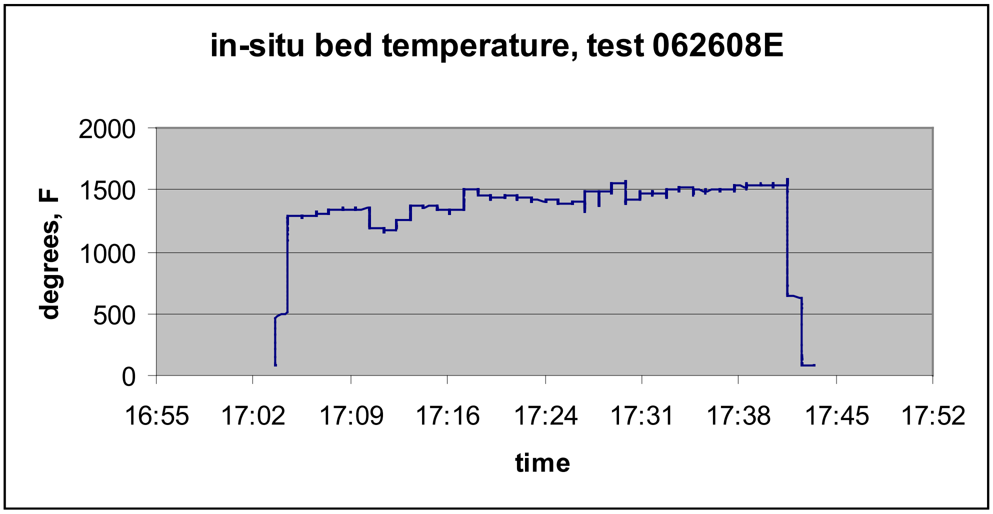


Figure 4-34. ACB Bed Temperature Taken during the Afternoon of June 26, 2008 (C&D Run 3).

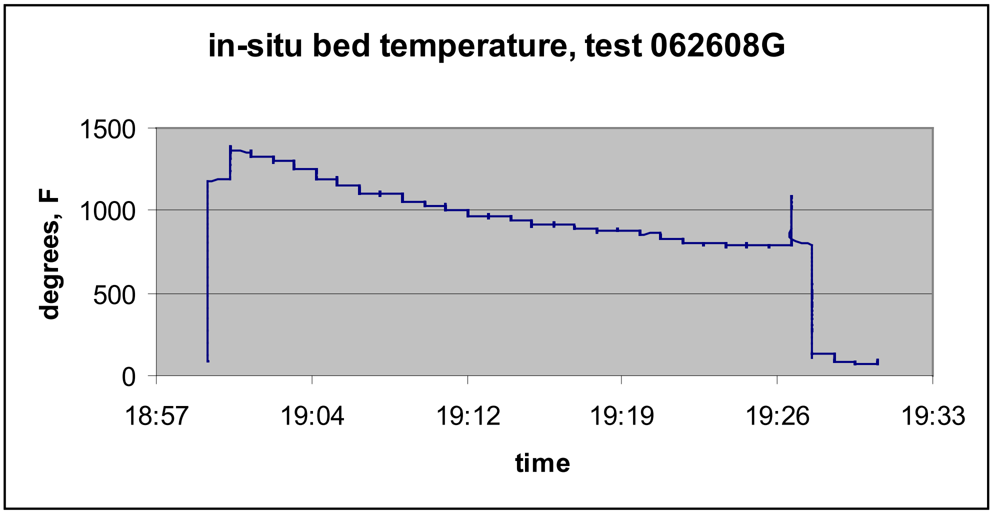


Figure 4-35. ACB Bed Temperature Taken during the Afternoon of June 26, 2008 (C&D Run 3).

The following notes and observations pertain to the data shown in Figures 4-28 through 4-35:

- Ambient temperatures were approximately 90 ºF, as indicated by the initial temperature data in each figure, recorded prior to placing the in-situ measurement device in the ACB.

- Once the device was placed in the bed (the start of the temperature trace), a steep temperature rise can be seen for a few minutes, at which point the rate of temperature increase diminishes or levels off.

- Tests in which the all of the temperature data were valid, i.e., none of the data were removed due to low battery voltage, are shown in Figures 4-29, 4-34, and 4-35. Note in these figures that the steep drop in temperature at the end of the test was occurred when the device was removed from the bed and then quenched in water.

- Excluding the temperature data taken during the initial placement or removal of the device, bed temperatures ranged between approximately 800 – 1700 ºF, with the majority of tests having bed temperatures stabilizing around 1500 – 1600 ºF.

- Because the duration of each test and the amount of time in which valid data were available varied, the time scale for the figures (x-axis) is variable as well.

4.5 ACB Performance Test Sampling Results

4.5.1 ACB Ash Characteristics

The ash present in the ACB from the previous day's testing was sampled prior to initiation of subsequent operation. The ash present in the bed after sitting overnight had the visual appearance of a charcoal-like material. Normal ACB operation would involve movement of the ACB unit to a new location, allowing the ash to achieve complete burnout while outside the ACB. In this case, however, due to space constraints, the ash was removed using heavy equipment and the ACB unit was not moved. Subsequent runs were initiated on the hot bed of ash left over from the previous day, and not until the completion of the tests was the ash allowed to completely burn out prior to sampling.

Results from proximate/ultimate analysis performed by Standard Laboratories, Inc., for vegetative debris, vegetative ash, and C&D ash are presented in Table 4-10. TCLP analysis (U.S. EPA, 1992) for metals was also performed on the ash. These results are shown in Table 4-11. TCLP results indicated that the ash from all samples could be disposed of as non-hazardous waste. Other than the final ash sample, acquired several days after the burn, the ash had significant carbon content and heating value, consistent with its charcoal-like characteristics.

4.5.2 ACB Combustion Gas Test Results

Duct concentrations of the target analytes are reported in the following subsections. Note that concentrations below the detection limits are listed as "ND – not detected" in the following tables. If the detection limits are needed, please see the corresponding data tables in Appendix A, Test Results.

4.5.2.1 Dioxin/Furan and PCB Test Results

Table 4-12 details the dioxin, furan, and PCB raw test results for each of the vegetative and C&D debris burns. The Toxicity Equivalency Factors (TEFs) and calculated Toxicity Equivalency Quotients (TEQs) for each congener are also shown, based on the 2005 World Health Organization TEFs (Van den Berg et al., 2006). Table 4-13 shows the data corrected to 12 percent CO_2.

Table 4-10. Ash and Vegetative Debris Composition

	Vegetative Debris 6/25		**Vegetative Debris 6/25***		**Vegetative Ash 6/25**		**C&D Ash 6/26**		**C&D Ash 6/27**	
	As Received (%)	Dry Basis (%)	As Received (%)	Dry Basis (%)	As Received (%)	Dry Basis (%)	As Received (%)	Dry Basis (%)	As Received (%)	Dry Basis (%)
Moisture	27		30		2.0		1.1		0.82	
Volatile	60	82	57	81	5.9	6.0	11	11	4.1	4.1
Fixed Carbon	11	16	12	17	58	59	29	29	-0.40	-0.40
Ash	1.7	2.3	1.0	1.4	34	35	59	60	95	96
Sulfur	0.08	0.11	0.14	0.20	0.09	0.09	3.8	3.9	0.10	0.10
Carbon	35	48	36	51	61	63	34	35	1.5	1.5
Hydrogen	4.1	5.7	4.0	5.7	0.98	1.0	1.3	1.3	0.04	0.04
Nitrogen	0.14	0.20	0.28	0.41	0.36	0.36	0.34	0.34	0.38	0.38
Oxygen	32	44	29	41	1.3	1.4	0	0	1.7	1.7
Chlorine, ppmw			294	422						
BTU/Lb	6520	8990	6235	8960	9159	9345	5831	5896	40	40
MAF BTU/Lb		9204		9083		14285		14602		1078
Lbs SO_2/mBTU		0.24		0.45		0.19		13		50
Lbs S/mBTU	0.12		0.23		0.10		6.6		25	

- * Re-analysis with chlorine added as an analyte

Table 4-11. Metals TCLP Results

	Wood Ash 6/25/08 mg/L	**C/D Ash 06/26/08 mg/L**	**C/D Ash 06/27/08 mg/L**
Arsenic	0.22	<0.2	0.3
Barium	<1	<1	<1
Cadmium	<0.1	<0.1	<0.1
Chromium	<0.2	<0.2	<0.2
Lead	<0.2	<0.2	<0.2
Selenium	<0.5	<0.5	<0.5
Silver	<0.1	<0.1	<0.1
Mercury	<0.02	<0.02	<0.02

Table 4-12. Dioxin, Furan, and PCB Test Results, Uncorrected (dry basis)

Pollutant	TEF*	Veg Run 1	Veg Run 2	Veg Run 3	C&D Run 1	C&D Run 2	C&D Run 3
		I-ACD-M23-1	I-ACD-M23-2	I-ACD-M23-3	II-ACD-M23-1	II-ACD-M23-2	II-ACD-M23-3
		pg/DSCM	pg/DSCM	pg/DSCM	pg/DSCM	pg/DSCM	pg/DSCM
2,3,7,8-TCDD	1	159	109	389	1339	1868	2293
Other TCDD		3599	3211	10764	27593	37334	54771
1,2,3,7,8-PeCDD	0.5	286	334	827	3163	3815	6335
Other PeCDD		2896	3630	9880	29723	35650	64145
1,2,3,4,7,8-HxCDD	0.1	147	214	491	1544	1979	3974
1,2,3,6,7,8-HxCDD	0.1	162	285	635	2120	2894	5842
1,2,3,7,8,9-HxCDD	0.1	163	278	596	2103	2710	4687
Other HxCDD		1469	2668	6897	18673	26358	55807
1,2,3,4,6,7,8-HpCDD	0.01	443	1762	2312	11914	28415	25814
Other HpCDD		403	2029	1805	9830	23153	25644
1,2,3,4,6,7,8,9-OCDD	0.001	249	5302	1634	44207	115502	28871
Total CDD		9977	19822	36229	152209	279679	278183
2,3,7,8-TCDF	0.1	1130	637	2555	6200	9814	11820
Other TCDF		24675	13140	53210	145829	238819	341428
1,2,3,7,8-PeCDF	0.05	739	486	1732	6361	8261	14249
2,3,4,7,8-PeCDF	0.5	1130	902	3224	9255	11892	22588
Other PeCDF		9480	6814	25461	79447	109819	207720
1,2,3,4,7,8-HxCDF	0.1	516	436	1486	4996	5920	14707
1,2,3,6,7,8-HxCDF	0.1	516	466	1551	5319	5920	14079
2,3,4,6,7,8-HxCDF	0.1	546	612	2129	5481	6051	15845
1,2,3,7,8,9-HxCDF	0.1	154	180	645	1815	1763	4806
Other HxCDF		3002	2815	10086	28932	34019	82691

Pollutant	TEF*	Veg Run 1	Veg Run 2	Veg Run 3	C&D Run 1	C&D Run 2	C&D Run 3
		I-ACD-M23-1	I-ACD-M23-2	I-ACD-M23-3	II-ACD-M23-1	II-ACD-M23-2	II-ACD-M23-3
		pg/DSCM	pg/DSCM	pg/DSCM	pg/DSCM	pg/DSCM	pg/DSCM
1,2,3,4,6,7,8-HpCDF	0.01	686	842	2758	7368	8025	25135
1,2,3,4,7,8,9-HpCDF	0.01	111	176	574	1556	1452	3770
Other HpCDF		385	632	2103	5165	5257	12534
1,2,3,4,6,7,8,9-OCDF	0.001	116	344	866	2785	3131	6471
Total CDF		43188	28482	108381	310509	450143	777844
Total CDD/CDF		53165	48304	144610	462718	729822	1056027
PCDD/PCDF TEQ		1250	1095	3569	11079	14337	25625
		pg/DSCM	pg/DSCM	pg/DSCM	pg/DSCM	pg/DSCM	pg/DSCM
PCB-77 (3,3',4,4'-Tetrachlorobiphenyl)	0.0001	1090	3694	2089	8212	14549	20720
PCB-81 (3,4,4',5-Tetrachlorobiphenyl)	0.0003	188	57	318	1141	2920	4348
PCB-105 (2,3,3',4,4'-Pentachlorobiphenyl)	0.00003	263	116	552	5031	20889	10802
PCB-114 (2,3,4,4',5-Pentachlorobiphenyl)	0.00003	52	21	89	525	2002	1615
PCB-118 (2,3',4,4',5-Pentachlorobiphenyl)	0.00003	393	152	627	7206	45514	14215
PCB-123 (2,3',4,4',5'-Pentachlorobiphenyl)	0.00003	49	27	111	636	1539	1430
PCB-126 (3,3',4,4',5-Pentachlorobiphenyl)	0.1	353	156	858	3235	7209	14606
PCB-156/157 (2,3,3',4,4',5-Hexachlorobiphenyl)	0.00003	238	110	513	1833	10576	8781
PCB-167 (2,3',4,4',5,5'-Hexachlorobiphenyl)	0.00003	80	37	164	613	3315	2429
PCB-169 (3,3',4,4',5,5'-Hexachlorobiphenyl)	0.03	63	33	157	1689	2762	3006
PCB-189 (2,3,3',4,4',5,5'-Heptachlorobiphenyl)	0.00003	83	35	170	401	1031	2497
PCB-209 (2,2',3,3',4,4',5,5',6,6'-Decachlorobiphenyl)		54	33	186	593	800	887
Total Mono-CB		37083	5129	31434	44025	230992	234375
Total Di-CB		21624	4807	22511	49955	121547	99015

Pollutant	TEF*	Veg Run 1	Veg Run 2	Veg Run 3	C&D Run 1	C&D Run 2	C&D Run 3
		I-ACD-M23-1	I-ACD-M23-2	I-ACD-M23-3	II-ACD-M23-1	II-ACD-M23-2	II-ACD-M23-3
		pg/DSCM	pg/DSCM	pg/DSCM	pg/DSCM	pg/DSCM	pg/DSCM
Total Tri-CB		12152	4311	14520	87871	117864	102921
Total Tetra-CB		9546	3940	16386	111950	145488	116338
Total Penta-CB		4335	1544	6023	55166	331492	124660
Total Hexa-CB		5863	1001	3772	26415	239937	65048
Total Hepta-CB		15986	565	6388	10386	59984	20720
Total Octa-CB		13029	312	5090	4708	16627	7558
Total Nona-CB		1566	116	929	1626	2363	2310
Total PCBs (Mono-Nona)		121185	21724	107054	392102	1266293	772945
PCB TEQ		37	17	91	376	809	1555
PCDD/F TEQ+PCB TEQ		1287	1112	3660	11454	15146	27180

*WHO 2005 TEF Values (Van den Berg, et al., 2006)

Table 4-13. Dioxin, Furan, and PCB Test Results, Corrected to 12% CO_2 (dry basis)

Pollutant	TEF*	Veg Run 1	Veg Run 2	Veg Run 3	C&D Run 1	C&D Run 2	C&D Run 3
		I-ACD-M23-1	I-ACD-M23-2	I-ACD-M23-3	II-ACD-M23-1	II-ACD-M23-2	II-ACD-M23-3
		pg/DSCM	pg/DSCM	pg/DSCM	pg/DSCM	pg/DSCM	pg/DSCM
2,3,7,8-TCDD	1	1003	1004	2596	12358	37361	30570
Other TCDD		22732	29644	71758	254708	746686	7302741
1,2,3,7,8-PeCDD	1	1804	3088	5516	29195	76300	84463
Other PeCDD		18292	33507	65864	274365	713009	855270
1,2,3,4,7,8-HxCDD	0.1	929	1974	3272	14249	39571	52987
1,2,3,6,7,8-HxCDD	0.1	1024	2630	4231	19574	57883	77896
1,2,3,7,8,9-HxCDD	0.1	1032	2562	3975	19408	54199	62498
Other HxCDD		9279	24626	45977	172366	527153	744087
1,2,3,4,6,7,8-HpCDD	0.01	2801	16262	15411	109978	568303	344191
Other HpCDD		2548	18732	12032	90736	463061	341927
1,2,3,4,6,7,8,9-OCDD	0.0003	1570	48945	10896	408064	2310045	384951
Total CDD		63012	182973	241527	1405002	5593570	3709112
2,3,7,8-TCDF	0.1	7136	5878	17034	57229	196275	157603
Other TCDF		155844	121288	354733	1346115	4776372	4552380
1,2,3,7,8-PeCDF	0.03	4668	4483	11545	58723	165229	189984
2,3,4,7,8-PeCDF	0.3	7136	8325	21495	85428	237845	301167
Other PeCDF		59875	62897	169742	733355	2196384	2769606
1,2,3,4,7,8-HxCDF	0.1	3260	4025	9909	46115	118396	196098
1,2,3,6,7,8-HxCDF	0.1	3260	4300	10342	49100	118396	187720
2,3,4,6,7,8-HxCDF	0.1	3449	5649	14195	50593	121027	211270
1,2,3,7,8,9-HxCDF	0.1	975	1663	4299	16754	35256	64083
Other HxCDF		18963	25989	67242	267067	680384	1102544

Pollutant	TEF*	Veg Run 1	Veg Run 2	Veg Run 3	C&D Run 1	C&D Run 2	C&D Run 3
		I-ACD-M23-1	I-ACD-M23-2	I-ACD-M23-3	II-ACD-M23-1	II-ACD-M23-2	II-ACD-M23-3
		pg/DSCM	pg/DSCM	pg/DSCM	pg/DSCM	pg/DSCM	pg/DSCM
1,2,3,4,6,7,8-HpCDF	0.01	4336	7776	18386	68011	160493	335133
1,2,3,4,7,8,9-HpCDF	0.01	704	1622	3826	14365	29047	50270
Other HpCDF		2429	5835	14019	47674	105136	167114
1,2,3,4,6,7,8,9-OCDF	0.0003	731	3179	5773	25711	62619	86274
Total CDF		272765	262909	722538	2866239	9002860	10371247
Total CDD/CDF		335777	445882	964065	4271242	14596430	14080359
PCDD/PCDF TEQ		7273	9864	22013	98299	272361	319535
		pg/DSCM	pg/DSCM	pg/DSCM	pg/DSCM	pg/DSCM	pg/DSCM
PCB-77 (3,3',4,4'-Tetrachlorobiphenyl)	0.0001	6884	3408	13926	140778	218232	414402
PCB-81 (3,4,4',5-Tetrachlorobiphenyl)	0.0003	1185	531	2123	19561	43804	86957
PCB-105 (2,3,3',4,4'-Pentachlorobiphenyl)	0.00003	1662	1075	3677	86253	313339	216033
PCB-114 (2,3,4,4',5-Pentachlorobiphenyl)	0.00003	328	192	594	8995	30032	32303
PCB-118 (2,3',4,4',5-Pentachlorobiphenyl)	0.00003	2485	1407	4178	123527	682715	284307
PCB-123 (2,3',4,4',5'-Pentachlorobiphenyl)	0.00003	309	252	738	10905	23086	28601
PCB-126 (3,3',4,4',5-Pentachlorobiphenyl)	0.1	2231	1439	5719	55449	108129	292120
PCB-156/157 (2,3,3',4,4',5-Hexachlorobiphenyl)	0.00003	1505	1015	3421	31421	158642	175611
PCB-167 (2,3',4,4',5,5'-Hexachlorobiphenyl)	0.00003	503	338	1096	10504	49724	48573
PCB-169 (3,3',4,4',5,5'-Hexachlorobiphenyl)	0.03	397	302	1044	28956	41436	60122
PCB-189 (2,3,3',4,4',5,5'-Heptachlorobiphenyl)	0.00003	524	325	1130	6869	15470	49932
PCB-209 (2,2',3,3',4,4',5,5',6,6'-Decachlorobiphenyl)		339	302	1242	10166	11997	17731
Total Mono-CB		234211	47343	209559	754717	3464878	4687500
Total Di-CB		136570	44370	150071	856373	1823204	1980299

Pollutant	TEF*	Veg Run 1	Veg Run 2	Veg Run 3	C&D Run 1	C&D Run 2	C&D Run 3
		I-ACD-M23-1	I-ACD-M23-2	I-ACD-M23-3	II-ACD-M23-1	II-ACD-M23-2	II-ACD-M23-3
		pg/DSCM	pg/DSCM	pg/DSCM	pg/DSCM	pg/DSCM	pg/DSCM
Total Tri-CB		76752	39796	96803	1506353	1767956	2058424
Total Tetra-CB		60294	36365	109241	1919137	2182320	2326766
Total Penta-CB		27377	14249	40154	945707	4972376	2493207
Total Hexa-CB		37031	9240	25147	452830	3599053	1300951
Total Hepta-CB		100964	5215	42588	178052	899763	414402
Total Octa-CB		82290	2882	33935	80709	249408	151155
Total Nona-CB		9891	1068	6192	27878	35438	46196
Total PCBs (Mono-Nona)		765380	200527	713689	6721756	18994396	15458899
PCB TEQ		236	154	606	6442	12129	31108
PCDD/F TEQ + PCB TEQ		7510	10018	22619	104741	284491	350643

*WHO 2005 TEF Values (Van den Burg, et al., 2006)

CB = chlorobiphenyl

4.5.2.2 Metal Test Results

Table 4-14 details the raw metal test results for each of the vegetative and C&D debris burns. Table 4-15 shows the data corrected to 12 percent CO_2. During C&D debris metals Run 3, it was necessary to estimate dry gas meter temperatures due to a thermocouple readout failure after a sudden violent storm. Dry gas meter temperatures of an operating readout on an adjacent sampling train were used to aid the estimate. This procedure could have led to a small error (1-2%) in final sample gas volume. It should be noted that arsenic is normally present in negligible quantities in virgin wood (Zhurinsh et al., 2005). The fact that arsenic emissions were observed in the effluent from the ACB suggests that the environment that the wood was exposed to (which included sediments from the storm) may have impacted As emissions. A 2001 U.S. Geological Survey Report showed approximately 10 mg/kg of arsenic in the New Orleans area (U.S. Geological Survey, 2001).

4.5.2.3 PAH Test Results

Table 4-16 details the raw PAH test results for each of the vegetative and C&D debris burns. Table 4-17 shows the data corrected to 12 percent CO_2. PAHs were collected in the same sampling train as dioxins/furans. Separate aliquots were used for the analyses.

4.5.2.4 M5 Particulate and Acid Gas Test Results

Table 4-18 details the raw M5 particulate and acid gas test results for each of the vegetative and C&D debris burns. Table 4-19 shows the data corrected to 12 percent CO_2. Note that the vegetative debris used in these tests consisted primarily of driftwood material recovered from the aftermath of Hurricane Katrina, after having soaked in brackish water for an undetermined period of time. The presence of chloride in the vegetative material due to the brackish water may contribute to elevated levels of HCl and chlorinated organic compounds. During C&D debris particulate and acid gas Run 3, it was necessary to estimate dry gas meter temperatures due to a thermocouple readout failure after a sudden violent storm. Dry gas meter temperatures of an operating readout on an adjacent sampling train were used to aid the estimate. This procedure could have led to a small error (1-2%) in final sample gas volume.

