Prepared for
Canadian Energy Partnership for Environmental Innovation
Guelph, Ontario

Prepared by
Ramboll Environ,
Irvine, California

Document type
Final (Revision 0.1)

Date
June 30, 2016 (revised August 18, 2016)

CEPEI PM2.5 EMISSION FACTOR DEVELOPMENT

TEST REPORT
NATURAL GAS-FIRED RECIPROCATING AND GAS TURBINE ENGINES

RAMBOLL ENVIRON

REVISION HISTORY

Revision No.	Date	Approved By	Comment
Draft A	12 January 2016	Glenn England	For review
Draft B	25 January 2016	Glenn England	For review; updated results
Draft C	28 January 2016	Glenn England	For review; updated results; added re-calculation worksheets to Appendix A
Revision 0	30 June 2016	Glenn England	Final incorporating responses to CEPEI review comments
Revision 0.1	18 August 2016	Glenn England	Corrected Table E-1. See Errata. Minor changes to Appendix D.

Distribution

Jasmine Urisk (CEPEI)

Glenn England (Ramboll Environ)

ERRATA

18 August 2016: The reciprocating engine PM2.5 mass emission rate given in Table E-1 should be the same as given in Table 6-1, 0.00156 (1.56E-03) kg/GJ. Corrected Table E-1.

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ACRONYMS AND ABBREVIATIONS

%	percent
°C	degrees Centigrade
°F	degrees Fahrenheit
Ag	silver
Al	aluminum
As	arsenic
Au	gold
Ba	barium
BC	British Columbia
Br	bromine
Br	bromine
Btu	British thermal unit
Ca	calcium
Cd	cadmium
Ce	cerium
CEPEI	Canadian Energy Partnership for Environmental Innovation
cfm	cubic feet per minute
Cl^-	chloride ion
Cl	chlorine
CO	carbon monoxide
Co	cobalt
CO_2	carbon dioxide
Cr	chromium
Cs	cesium
CTM 39	U.S. EPA Conditional Test Method 039
Cu	copper
dscf	dry standard cubic foot (unless otherwise noted, standard reference conditions are 528°R, 29.92 in. Hg)
dscm	dry standard cubic meters
EC	elemental carbon
Eu	europium
Fd	O_2-based F factor, dry basis
Fe	iron

Ga	gallium
GJ/hr	gigajoules per hour
HEPA	high efficiency particulate arrest (filter)
Hf	hafnium
Hg	mercury
In	indium
in. Hg	inch of mercury (pressure)
Ir	iridium
K	potassium
kg/GJ	kilograms per gigajoule
kg/s	kilograms per second
kW	kilowatt
La	lanthanum
lb/MMBtu	pounds per million British thermal units
Mg	magnesium
mg/dscm	milligrams per dry standard cubic meter
mm	millimeter
MMBtu	million British thermal units
Mn	manganese
Mo	molybdenum
MW	megawatt
Na	sodium
Na^+	sodium ion
Nb	niobium
NH_4^+	ammonium ion
Ni	nickel
NO_3^-	nitrate ion
NO_X	nitrogen oxides
O_2	oxygen (molecular)
OC	organic carbon
OGRIS	Oil and Gas Research and Innovation Society
P	phosphorus
Pb	lead
Pd	palladium

PM10	particulate matter with aerodynamic diameter of 10 micrometers and smaller
PM2.5	particulate matter with aerodynamic diameter of 2.5 micrometers and smaller
PTAC	Petroleum Technology Alliance of Canada
QA	quality assurance
QFF	quartz fiber filter
Rb	rubidium
RPM	revolutions per minute
S	sulfur
Sb	antimony
Sc	scandium
Se	selenium
Si	silicon
Sm	samarium
Sn	tin
SO_4^{2}	sulfate ion
Sr	strontium
STFB	sample train field blank
Ta	tantalum
Tb	terbium
Ti	titanium
Tl	thallium
TMF	Teflon® membrane filter
U	uranium
U.S. EPA	U.S. Environmental Protection Agency
ULPA	ultra low penetration air (filter)
V	vanadium
VOC	volatile organic compound
W	wolfram (tungsten)
Zn	zinc
Zr	zirconium