4.5.2.5 SVOC Test Results

Table 4-20 details the raw SVOC test results for each of the vegetative and C&D debris burns. Table 4-21 shows the data corrected to 12 percent CO_2. Note that some of the SVOC target analytes are also target analytes for the PAH test method. Any differences in observed concentrations may be due to the fact that the PAH-specific analytical method uses Selective Ion Monitoring (SIM) which is more sensitive than the full-scan method used for the SVOC analysis, and the fact that the sample train start and stop times for the two methods may not coincide. Note the presence of chlorinated aromatic compounds in the vegetative runs; not every run had every chlorinated benzene or chlorinated phenol that was a target, but given that these chlorinated SVOCs are not typically found from the combustion of clean vegetative material (Lemieux et al., 2004), it is possible that the soaking of the debris in brackish water in the aftermath of the hurricane led to increases in emissions of chlorinated organic compounds.

4.5.2.6 VOC Test Results

Table 4-22 details the raw VOC test results for each of the vegetative and C&D debris burns. Table 4-23 shows the data corrected to 12 percent CO_2.

Table 4-14. Metal Test Results, Uncorrected (dry basis)

Pollutant	Veg Run 1 I-ACB-M29-01 µg/DSCM	Veg Run 2 I-ACB-M29-02 µg/DSCM	Veg Run 3 I-ACB-M29-03 µg/DSCM	C&D Run 1 II-ACB-M29-01 µg/DSCM	C&D Run 2 II-ACB-M29-02 µg/DSCM	C&D Run 3 II-ACB-M29-03 µg/DSCM
Antimony	5.7	11	1.5	40	122	7.0
Arsenic	39	3.7	74	22	4.6	245
Barium	7.9	5.9	11	9.4	21	7.9
Beryllium	0.03	0.03	0.02	0.01	0.02	ND
Cadmium	3.5	3.4	4.6	8.3	21	8.7
Chromium	22	17	8.2	4.6	8.6	63
Cobalt	ND	ND	21	ND	ND	0.60
Lead	60	62	38	327	329	632
Manganese	21	25	45	31	25	27
Mercury	ND	ND	ND	1.4	3.1	0.57
Nickel	23	24	9.5	6.5	7.9	44
Selenium	0.74	ND	ND	ND	ND	ND
Silver	0.59	0.45	0.22	0.2	0.32	0.41

Table 4-15. Metal Test Results, Corrected to 12% CO_2 (dry basis)

Pollutant	Veg Run 1 I-ACB-M29-01 µg/DSCM	Veg Run 2 I-ACB-M29-02 µg/DSCM	Veg Run 3 I-ACB-M29-03 µg/DSCM	C&D Run 1 II-ACB-M29-01 µg/DSCM	C&D Run 2 II-ACB-M29-02 µg/DSCM	C&D Run 3 II-ACB-M29-03 µg/DSCM
Antimony	36	102	9.7	682	1825	140
Arsenic	248	34	491	374	69	4895
Barium	50	54	71	160	308	157
Beryllium	0.16	0.25	0.12	0.23	0.32	ND
Cadmium	22	32	31	142	311	173
Chromium	141	160	54	79	130	1261
Cobalt	ND	ND	143	ND	ND	12
Lead	376	576	250	5598	4928	12645
Manganese	134	229	297	527	368	539
Mercury	ND	ND	ND	23	47	11
Nickel	147	217	63	111	118	871
Selenium	4.7	ND	ND	ND	ND	ND
Silver	3.7	4.2	1.5	3.4	4.9	8.2

Table 4-16. PAH Test Results, Uncorrected (dry basis)

Pollutant	Veg. Run 1 I-ACB-M29-01 ng/DSCM	Veg. Run 2 I-ACB-M29-02 ng/DSCM	Veg. Run 3 I-ACB-M29-03 ng/DSCM	C&D Run 1 II-ACB-M29-01 ng/DSCM	C&D Run 2 II-ACB-M29-02 ng/DSCM	C&D Run 3 II-ACB-M29-03 ng/DSCM
Naphthalene	32573	34192	77266	71159	116811	72690
2-Methylnaphthalene	5487	6244	6733	10332	29992	22079
Acenaphthylene	4210	3444	7564	23001	49461	32439
Acenaphthene	481	468	229	1001	5578	2819
Fluorene	922	1058	3184	5229	18179	10836
Phenanthrene	6440	7086	24741	23181	49724	32779
Anthracene	621	607	1152	3163	14312	6301
Fluoranthene	2325	2503	13547	11393	21731	12449
Pyrene	1461	1506	5232	4798	6604	4399
Benzo(a)Anthracene	199	253	797	1923	5236	3448
Chrysene	376	453	1910	2444	5867	3889
Benzo(b)Fluoranthene	276	310	1775	2731	6051	3516
Benzo(k)Fluoranthene	85	104	661	943	1873	1104
Benzo(e)Pyrene	150	164	868	1630	3657	1588
Benzo(a)Pyrene	85	47	78	728	2947	1014
Perylene	14	5.0	0.7	82	418	80
Indeno(1,2,3-cd)Pyrene	97	122	639	1391	2342	1163
Dibenzo(a,h)Anthracene	17	18	75	182	631	360
Benzo(ghi)Perylene	113	124	487	1283	2544	1000

Table 4-17. PAH Test Results, Corrected to 12% CO_2 (dry basis)

Pollutant	Veg Run 1 I-ACB-M29-01 ng/DSCM	Veg Run 2 I-ACB-M29-02 ng/DSCM	Veg Run 3 I-ACB-M29-03 ng/DSCM	C&D Run 1 II-ACB-M29-01 ng/DSCM	C&D Run 2 II-ACB-M29-02 ng/DSCM	C&D Run 3 II-ACB-M29-03 ng/DSCM
Naphthalene	205726	31562	515109	1219869	1557485	1453804
2-Methylnaphthalene	34657	57635	44886	177127	399895	441576
Acenaphthylene	26586	31791	50429	394301	659476	648777
Acenaphthene	3038	4323	1528	17158	74366	56386
Fluorene	5824	9766	21226	89642	242392	216712
Phenanthrene	40670	65411	164943	397382	662983	655571
Anthracene	3925	5603	7679	54216	190827	126019
Fluoranthene	14686	23100	90313	195302	289748	248981
Pyrene	9226	13906	34881	82249	88047	87976
Benzo(a)Anthracene	1258	2333	5313	32961	69806	68954
Chrysene	2374	4185	12736	41894	78225	77785
Benzo(b)Fluoranthene	1741	2859	11830	46823	80681	70313
Benzo(k)Fluoranthene	540	963	4407	16173	24976	22079
Benzo(e)Pyrene	946	1516	5787	27940	48759	31760
Benzo(a)Pyrene	540	432	519	12476	39288	20279
Perylene	85	46	4.9	1405	5577	1607
Indeno(1,2,3-cd)Pyrene	611	1128	4259	23843	31220	23268
Dibenzo(a,h)Anthracene	106	161	499	3111	8419	7201
Benzo(ghi)Perylene	715	1141	3245	21995	33921	20007

Table 4-18. M5 Particulate and Acid Gas Test Results, Uncorrected (dry basis)

Pollutant	Veg Run 1 I-ACB-M29-01 mg/DSCM	Veg Run 2 I-ACB-M29-02 mg/DSCM	Veg Run 3* I-ACB-M29-03 mg/DSCM	C&D Run 1 II-ACB-M29-01 mg/DSCM	C&D Run 2 II-ACB-M29-02 mg/DSCM	C&D Run 3 II-ACB-M29-03 mg/DSCM
Filterable Particulate	66	41	N/A	39	46	32
HCl	8.5	0.77	N/A	14	30	110
HF	0.25	0.21	N/A	0.28	0.59	0.51
HBr	0.29	0.30	N/A	0.40	0.49	0.47
Cl_2	0.27	0.25	N/A	0.32	0.48	0.52
Br_2	0.12	0.14	N/A	0.08	0.10	0.09

* Sample lost prior to laboratory analysis.

N/A = Not available.

Table 4-19. M5 Particulate and Acid Gas Test Results, Corrected to 12% CO_2 (dry basis)

Pollutant	Veg Run 1 I-ACB-M29-01 mg/DSCM	Veg Run 2 I-ACB-M29-02 mg/DSCM	Veg Run 3* I-ACB-M29-03 mg/DSCM	C&D Run 1 II-ACB-M29-01 mg/DSCM	C&D Run 2 II-ACB-M29-02 mg/DSCM	C&D Run 3 II-ACB-M29-03 mg/DSCM
Filterable Particulate	414	375	N/A	259	607	636
HCl	53	7.1	N/A	96	404	2197
HF	1.6	1.9	N/A	1.9	7.9	10
HBr	1.9	2. 8	N/A	2.7	6.6	9.4
Cl_2	1.7	2.3	N/A	2.2	6. 5	10
Br_2	0.73	1.3	N/A	0.5	1.4	1.9

* Sample lost prior to laboratory analysis.

N/A = Not available.

Table 4-20. SVOC Test Results, Uncorrected (dry basis)

Pollutant	Veg Run 1 I-ACB-M29-01 µg/DSCM	Veg Run 2 I-ACB-M29-02 µg/DSCM	Veg Run 3 I-ACB-M29-03 µg/DSCM	C&D Run 1 II-ACB-M29-01 µg/DSCM	C&D Run 2 II-ACB-M29-02 µg/DSCM	C&D Run 3 II-ACB-M29-03 µg/DSCM
Pyridine	ND	ND	ND	ND	ND	ND
N-Nitrosodimethylamine	ND	ND	ND	ND	ND	ND
Phenol	ND	ND	ND	ND	ND	ND
Aniline	ND	ND	ND	ND	ND	13
s-Dichloroethyl ether	ND	ND	ND	ND	ND	ND
2-Chlorophenol	ND	ND	ND	22	60	37
1,3-Dichlorobenzene	ND	ND	ND	ND	2.8	2.6
1,4-Dichlorobenzene	ND	0.8	ND	ND	2.7	2.4
Benzyl Alcohol	27	ND	13	ND	34	22
1,2-Dichlorobenzene	ND	ND	ND	ND	ND	2.2
2-Methylphenol	ND	ND	ND	ND	58	32
Bis(2-chloroisopropyl)ether	ND	ND	ND	ND	ND	ND
3- & 4-Methylphenol	ND	ND	ND	11	100	47
N-nitroso-di-*n*-propylamine	ND	ND	ND	ND	ND	ND
Hexachloroethane	ND	ND	ND	ND	ND	ND
Nitrobenzene	ND	ND	ND	10	180	83
Isophorone	ND	ND	ND	ND	ND	ND
2-Nitrophenol	ND	ND	17	14	29	24
2,4-Dimethylphenol	ND	ND	ND	3.2	24	15
Bis(2-chloroethoxy)methane	ND	ND	ND	ND	17	ND
2,4-Dichlorophenol	21	ND	ND	ND	30	23
1,2,4-Trichlorobenzene	ND	ND	0.2	ND	ND	1.0
Naphthalene	23	16	88	74	273	144
p-Chloroaniline	ND	ND	ND	ND	ND	ND
Hexachloro- 1,3-butadiene	ND	ND	ND	ND	ND	ND
4-Chloro-3-methylphenol	ND	ND	ND	ND	ND	15
2-Methylnaphthalene	14	7.8	10	15	42	27
1-Methylnaphthalene	3.4	2.0	2.4	5.7	ND	ND
Hexachlorocyclopentadiene	ND	ND	ND	ND	ND	ND
2,4,6-Trichlorophenol	ND	ND	ND	ND	ND	ND
2,4,5-Trichlorophenol	1.2	ND	ND	ND	ND	ND
2-Chloronaphthalene	ND	ND	0.2	ND	ND	0.8
2-Nitroaniline	ND	ND	0.7	ND	22	ND
1,4-Dinitrobenzene	ND	ND	ND	ND	ND	ND

Pollutant	Veg Run 1 I-ACB-M29-01 µg/DSCM	Veg Run 2 I-ACB-M29-02 µg/DSCM	Veg Run 3 I-ACB-M29-03 µg/DSCM	C&D Run 1 II-ACB-M29-01 µg/DSCM	C&D Run 2 II-ACB-M29-02 µg/DSCM	C&D Run 3 II-ACB-M29-03 µg/DSCM
Dimethyl phthalate	1.5	ND	ND	ND	1.8	ND
1,3-Dinitrobezene	ND	ND	1.9	9.8	36	16
Acenaphthylene	1.7	1.2	2.9	12	44	20
2,6-Dinitrotoluene	1.5	ND	ND	ND	ND	ND
1,2-Dinitrobenzene	ND	ND	ND	ND	ND	ND
3-Nitroaniline	ND	ND	ND	ND	ND	ND
Acenaphthene	0.3	ND	ND	ND	4.0	ND
2,4-Dinitrophenol	ND	ND	ND	ND	ND	ND
4-Nitrophenol	ND	ND	ND	ND	50	29
Dibenzofuran	2.3	1.3	5.3	7.6	31	14
2,4-Dinitrotoluene	ND	ND	ND	ND	ND	2.1
2,3,4,6-Tetrachlorophenol	ND	ND	ND	ND	ND	4.6
2,3,5,6-Tetrachlorophenol	ND	ND	ND	ND	ND	3.5
Diethyl phthalate	2.1	ND	1.9	ND	1.8	ND
4-Chlorophenyl phenyl ether	ND	ND	ND	ND	ND	ND
Fluorene	ND	0.3	0.8	2.3	14	5.7
4-Nitroaniline	ND	0.8	ND	ND	ND	ND
4,6-Dinitro-2-methylphenol	ND	ND	ND	ND	ND	2.1
Diphenylamine	ND	ND	ND	ND	ND	ND
Azobenzene	ND	ND	ND	ND	1.2	ND
4-Bromophenyl phenyl ether	ND	ND	ND	ND	ND	ND
Hexachlorobenzene	ND	ND	ND	ND	ND	ND
Pentachlorophenol	ND	ND	ND	ND	ND	ND
Phenanthrene	4.6	4.1	15	20	87	32
Anthracene	5.1	4.8	17	23	83	33
Carbazole	ND	0.2	ND	0.3	1.8	ND
Di-*n*-butyl phthalate	19	3.0	2.5	4.7	ND	2.7
Fluoranthene	1.4	ND	7.9	9.2	26	8.6
Pyrene	1.1	ND	6.4	8.4	23	7.1
Benzyl butyl phthalate	ND	ND	ND	1.1	ND	ND
Bis(2-ethylhexyl)adipate	ND	ND	ND	ND	ND	ND
Benz[a]anthracene	ND	ND	ND	ND	6.7	2.8
Chrysene	ND	ND	ND	ND	25	14
Bis(2-ethylhexyl) phthalate	14	3.8	3.5	8.7	219	15
Di-*n*-octyl phthalate	21	ND	ND	ND	ND	0.7

Pollutant	Veg Run 1 I-ACB-M29-01 µg/DSCM	Veg Run 2 I-ACB-M29-02 µg/DSCM	Veg Run 3 I-ACB-M29-03 µg/DSCM	C&D Run 1 II-ACB-M29-01 µg/DSCM	C&D Run 2 II-ACB-M29-02 µg/DSCM	C&D Run 3 II-ACB-M29-03 µg/DSCM
Benzo[b]fluoranthene	ND	ND	ND	ND	ND	ND
Benzo[k]fluoranthene	ND	ND	ND	ND	ND	ND
Benzo[a]pyrene	ND	ND	ND	ND	ND	ND
Indeno[1,2,3-cd]pyrene	ND	ND	ND	ND	ND	ND
Dibenz[a,h]anthracene	ND	ND	ND	ND	0.5	ND
Benzo[ghi]perylene	ND	ND	ND	ND	ND	ND

Table 4-21. SVOC Test Results, Corrected to 12% CO_2 (dry basis)

Pollutant	Veg Run 1 I-ACB-M29-01 µg/DSCM	Veg Run 2 I-ACB-M29-02 µg/DSCM	Veg Run 3 I-ACB-M29-03 µg/DSCM	C&D Run 1 II-ACB-M29-01 µg/DSCM	C&D Run 2 II-ACB-M29-02 µg/DSCM	C&D Run 3 II-ACB-M29-03 µg/DSCM
Pyridine	ND	ND	ND	ND	ND	ND
N-Nitrosodimethylamine	ND	ND	ND	ND	ND	ND
Phenol	ND	ND	ND	ND	ND	ND
Aniline	ND	ND	ND	ND	ND	267.86
s-Dichloroethyl ether	ND	ND	ND	ND	ND	ND
2-Chlorophenol	ND	ND	ND	204.25	803.93	746.08
1,3-Dichlorobenzene	ND	ND	ND	ND	37.67	51.81
1,4-Dichlorobenzene	ND	7.26	ND	ND	35.54	48.91
Benzyl Alcohol	171	ND	88.18	ND	458.84	441.81
1,2-Dichlorobenzene	ND	ND	ND	ND	ND	43.64
2-Methylphenol	ND	ND	ND	ND	771.88	638.62
Bis(2-chloroisopropyl)ether	ND	ND	ND	ND	ND	ND
3- & 4-Methylphenol	ND	ND	ND	98.08	1330.32	940.56
N-nitroso-di-*n*-propylamine	ND	ND	ND	ND	ND	ND
Hexachloroethane	ND	ND	ND	ND	ND	ND
Nitrobenzene	ND	ND	ND	93.47	2401.90	1653.17
Isophorone	ND	ND	ND	ND	ND	ND
2-Nitrophenol	ND	ND	116.10	126.19	383.37	488.57
2,4-Dimethylphenol	ND	ND	ND	29.57	316.80	293.37
Bis(2-chloroethoxy)methane	ND	ND	ND	ND	231.88	ND
2,4-Dichlorophenol	134	ND	ND	ND	402.68	466.82
1,2,4-Trichlorobenzene	ND	ND	1.42	ND	ND	20.57
Naphthalene	147	151.59	586.77	683.86	3636.38	2878.07
p-Chloroaniline	ND	ND	ND	ND	ND	ND
Hexachloro- 1,3-butadiene	ND	ND	ND	ND	ND	ND
4-Chloro-3-methylphenol	ND	ND	ND	ND	ND	298.03
2-Methylnaphthalene	86	72.38	69.16	138.74	558.91	547.22
1-Methylnaphthalene	21	18.45	16.22	52.91	ND	ND
Hexachlorocyclopentadiene	ND	ND	ND	ND	ND	ND
2,4,6-Trichlorophenol	ND	ND	ND	ND	ND	ND
2,4,5-Trichlorophenol	ND	ND	ND	ND	ND	ND
2-Chloronaphthalene	ND	ND	1.42	ND	ND	15.19
2-Nitroaniline	ND	ND	4.88	ND	297.66	ND
1,4-Dinitrobenzene	ND	ND	ND	ND	ND	ND

Pollutant	Veg Run 1 I-ACB-M29-01 µg/DSCM	Veg Run 2 I-ACB-M29-02 µg/DSCM	Veg Run 3 I-ACB-M29-03 µg/DSCM	C&D Run 1 II-ACB-M29-01 µg/DSCM	C&D Run 2 II-ACB-M29-02 µg/DSCM	C&D Run 3 II-ACB-M29-03 µg/DSCM
Dimethyl phthalate	9.4	ND	ND	ND	ND	ND
1,3-Dinitrobezene	ND	ND	12	90	484	310
Acenaphthylene	11	11	19	114	586	391
2,6-Dinitrotoluene	9.4	ND	ND	ND	ND	ND
1,2-Dinitrobenzene	ND	ND	ND	ND	ND	ND
3-Nitroaniline	ND	ND	ND	ND	ND	ND
Acenaphthene	1.9	ND	ND	ND	54	ND
2,4-Dinitrophenol	ND	ND	ND	ND	ND	ND
4-Nitrophenol	ND	ND	ND	ND	659	578
Dibenzofuran	15	12	35	70	417	277
2,4-Dinitrotoluene	ND	ND	ND	ND	ND	42
2,3,4,6-Tetrachlorophenol	ND	ND	ND	ND	ND	92
2,3,5,6-Tetrachlorophenol	ND	ND	ND	ND	ND	70
Diethyl phthalate	13	ND	13		23	ND
4-Chlorophenyl phenyl ether	ND	ND	ND	ND	ND	ND
Fluorene	ND	2.8	5.6	22	186	114
4-Nitroaniline	ND	7.3	ND	ND	ND	ND
4,6-Dinitro-2-methylphenol	ND	ND	ND	ND	ND	43
Diphenylamine	ND	ND	ND	ND	ND	ND
Azobenzene	ND	ND	ND	ND	16	ND
4-Bromophenyl phenyl ether	ND	ND	ND	ND	ND	ND
Hexachlorobenzene	ND	ND	ND	ND	ND	ND
Pentachlorophenol	ND	ND	ND	ND	ND	ND
Phenanthrene	29	38	101	189	1160	641
Anthracene	32	45	112	208	1102	664
Carbazole	ND	2.3	ND	2. 9	24	ND
Di- *n*-butyl phthalate	119	28	17	43	ND	54
Fluoranthene	9.0	ND	53	85	348	172
Pyrene	7.1	ND	43	77	300	142
Benzyl butyl phthalate	ND	ND	ND	11	ND	ND
Bis(2-ethylhexyl)adipate	ND	ND	ND	ND	ND	ND
Benz[a]anthracene	ND	ND	ND	ND	89	56
Chrysene	ND	ND	ND	ND	333	271
Bis(2-ethylhexyl) phthalate	89	35	23	81	2916	296
Di-*n*-octyl phthalate	133	ND	ND	ND	ND	15

Pollutant	Veg Run 1 I-ACB-M29-01 µg/DSCM	Veg Run 2 I-ACB-M29-02 µg/DSCM	Veg Run 3 I-ACB-M29-03 µg/DSCM	C&D Run 1 II-ACB-M29-01 µg/DSCM	C&D Run 2 II-ACB-M29-02 µg/DSCM	C&D Run 3 II-ACB-M29-03 µg/DSCM
Benzo[b]fluoranthene	ND	ND	ND	ND	ND	ND
Benzo[k]fluoranthene	ND	ND	ND	ND	ND	ND
Benzo[a]pyrene	ND	ND	ND	ND	ND	ND
Indeno[1,2,3-cd]pyrene	ND	ND	ND	ND	ND	ND
Dibenz[a,h]anthracene	ND	ND	ND	ND	7.0	ND
Benzo[ghi]perylene	ND	ND	ND	ND	ND	ND

Table 4-22. VOC Test Results, Uncorrected (dry basis)

Pollutant	Veg Run 3 Total µg/DSCM	C&D Run 1 Total µg/DSCM	C&D Run 2 Total µg/DSCM	C&D Run 3 Total µg/DSCM
Dichlorodifluoromethane (Freon 12)	ND	2.8	ND	2.5
1,2-Chloro-1,1,2,2-tetrafluoroethane	ND	ND	ND	ND
Chloromethane	25	34	ND	250
Vinyl chloride	ND	8.4	37	86
1,3-Butadiene	5.9	42	279	292
Bromomethane	ND	9.9	ND	15
Chloroethane	ND	ND	ND	ND
Trichlorofluoromethane	2.9	2.9	2.9	2.9
1,1-Dichloroethene	1.8	ND	ND	1.4
1,1,2-Trichloro-1,2,2-trifluoroethane	ND	ND	ND	ND
Ethanol	58	19	ND	36
Carbon disulfide	104	44	ND	60
Isopropyl alcohol	1.3	ND	ND	ND
Methylene chloride	19	46	61	18
Acetone	110	130	688	133
t-1,2-dichloroethene	ND	ND	ND	ND
Hexane	ND	ND	ND	ND
Methyl-*t*-butyl ether (MTBE)	ND	ND	ND	ND
1,1-Dichloroethane	ND	ND	ND	ND
Vinyl acetate	ND	3.2	3.0	3.8
cis-1,2-dichloroethene	ND	ND	ND	ND
Cyclohexane	ND	ND	ND	ND
Chloroform	ND	ND	3.9	2.2
Ethyl Acetate	ND	7.8	11	28
Tetrahydrofuran	ND	1.7	4.2	5.5
1,1,1-Trichloroethane	ND	ND	ND	ND
Carbon tetrachloride	ND	ND	ND	3.7
2-Butanone	ND	27	ND	84
Heptane	23	2.8	22	ND
Benzene	1131	282	1094	859
1,2-Dichloroethane	ND	ND	ND	ND
Trichloroethylene	3.4	2.4	27	2.7
1,2-Dichloropropane	ND	ND	ND	ND
Bromodichloromethane	ND	ND	ND	ND

Pollutant	**Veg Run 3 Total µg/DSCM**	**C&D Run 1 Total µg/DSCM**	**C&D Run 2 Total µg/DSCM**	**C&D Run 3 Total µg/DSCM**
1,4-Dioxane	2.2	1.8	1.6	ND
cis-1,3-Dichloropropene	ND	ND	ND	ND
Toluene	93	51	209	212
4-Methyl-2-pentanone (MIBK)	2.7	2.1	2.7	ND
t-1,3-Dichloropropene	ND	ND	ND	ND
Tetrachloroethylene	4.3	4.0	11	ND
1,1,2-Trichloroethane	ND	ND	ND	ND
Dibromochloromethane	ND	ND	ND	ND
1,2-Dibromoethane	ND	ND	ND	ND
2-Hexanone	ND	ND	ND	ND
Ethylbenzene	6.1	8.4	22	32
Chlorobenzene	5.2	3.6	11	18
m-/*p*-Xylene	10	18	29	49
o-Xylene	3.9	6.7	12	19
Styrene	26	32	81	273
Tribromomethane	ND	ND	5.1	ND
1,1,2,2-Tetrachloroethane	ND	ND	ND	ND
1-Ethyl-4-methylbenzene	ND	6.2	ND	13
1,3,5-Trimethylbenzene	1.9	ND	ND	ND
1,2,4-Trimethylbenzene	2.7	6.9	4.6	9.5
1,3-Dichlorobenzene	ND	ND	ND	ND
1,4-Dichlorobenzene	ND	ND	ND	ND
Benzyl chloride	ND	6.6	ND	154
1,2-Dichlorobenzene	ND	ND	ND	3.6
1,1,2,3,4,4-Hexachloro-1,3-butadiene	ND	ND	ND	ND
1,2,4-Trichlorobenzene	ND	ND	ND	ND

Table 4-23. VOC Test Results, Corrected to 12% CO_2 (dry basis)

Pollutant	Veg Run 3 Total µg/DSCM	C&D Run 1 Total µg/DSCM	C&D Run 2 Total µg/DSCM	C&D Run 3 Total µg/DSCM
Dichlorodifluoromethane (Freon 12)	ND	48	ND	49
1,2-Chloro-1,1,2,2-tetrafluoroethane	ND	ND	ND	ND
Chloromethane	169	576	ND	5000
Vinyl chloride	ND	144	557	1725
1,3-Butadiene	39	716	4178	5834
Bromomethane	ND	169	ND	306
Chloroethane	ND	ND	ND	ND
Trichlorofluoromethane	19	49	43	57
1,1-Dichloroethene	12	ND	ND	28
1,1,2-Trichloro-1,2,2-trifluoroethane	ND	ND	ND	ND
Ethanol	386	333	ND	715
Carbon disulfide	695	752	ND	1206
Isopropyl alcohol	8.3	ND	ND	ND
Methylene chloride	124	796	907	354
Acetone	733	2220	10319	2655
t-1,2-Dichloroethene	ND	ND	ND	ND
Hexane	ND	ND	ND	ND
Methyl-*t*-butyl ether (MTBE)	ND	ND	ND	ND
1,1-Dichloroethane	ND	ND	ND	ND
Vinyl acetate	ND	55	46	76
cis-1,2-Dichloroethene	ND	ND	ND	ND
Cyclohexane	ND	ND	ND	ND
Chloroform	ND	ND	58	44
Ethyl Acetate	ND	133	160	555
Tetrahydrofuran	ND	30	63	109
1,1,1-Trichloroethane	ND	ND	ND	ND
Carbon Tetrachloride	ND	ND	ND	73
2-Butanone	ND	461	ND	1671
Heptane	154	47	335	ND
Benzene	7541	4836	16417	17174
1,2-Dichloroethane	ND	ND	ND	ND
Trichloroethylene	23	42	409	54
1,2-Dichloropropane	ND	ND	ND	ND
Bromodichloromethane	ND	ND	ND	ND

Pollutant	Veg Run 3 Total µg/DSCM	C&D Run 1 Total µg/DSCM	C&D Run 2 Total µg/DSCM	C&D Run 3 Total µg/DSCM
1,4-Dioxane	15	31	24	ND
cis-1,3-Dichloropropene	ND	ND	ND	ND
Toluene	618	868	3137	4231
4-Methyl-2-pentanone (MIBK)	18	36	41	ND
t-1,3-Dichloropropene	ND	ND	ND	ND
Tetrachloroethylene	29	69	160	ND
1,1,2-Trichloroethane	ND	ND	ND	ND
Dibromochloromethane	ND	ND	ND	ND
1,2-Dibromoethane	ND	ND	ND	ND
2-Hexanone	ND	ND	ND	ND
Ethylbenzene	41	144	330	630
Chlorobenzene	35	61	168	359
m-/*p*-Xylene	69	300	437	985
o-Xylene	26	114	178	376
Styrene	176	555	1208	5452
Tribromomethane	ND	ND	76	ND
1,1,2,2-Tetrachloroethane	ND	ND	ND	ND
1-Ethyl-4-methylbenzene	ND	106	ND	253
1,3,5-Trimethylbenzene	13	ND	ND	
1,2,4-Trimethylbenzene	18	119	69	190
1,3-Dichlorobenzene	ND	ND	ND	ND
1,4-Dichlorobenzene	ND	ND	ND	ND
Benzyl chloride	ND	113	ND	3087
1,2-Dichlorobenzene	ND	ND	ND	72
1,1,2,3,4,4-Hexachloro-1,3-butadiene	ND	ND	ND	ND
1,2,4-Trichlorobenzene	ND	ND	ND	ND

4.5.2.7 Tentatively Identified Compounds (TICs)

TICs for each sample are shown in Tables 4-24 (raw) and 4-25 (corrected to 12% CO_2). TICs are compounds collected in the same SUMMA© canisters as VOCs. TICs are tentatively identified in the sense that they match an elution time and/or a mass class that is contained in the mass spectrometer reference library, possibly as fragments. However, TICs have not been specifically calibrated as targets.

Table 4-24. Tentatively Identified Compounds, Uncorrected (dry basis)

TICs	Veg Run 3		C&D Run 1		C&D Run 2		C&D Run 3	
	I-ACB-M29-03A ppbv	I-ACB-M29-03B ppbv	II-ACB-M29-01A ppbv	II-ACB-M29-01B ppbv	II-ACB-M29-02A ppbv	II-ACB-M29-02B ppbv	II-ACB-M29-03A ppbv	II-ACB-M29-03B ppbv
Propene	Not Found	Not Found	Not Found	Not Found	60	19	Not Found	Not Found
1,3-Butadiene	Not Found	Not Found	Not Found	Not Found	Not Found	25	Not Found	Not Found
1,2-Pentadiene	Not Found	Not Found	Not Found	Not Found	30	Not Found	Not Found	Not Found
Furan	Not Found	Not Found	Not Found	Not Found	50	Not Found	Not Found	Not Found
1-Butanol	Not Found	Not Found	Not Found	Not Found	Not Found	12	Not Found	Not Found
2-Butene	Not Found	Not Found	Not Found	Not Found	Not Found	Not Found	53.37	13.66
Furan, 2-methyl-	Not Found	Not Found	Not Found	Not Found	Not Found	Not Found	35.71	20.09
Methane, bromochloro-	21	21	44	16	100	Not Found	32.99	Not Found
Disulfide, dimethyl	Not Found	Not Found	Not Found	31	49	Not Found	Not Found	Not Found
Hexane, 3,3,4,4-tetrafluoro-	Not Found	Not Found	7.7	Not Found	Not Found	Not Found	Not Found	Not Found
1,3,5-Cycloheptatriene	Not Found	107	9.7	63	244	62	168.51	42.25
2-Cyclopenten-1-one, 2-methyl-	Not Found	Not Found	Not Found	Not Found	Not Found	Not Found	Not Found	8.96
Cyclopenta[c]pyran-1,3-dione, 4,4a,5,6-t	Not Found	Not Found	Not Found	Not Found	Not Found	15	Not Found	Not Found
Hexanal, 2-ethyl-	Not Found	Not Found	Not Found	Not Found	Not Found	Not Found	Not Found	19.79/85.84
1-Hexene, 3,5-dimethyl-	45	Not Found	25	25	Not Found	31	Not Found	Not Found
Phenol	Not Found	Not Found	Not Found	Not Found	Not Found	489	Not Found	Not Found
Azulene	Not Found	Not Found	Not Found	Not Found	Not Found	184	Not Found	Not Found
Camphene	Not Found	Not Found	11	Not Found	Not Found	Not Found	47.27	Not Found
1-Butyne, 3-methyl-	Not Found	Not Found	Not Found	Not Found	Not Found	Not Found	30.23	Not Found
Cyclohexene, 1-methyl-4-(1-methylethenyl	Not Found	Not Found	Not Found	Not Found	Not Found	Not Found	64.89	Not Found
Phenylethyne	Not Found	22	Not Found	Not Found	Not Found	Not Found	Not Found	Not Found
Methyl isopropyl disulfide	Not Found	Not Found	Not Found	16	Not Found	Not Found	Not Found	Not Found
Furfural	Not Found	15	Not Found	52	Not Found	Not Found	132.46	63.35

TICs	Veg Run 3		C&D Run 1		C&D Run 2		C&D Run 3	
	I-ACB-M29-03A ppbv	I-ACB-M29-03B ppbv	II-ACB-M29-01A ppbv	II-ACB-M29-01B ppbv	II-ACB-M29-02A ppbv	II-ACB-M29-02B ppbv	II-ACB-M29-03A ppbv	II-ACB-M29-03B ppbv
1-Hepten-3-one	Not Found	13	Not Found	Not Found	Not Found	Not Found	Not Found	Not Found
Heptanal	Not Found	Not Found	12	Not Found	35	Not Found	Not Found	Not Found
1-Hexanol, 2-ethyl-	Not Found	Not Found	Not Found	Not Found	Not Found	Not Found	Not Found	85.84
Benzonitrile	Not Found	35	Not Found	Not Found	76	Not Found	Not Found	Not Found
Benzaldehyde, 4-methyl-	Not Found	14	Not Found	Not Found	Not Found	Not Found	Not Found	Not Found
Benzene, 1-methyl-3-(1-methylethyl)-	Not Found	Not Found	Not Found	28	Not Found	Not Found	Not Found	Not Found
Benzene, 1-methyl-4-(1-methylethyl)-	Not Found	Not Found	60	Not Found	Not Found	Not Found	32.79	Not Found
Benzene, 1-propynyl-	Not Found	Not Found	Not Found	Not Found	Not Found	Not Found	114.58	Not Found
Benzaldehyde, 3-methyl-	Not Found	Not Found	Not Found	Not Found	Not Found	Not Found	47.93	Not Found
Benzene, 1-ethynyl-4-methyl-	Not Found	Not Found	Not Found	18	Not Found	Not Found	Not Found	Not Found
Cyclohexanemethyl propanoate	Not Found	16	Not Found	19	76	43	Not Found	9.92
2,2-Dimethyl-propyl 2,2-dimethyl-propane	12	Not Found	Not Found	Not Found	Not Found	Not Found	Not Found	Not Found
Naphthalene	96	346	100	102	232	Not Found	140.73	26.77
Benzaldehyde, 4-(1-methylethyl)-	Not Found	Not Found	Not Found	19	Not Found	Not Found	Not Found	Not Found

NOTE: Multiple cell entries separated by a slash indicate likelihood of multiple isomers detected

Table 4-25. Tentatively Identified Compounds, Corrected to 12% CO_2 (dry basis)

TICs	Veg Run 3		C&D Run 1		C&D Run 2		C&D Run 3	
	I-ACB-M29-03A ppbv	I-ACB-M29-03B ppbv	II-ACB-M29-01A ppbv	II-ACB-M29-01B ppbv	II-ACB-M29-02A ppbv	II-ACB-M29-02B ppbv	II-ACB-M29-03A ppbv	II-ACB-M29-03B ppbv
Propene	Not Found	Not Found	Not Found	Not Found	900	284	Not Found	Not Found
1,3-Butadiene	Not Found	Not Found	Not Found	Not Found	Not Found	371	Not Found	Not Found
1,2-Pentadiene	Not Found	Not Found	Not Found	Not Found	447	Not Found	Not Found	Not Found
Furan	Not Found	Not Found	Not Found	Not Found	747	Not Found	Not Found	Not Found
1-Butanol	Not Found	Not Found	Not Found	Not Found	Not Found	178	Not Found	Not Found
2-Butene	Not Found	Not Found	Not Found	Not Found	Not Found	Not Found	1067	273
Furan, 2-methyl-	Not Found	Not Found	Not Found	Not Found	Not Found	Not Found	714	402
Methane, bromochloro-	138	142	759	277	1501	Not Found	660	Not Found
Disulfide, dimethyl	Not Found	Not Found	Not Found	533	741	Not Found	Not Found	Not Found
Hexane, 3,3,4,4-tetrafluoro-	Not Found	Not Found	133	Not Found	Not Found	Not Found	Not Found	Not Found
1,3,5-Cycloheptatriene	Not Found	714	166	1084	3663	924	3370	845
2-Cyclopenten-1-one, 2-methyl-	Not Found	Not Found	Not Found	Not Found	Not Found	Not Found	Not Found	179
Hexanal, 2-ethyl-	Not Found	Not Found	Not Found	Not Found	Not Found	Not Found	Not Found	396/1717
1-Hexene, 3,5-dimethyl-	303	Not Found	429	425	Not Found	472	Not Found	Not Found
Phenol	Not Found	Not Found	Not Found	Not Found	Not Found	7335	Not Found	Not Found
Azulene	Not Found	Not Found	Not Found	Not Found	Not Found	2766	Not Found	Not Found
Camphene	Not Found	Not Found	188	Not Found	Not Found	Not Found	945	Not Found
1-Butyne, 3-methyl-	Not Found	Not Found	Not Found	Not Found	Not Found	Not Found	605	Not Found
Cyclohexene, 1-methyl-4-(1-methylethenyl	Not Found	Not Found	Not Found	Not Found	Not Found	Not Found	1298	Not Found
Phenylethyne	Not Found	145	Not Found	Not Found	Not Found	Not Found	Not Found	Not Found
Methyl isopropyl disulphide	Not Found	Not Found	Not Found	276	Not Found	Not Found	Not Found	Not Found
Furfural	Not Found	100	Not Found	893	Not Found	Not Found	2649	1267

TICs	Veg Run 3		C&D Run 1		C&D Run 2		C&D Run 3	
	I-ACB-M29-03A ppbv	I-ACB-M29-03B ppbv	II-ACB-M29-01A ppbv	II-ACB-M29-01B ppbv	II-ACB-M29-02A ppbv	II-ACB-M29-02B ppbv	II-ACB-M29-03A ppbv	II-ACB-M29-03B ppbv
1-Hepten-3-one	Not Found	84	Not Found	Not Found	Not Found	Not Found	Not Found	Not Found
Heptanal	Not Found	Not Found	200	Not Found	532	Not Found	Not Found	Not Found
1-Hexanol, 2-ethyl-	Not Found	Not Found	Not Found	Not Found	Not Found	Not Found	Not Found	1717
Benzonitrile	Not Found	231	Not Found	Not Found	1140	Not Found	Not Found	Not Found
Benzaldehyde, 4-methyl-	Not Found	94	Not Found	Not Found	Not Found	Not Found	Not Found	Not Found
Benzene, 1-methyl-3-(1-methylethyl)-	Not Found	Not Found	Not Found	481	Not Found	Not Found	Not Found	Not Found
Benzene, 1-methyl-4-(1-methylethyl)-	Not Found	Not Found	1023	Not Found	Not Found	Not Found	656	Not Found
Benzene, 1-propynyl-	Not Found	Not Found	Not Found	Not Found	Not Found	Not Found	2292	Not Found
Benzaldehyde, 3-methyl-	Not Found	Not Found	Not Found	Not Found	Not Found	Not Found	959	Not Found
Benzene, 1-ethynyl-4-methyl-	Not Found	Not Found	Not Found	302	Not Found	Not Found	Not Found	Not Found
Cyclohexanemethyl propanoate	Not Found	108	Not Found	328	1146	647	Not Found	198
2,2-Dimethyl-propyl 2,2-dimethyl-propane	79	Not Found	Not Found	Not Found	Not Found	Not Found	Not Found	Not Found
Naphthalene	637	2306	1716	1740	3477	Not Found	2815	535
Benzaldehyde, 4-(1-methylethyl)-	Not Found	Not Found	Not Found	332	Not Found	Not Found	Not Found	Not Found

NOTE: Multiple cell entries separated by a slash indicate likelihood of multiple isomers detected

4.5.2.8 Brominated Organic Compounds

The Method 23 extracts were analyzed for polybrominated dibenzo-p-dioxins and polybrominated dibenzofurans (PBDDs/PBDFs), as well as for brominated diphenyl ethers (PBDPEs). The results for the analyses are shown in Table 4-26. The analysis was done using GC/MS under a full-scan mode, using response factors based on Octachlorodibenzodioxin (OCDD). This was done because standards for the PBDDs, PBDFs, and PBDPEs are not generally available at commercial laboratories. It must also be noted that Method 23 has not been validated for PBDDs/PBDFs and PBDPE analysis.

Based on examination of the chromatograms and mass spectral results, it is believed that there is good confidence in the identification of the brominated compounds, but because the quantifications were based on using the OCDD response factor, and the fact that OCDD was present in these samples only at low levels, there is not good confidence in the concentrations presented here, so the reported values are semi-quantitative at best.

The brominated targets were only found in the emissions from the C&D tests. This is consistent with intuition because it is likely that brominated compounds released as combustion emissions from vegetative debris would be at exceedingly low concentrations and not likely to be identified in a full-scan mass spectral run. Brominated flame retardants, however, are in widespread used in a variety of commercial applications including carpet, draperies, furniture, and consumer electronics items. There is a high likelihood of finding any or all of these types of materials in C&D debris. The investigators witnessed a mattress and sofa being fed into the ACB during the C&D Runs.

The samples from C&D Runs 1 and 3 showed significant levels of tetra- and penta- brominated diphenyl ethers, and lesser amounts of TBDF and PeBDF. This is consistent with emissions of undestroyed flame retardants, which are a mix of tetra- and penta- brominated diphenyl ethers (La Guardia et al., 2006). This particular flame retardant mix has been shown to have trace levels of PBDFs as contaminants in the mix (Hanari et al., 2006) in a manner similar to the presence of TCDDs found as trace contaminants in the herbicide 2,4,5-trichlorophenoxyacetic acid (otherwise known as 2,4,5-T or Agent Orange). Therefore it is likely that the brominated compounds that are reported here were released as undestroyed flame retardant material from the C&D debris rather than as products of incomplete combustion.

Because of the semi-quantitative nature of these results, values corrected to 12% CO2 were not estimated, and emission factors were not calculated.

4.5.2.9 Particle Sizing Test Results

Particle sizing test results can be seen visually in Figures 4-36 through 4-40. The graphs represent a plot of derived particle aerodynamic diameter (Di) vs. mass distribution (dM/dlogDp). The graphical presentation allows the particle size distribution across the sampled size range to be seen more easily.

4.5.2.10 Visible Emissions during Vegetative Debris Burning

The results of visible emissions determination using EPA Method 9 are presented in Table 4-27. Each of the vegetative burns was sampled for two sequential 30-minute periods, and the results from both runs are shown.

Table 4-26. Brominated Compounds, Uncorrected (Dry Basis)

	C&D Run 1 (ng/DSCM)*	C&D Run 2 (ng/DSCM)*	C&D Run 3 (ng/DSCM)*
TriBrDPE	2,174	ND	ND
TBrDPE	19,586,703	ND	703
PeBrDPE	3,234,501	ND	1,150
HxBrDPE	26,056	ND	22
HpBrDPE	442	ND	ND
OBrDPE	262	ND	ND
NBrDPE	282	ND	ND
DBrDPE	99	ND	11
TBrDF	8,392	ND	761
PeBrDF	2,282	ND	226
HxBrDF	455	ND	73
HpBrDF	163	ND	11

* -- Note that quantitations of all analytes in this table was done based on a response factor for OCDD, which was not present in high levels; therefore these concentration estimates should be considered as semiquantitative.

4.5.2.11 Filterable and Condensable Particulate Matter Test Results

Filterable and condensable particulate matter test results are presented in Table 4-28 for two vegetative and three C&D debris burns.