1. EXECUTIVE SUMMARY

These tests generated new data for development of updated fine particle (particles with aerodynamic diameter of 2.5 micrometers and smaller, PM2.5) air emission factors for natural gas-fired engines applicable to upstream and downstream oil and gas operations and natural gas end users. The tests were conducted using a stationary source dilution sampling method combined with ambient air sample collection and analysis methods to determine both the mass and chemical speciation of combined filterable plus condensable PM2.5 emissions. The chemical composition of the collected aerosols also was determined (51 elements, selected ions and organic and elemental carbon).

Tests were conducted on a 27.5 megawatt natural gas-fired combustion (gas) turbine engine employing lean premix low-NO_X combustors and a 2.3 megawatt natural gas-fired four-stroke lean burn reciprocating engine, both at natural gas pipeline compressor stations in Canada. Neither unit employs post-combustion emission controls.

Average PM2.5 mass emission rates in kilograms per gigajoule (kg/GJ) are summarized in Table E-1. Reconstructed mass (i.e., the sum of individual species adjusted for oxides and organic carbon artifact) and measured mass agree well (within ±6%) for the reciprocating engine tests. The measured PM2.5 mass for gas turbine engine Run 1 is very high relative to the measured mass for Runs 2 and 3. This is accounted for primarily by silicon. This strongly suggests sample contamination for Run 1, which may have been introduced during sample train operation troubleshooting prior to starting the run. The measured mass is much lower than the reconstructed mass for gas turbine Runs 2 and 3. On average, the measured and reconstructed masses are nearly the same. Because the reconstructed masses are more consistent from run to run, excluding silicon in Run 1, these were used to calculate the average gas turbine PM2.5 mass emission rate shown in Table E-1.

Table E-1: Average PM2.5 mass emission factors for natural gas-fired reciprocating engine and gas turbine .

Unit	PM2.5, kg/GJ
Reciprocating Engine (Site Alfa)	0.00156
Gas Turbine Engine (Site Buick)	0.000236

(Table E-1 corrected 18 August 2016)

Thirty-one elements and ions were not detected in any runs on the reciprocating engine. Twenty species that were detected in at least one reciprocating engine run account for 99.69% of total reconstructed mass (Table E-2). Ninety-four percent of total mass is accounted for by organic carbon, followed by sulfur, elemental carbon and calcium which account for 4.5% of total mass. Nitrate ion accounts for 0.33% of total mass.

Table E-2: PM2.5 species profile – reciprocating engine (detected in at least one test run, as fraction of reconstructed mass).

Species	Mass Fraction	Species	Mass Fraction
Organic carbon	0.94	Europium	0.000638
Sulfur	0.018	Sodium ion	0.000501
Elemental carbon	0.017	Barium	0.000313
Calcium	0.011	Iron	0.000279
Nitrate ion	0.0033	Titanium	0.000238
Zinc	0.0015	Tungsten	0.000214

Table E-2: PM2.5 species profile – reciprocating engine (detected in at least one test run, as fraction of reconstructed mass).

Species	Mass Fraction	Species	Mass Fraction
Chlorine	0.0014	Cerium	0.000216
Silicon	0.0013	Potassium	0.000211
Phosphorus	0.0012	Cesium	0.000178
Aluminum	0.00060	Lanthanum	0.000124

Thirty-six elements and ions were not detected in any runs on the gas turbine engine. Twenty species account for 98.9% of reconstructed mass (Table E-3). Organic carbon accounts for 80% of total reconstructed mass, followed by sodium, elemental carbon and magnesium.