D50 (um)	Log D50	dlogDp	Di (um)	dM/dlogDp	PM (mg)	[PM]	dM	N (particles)
0.200	-0.699	0.352	0.300	20.452593	141.9	35.4573	7.20305	1.00E+14
0.450	-0.347	0.173	0.549	11.996163	19.7	4.92254	2.07368	2.27E+12
0.670	-0.174	0.215	0.858	6.893877	9.5	2.37381	1.48438	2.87E+11
1.100	0.0414	0.301	1.556	6.0743828	6.4	1.5992	1.82857	3.25E+10
2.200	0.3424	0.189	2.735	5.1425028	3.5	0.87456	0.97222	3.27E+09
3.400	0.5315	0.167	4.123	16.533601	3.6	0.89955	2.76923	9.81E+08
5.000	0.699	0.164	6.042	9.8872635	1.3	0.32484	1.625	1.13E+08
7.300	0.8633	0.209	9.281	1.0959549	0.8	0.1999	0.22857	1.91E+07

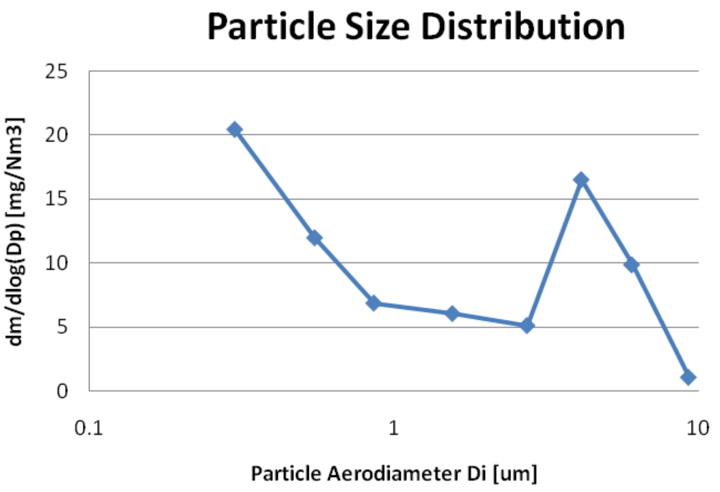


Figure 4-36. Andersen 1 - 24 June 2008, Vegetative Run 2

D50 (um)	Log D50	dlogDp	Di (um)	dM/dlogDp	PM (mg)	[PM]	dM	N (particles)
0.2	-0.69897	0.361728	0.303	28.263043	86.9	46.44575	10.22353	5.95E+13
0.46	-0.33724	0.169751	0.559	6.8593587	8.5	4.543025	1.164384	9.28E+11
0.68	-0.16749	0.208884	0.865	7.4356733	7.3	3.901657	1.553191	2.16E+11
1.1	0.041393	0.30103	1.556	4.7312309	4.7	2.512026	1.424242	2.38E+10
2.2	0.342423	0.201645	2.775	13.637804	3.3	1.763763	2.75	2.95E+09
3.5	0.544068	0.163502	4.225	2.6211978	1.2	0.641368	0.428571	3.04E+08
5.1	0.70757	0.167491	6.185	167.17307	2.8	1.496526	28	2.26E+08
7.5	0.875061	0.20412	9.487	0.5443422	0.1	0.053447	0.111111	2.24E+06

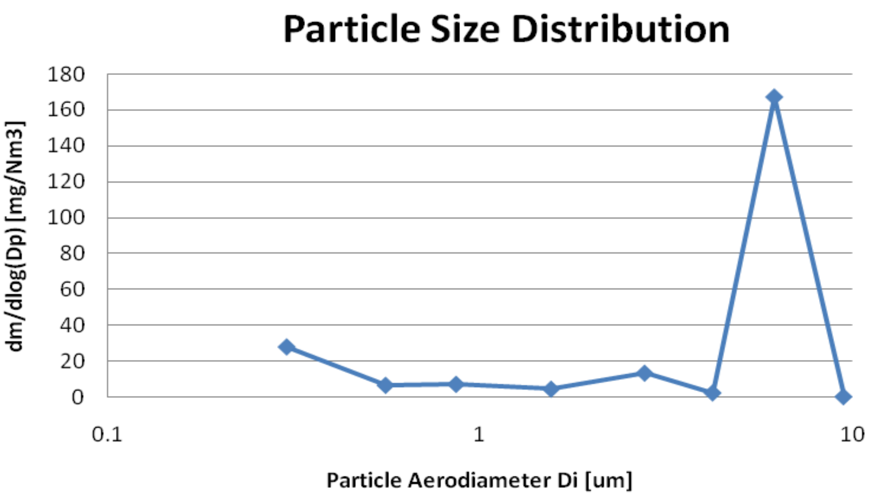


Figure 4-37. Andersen 2 - 25 June 2008, Vegetative Run 3

D50 (um)	Log D50	dlogDp	Di (um)	dM/dlogDp	PM (mg)	[PM]	dM	N (particles)
0.2	-0.69897	0.30103	0.283	22.293252	85.9	32.0164	6.710938	7.25E+13
0.4	-0.39794	0.168792	0.486	8.1540827	12.8	4.770779	1.376344	2.13E+12
0.59	-0.22915	0.18339	0.729	42.25955	9.3	3.466269	7.75	4.59E+11
0.9	-0.04576	0.324511	1.308	0.8404251	1.2	0.447261	0.272727	1.02E+10
1.9	0.278754	0.198368	2.387	7.1551728	4.4	1.639955	1.419355	6.18E+09
3	0.477121	0.176091	3.674	5.3346994	3.1	1.155423	0.939394	1.19E+09
4.5	0.653213	0.166331	5.450	19.839907	3.3	1.229966	3.3	3.89E+08
6.6	0.819544	0.201645	8.325	4.132668	1	0.372717	0.833333	3.31E+07

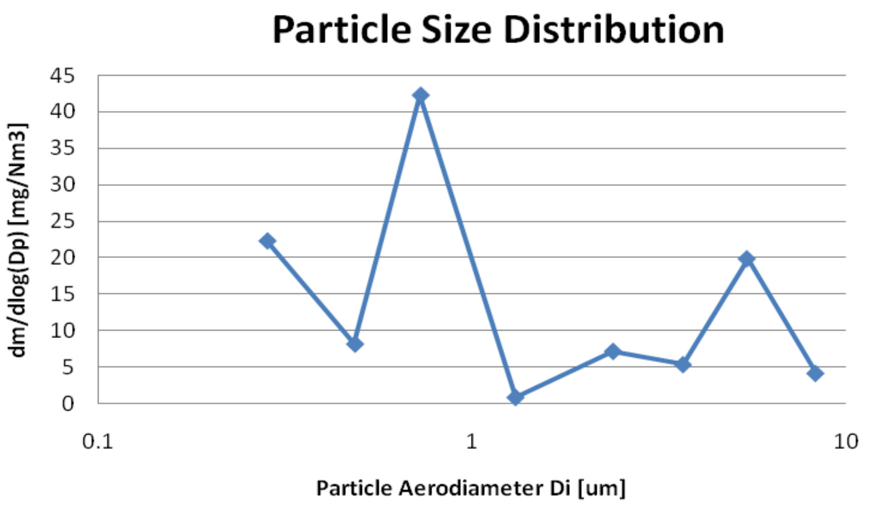


Figure 4-38. Andersen 3 - 25 June 2008, C&D Run 1

D50 (um)	Log D50	dlogDp	Di (um)	dM/dlogDp	PM (mg)	[PM]	dM	N (particles)
0.2	-0.69897	0.352183	0.300	35.355568	38.6	16.7462	12.45161	2.73E+13
0.45	-0.34679	0.166331	0.545	5.0371591	3.1	1.344902	0.837838	3.66E+11
0.66	-0.18046	0.221849	0.852	3.4745895	3.7	1.605206	0.770833	1.14E+11
1.1	0.041393	0.30103	1.556	11.389468	4.8	2.08243	3.428571	2.44E+10
2.2	0.342423	0.189056	2.735	3.702602	1.4	0.607375	0.7	1.31E+09
3.4	0.531479	0.167491	4.123	2.2530064	2	0.867679	0.377358	5.45E+08
5	0.69897	0.164353	6.042	10.077403	5.3	2.299349	1.65625	4.59E+08
7.3	0.863323	0.204863	9.242	7.8100974	3.2	1.388286	1.6	7.74E+07

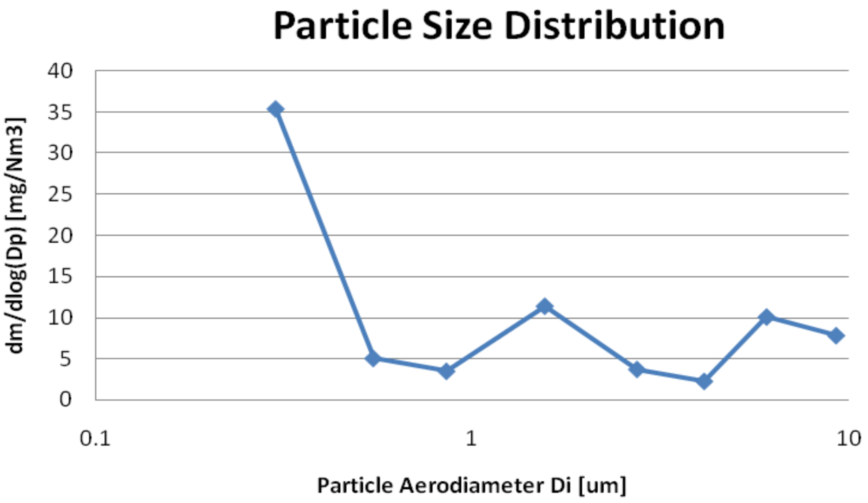


Figure 4-39. Andersen 4 - 25 June 2008, C&D Run 2

D50 (um)	Log D50	dlogDp	Di (um)	dM/dlogDp	PM (mg)	[PM]	dM	N (particles)
0.2	-0.69897	0.332438	0.293	12.163088	83.7	38.28911	4.043478	6.34E+13
0.43	-0.36653	0.165872	0.520	12.479495	20.7	9.46935	2.07	2.80E+12
0.63	-0.20066	0.200659	0.794	16.076026	10	4.574565	3.225806	3.82E+11
1	0	0.322219	1.449	6.8719836	3.1	1.418115	2.214286	1.95E+10
2.1	0.322219	0.182931	2.592	4.0279853	1.4	0.640439	0.736842	1.53E+09
3.2	0.50515	0.166948	3.878	3.0758912	1.9	0.869167	0.513514	6.22E+08
4.7	0.672098	0.173	5.736	7.6383074	3.7	1.692589	1.321429	3.74E+08
7	0.845098	0.20412	8.854	0.7706417	2.8	1.280878	0.157303	7.70E+07

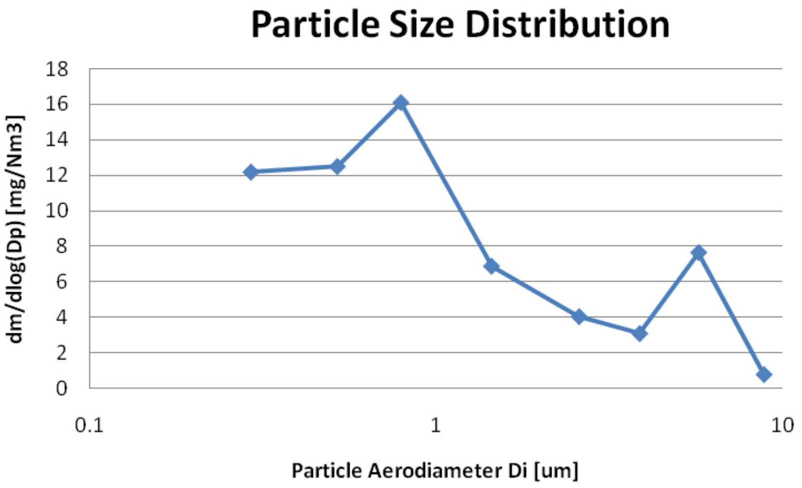


Figure 4-40. Andersen 5 - 25 June 2008, C&D Run 3

Table 4-27. Visible Emissions (% Opacity)

	Veg Run 1 **6-24-M9-1**	**Veg Run 2** **6-24-M9-2**	**Veg Run 3** **6-25-M9-1**	**C&D Run 1** **6-25-M9-2**	**C&D Run 2** **6-26-M9-1**	**C&D Run 3** **6-26-M9-2**
Single Highest 6-Minute Rolling Average	13 8.3	17 8.3	17 17	19 19	8.8 4.8	15 13
Highest Observed Opacity Reading	30 15	25 20	25 25	30 35	20 15	25 35
Lowest Observed Opacity Reading	0 0	0 0	0 0	0 0	0 0	0 0

Table 4-28. Filterable and Condensable Particulate Test Results for All Vegetative and C&D Debris Burns

	Veg Run 1 I-ACB-M202-01 mg/DSCM	Veg Run 2 I-ACB-M202-02 mg/DSCM	C&D Run 1 II-ACB-M202-01 mg/DSCM	C&D Run 2 II-ACB-M202-02 mg/DSCM	C&D Run 3 II-ACB-M202-03 mg/DSCM
Filterable Particulate $<PM_{10}$	42	52	35	40	35
Filterable Particulate $>PM_{10}$	16	9.8	12	21	3.8
Organic Condensable Particulate	1.8	1.1	1.8	5.0	1.4
Inorganic Condensable Particulate	62	23	27	28	67
Total Particulate $<PM_{10}$	106	76	64	73	103
Total Filterable Particulate	58	62	48	61	39
Total Condensable Particulate	64	24	28	33	68
Total Particulate	122	86	76	94	107

4.5.2.12 Results of Microscopy Analysis of Air Samples and Ash

Samples collected for asbestos analysis during the incinerator study were analyzed by Bureau Veritas (BV) of Kennesaw, GA. The samples collected were analyzed for the presence of asbestos fibers and for sterite fibers. Samples analyzed included three air emission samples and two bulk samples of ash. The air emission samples, taken during C&D burning, were analyzed by transmission electron microscopy (TEM) utilizing ISO 10312 (U.S. EPA, 1987). The ash samples were analyzed using the EPA 600 polarized light microscopy (PLM) method and by drop mount TEM qualitative verification.

4.5.2.12.1 Airborne Asbestos Samples

The water impinger samples were sonicated and the entire volume was filtered onto new MCE 47 mm 0.45 micron filters. The filters were then ashed in a muffle furnace to remove organic particles that may have been present. The ashed residue was then treated with dilute hydrochloric acid to remove soluble materials. This residual material was then suspended in 100 mL deionized water and sonicated. The entire contents were then filtered onto MCE 47 mm 0.45 micron filters. Portions of the filter were then prepared and examined as indicated below.

The air samples were analyzed by TEM using ISO 10312; structures were counted according to the protocol in ISO 10312, Annex C, "Structure counting criteria”. The method was modified to count all structures ≥0.5 µm with a length to width aspect ratio of ≥3:1. Phase Contrast Microscopy Equivalent (PCME) structures (structures > 5 µm in length and 0.2 to 3 µm in width) are also reported. BV observed tremolite in all three samples; chrysotile, and actinolite were also observed in two of the three samples. No forsterite was observed in any of the air samples. The results of analysis are in Table 4-29.

Table 4-29. Analytical Results of TEM Asbestos Analysis of Air Samples

Sam-ple	Vol-ume (DSCM)	Number of Structures		Structures/mm^2 on Filter		Laboratory Analytical Limit of Detection (structures / mm^2)		Structures/cc in Stack Gas				Laboratory Analytical Sensitivity (structures/cc)	
		Total	PCME	Total	PCME	Total	PCME	Total	MDL*	PCME	MDL*	Total	PCME
C&D Run 1	1.816	8[a]	1	8.2	3.1	3.1	3.1	0.0060	0.0022	0.00075	0.0022	0.00075	0.00075
C&D Run 2	1.327	3[b]	1	3.1	3.1	3.1	3.1	0.0031	0.0031	0.0010	0.0031	0.0010	0.0010
C&D Run 3	2.678	3[c]	0	3.1	<3.1	3.1	3.1	0.0015	0.0015	<0.00050	0.0015	0.00050	0.00050

*MDL – total method detection limit
a – tremolite, chrysotile, and actinolite
b – tremolite, chrysotile
c – tremolite, actinolite

On each sample, 94 grid openings of 0.0104 mm^2 were analyzed, for a total analytical area of 0.98 mm^2 on a filter of 1320 mm^2 effective filter area. The analytical sensitivity of the method is based on a single fiber; the limit of detection for the method is based on 2.99 fibers per analysis (as per ISO 10312). These counts were obtained during two rounds of analyses and summed to obtain the results shown in Table 4-28. The second round of analyses was ordered to add examinations of many more grid openings than were counted in the first round for the purpose of improving the analytical sensitivity and increasing the confidence in the results. Both analytical reports can be seen in Appendix C. The second analytical report incorporates data from the first, i.e., the second report is a revised report rather than a supplemental report.

4.5.2.12.2 Ash Samples

Two ash samples were analyzed by PLM using EPA/600/R-93/116 (U.S. EPA, 1993) with the visual estimation technique and identification by refractive index measurement. No asbestos or forsterite was found by BV. The ash samples were also analyzed by preparing a drop mount on a carbon-coated grid to verify at high magnification the presence or absence of asbestos or forsterite fibers in the bulk sample. No such fibers in either sample were found by TEM analysis. Results of PLM and TEM analysis of ash samples are in Table 4-30. The reliable limit of quantitation of the method is 1%, although asbestos may be qualitatively detected at concentrations less than 1%. Samples in which asbestos is detected at <1% are reported as “trace, <1%”. “None detected” indicates that no asbestos fibers were observed.

Table 4-30. Analytical Results PLM and TEM Analysis of Ash Samples

Sample	PLM Analysis	TEM Analysis
Composite Ash Sample 1	No asbestos detected	No asbestos detected
Composite Ash Sample 2	No asbestos detected	No asbestos detected

5. Discussion of Results

All emissions results were estimated based on the use of the air flow calculations of Equation (10) in Section 3.4 and averaging over the triplicate samples. Those averages are presented in the following tables. Non-detects were taken as zero for the purposes of averaging within conditions. If a more complete analysis is desired that includes detection limits and the raw data, please see the appendices. In the appendix containing the emissions calculations, analytes that fell below laboratory detection limits were calculated as if they were in fact seen at those limits and are reported in red. These values were carried forward into the "within condition" averages and represent a "worst case" result.

Isokineticity of the sampling scoop during the sampling program averaged 65.9% percent with variation between 47.8% and 90.9% based on a bulk gas velocity of 15 feet per second (seen during the 2005 preliminary test) and scoop temperature variation due to ACB feed irregularities. This non-ideal isokineticity (in comparison with the EPA requirement of maintaining between 90% and 110% isokinetic during compliance testing using EPA Method 5) would result in a slight overestimation of the emission rates of any analyte existing in particulate form or associated with particulate matter.

If isokinetic rate calculations are based upon the estimated total flow rates presented in Table 5-1, variation was between 6.1% and 46.5% isokinetic. The values in Table 5-1 were affected by significant wind during the tests; the wind was calm during the 2005 pre-test period.

The following assumptions were made in order to generate the emissions estimates:

- The feed composition of all the vegetative debris and C&D debris is based on the feed composition for the one vegetative debris sample that was taken during the test (i.e., the C&D debris was too heterogeneous to procure a representative sample to use for proximate and ultimate analysis). This detail is relevant because all mass emission rates and emission factors presented below are calculated based on the exhaust flow rates, and the ACB exhaust flow rates were calculated based on the carbon and hydrogen content of the vegetative debris sample. As explained in Section 5.1, this assumption is supported by the fact that the NO_X results for vegetative and C&D debris are quite similar.

- The gas sample that is being withdrawn by the sampling scoop represents gases that enter the ACB through the blower, entrained into the gas flow due to fluid mechanics, drawn into the ACB through gaps in the equipment due to natural draft, and ambient air due to wind blowing across the top of the ACB unit and being drawn into the scoop. The additional dilution due to the wind does not affect the mass emission rate or emission factor calculations.

- The mean pollutant concentrations in the sampling duct were equal to the mean pollutant concentration emitted into the atmosphere from the ACB; based on visual observations and previous velocity traverses (Miller and Lemieux, 2007). This appears to be a reasonable assumption. There does not appear to be a significant velocity or concentration gradient along the long end of the ACB opposite the air plenum.

- The water vapor measured in the sampling duct was due only to water present in the feed or water generated during the combustion process (i.e., rainfall and overspray from debris misting procedures did not significantly affect measured water vapor estimates).

- All of the carbon in the feed is converted to CO, hydrocarbons, or CO_2 or remains behind in the ash. Although this assumption is not quantitatively correct, since some of the carbon is emitted in the form of soot and trace organic air toxics that are not detected by the hydrocarbon analyzer, the relative contribution of these species to the overall amount of carbon released into the air is very small.

- The amount of moisture remaining behind in the ash is negligible. Although the ash was sampled for moisture as part of the proximate and ultimate analysis, the ash removal process involved significant quantities of water being sprayed on the ash, and since the ash was above the boiling point of water while in the ACB, the moisture in the ash is assumed to be negligible.

- The emission factors from C&D debris combustion inherently contain the emissions from the vegetative debris used as supplemental fuel.

Care must be taken in examining the mass emissions rates and estimated emission factors due to the differences in engineering units used to present the data. The units to present the data were selected to have a range of values appropriate for visual comparison in tabular format.

Section 5.8 includes an analysis of variance, where a discussion is included about whether emissions of a given pollutant or set of pollutants were higher from combustion of C&D debris than from combustion of the vegetative debris used in the tests.

5.1 Fixed Combustion Gases

Emissions rates and estimated emission factors for CO, NO_X (reported as NO), SO_2, and THC (reported as propane) are shown in Table 5-1. Figure 5-1 shows the data from Table 5-1 in graphical form. As mentioned in the evaluation of the CEM data, the emissions of NO_X are virtually identical from both the vegetative and C&D debris. Since NO_X emissions are primarily a function of the firebox temperature for a combustion system like an ACB that is burning debris, the fact that the estimated emission factor for NO_X was essentially the same for both vegetative and C&D debris suggests that the initial assumption that the bulk composition of the C&D debris was the same as the vegetative debris was a reasonable assumption, and that observed differences between vegetative and C&D debris were primarily due to effects resulting from minor or maybe even trace constituents in the C&D debris. Section 5.8.7 includes a discussion of the statistical significance of differences in emissions of fixed combustion gases between the Veg and C&D test conditions.

Table 5-1. Emission Rates and Estimated Emission Factors for CO, NO_X, SO_2, and THC

	Emission Rate (g/hr)						Emission Factor (mg/kg debris)					
	Veg Run 1	**Veg Run 2**	**Veg Run 3**	**C&D Run 1**	**C&D Run 2**	**C&D Run 3**	**Veg Run 1**	**Veg Run 2**	**Veg Run 3**	**C&D Run 1**	**C&D Run 2**	**C&D Run 3**
CO	8494	17325	26880	46426	81253	46550	1951	3979	4357	6916	9735	10917
NOx (as NO)	2950	3345	5767	8982	7280	3215	678	768	935	1338	872	754
SO2	1838	1136	346	9572	35331	6059	422	261	56	1426	4233	1421
THC (as propane)	737	1123	1194	4198	10978	5363	169	258	194	625	1315	1258

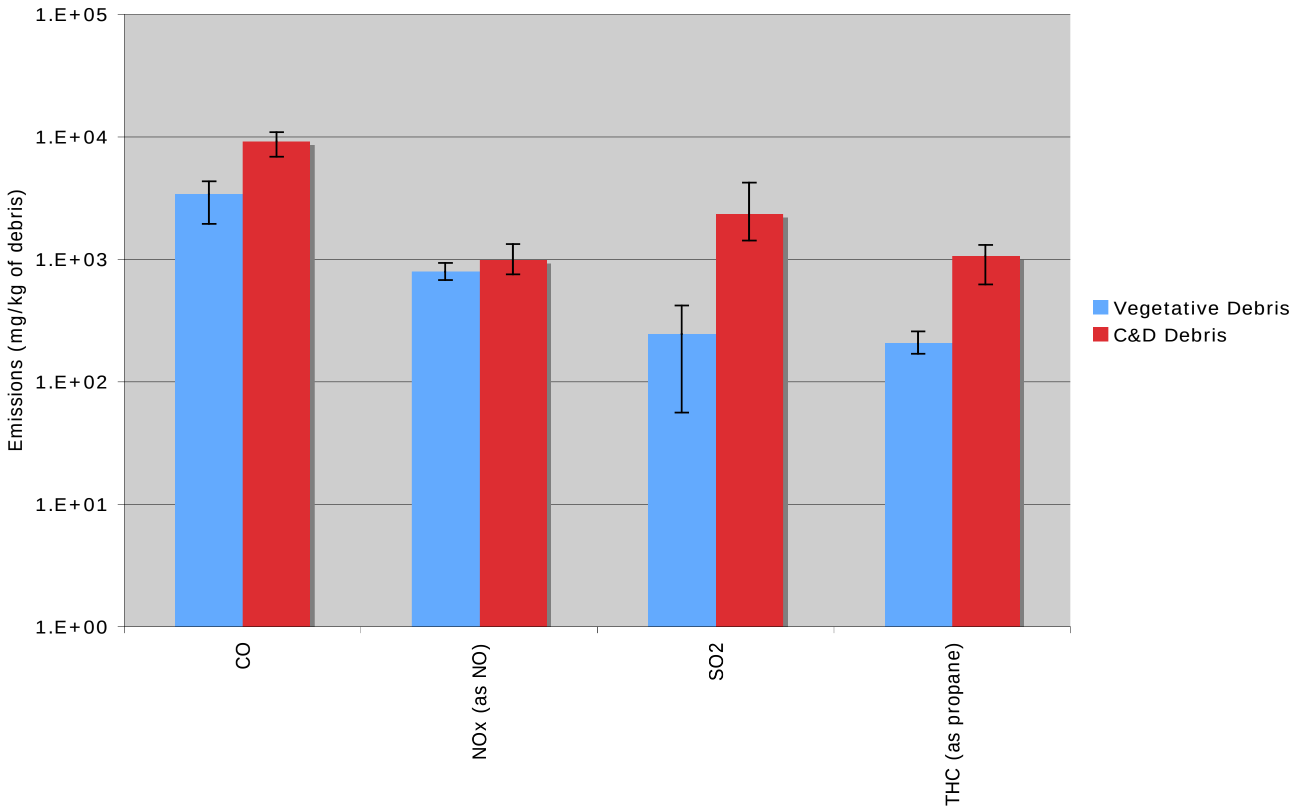


Figure 5-1. Emission Factors for Fixed Combustion Gases: Vegetative Debris vs. C&D Debris (Error bars represent the range of data)

Table 5-2. Emission Rates and Estimated Emission Factors for PCDDs/Fs and PCBs

	Emission Rate (µg/hr)						**Emission Factor (ng/kg debris)**					
	Veg Run 1	**Veg Run 2**	**Veg Run 3**	**C&D Run 1**	**C&D Run 2**	**C&D Run 3**	**Veg Run 1**	**Veg Run 2**	**Veg Run 3**	**C&D Run 1**	**C&D Run 2**	**C&D Run 3**
Total CDD/CDF	6896	9979	28134	257695	338804	426233	1584	2292	4561	38386	40594	99965
PCDD/PCDF TEQ	162	226	694	6170	6656	10343	37	52	113	919	797	2426
Total PCBs (Mono-Nona)	15718	4488	20827	218368	587849	311976	3610	1031	3376	32528	70433	73168
PCB TEQ	5	3	18	209	375	628	1	1	3	31	45	147
PCDD/F TEQ+PCB TEQ	167	230	712	6379	7031	10971	38	53	115	950	842	2573

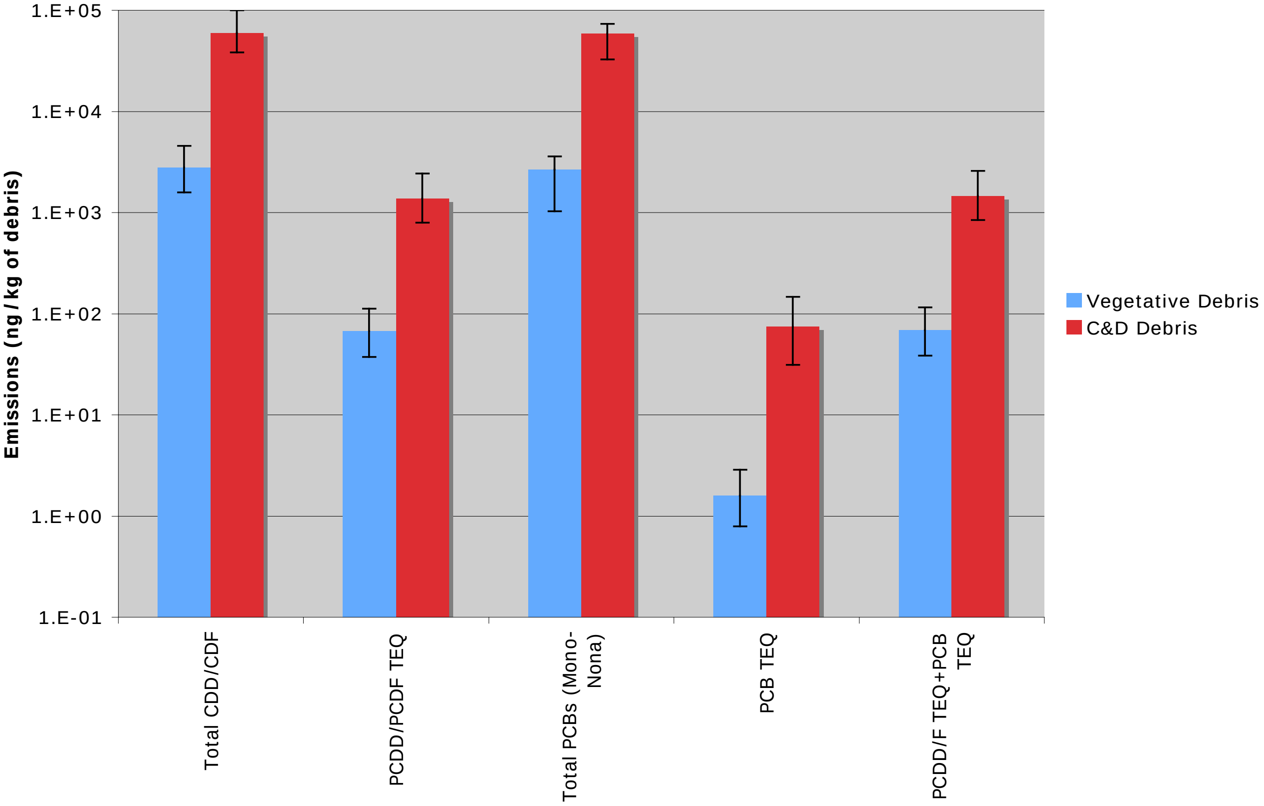


Figure 5-2. Emission Factors for PCDDs/Fs and PCBs: Vegetative Debris vs. C&D Debris (Error bars represent the range of data)

5.2 Dioxins and PCBs

Table 5-2 lists the emission rates and estimated emission factors for dioxins and PCBs, both in terms of total emissions and emissions in terms of the WHO 1998 TEQ values. Figure 5-2 illustrates these results graphically. In terms of TEQ, the emission factors from vegetative debris were slightly higher than published literature from combustion of biomass in forest fires (Gullett and Touati, 2003, UNEP, 2005) and slightly lower than combustion of trash in burn barrels (Lemieux et al., 2003). The emissions of these chlorinated organic compounds from C&D debris were significantly higher than from the vegetative debris. One possible explanation for the PCDD/F levels from the vegetative debris burns being elevated over that of forest fires and other agricultural burning is that the vegetative debris used in these tests had sat for an unknown period of time in brackish water prior to being dried out and brought to the test site. It is not necessary to have an organic source of chlorine to form PCDD/F (Preto et al., 2005, Wikstrom and Marklund, 2001), although in the case of the C&D debris, the presence of plastics (possibly chlorinated) and household wiring (which commonly has polyvinyl chloride insulation) were visually observed. Another possible explanation is that the time-temperature history in an ACD is more amenable to PCDD/F formation. It is not possible to determine which explanation is more likely, although the presence of chlorophenols in the emissions from the vegetative burns where chlorophenols are not a likely air pollutant from the combustion of clean wood (Lemieux et al., 2004), does suggest that there were elevated levels of potential precursors for PCDD/F formation (Altarawneh et al., 2009, Briois et al., 2007) in the emissions from burning the vegetative debris used in these tests. Section 5.8.5 includes a discussion of the statistical significance of differences in PCCD/F emissions between the Veg and C&D test conditions.

5.3 Metals

Table 5-3 lists the emission rates and estimated emission factors for airborne metals. It should be noted that arsenic is normally present in negligible quantities in virgin wood (Zhurinsh et al., 2005). The fact that arsenic emissions were observed in the effluent from the ACB suggests that the environment that the wood was exposed to (which included sediments from the storm) may have impacted As emissions. Figure 5-3 shows the results in graphical format. Mercury was not detected from the vegetative debris runs and selenium was not detected in the C&D debris runs. The C&D airborne metal results appeared to be consistently higher than from the vegetative debris. Section 5.8.1 includes a discussion of the statistical significance of differences in metal emissions between the Veg and C&D test conditions.

5.4 Particulate Matter and Acid Gases

Filterable PM measurements were made using two different sampling methods: one specifically directed at PM (Method 5/202), and the other on the filter used in the hydrogen halide acid gas sampling train (Method 26). Both are presented here. Emissions rates and estimated emission factors for the Method 5/202 sampling train are shown in Table 5-4. Emissions rates and estimated emission factors for the Method 26 sampling train are shown in Table 5-5. HCl emissions were significantly higher for the C&D debris. Other species, with the exception of Br_2, were about a factor of 2 higher for the C&D debris burns. Br_2 emissions were about the same for both feed types. Figures 5-4 and 5-5 show the same data in graphical form. Section 5.8.3 includes a discussion of the statistical significance of differences in PM and acid gas emissions between the Veg and C&D test conditions.

5.5 Semivolatile Organic Compounds (SVOCs)

Table 5-6 lists the emissions rates and estimated emission factors for SVOC target analytes that were identified at levels above the detection limit. Table 5-7 lists the emission rates and estimated emission factors for PAHs. Note that some of the target analytes for the SVOC analysis were also target analytes for the PAH analysis. However, the PAH analytical method is more specific and accurate for those analytes than the general SVOC method. In general, SVOC emissions were higher from C&D debris. Section 5.8.4 includes a discussion of the statistical significance of differences in SVOC emissions between the Veg and C&D test conditions.

5.6 Volatile Organic Compounds (VOCs)

Table 5-8 lists the VOC results for target analytes that were present above the detection limits. In general, the VOC emissions from C&D debris appeared to be higher than the emissions from vegetative debris. However, for most compounds this difference may not be statistically significant.

5.7 Asbestos

Conversion of asbestos results in Table 4-28 into emission rates and estimated emission factors yields the results in Table 5-9. Great care must be taken in using these values, however, since these values are essentially derived by extrapolating a small number of fibers in a sampling train to a large volume of gas and debris feed. The analytical results thus range from 1.0x to 2.7x the limit of detection of the method as expressed in ISO 10312 which is based on 2.99 fibers per sample. For the PCME fraction, the analytical results are all less than or equal to one-third of the limit of detection. Therefore, while the results are extrapolated by calculation of all factors into what appears to be a quite high concentration of structures/hour, the basis of this result is in fact a numerically very few fibers found by TEM analysis.

Table 5-3. Emission Rates and Estimated Emission Factors for Airborne Metals

	Emission Rate (mg/hr)						**Emission Factor (µg/kg debris)**					
	Veg Run 1	**Veg Run 2**	**Veg Run 3**	**C&D Run 1**	**C&D Run 2**	**C&D Run 3**	**Veg Run 1**	**Veg Run 2**	**Veg Run 3**	**C&D Run 1**	**C&D Run 2**	**C&D Run 3**
Antimony	735	2278	284	22150	56483	2819	169	523	46	3299	6767	661
Arsenic	5099	765	14332	12155	2122	98791	1171	176	2323	1811	254	23169
Barium	1022	1214	2058	5212	9525	3174	235	279	334	776	1141	744
Beryllium	3.2	5.6	3.5	7.4	10	ND	0.7	1.3	0.6	1.1	1.2	ND
Cadmium	455	711	890	4609	9629	3500	104	163	144	687	1154	821
Chromium	2901	3585	1589	2569	4011	25444	666	823	258	383	481	5967
Cobalt	ND	ND	4181	ND	ND	241	ND	ND	678	ND	ND	57
Lead	7731	12882	7308	181854	152520	255198	1775	2958	1185	27089	18274	59852
Manganese	2760	5116	8677	17106	11397	10868	634	1175	1407	2548	1366	2549
Mercury	ND	ND	ND	763	1454	229	ND	ND	ND	114	174	54
Nickel	3016	4863	1838	3592	3660	17585	693	1117	298	535	438	4124
Selenium	96	ND	ND	ND	ND	ND	22	ND	ND	ND	ND	ND

Silver	77	93	43	112	150	165	18	21	6.9	17	18	39

ND – not detected

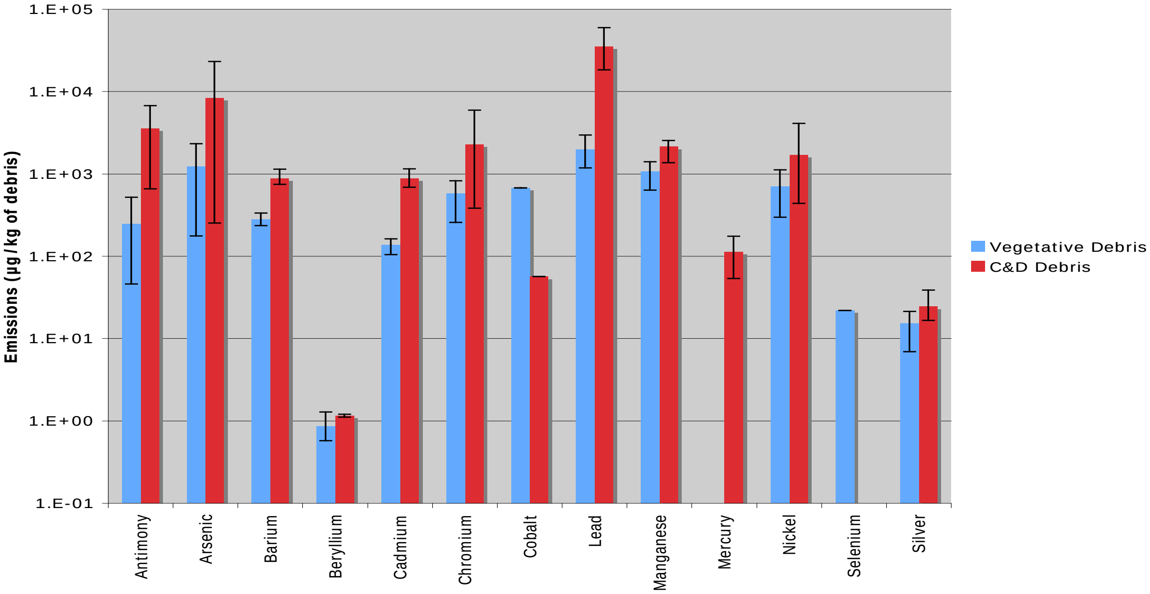


Figure 5-3. Emission Factors for Airborne Metals: Vegetative Debris vs. C&D Debris (Error bars represent the range of data)

Table 5-4. Emission Rates and Estimated Emission Factors of Particulate Matter

	Emission Rate (g/hr)						Emission Factor (mg/kg debris)					
	Veg Run 1	**Veg Run 2**	**Veg Run 3**	**C&D Run 1**	**C&D Run 2**	**C&D Run 3**	**Veg Run 1**	**Veg Run 2**	**Veg Run 3**	**C&D Run 1**	**C&D Run 2**	**C&D Run 3**
Filterable Particulate <PM2.5	5383	10804	NA	19603	18523	14167	1236	2481	NA	2920	2219	3323
Filterable Particulate >PM2.5	2101	2024	NA	6906	9795	1534	483	465	NA	1029	1174	360
Organic Condensible Particulate	233	227	NA	1002	2321	565	54	52	NA	149	278	133
Inorganic Condensible Particulate	8081	4689	NA	14870	13138	26841	1856	1077	NA	2215	1574	6295
Total Particulate <PM2.5	13684	15741	NA	35420	33935	41532	3142	3615	NA	5276	4066	9741
Total Filterable Particulate	7471	12829	NA	26509	28318	15701	1716	2946	NA	3949	3393	3682
Total Condensible Particulate	8314	4917	NA	15816	15412	27406	1909	1129	NA	2356	1847	6427
Total Particulate	15785	17766	NA	42326	43730	43066	3625	4080	NA	6305	5240	10100

NA – Not Available

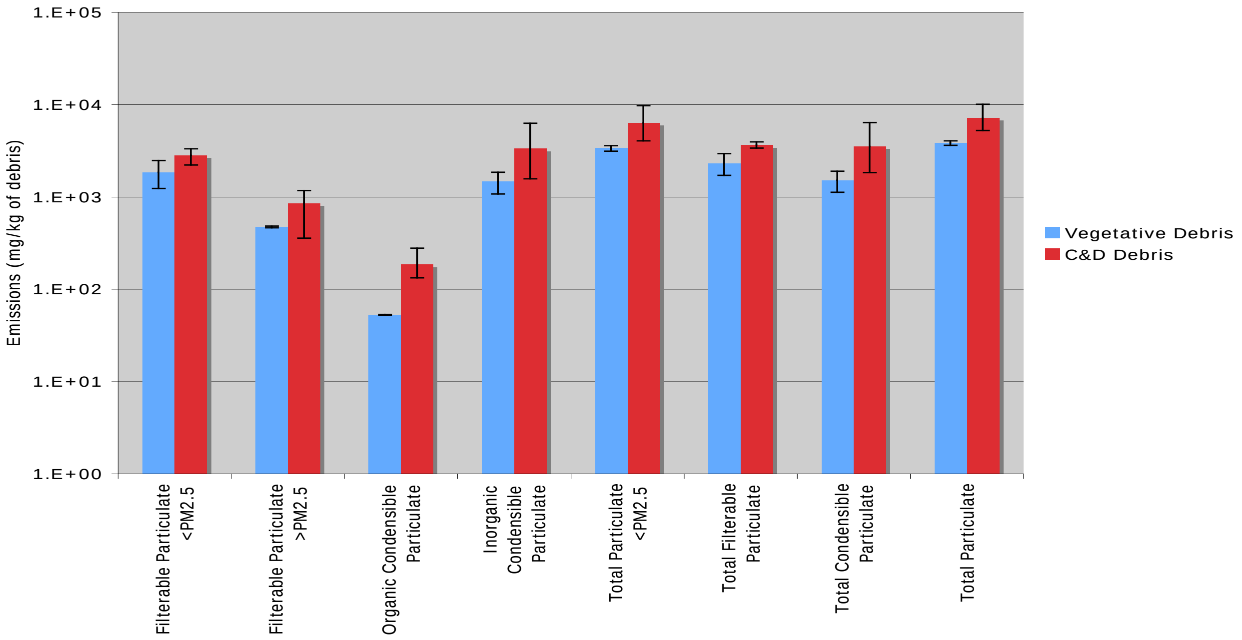


Figure 5-4. Emission Factors for Particulate Matter: Vegetative Debris vs. C&D Debris (Error bars represent the range of data)

Table 5-5. Emission Rates and Estimated Emission Factors of Filterable Particulate Matter and Acid Gases

	Emission Rate (g/hr)						Emission Factor (mg/kg debris)					
	Veg Run 1	Veg Run 2	Veg Run 3	C&D Run 1	C&D Run 2	C&D Run 3	Veg Run 1	Veg Run 2	Veg Run 3	C&D Run 1	C&D Run 2	C&D Run 3
Filterable Particulate	8507	8398	NA	21605	21150	12844	1954	1928	NA	3218	2534	3012
HCl	1097	159	NA	8015	14055	44338	252	37	NA	1194	1684	10399
HF	33	43	NA	156	274	206	7.5	10	NA	23	33	48
HBr	38	62	NA	221	228	189	9	14	NA	33	27	44
Cl2	35	51	NA	180	225	210	8	12	NA	27	27	49
Br2	15	29	NA	44	48	38	3.4	6.6	NA	6.5	5.8	9

NA – Not Available

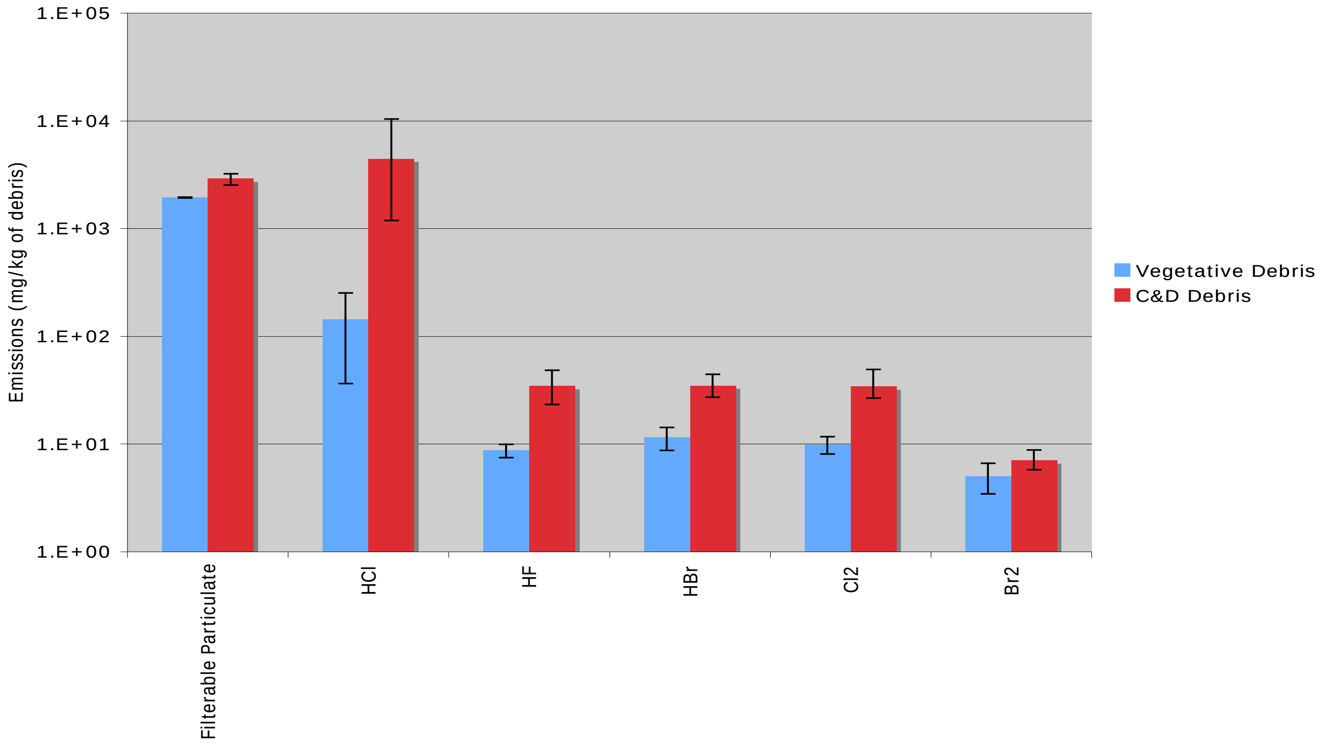


Figure 5-5. Emission Factors for Particulate Matter and Acid Gases: Vegetative Debris vs. C&D Debris (Error bars represent the range of data)

Table 5-6. Emission Rates and Estimated Emission Factors for SVOCs

	Emission Rate (mg/hr)						**Emission Factor (µg/kg debris)**					
	Veg Run 1	**Veg Run 2**	**Veg Run 3**	**C&D Run 1**	**C&D Run 2**	**C&D Run 3**	**Veg Run 1**	**Veg Run 2**	**Veg Run 3**	**C&D Run 1**	**C&D Run 2**	**C&D Run 3**
Aniline	ND	ND	ND	ND	ND	5406	ND	ND	ND	ND	ND	1268
2-Chlorophenol	ND	ND	ND	12323	27990	15057	ND	ND	ND	1836	3354	3531
1,3-Dichlorobenzene	ND	ND	ND	ND	1312	1046	ND	ND	ND	ND	157	245
1,4-Dichlorobenzene	ND	163	ND	ND	1237	987	ND	37	ND	ND	148	231
Benzyl Alcohol	3502	ND	2573	ND	15976	8916	804	ND	417	ND	1914	2091
1,2-Dichlorobenzene	ND	ND	ND	ND	ND	881	ND	ND	ND	ND	ND	207
2-Methylphenol	ND	ND	ND	ND	26875	12888	ND	ND	ND	ND	3220	3023
3 & 4-Methylphenol	ND	ND	ND	5917	46318	18981	ND	ND	ND	881	5550	4452
Nitrobenzene	ND	ND	ND	5639	83627	33363	ND	ND	ND	840	10020	7825
2-Nitrophenol	ND	ND	3388	7613	13348	9860	ND	ND	549	1134	1599	2312
2,4-Dimethylphenol	ND	ND	ND	1784	11030	5921	ND	ND	ND	266	1322	1389
Bis(2-chloroethoxy)methane	ND	ND	ND	ND	8073	ND	ND	ND	ND	ND	967	ND
2,4-Dichlorophenol	2758	ND	ND	ND	14020	9421	633	ND	ND	ND	1680	2209
1,2,4-Trichlorobenzene	ND	ND	41	ND	ND	415	ND	ND	7	ND	ND	97
Naphthalene	3023	3393	17124	41259	126608	58082	694	779	2776	6146	15169	13622
4-Chloro-3-methylphenol	ND	ND	ND	ND	ND	6015	ND	ND	ND	ND	ND	1411
2-Methylnaphthalene	1773	1620	2018	8371	19460	11044	407	372	327	1247	2332	2590
1-Methylnaphthalene	440	413	473	3192	ND	ND	101	95	77	476	ND	ND
2,4,5-Trichlorophenol	151	ND	ND	ND	ND	ND	35	ND	ND	ND	ND	ND
2-Chloronaphthalene	ND	ND	41	ND	ND	307	ND	ND	7	ND	ND	72
2-Nitroaniline	ND	ND	142	ND	10364	ND	ND	ND	23	ND	1242	ND
Dimethyl phthalate	193	ND	ND	ND	834	ND	44	ND	ND	ND	100	ND
1,3-Dinitrobezene	ND	ND	361	5454	16855	6257	ND	ND	59	812	2020	1467
Acenaphthylene	222	248	562	6898	20409	7888	51	57	91	1028	2445	1850
2,6-Dinitrotoluene	194	ND	ND	ND	ND	ND	44	ND	ND	ND	ND	ND
Acenaphthene	40	ND	ND	ND	1880	ND	9	ND	ND	ND	225	ND
4-Nitrophenol	ND	ND	ND	ND	22957	11673	ND	ND	ND	ND	2751	2738
Dibenzofuran	298	266	1030	4205	14506	5599	68	61	167	626	1738	1313
2,4-Dinitrotoluene	ND	ND	ND	ND	ND	857	ND	ND	ND	ND	ND	201
2,3,4,6-Tetrachlorophenol	ND	ND	ND	ND	ND	1847	ND	ND	ND	ND	ND	433
2,3,5,6-Tetrachlorophenol	ND	ND	ND	ND	ND	1420	ND	ND	ND	ND	ND	333
Diethylphthalate	266	ND	372	ND	814	ND	61	ND	60	ND	98	ND
Fluorene	ND	63	163	1309	6488	2302	ND	14	26	195	777	540
4,6-Dinitro-2-methylphenol	ND	ND	ND	ND	ND	866	ND	ND	ND	ND	ND	203
Azobenzene	ND	ND	ND	ND	545	ND	ND	ND	ND	ND	65	ND

	Emission Rate (mg/hr)						**Emission Factor (µg/kg debris)**					
	Veg Run 1	**Veg Run 2**	**Veg Run 3**	**C&D Run 1**	**C&D Run 2**	**C&D Run 3**	**Veg Run 1**	**Veg Run 2**	**Veg Run 3**	**C&D Run 1**	**C&D Run 2**	**C&D Run 3**
Phenanthrene	598	854	2951	11388	40396	12926	137	196	478	1696	4840	3032
Anthracene	660	1002	3257	12569	38353	13391	152	230	528	1872	4595	3141
Carbazole	ND	51	ND	175	850	ND	ND	12	ND	26	102	ND
Di-n-butyl phthalate	2450	621	490	2595	ND	1091	563	143	79	387	ND	256
Fluoranthene	185	ND	1546	5150	12114	3479	42	ND	251	767	1451	816
Pyrene	146	ND	1250	4672	10433	2859	33	ND	203	696	1250	671
Benzyl butyl phthalate	ND	ND	ND	633	ND	ND	ND	ND	ND	94	ND	ND
Benz[a]anthracene	ND	ND	ND	ND	3114	1132	ND	ND	ND	ND	373	265
Chrysene	ND	ND	ND	ND	11600	5475	ND	ND	ND	ND	1390	1284
Bis(2-ethylhexyl) phthalate	1826	775	673	4866	101527	5976	419	178	109	725	12164	1402
Di-n-octyl phthalate	2726	ND	ND	ND	ND	296	626	ND	ND	ND	ND	69
Dibenz[a,h]anthracene	ND	ND	ND	ND	243	ND	ND	ND	ND	ND	29	ND

ND – Not Detected

Table 5-7. Emission Rates and Estimated Emission Factors for PAHs

	Emission Rate (mg/hr)						**Emission Factor (µg/kg debris)**					
	Veg Run 1	Veg Run 2	Veg Run 3	C&D Run 1	C&D Run 2	C&D Run 3	Veg Run 1	Veg Run 2	Veg Run 3	C&D Run 1	C&D Run 2	C&D Run 3
Naphthalene	4225	7063	15032	39630	54227	29339	970	1622	2437	5903	6497	6881
2-Methylnaphthalene	712	1290	1310	5754	13923	8911	163	296	212	857	1668	2090
Acenaphthylene	546	711	1472	12810	22961	13093	125	163	239	1908	2751	3071
Acenaphthene	62	97	45	557	2589	1138	14	22	7.2	83	310	267
Fluorene	120	219	619	2912	8439	4373	27	50	100	434	1011	1026
Phenanthrene	835	1464	4813	12910	23083	13230	192	336	780	1923	2766	3103
Anthracene	81	125	224	1761	6644	2543	19	29	36	262	796	596
Fluoranthene	302	517	2636	6345	10088	5025	69	119	427	945	1209	1178
Pyrene	189	311	1018	2672	3066	1775	44	71	165	398	367	416
Benzo(a)Anthracene	26	52	155	1071	2430	1392	5.9	12	25	160	291	326
Chrysene	49	94	372	1361	2724	1570	11	22	60	203	326	368
Benzo(b)Fluoranthene	36	64	345	1521	2809	1419	8	15	56	227	337	333
Benzo(k)Fluoranthene	11	22	129	525	870	446	2.5	4.9	21	78	104	105
Benzo(e)Pyrene	19	34	169	908	1698	641	4.5	8	27	135	203	150
Benzo(a)Pyrene	11	10	15	405	1368	409	2.5	2.2	2.5	60	164	96
Perylene	1.7	1.0	0.1	46	194	32	0.4	0.2	0.02	6.8	23	7.6
Indeno(1,2,3-cd)Pyrene	13	25	124	775	1087	470	2.9	5.8	20	115	130	110
Dibenzo(a,h)Anthracene	2.2	3.6	15	101	293	145	0.5	0.8	2.4	15	35	34
Benzo(ghi)Perylene	15	26	95	715	1181	404	3.4	5.9	15	106	142	95

Table 5-8. Emission Rates and Estimated Emission Factors for VOCs

	Emission Rate (mg/hr)						**Emission Factor (µg/kg debris)**					
	Veg Run 1	**Veg Run 2**	**Veg Run 3**	**C&D Run 1**	**C&D Run 2**	**C&D Run 3**	**Veg Run 1**	**Veg Run 2**	**Veg Run 3**	**C&D Run 1**	**C&D Run 2**	**C&D Run 3**
Dichlorodifluoromethane	NA	NA	ND	1553	ND	994	NA	NA	ND	231	ND	233
Chloromethane	NA	NA	4935	18706	ND	100897	NA	NA	800	2786	ND	23663
Vinyl chloride	NA	NA	ND	4691	17241	34807	NA	NA	ND	699	2066	8163
1,3-Butadiene	NA	NA	1149	23255	129294	117735	NA	NA	186	3464	15491	27613
Bromomethane	NA	NA	ND	5495	ND	6182	NA	NA	ND	819	ND	1450
Trichloromonofluoromethane	NA	NA	556	1592	1327	1153	NA	NA	90	237	159	271
1,1-dichloroethene	NA	NA	349	ND	ND	570	NA	NA	57	ND	ND	134
Ethanol	NA	NA	11276	10818	ND	14427	NA	NA	1828	1612	ND	3384
Carbon disulfide	NA	NA	20284	24420	ND	24346	NA	NA	3288	3638	ND	5710
Isopropyl alcohol	NA	NA	243	ND	ND	ND	NA	NA	39	ND	ND	ND
Methylene chloride	NA	NA	3631	25844	28084	7134	NA	NA	589	3850	3365	1673
Acetone	NA	NA	21401	72130	319357	53573	NA	NA	3469	10744	38264	12564
Vinyl acetate	NA	NA	ND	1775	1413	1525	NA	NA	ND	264	169	358
Chloroform	NA	NA	ND	ND	1787	882	NA	NA	ND	ND	214	207
Ethyl Acetate	NA	NA	ND	4326	4950	11197	NA	NA	ND	644	593	2626
Tetrahydrofuran	NA	NA	ND	969	1935	2209	NA	NA	ND	144	232	518
Carbon Tetrachloride	NA	NA	ND	ND	ND	1472	NA	NA	ND	ND	ND	345
2-Butanone	NA	NA	ND	14966	ND	33731	NA	NA	ND	2229	ND	7911
Heptane	NA	NA	4496	1531	10362	ND	NA	NA	729	228	1241	ND
Benzene	NA	NA	220079	157106	508089	346581	NA	NA	35675	23402	60876	81284
Trichloroethylene	NA	NA	664	1354	12661	1080	NA	NA	108	202	1517	253
1,4-dioxane	NA	NA	435	999	740	ND	NA	NA	70	149	89	ND
Toluene	NA	NA	18040	28197	97090	85395	NA	NA	2924	4200	11633	20028
4-Methyl-2-pentanone	NA	NA	519	1172	1257	ND	NA	NA	84	175	151	ND
Tetrachloroethylene	NA	NA	839	2247	4947	ND	NA	NA	136	335	593	ND
Ethylbenzene	NA	NA	1195	4674	10203	12713	NA	NA	194	696	1222	2982
Chlorobenzene	NA	NA	1016	1982	5186	7241	NA	NA	165	295	621	1698
m/p-Xylene	NA	NA	2008	9760	13538	19888	NA	NA	326	1454	1622	4664
o-Xylene	NA	NA	761	3715	5496	7596	NA	NA	123	553	659	1781
Styrene	NA	NA	5123	18045	37396	110024	NA	NA	830	2688	4481	25804
Tribromomethane	NA	NA	ND	ND	2368	ND	NA	NA	ND	ND	284	ND
1-ethyl-4-methylbenzene	NA	NA	ND	3439	ND	5106	NA	NA	ND	512	ND	1197
1,3,5-trimethylbenzene	NA	NA	375	ND	ND	ND	NA	NA	61	ND	ND	ND
1,2,4-trimethylbenzene	NA	NA	520	3857	2124	3834	NA	NA	84	574	254	899
Benzyl chloride	NA	NA	ND	3680	ND	62300	NA	NA	ND	548	ND	14611
1,2-dichlorobenzene	NA	NA	ND	ND	ND	1444	NA	NA	ND	ND	ND	339

NA – Not Available; ND – Not Detected

Table 5-9. Emission Rates and Estimated Emission Factors for Asbestos

	Emission Rate (structures/hr)			**Emission Factor (structures/kg debris)**		
	C&D Run 1	**C&D Run 2**	**C&D Run 3**	**C&D Run 1**	**C&D Run 2**	**C&D Run 3**
Based on Total Structures	3.3E+09	1.4E+09	6.1E+08	5.0E+05	1.7E+05	1.4E+05
Based on PCME	4.2E+08	4.6E+08	ND	6.2E+04	5.6E+04	ND
Based on Method Detection Limit	1.2E+09	1.4E+09	6.1E+08	1.8E+05	1.7E+05	1.4E+05

ND = Not Detected

5.8 Analysis of Variance between Vegetative Debris and C&D Debris Emission Factors

A One-Way Analysis of Variance (ANOVA) statistical analysis was performed on the emission factor data to determine whether a statistically significant difference was observed between emissions of different pollutants from burning vegetative (VEG) or C&D (CD) debris in an ACB.

There are some assumptions that must hold true for a standard ANOVA analysis to be valid. First, the data must be normally distributed; second, the variances in the conditions being investigated must be equal. Unfortunately, with a maximum of only three data points, one cannot adequately assess the validity of these assumptions. However, even with only three observations, the data do suggest that there is a difference between the variability exhibited by the VEG and CD emissions and that a normality assumption is problematic.

Because of this, a standard ANOVA was not utilized, and a nonparametric analysis (hereafter referenced as HL) was performed by Alion Science and Technology, Inc. to analyze the data for differences between the test conditions. The difference between the CD and VEG emissions levels was estimated (as CD minus VEG) using Hodges-Lehmann estimates (Hodges and Lehmann, 1963, Hollander and Wolfe, 1973). Briefly, these estimates are formed by calculating all possible differences for the given chemical and using the median of these differences as the estimate. The differences were also used to provide a 90% confidence interval for this difference (Hollander and Wolfe, 1973). One may utilize the confidence intervals for a formal statistical significance test as follows. If the number 0 lies outside the confidence interval, then the VEG and CD emissions are statistically significantly different at the 10% level. (N. B., The reader will note that many of the confidence intervals displayed below contain 0 as one of the bounds. The decision to declare statistical significance only if 0 is strictly outside the confidence interval is conservative. This was deemed appropriate for this experiment because only three samples, at most, were available for either VEG or CD, and here the value of 0 for the difference resulted from at least one sample for both VEG and CD being below the detection limit.)

However, it is more intuitive to give more focus to the estimate itself, rather than formal significance testing for these data. The reason for this is that the small sample size of 3 forced the use of the maximum difference as the upper bound and the minimum difference for the lower bound. These extremes are valid statistics, but they are inherently very variable. On the other hand, the estimate of the difference is based on the median, which is more stable. Therefore, the statisticians who performed the HL analysis believed that the estimate of the difference is a more robust quantity for this data set than the confidence interval.

Note that when the VEG sample size was below 3 (as for VOCs and the particulates and acid gases) a confidence interval was not even formed. A sample size of 3 for both CD and VEG was required for a 90% confidence interval, and the fact that only three observations (maximum) were available precluded using a tighter confidence interval (say 95%).

While these estimates provide some insight in terms of absolute differences between CD and VEG, the relative difference was also examined. This was done by simply taking the ratio of the median CD value to the median VEG value. Based on observations of variability between duplicate conditions, the heterogeneity of the feed materials, and the batch nature of the process, in the opinion of the authors, any difference in the ratio of median values less than 2 indicates a negligible difference between the two conditions, and only a marginal difference with ratios of median values up to 4. In addition, below detection limit (BDL) counts were made for each chemical species for both VEG and CD.

5.8.1 Metals

Of all the metal target analytes, antimony, barium, cadmium, lead, and mercury showed a statistically significant difference between the two feed types. The analytes with the largest difference between VEG and CD conditions were mercury (with the ratio of the medians being undefined since no mercury was detected in the VEG runs), antimony (with the ratio of the medians equal to 19.6), and lead (with the ratio of the medians equal to 15.3). Table 5.10 lists the results from the HL analysis of the metals emission factors, with only the analytes with a significant difference between the VEG and CD not being grayed out.

5.8.2 PAHs

All of the PAHs were significantly higher from C&D debris combustion than from vegetative debris combustion. The ratio of the median values ranged from a high of 41.1 for Dibenzo(a,h)Anthracene to a low of 4.0 for Naphthalene. Table 5.11 summarizes the results from the HL analysis of the PAH emission factors. Note that none of the rows are grayed out, indicating that all PAHs were significantly higher for C&D debris.

5.8.3 Particulate and Acid Gases

It was not possible to determine confidence intervals for the PM and Acid Gas measurements because only two VEG data points were available. However, based on the ratio of the medians, the PM was not significantly higher for the CD condition than it was for the VEG condition, except possibly the organic condensables, with a ratio of medians of only 2.8. The acid gases, other than HCl, which showed a ratio of medians of 11.7, only showed a marginal difference between the VEG and CD cases. Table 5.12 lists the results from the HL analysis of the PM and acid gas emission factors, with only the analytes with a significant difference between the VEG and CD not being grayed out.

Table 5.10. Results from Analysis of Metals Emission Factors.

Name	Difference Estimate (CD – VEG)	Med CD / Med VEG	90% CI Lower Bound	90% CI Upper Bound	VEG BDL	CD BDL
Antimony	3130.7	19.55	137.9	6721.4	0	0
Arsenic	639.6	1.55	-2069	22993.7	0	0
Barium	509.6	2.79	410.9	906.5	0	0
Beryllium	-0.1	1.51	-1.3	0.6	0	1
Cadmium	676.7	5.69	523.1	1049.2	0	0
Chromium	125	0.72	-440.6	5709.7	0	0
Cobalt	0	*	-677.8	56.6	2	2
Lead	25313.3	15.26	15315.8	58667.1	0	0
Manganese	1142.3	2.17	-41.1	1915	0	0
Mercury	113.7	*	53.6	174.2	3	0
Nickel	140.6	0.77	-678.4	3826.2	0	0
Selenium	0	*	-22	0	2	3
Silver	9.7	1.02	-4.8	31.8	0	0

* Ratio Undefined Because Median VEG = 0.

Table 5.11. Results from Analysis of PAH Emission Factors.

Name	Difference Estimate (CD – VEG)	Med CD / Med VEG	90% CI Lower Bound	90% CI Upper Bound	VEG BDL	CD BDL
Naphthalene	4875.1	4.01	3466.4	5910.7	0	0
2-Methylnaphthalene	1455.9	7.86	561	1926.6	0	0
Acenaphthylene	2587.7	16.84	1669.5	2945.3	0	0
Acenaphthene	252.6	18.62	60.8	303	0	0
Fluorene	925.3	20.15	333.4	998.2	0	0
Phenanthrene	2322.6	8.23	1142.7	2911.1	0	0
Anthracene	567.7	20.71	226.1	777.6	0	0
Fluoranthene	875.8	9.93	517.9	1139.4	0	0
Pyrene	323.8	5.57	202.3	372.9	0	0
Benzo(a)Anthracene	279.2	24.29	134.4	320.5	0	0
Chrysene	304.8	15.17	142.5	357	0	0
Benzo(b)Fluoranthene	280.6	22.65	170.6	328.4	0	0
Benzo(k)Fluoranthene	83.7	21.05	57.5	102	0	0
Benzo(e)Pyrene	142.5	19.29	107.8	198.9	0	0
Benzo(a)Pyrene	93.5	39.08	57.9	161.7	0	0
Perylene	7.4	32.03	6.4	23.3	0	0
Indeno(1,2,3-cd)Pyrene	109.6	19.91	90	127.3	0	0
Dibenzo(a,h)Anthracene	32.7	41.13	12.7	34.6	0	0
Benzo(ghi)Perylene	100.6	18.15	79.3	138.1	0	0

Table 5.12. Results from Analysis of Particulate and Acid Gas Emission Factors.

Name	Difference Estimate (CD – VEG)	Med CD / Med VEG	90% CI Lower Bound	90% CI Upper Bound	VEG BDL	CD BDL
M5 Filterable Particulate	1071.3	1.55	-	-	0†	0
HCl	1539.7	11.67	-	-	0†	0
HF	24.1	3.76	-	-	0†	0
HBr	21.5	2.87	-	-	0†	0
Cl2	18.8	2.73	-	-	0†	0
Br2	2.3	1.30	-	-	0†	0
Filterable Particulate <PM2_5	912.3	1.57	-	-	0†	0
Filterable Particulate >PM2_5	554.9	2.17	-	-	0†	0
Organic Condensable Particulate	96.4	2.82	-	-	0†	0
Inorganic Condensable Particulate	817.6	1.51	-	-	0†	0
Total Particulate <PM2_5	1897.4	1.56	-	-	0†	0
Total Filterable Particulate	1340.0	1.58	-	-	0†	0
Total Condensable Particulate	972.2	1.55	-	-	0†	0
Total Particulate	2452.3	1.64	-	-	0†	0

† Only two observations of Veg were provided.

5.8.4 SVOCs

In spite of the large number of SVOCs that were identified and quantified, the majority of the target analytes did not show a statistically significant difference between the two debris types. Other than 2-chlorophenol and some nitro-substituted aromatics most of those targets that showed a statistically significant difference between the VEG and CD were already targets in the PAH analysis. Other SVOCs of interest, particularly the chlorinated benzenes, did not show a statistically significant difference. Table 5.13 lists the results from the HL analysis of the SVOC emission factors, with only the analytes with a significant difference between the VEG and CD not being grayed out.

Table 5.13. Results from Analysis of SVOC Emission Factors.

Name	Difference Estimate (CD – VEG)	Med CD / Med VEG	90% CI Lower Bound	90% CI Upper Bound	VEG BDL	CD BDL
Aniline	0	*	0	1267.8	3	2
2-Chlorophenol	3353.7	*	1835.6	3531.2	3	0
1,3-Dichlorobenzene	157.1	*	0	245.2	3	1
1,4-Dichlorobenzene	148.2	*	-37.3	231.5	2	1
Benzyl-Alcohol	1286.9	4.59	-804.2	2091.1	1	1
1,2-Dichlorobenzene	0	*	0	206.6	3	2
2-Methylphenol	3022.6	*	0	3220	3	1
3-and-4-Methylphenol	4451.7	*	881.4	5549.5	3	0
Nitrobenzene	7824.5	*	840	10019.7	3	0
2-Nitrophenol	1599.3	*	584.8	2312.4	2	0
2,4-Dimethylphenol	1321.6	*	265.7	1388.5	3	0
Bis(2-chloroethoxy)methane	0	*	0	967.3	3	2
2,4-Dichlorophenol	1576.2	*	-633.3	2209.5	2	1
1,2,4-Trichlorobenzene	0	*	-6.7	97.3	2	2
Naphthalene	12393.7	17.49	3370.1	14475.2	0	0
4-Chloro-3-methylphenol	0	*	0	1410.6	3	2
2-Methylnaphthalene	1959.5	6.27	839.7	2262.8	0	0
1-Methylnaphthalene	-76.7	0.00	-101.1	398.8	0	2
2,4,5-Trichlorophenol	0	*	-34.8	0	2	3
2-Chloronaphthalene	0	*	-6.7	71.9	2	2
2-Nitroaniline	0	*	-23.1	1241.7	2	2
Dimethylphthalate	0	*	-44.4	99.9	2	2
1,3-Dinitrobezene	1467.4	*	753.8	2019.5	2	0
Acenaphthylene	1793	32.43	936.5	2394.2	0	0
2,6-Dinitrotoluene	0	*	-44.5	0	2	3
Acenaphthene	0	*	-9.1	225.3	2	2
4-Nitrophenol	2737.6	*	0	2750.5	3	1
Dibenzofuran	1244.7	19.21	459.5	1676.8	0	0
2,4-Dinitrotoluene	0	*	0	201	3	2
2,3,4,6-Tetrachlorophenol	0	*	0	433.1	3	2
2,3,5,6-Tetrachlorophenol	0	*	0	333.1	3	2
Diethylphthalate	0	0.00	-61.2	97.5	1	2
Fluorene	525.6	37.49	168.5	777.4	1	0
4-Nitroaniline	0	*	-37.3	0	2	3
4,6-Dinitro-2-methylphenol	0	*	0	203	3	2
Azobenzene	0	*	0	65.3	3	2
Phenanthrene	2835.6	15.47	1218	4702.7	0	0

Name	**Difference Estimate (CD – VEG)**	**Med CD / Med VEG**	**90% CI Lower Bound**	**90% CI Upper Bound**	**VEG BDL**	**CD BDL**
Anthracene	2910.5	13.65	1344.3	4443.7	0	0
Carbazole	26	*	-11.6	101.9	2	1
Di-n-butylphthalate	-79.5	1.79	-562.6	307	0	1
Fluoranthene	773.5	19.24	516.5	1451.4	1	0
Pyrene	670.5	20.81	467.9	1250.1	1	0
Benzylbutylphthalate	0	*	0	94.4	3	2
Benz[a]anthracene	265.4	*	0	373.1	3	1
Chrysene	1284.1	*	0	1389.8	3	1
Bis(2-ethylhexyl)phthalate	1223.6	7.87	305.5	12055.4	0	0
Di-n-octylphthalate	0	*	-625.9	69.4	2	2
Dibenz[a,h]anthracene	0	*	0	29.1	3	2

5.8.5 Dioxins, Furans, and PCBs

The HL analysis of the dioxins, furans, and PCBs showed a statistically significant difference between the VEG and CD conditions. The ratios of the medians ranged from 40.4 for the PCB TEQ down to 17.7 for the Total CDD/CDF and the PCDD/PCDF TEQ. The fact that chlorophenols (see the SVOC section) were significantly higher for the C&D debris than for the vegetative debris is consistent with the observation of the higher dioxins and furans from the C&D debris, since chlorinated phenols are considered precursors in the formation process for dioxins and furans (Altarawneh et al., 2009, Briois et al., 2007). Table 5.14 lists the results from the HL analysis of the dioxin, furan, and PCB emission factors. No rows are grayed out for these analytes indicating that all analytes showed a statistically significant difference between the test conditions.

Table 5.14. Results from Analysis of Dioxin, Furan, and PCB Emission Factors.

Name	**Difference Estimate (CD – VEG)**	**Med CD / Med VEG**	**90% CI Lower Bound**	**90% CI Upper Bound**	**VEG BDL**	**CD BDL**
Total CDD/CDF	38302.1	17.71	33825.2	98381.1	0	0
PCDD/PCDF TEQ	867.1	17.69	684.9	2388.5	0	0
Total PCBs (Mono-Nona)	67056.6	20.86	28918.2	72137.2	0	0
PCB TEQ	43.9	40.36	28.3	146.4	0	0
PCDD/F TEQ+PCB TEQ	897.4	18.01	727	2534.6	0	0

5.8.6 VOCs

Because there was only 1 VOC run it was not possible to perform the HL analysis of the VOCs.

5.8.7 Fixed Combustion Gases

Of the combustion gas samples acquired with the CEMs, CO, SO_2, and THC showed a statistically significant increase for the C&D debris over the vegetative debris. NO_x did not exhibit a statistically significant difference. Table 5.15 lists the results from the HL analysis of the fixed combustion gas emission factors, with only the analytes with a significant difference between the VEG and CD not being grayed out.

Table 5.15. Results from Analysis of Fixed Combustion Gas Emission Factors.

Name	Difference Estimate (CD – VEG)	Med CD / Med VEG	90% CI Lower Bound	90% CI Upper Bound	VEG BDL	CD BDL
CO	5756	2.45	2559	8966	0	0
NOx (as NO)	104	1.14	-181	660	0	0
SO_2	1365	5.47	999	4177	0	0
THC (as propane)	1057	6.50	367	1146	0	0

5.9 Comparison Between ACB Technology and Other Combustion Sources

In an effort to put the emissions of pollutants of interest from ACBs into perspective with other, more familiar combustion sources, emission factors for CO, total filterable PM, and PCDD/F (in TEQ units) were compared. Combustion sources that were used in this comparison included coal and wood-fired boilers, municipal solid waste combustors, and common open burning sources including forest fires, open burning of land clearing debris and domestic waste, and landfill fires. The summary of these comparisons can be found in Table 5.16.

Table 5.16. Comparison of Emission Factors of Various Combustion Sources

Source	CO (mg/kg)	Filterable PM (mg/kg)	PCDD/F (ng TEQ/kg)	Reference
Bituminous Coal Spreader Stoker with cyclones	2500	8500	0.3	(U.S. EPA, 1995a, UNEP, 2005)
Wood-Fired Boiler, no controls	3869	2386	0.8	(U.S. EPA, 1995a, UNEP, 2005)
Residential Woodstove	115400	15300	1.5	(U.S. EPA, 1995a, UNEP, 2005)
Municipal Waste Combustor, Well Controlled	232	31	0.5	(U.S. EPA, 1995a, UNEP, 2005)
Open Burning, Forest Residues	70000	8500	0.5	(U.S. EPA, 1995a, UNEP, 2005)
Forest Fires	114000	16600	5.0	(Lemieux et al., 2004, UNEP, 2005)
Open Burning, Domestic Waste in Barrels	42000	8000	300	(Lemieux et al., 2004, UNEP, 2005)
Landfill Fires	NA	NA	1000	(UNEP, 2005)
Air Curtain Burner, Vegetative Debris	3429	3852	69	
Air Curtain Burner, C&D Debris	9189	7215	1455	

NA – no data were available

A graphical comparison of these sources can be found in Figures 5.6 through 5.8, showing CO, PM, and PCDD/F, respectively. In the case of CO, emissions from ACBs are not quite as low as very well controlled combustion units such as the Municipal Waste Combustor, but are significantly lower than the uncontrolled sources. PM emissions from the ACBs are significantly lower than the uncontrolled combustion sources, and although they are higher than the well-controlled combustion sources, are on the same order of magnitude as some conventional stationary sources equipped with low-tech PM controls (e.g., coal-fired spreader stoker with cyclones). The PCDD/F emission factors show a wide degree of variation, with the PCDD/F emissions from ACBs burning vegetative debris being significantly higher than the well-controlled combustion sources, and slightly higher than forest fires. Note that the ACB PCDD/F emission factor burning vegetative debris resulting from hurricanes is somewhat higher than open burning of conventional vegetative debris. The vegetative debris used in the VEG runs was recovered from the Hurricane Katrina response and had sat in brackish water for an unknown period of time prior to being moved to the Old Paris Road Landfill for these tests. This likely contributed to an increase in chlorine content of the vegetative debris beyond the level that would have been present in the wood, and it is not necessary to have an organic source of chlorine in order to form PCDD/F during combustion processes (Preto et al., 2005, Wikstrom and Marklund, 2001). This increased chlorine level may have contributed to the vegetative PCDD/F emission factors being higher than forest fires. Other factors could have contributed as well, included the time-temperature environment that the gases and particles leaving the ACB were subjected to as it was emitted into the atmosphere. The fact that chlorinated phenols were identified in the emissions from the vegetative debris combustion supports the hypothesis that the increased chlorine due to sitting in brackish water may have contributed to an increase in PCDD/F emissions. Chlorinated phenols are not typical products of incomplete combustion from the combustion of clean woody material (Lemieux et al., 2004) and have been implicated as precursors in the mechanism of PCDD/F formation in combustion sources (Altarawneh et al., 2009, Briois et al., 2007). The PCDD/F emission factors from ACBs burning C&D debris are higher than uncontrolled domestic waste burning, and are on the same order of magnitude as landfill fires. It is not surprising that C&D debris has higher PCDD/F emissions than vegetative debris, since the presence of plastics (some of which was likely chlorinated) and household wiring (which frequently has polyvinyl chloride insulation) were visually observed in the C&D debris stream.

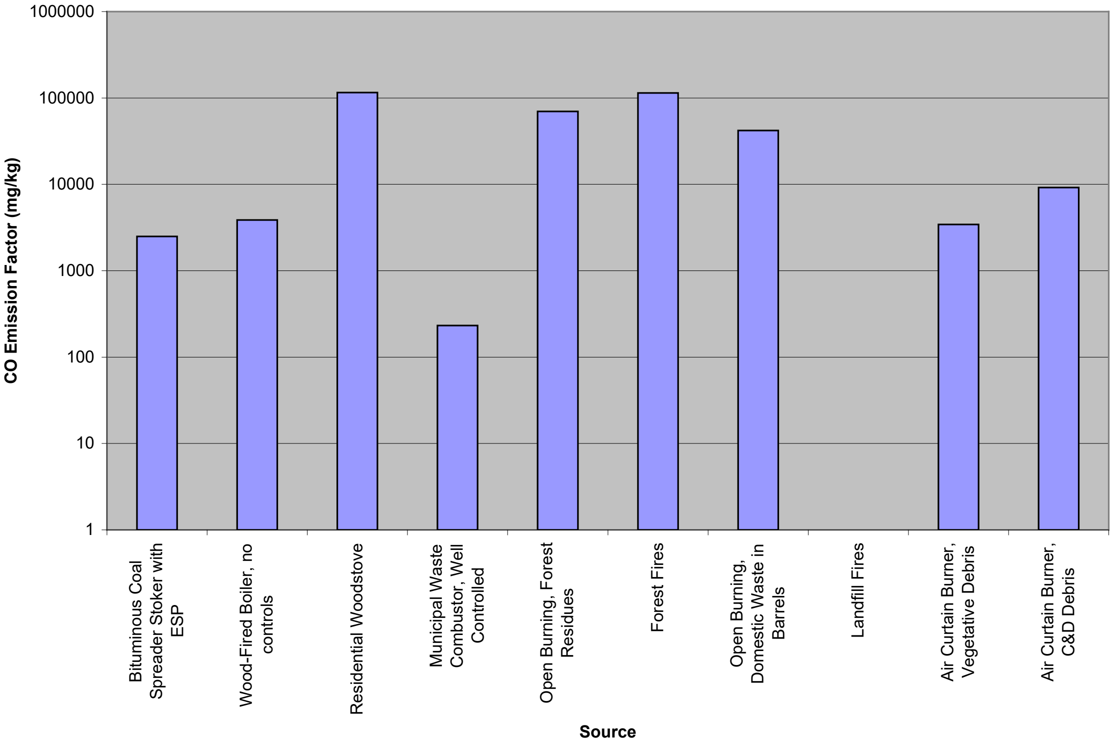


Figure 5.6. Comparison of CO Emission Factors Among Several Combustion Sources

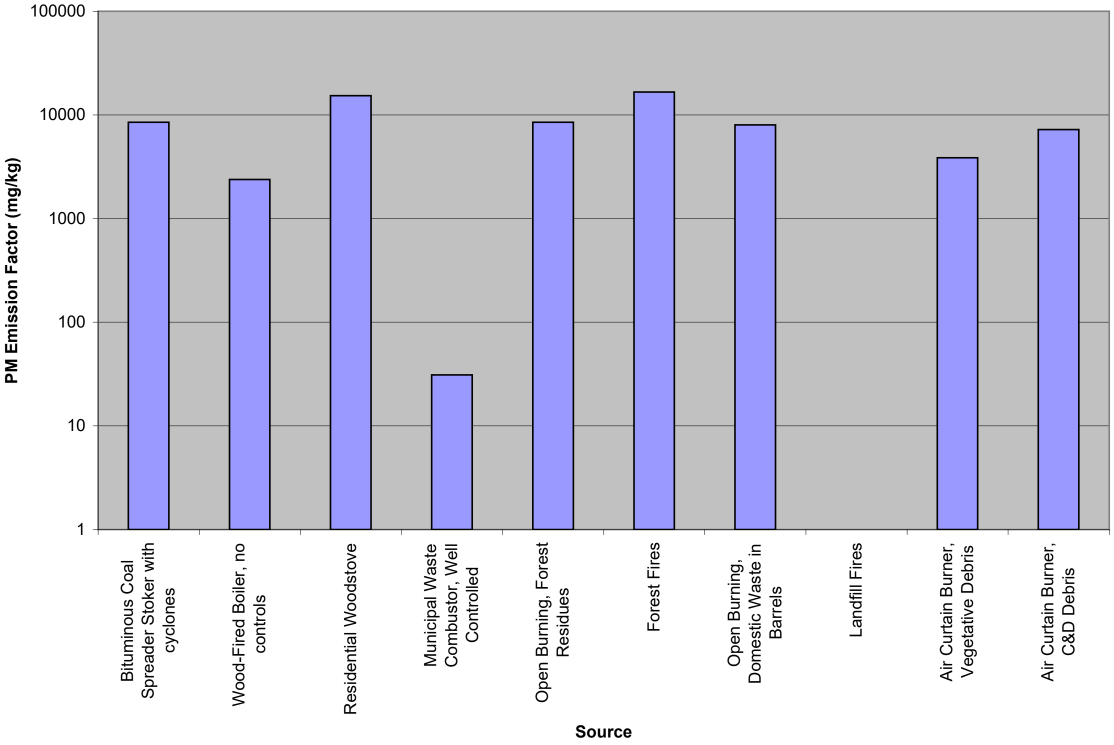


Figure 5.7. Comparison of PM Emission Factors Among Several Combustion Sources

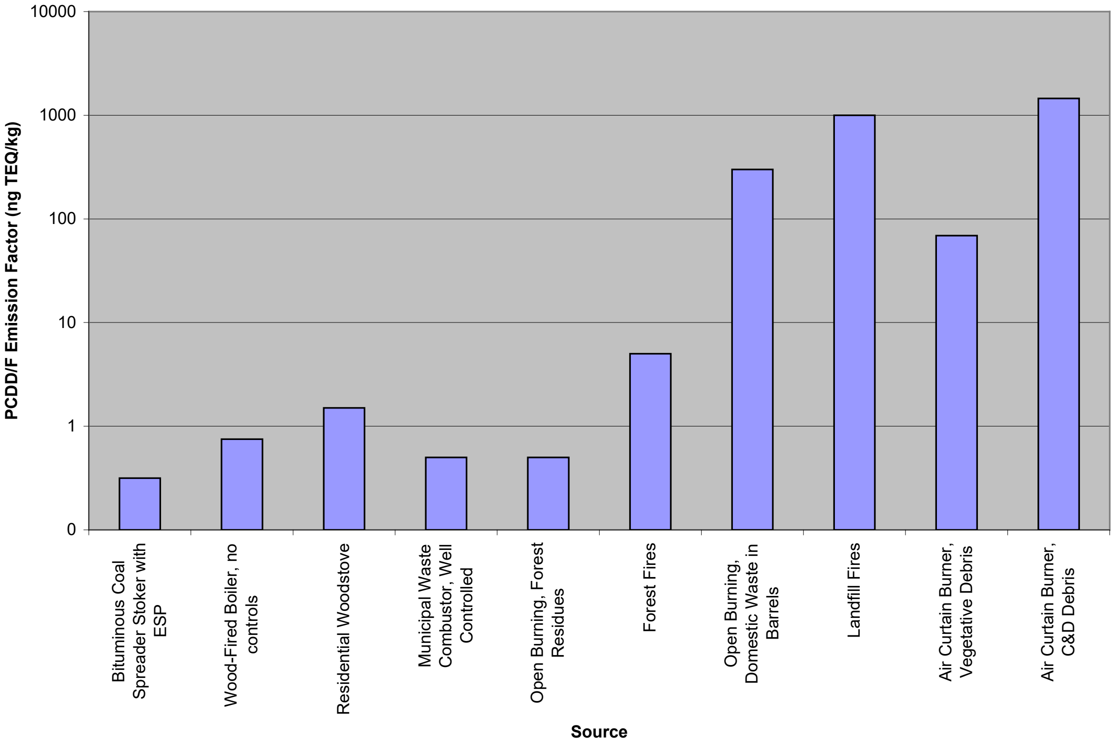


Figure 5.8. Comparison of PCDD/F Emission Factors Among Several Combustion Sources

6. Data Quality Assessment

Measurement Quality Objectives (MQOs) were established in terms of accuracy, precision and completeness for all critical measurements in the QAPP. These goals are shown in Table 6-1 and are assessed in the subsections that follow. Additional analyses were performed that were not deemed critical. The acceptance criteria for those analyses are based on the method acceptance criteria and are also assessed in this section.

Table 6-1. Measurement Quality Objectives

Measurement	Sampling Method	Sub-Parameter	Analysis Method	Acceptance Criteria (Bias/Recovery)	Completeness
Moisture	EPA Method 4	Post-test Calibration	Standard meter comparison	± 0.02% of dry gas meter pre-run calibration gamma	100%
		Balance check	Gravimetric S-Class weights	± 0.5g	N/A
CO_2/O_2	EPA Method 3A	Calibration error	Instrumental Calibration Gases	± 2%	90%
		Sampling system bias		± 5%	
		Zero & calibration drift		± 3%	
SO_2	EPA Method 6C	Calibration error	Instrumental Calibration Gases	± 2%	90%
		Sampling system bias		± 5%	
		Zero & calibration drift		±3%	
NO_X	EPA Method 7E	Calibration error	Instrumental Calibration Gases	± 2%	90%
		Sampling system bias		± 5%	
		Zero & calibration drift		± 3%	
CO	EPA Method 10	Calibration error	Instrumental Calibration Gases	± 2%	90%
		Sampling system bias		± 5%	
		Zero & calibration drift		± 3%	
VOCs	Modified EPA Method 0040	N/A	EPA Method 0040	N/A	75% (minimum 6 of 8) Precision criteria is ± 10% using duplicates

Measurement	Sampling Method	Sub-Parameter	Analysis Method	Acceptance Criteria (Bias/Recovery)	Completeness
Acid Gases	EPA Method 26A	Post-test meter calibration check	Standard Meter Comparison	± 0.5g of pre-calibration	75% (minimum 6 of 8) Precision criteria is ± 10% using duplicates
Total/Condensable Particulate	EPA Method 5/202	Post-test meter calibration check	Standard Meter Comparison	± 0.5g of pre-calibration	67% (minimum 4 of 6)
Metals	EPA Method 29	Laboratory QC Samples	EPA Method 29	± 25%	67% (minimum 4 of 6)
Asbestos	Modification of EPA Method 5 Using polycarbonate filter or distilled water for sample collection – determination made in field based on PCM analyses	Post-test meter calibration check	Standard Meter Comparison	± 0.5g of pre-calibration	100%
ACB Bed Temperature (Direct)	N/A	Calibration error	K-type thermocouple	± 3ºF	100%
ACB Bed Temperature (Remote)	N/A	Manufacturer's internal calibration check	Infrared pyrometer	± 10% of temperature range	100%

6.1 CEMs

All MQOs were met for O_2 and CO_2 (100% complete). For the remaining measurements, MQOs were met with the following exceptions:

- CO: MQO was ±2 percent for both bias and drift, a value which was slightly exceeded on 50 percent of the bias checks ranging from 2.3 to 3.3 percent. The 90 percent completeness goal was not met.

- SO_2: MQO was ±5 percent bias/±3 percent drift which was exceeded once on a pre-test bias check at -6.3 percent and once on a drift check at 3.1 percent. The 90 percent completeness goal was met.

- THC: There were no criteria in the QAPP for this measurement. Method states ±3 percent for both bias and drift. Two post-test bias checks and drift values exceeded MQO criteria ranging from 6.6 to 7.6 percent.

- NO_X: MQO for NO_X was 2 percent for both bias and drift. This bias MQO was slightly exceeded in 4 out of 6 pre-test calibration checks ranging from 2.7 to 4.1 percent. Drift MQOs were also exceeded 4 out of 6 times ranging from 2.2 to 4.0 percent. The 90 percent completeness goal was not met.

Overall, due to the huge transient fluctuations in the measurements with respect to time, these minor issues of not meeting MQOs for every instrument on every test will not adversely impact the data. This is true particularly since all MQOs for O_2 and CO_2 were met, so the dilution corrections will not introduce errors.

6.2 VOCs/TO-15

Research Triangle Park Laboratories, Inc. performed SUMMA© canister analysis. Samples were analyzed for 60 VOCs by EPA Method TO-15/GC/MS (U.S. EPA, 1999). In addition, a library search was performed for unknown VOCs using EPA/National Institute of Standards and Technology's 129,000 compound mass spectral database for TICs. Nine samples were submitted which included one field blank. The only compounds identified in the blank were:

- Methylene chloride 7.3 ppbv

- Acetone 6.6 ppbv

These compounds are common VOC contaminants. Any concentrations reported in the samples less than 10X the concentration reported in the blank are flagged as non-detects. Accuracy is assessed using recovery of internal and surrogate standards. All recoveries met method criteria. Precision is assessed by performing duplicate injections. Relative percent differences between duplicate injections met laboratory acceptance criteria. No other QC problems were noted by the laboratory. These analyses were 100 percent complete.

6.3 Acid Gases (HCl, HF, HBr, Cl_2 and Br_2) by EPA Method 26/26A

Samples were analyzed by Resolution Analytics, Inc., in Sanford, North Carolina, on July 28, 2008, several days beyond the recommended 4-week hold time for the method. This exceedance is not expected to affect the analytical results.

The field blank had a Cl_2 result of 0.217 mg compared to the following sample results:

I-ACB-M5/26A-01	0.570 mg
I-ACB-M5/26A-02	0.529 mg
II-ACB-M5/26A-01	0.958 mg
II-ACB-M5/26A-02	1.33 mg
II-ACB-M5/26A-03	1.65 mg

No analytical or data quality issues were noted by the laboratory. All calibration curves and internal audit QC results were within the laboratory control limits, as were the percent differences between the duplicate injections. Therefore, accuracy and precision goals were met. The matrix spike recoveries were also within laboratory acceptance criteria. One sample was lost prior to analysis (I-ACB-M5/M26A-03), a completeness that represents 83 percent, which meets the 75 percent goal.

6.4 Filterable and Condensable Particulate by EPA Method 5/201A/202 and Particle Sizing

Filterable particulate was determined by EPA Method 5. All weights recorded include filterable particulate catch only. The total catch reported for each run was a sum of the filter and rinse catches. The laboratory subtracted the acetone blank catch (0.2 mg) from the sample rinse catches in proportion to their respective volumes.

The Field Blank has a filterable particulate (EPA Method 5) of 5.1 mg, and the acetone blank had 0.2 mg (100 mL).

I-ACB-M5/25A-FB	**5.1 mg**
I-ACB-M5/26A-01	138.0 mg
I-ACB-M5/26A-02	87.4 mg
II-ACB-M5/26A-01	115.1 mg
II-ACB-M5/26A-02	125.2 mg
II-ACB-M5/26A-03	101.1 mg

Filterable particulate/particle sizing was determined by EPA Method 5, and no modifications were made to the method. All weights recorded include filterable particulate catch only. The total catch reported for each run was a sum of the filter catches. Acetone rinses were not sent with the dry filters and the reagent blanks from another project were used. The Field Blank had measurable results at all stages. These results are summarized in Table 6-2.

Table 6-2. Field Blank and Filterable Particulate Results

Stage ID	ACB-PM-10-FB (mg)	R1-ACB-PM-10-1 (mg)	R1-ACB-PM-10-2 (mg)	R2-ACB-PM-10-1 (mg)	R2-ACB-PM-10-2 (mg)	R2-ACB-PM-10-3 (mg)
Stage 0	0.2	3.5	0.9	1.2	2.0	17.8
Stage 1	0.1	0.8	0.1	1.0	3.2	2.8
Stage 2	0.6	1.3	2.8	3.3	5.3	3.7
Stage 3	1.4	3.6	1.2	3.1	2.0	1.9
Stage 4	1.1	3.5	3.3	4.4	1.4	1.4
Stage 5	1.1	6.4	4.7	1.2	4.8	3.1
Stage 6	1.6	9.5	7.3	9.3	3.7	10
Stage 7	0.7	20	8.5	13	3.1	21
Solid Filter Precutter Rinse	2.5	142	87	86	39	84

EPA Method 201A was used to determine PM_{10}. All weights recorded include filterable particulate catch only. The total catch reported for each run was a sum of the filter and rinse catches. The laboratory subtracted the acetone blank catch (0.2 mg/100 mL) from the sample rinse catches in proportion to their respective volumes. The methylene chloride blank for the organic particulate was 0.3 mg/90 mL and the water blank for the inorganic particulate was 0.5 mg/100 mL.

EPA Method 202 was used to determine condensable particulate. The total catch reported for each run was a sum of the condensable (organic and inorganic) catches. The H_20 impinger samples had a pH <4.5 and were therefore adjusted for NH_4Cl and $(NH_4)_2SO_4$ reaction products per EPA Method 5F (ion Chromatography). The solvent catch weights were subtracted from sample catches in proportion to their respective solvent volumes. Note that the hard copy report had incorrectly calculated the Total Particulate for samples Field Blank, R2-ACB-PM-2.5-2 and R2-ACB-PM-2.5-3. These results are summarized in Table 6-3.

Table 6-3. Field Blank and Particulate Data Summary

Sample ID	Filterable Particulate (mg)	Organic Particulate (mg)	Inorganic Particulate (mg)	Total Particulate (mg)
Field Blank	**1.9**	**0.9**	**0.8**	**1.6**
R1-ACB-PM-2.5-1	78	2.4	84	**87**
R1-ACB-PM-2.5-2	55	1.0	20	**21**
R2-ACB-PM-2.5-1	35	1.3	20	**21**
R2-ACB-PM-2.5-2	47	3.8	22	**26**
R2-ACB-PM-2.5-3	17	0.6	30	**30**

Sample ID	≤ 10μM Particulate (mg)	≥ 10μM Particulate (mg)	Filterable Particulate (mg)
Field Blank	**1.9**	**0.0**	**1.9**
R1-ACB-PM-2.5-1	56	22	78
R1-ACB-PM-2.5-2	46	8.6	55
R2-ACB-PM-2.5-1	26	9.2	35
R2-ACB-PM-2.5-2	31	16	47
R2-ACB-PM-2.5-3	16	1.7	17

Sulfate was determined by EPA Method 202/5F. The calibration curve and internal audit QC result were within the laboratory control limits, as were the percent differences between the duplicate injections. The Field Blank had a reported sulfate catch of 0.101 mg, well below the next lowest reported result of 8.89 mg in R2-03.

6.5 Multi-Metals by EPA Method 29

All Multi-Metals by EPA Method 29 were analyzed by First Analytical Laboratories in Chapel Hill, North Carolina. No container 4 was provided for Run I-ACB-M29-01. All samples were received in good condition, with no apparent leakage or damage. Antimony, arsenic, beryllium, cadmium, chromium, cobalt, lead, manganese, nickel, selenium, and silver were determined by Graphite Furnace Atomic Absorption Spectrophotometry. Mercury was determined by Cold Vapor Atomic Absorption Spectrophotometry. Their Inductively Coupled Plasma system was not operational at the time, and the barium analysis was performed by the certified laboratory Microbac Laboratories, Inc., in Wilson, North Carolina.

All of the spike recoveries were within the acceptable range of 75 to 125 percent and all samples were analyzed in duplicate. Traces of cadmium, chromium, manganese and nickel were found in the blanks, which is normal. The laboratory stated in their narrative that the results should be blank-corrected by the user, since in some cases the sample levels are so low that the blank levels are significant. However, in all cases, the levels found in sample Field Blank were higher than those detected in any of the associated blanks for these metals. These results are shown in Table 6-4.

Table 6-4. Metals Field Blank and Sample Results Summary

Sample	Cd (µg)	Cr (µg)	Mn (µg)	Ni (µg)
ACB-M29-FB Front	**2.5**	**0.8**	**2.4**	**<1.0**
I-ACB-M29-01 Front	7.1	45	43	47
I-ACB-M29-02 Front	6.2	37	43	51
I-ACB-M29-03 Front	12	21	108	23
II-ACB-M29-01 Front	23	13	81	16
II-ACB-M29-02 Front	57	23	60	18
II-ACB-M29-03 Front	27	199	81	135
ACB-M29-FB Back	**1.9**	**1.6**	**11**	**2.0**
I-ACB-M29-01 Back*				
I-ACB-M29-02 Back	1.5	1.1	12	1.5
I-ACB-M29-03 Back	0.35	1.2	14	2.9
II-ACB-M29-01 Back	2.2	1.3	11	3.6
II-ACB-M29-02 Back	0.52	1.4	8.4	3.9
II-ACB-M29-03 Back	0.57	1.4	4.9	3.5

*Front and back half samples were combined by mistake prior to submittal to lab

6.6 SVOCs-EPA Method 0010/Method 8270

Seven sets (including one Field Blank) of EPA Method 0010 sample fractions (XAD-2 cartridges, filter, impinger contents) were analyzed by Research Triangle Park Laboratories, Inc. Sample fractions were combined, extracted and analyzed by EPA Method 8270 (U.S. EPA, 1998). The following compounds and concentrations were identified in the field blank:

N-nitro-di-*n*-propylamine	1.1 µg
Di-*n*-butyl phthalate	4.9 µg
Bis(2-ethylhexyl) phthalate	2.8 µg

Any samples with reported concentrations of these compounds less than 5X the concentrations reported in the blank are flagged as non-detects.

6.7 PCDD/PCDF (Method 23)

Samples were submitted to Analytical Perspectives for the determination of polychlorinated dibenzo-*p*-dioxins and dibenzofurans (PCDD/PCDF). Seven samples (including a field blank) were submitted, extracted and analyzed within method hold time criteria. No PCDD/PCDF concentrations were reported in the method blanks. The Field Blank had estimated concentrations (J flagged) for the following compounds:

OCDD	46.1J
2378 TCDD	7.35J
23478 PeCDD	14J
234678 HxCDD	6.53J
1234678 HpCDD	6.1J

Concentrations reported in the samples were orders of magnitude above the Field Blank so no qualification due to blanks was required. Accuracy is assessed by recovery of standards described in the method. Recoveries of extraction, surrogate and analysis standards were all excellent ranging from 84-106 percent. Precision is assessed by reviewing relative percent differences between initial calibration and continuing calibration standards and the analysis of laboratory control samples. All relative percent differences (RPDs) were within laboratory control limits. These analyses were 100 percent complete.

Concentrations for a number of congeners in the C&D debris runs exceeded the instrument calibration range. These values are flagged (*) in the reported data.

6.8 PCBs and PAHs

Samples were submitted to Analytical Perspectives for the determination of PCBs and PAHs. Seven samples (including a Field Blank) were submitted, extracted and analyzed within method hold time criteria.

The following PCB was reported in the method blank:

PCB-118	10.9J pg

The following PCBs were reported in the Field Blank:

PCB-77	21.1 pg
PCB-105	33 pg
PCB-118	96.7 pg
PCB 156/157	11.7J pg

All sample concentrations were orders of magnitude higher than concentrations reported in the blanks, so no further qualification due to blank contamination was required. An “RJ-D10” flag was appended to several of the Sample IDs indicating results reported from a second analysis/re-injection of the sample extract with a 10-fold dilution.

There were some issues noted in the case narrative for PAH analysis due to severe saturation of the detector by several analytes. Analysis was repeated for these samples using split injection equivalent to dilutions ranging from 300-500 times. These samples were flagged “SP300”, “SP400” or “SP500” depending upon the dilution factor. In addition, extraction standards for naphthalene and pyrene for samples requiring the highest dilutions had elevated recoveries. The measured recoveries for these standards are considered unreliable resulting in an underestimation of the corresponding analyte concentrations by a factor of two to three. The elevated recoveries are most probably the result of carryover from the detector and/or contributions due to the extremely high levels of the target analyte. Also, any analytes flagged “PR” were poorly resolved and any flagged “H” had alternate standard recoveries < 40 percent.

Table 6-5 represents concentrations of compounds found in the method blank and the Field Blank. Concentrations reported in samples were orders of magnitude higher than concentrations in the blanks. Therefore, no qualification of samples due to blank contamination was required.

Table 6-5. PAH Method and Field Blank Concentrations

Analyte	Method Blank (ng/Train)	Field Blank (ng/Train)
Naphthalene	814	1460
2-Methylnaphthalene	44	111
Acenaphthylene	0.82	493
Acenaphthene	4.6	15
Fluorene	48	100
Phenanthrene	29	147
Anthracene	1.4	<0.91
Fluoranthene	9.8	38
Pyrene	4.2	18
Benzo(a)Anthracene	1.2	2.9
Chrysene	<0.91	5
Benzo(b)Fluoranthene	1.7	5.7
Benzo(k)Fluoranthene	<0.30	1.7
Benzo(e)Pyrene	0.56	2.5
Benzo(a)Pyrene	1.0	2.1
Perylene	<0.49	0.73
Indeno(1,2,3-cd)Pyrene	<0.73	3.1
Dibenzo(a,h)Anthracene	<0.77	<4
Benzo(g,h,i)Perylene	1.2	2.3
TOTAL PAH	963	2410

6.9 Ash TCLP Analysis

All TCLP analyses were performed by Test America in Savannah, Georgia. Three solid samples collected on 06/25/08 (Wood Ash), 06/26/08 (C/D Ash) and 06/27/08 (C/D Ash) were submitted and received by the laboratory on 07/07/2008. Samples were received in good condition and were all within temperature requirements. For GC/MS volatiles, one sample was prepared outside of the preparation holding time

(Wood Ash 6/25). No other analytical or quality issues were noted for TCLP (Method 1311) results. All TCLP results were less than the laboratory reporting limits with the following exceptions:

- Arsenic 0.22 mg/L Wood Ash 6/25
- Arsenic 0.3 mg/L C/D Ash 6/27

Surrogate recoveries were all within the laboratory acceptance criteria. Results of method blanks and leachate blanks were all below detection limits. Results from all laboratory control spikes and laboratory control spike duplicates (LCS/LCSD) fell within laboratory acceptance criteria of 75 to 125 percent.

6.10 Asbestos Analysis

Samples collected for asbestos analysis during the incinerator study were analyzed by Bureau Veritas (BV) of Kennesaw, Georgia. The samples collected were analyzed for the presence of asbestos fibers and forsterite fibers. Those samples included three samples representing airborne particles, two personnel air samples, and two bulk samples of ash. The air samples were analyzed by TEM utilizing ISO 10312 (International Organization for Standardization). The personnel samples were analyzed with PCM utilizing NIOSH Method 7400 and the bulk samples were analyzed using the EPA 600 PLM method and by drop mount TEM qualitative verification.

RTI International re-analyzed the three airborne samples and the two bulk samples, and also performed verified analysis on the air sample grids.

6.10.1 Airborne Asbestos QA Samples

BV found no chrysotile asbestos or forsterite fibers on any of the three samples. At least three tremolite fibers were found on each of the samples. RTI performed verified analysis on the two grid openings where those fibers were located. The fibers were readily relocated by RTI, and qualitatively and quantitatively verified. Based on those two grid openings, BV has a 100 percent true positive, 0 percent false positive, and 0 percent false negative verified count rating.

RTI re-prepared all three samples for TEM analysis. Using BV’s count sheet format and performing analysis utilizing ISO 10312, RTI counted a sample area representing approximately 20% of the area analyzed by BV. In their analysis, RTI found four tremolite fibers (see Table 6-6).

Table 6-6. Comparison of BV and RTI TEM Fiber Counts

Sample	BV fibers/mm^2 found	RTI fibers/mm^2 found	Acceptable variance?
1	6.4	3.6	yes
2	2.4	7.2	yes
3	3.2	3.6	yes

Source emission samples analyzed by TEM using ISO 10312 used an analytical sensitivity of 0.00039 to 0.00080 structures per cubic centimeter (s/cc). Structures were counted according to the protocol in ISO 10312, Annex C, "Structure counting criteria."

The personnel samples analyzed by PCM by BV were not reanalyzed by RTI.

6.10.2 Ash QA Samples

Two ash samples were analyzed by PLM using EPA/600/R-93/116 with visual estimation technique and identification by refractive index measurement. No asbestos or forsterite was found by BV. RTI analyzed both samples using the same technique and found the same result (see Table 6-7). The ash samples were also analyzed by both laboratories by preparing a drop mount on a carbon-coated grid to verify at high magnification the presence or absence of asbestos or forsterite fibers in the bulk sample. Neither laboratory found any such fibers by TEM analysis.

Table 6-7. Comparison of BV and RTI Bulk Sample Analysis

Sample	BV Result PLM	RTI Result PLM	BV Result TEM	RTI Result TEM
1	none detected	none detected	none detected	none detected
2	none detected	none detected	none detected	none detected

6.11 Audits

A technical systems audit was performed for this project by the EPA QA Manager, Paul Groff, who was present on June 26, 2008, and Kenneth Cowen of Battelle, under subcontract to Neptune, a contractor to EPA. Dr. Cowen was present June 25 and 26, 2008. Project personnel present for the audit were Mr. Paul Lemieux of EPA, Mr. Gene Stephenson, Mr. Michal Derlicki, Mr. Charly King, Mr. Russell Logan, Mr. Richard Snow, Mr. John Foley, and Mr. Ed Brown, all from ARCADIS. This audit addressed measurement of key target analytes from the source and included the real-time measurement of CO_2, CO, SO_2 and NO_X, as well as the collection of integrated samples for particulate matter ($PM_{2.5}$, filterable/condensable PM, and particle size distribution) (Method 201A, Method 5/202, and CARB Method 501, respectively), asbestos, acid gases (Method 26), metals (Method 29), VOCs (Method 40), SVOCs (Method 0010), and PCBs and PCDDs/PCDFs (Method 23). Additionally, the audit included visible emissions monitoring according to Method 9. All measurements included in this audit were performed by ARCADIS and were performed according to the QAPP entitled "Air Curtain Destructor Performance Test" dated May 8, 2008, with an Addendum to the QAPP dated June 20, 2008.

The full audit report and audit checklist can be found in Appendix D, Supporting Documents, but findings and observations are summarized as follows:

- **Observation:** No documentation was available in the field to demonstrate that the source sampling personnel had read the signed QAPP. However, copies of the QAPP and associated methods were available at the sampling locations and it was clear that the field personnel were utilizing them.

- **Finding:** A velocity profile of the ACD was not performed. Near isokinetic conditions were not maintained in the sampling duct. To avoid condensation in the sampling duct, the blower was operated at maximum capacity for all test runs, resulting in temperatures from 200 to 400 ºF.

- **Observation:** The sampling scoop was located on the end of the ACD rather than in the center. The center was chosen as most representative, but that position was prone to breaking the scoop and associated equipment so the scoop was moved to the end.

- **Observation:** The sampling ports were located 3-10 duct diameters from each other. A large number of ports were required for all necessary sampling. Minimum interferences were expected from spacing of sampling probes, and the interferences due to spacing of sampling probes is expected to be small compared to other uncertainties in the sampling.

- **Observation:** No documentation was available in the field to demonstrate that the source sampling personnel had read the methods. Observation of the field personnel indicated that they were familiar with the methods and were following the necessary protocols.

- **Observation:** Sample collection forms and other documentation were legible and written in indelible ink. However,, corrections to entries were occasionally partially obliterated and frequently not initialed and dated. Additionally, some data form spaces were not filled in. For example, several sample collection data sheets did not identify the operator of the sample collection train, Also, although several pre- and post-test leak checks were observed, these leak checks were not promptly documented on the sample collection data sheets. Although perfect laboratory notebook practice was not observed, the laboratory notebook practices do not appear to obscure what was performed in the field.

- **Observation:** Calibration checks of the balance used for gravimetric measurements were not performed. Although the balance was calibrated, routine calibration checks should be performed to document balance performance during the use of the instrument

- **Observation:** The post-test bias cheeks for the SO_2 CEM for tests on June 25 were out of specification. This problem was corrected on 6-26-08 through adjustment of an interference compensator. The SO_2 values for this day should be checked for consistency with the other runs and noted in the final report.

- **Observation:** Sufficiently high quality reagents were used for samples. However, some reagents were transferred from their original containers without documentation. Transferring reagents should be avoided when possible to prevent potential contamination and transfer of reagents should be thoroughly documented when performed to maintain traceability.

- **Observation:** The EPA auditor witnessed a Method 26 train being collected from the impinger train in which the last impinger was empty except for some condensed water and was lighter than the initial weight (tare weight) recorded which apparently had silica gel as per the method. There was no explanation for the discrepancy.

- **Observation:** The traverse of the stack conducted as part of Method 2C included points inside the minimum distance from the stack wall. Eight points were included in the traverse, and four of these points were 0.1 inches inside the 0.5 inch minimum distance from the stack wall specified in Method 2A. This deviation did not appear to adversely impact data quality.

- **Observation:** Several boxes of glass nozzles were used for the various sampling trains. The following boxes were checked and of the four boxes that were checked, two of the boxes were out of calibration; **Box A 2/1/2007**; **Box B 2/1/2007**; Box C 5/1/2008; Box D 5/1/2008. Although two of the nozzles were out of calibration, the nozzles were made of glass and are not likely to have changed in diameter. There was no apparent damage to the nozzles, so their performance should not be adversely affected.

- **Observation**: Two meter boxes and two vacuum gauges failed during a heavy rain event on June 26. These meter box failures resulted in the need to estimate various temperatures measured during sample collection. Estimates of these temperatures may introduce a small error into the calculation of the sample volume and should be noted in the final report. Also, the failure of the vacuum gauges resulted in the need to collect grab samples for VOC analysis rather than integrated samples over one hour.

7. Summary

In an effort to expand available options to better manage natural disaster debris in the future, EPA evaluated the combustion of both vegetative debris and C&D debris in an air curtain burner (ACB). ACBs can be mobilized to where they are needed as a potential means of reducing waste volume while minimizing potentially harmful environmental impacts. These tests were conducted in June 2008 by EPA/ORD at the Old Paris Road Landfill in St. Bernard Parish, Louisiana.

Testing was comprised of triplicate tests for each of two main test conditions:

1. Evaluation of emissions while burning vegetative debris; and
2. Evaluation of emissions from burning a mixture of construction and demolition (C&D) debris which did not contain asbestos in sufficient quantities to be categorized as Regulated Asbestos Containing Materials (RACM) and vegetative debris (used as supplemental fuel to maintain operating temperatures).

The analytes measured in these tests included:

- Asbestos;
- Fine PM (less than or equal to 2.5 μm);
- Acid gases (HF, HCl, HBr, Cl_2, Br_2);
- Toxic metals (Antimony (Sb), Arsenic (As), Barium (Ba), Beryllium (Be), Cadmium (Cd), Chromium (Cr), Cobalt (Co), Lead (Pb), Manganese (Mn), Mercury (Hg), Nickel (Ni), Selenium (Se), Silver (Ag));
- Polychlorinated dibenzo-*p*-dioxins and furans (PCDDs/PCDFs);
- Co-planar polychlorinated biphenyls (PCBs);
- Polycyclic aromatic hydrocarbons (PAHs);
- Semivolatile organic compounds (SVOCs);
- Volatile organic compounds (VOCs); and
- Visible emissions (opacity).

These data are intended to be used in a risk assessment to support decision-making activities regarding disaster debris management. Later efforts will relate these results, where possible, to the operational parameters used in the field in execution of the daily burn cycle. Additionally, these data may be used to develop operational guidelines for operators and technical guidelines for local, state, and regional managers in using this technology.

The data suggest that for some of the pollutants (e.g., PM, NO_X), there is not a statistically significant difference between ACB operation on vegetative debris or on C&D debris. Other pollutants (e.g., CO, SO_2, HCl) were somewhat higher from combustion of C&D debris than from combustion of vegetative debris. Some pollutants (e.g., dioxins and furans), were significantly higher from burning C&D debris than from burning vegetative debris.

It must also be noted that the emission factors for vegetative debris reported in this study more accurately reflect emission factors for vegetative debris recovered from hurricane response operations rather than from clean vegetative debris that had not sat in brackish water, exposed to sediment and other sources of contaminants for an extended period of time prior to combustion.

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