The trace element concentrations with mass fractions less than 0.001 generally are near to the analytical minimum reporting limits and or field blank levels (less than 5 times higher than), and sodium results should be considered qualitative due to limitations of the analytical technique.

Table E-3: PM2.5 species profile – gas turbine engine (detected in at least one test run, as fraction of reconstructed mass).

Species	Mass Fraction	Species	Mass Fraction
Organic carbon	0.80	Nitrate ion	0.0018
Sodium	0.089	Tungsten	0.0012
Elemental carbon	0.042	Bromine	0.0015
Magnesium	0.023	Cesium	0.00049
Phosphorus	0.0076	Chlorine	0.00050
Samarium	0.0053	Potassium	0.00054
Europium	0.0046	Cadmium	0.00045
Silicon	0.0041	Barium	0.00041
Terbium	0.0033	Antimony	0.00033
Cesium	0.0023	Tin	0.00028

2. INTRODUCTION

2.1 Test Objectives

These tests generated new data for development of updated fine particle (particles with aerodynamic diameter of 2.5 micrometers and smaller, PM2.5) air emission factors for natural gas-fired engines applicable to upstream and downstream oil and gas operations and natural gas end users.

The primary objectives were:

- Measure PM2.5 mass concentrations and selected species (elements, ions, organic and elemental carbon) in the stack gas using a dilution sampler combined with ambient air sample collection and analysis methods;
- Measure oxygen (O_2) and carbon dioxide (CO_2) concentrations in the stack gas and fuel composition to enable calculation of PM2.5 emission factors via fuel factors (“F factors”) following U.S. EPA Method 19;

The secondary objectives were:

- Collect data needed to evaluate modified U.S. EPA Conditional Test Method 39 (CTM 39) method performance and optimize future test protocols, including collection and analysis of replicate sample and sample train blanks and replicate reagent blanks;
- Compare samples and blanks to determine significance of differences;
- Evaluate replicate blanks to determine overall method sensitivity and reporting limits.

The tests were conducted using a proven stationary source dilution sampling method combined with ambient air sample collection and analysis methods to determine both the mass and chemical speciation of PM2.5 emissions. A modified version of CTM 39 that has been recently applied to tests of several gas-fired sources was used. The modified method combines key elements of the scientifically proven dilution sampling method used in previous U.S. research programs within the general framework and equipment of a published U.S. EPA method.

The chemical composition of the collected aerosols also was determined (51 elements by x-ray fluorescence; sulfate, nitrate, chloride, ammonium & other ions by ion chromatography and colorimetry, and organic and elemental carbon by thermal optical reflectance). These results will clarify the contribution of sulfates to air emissions from these engines. Chemically-speciated PM2.5 profiles developed from the results will be useful for source apportionment and health risk analysis.

Tests were conducted on two units at different natural gas pipeline compressor stations: one is a natural gas-fired combustion (gas) turbine engine employing lean premix low-NO_X combustors; the other is a natural gas-fired four-stroke lean burn reciprocating engine. Neither site employs post-combustion emission controls. The engines are considered representative of engine sizes and configurations used in Canadian upstream and downstream oil and gas applications (such as compressor drives). They also may be representative of power generation and cogeneration applications. The tests were designed to assure that the data can be extrapolated to the widest range of gas burning engines.

The overall project is being carried out in six well-defined tasks: 1) Kickoff; 2) Test Planning and Preparation; 3) Field Tests (mobilisation/demobilisation, sample collection, field quality assurance oversight, sample analysis); 4) Test Report; 5) Emission Factor Update; 6) Review Meeting. This test report marks the completion of Tasks 1 through 4.

This test report includes a summary of the test design, sampling and analysis, data reduction, and reporting procedures used in the tests, and a summary of test results. A detailed test report with all supporting data is provided in Appendix A. The test plans for Site Alfa and Site Buick are provided in Appendices B. Natural gas sampling procedures and analysis results are provided in Appendix C.

2.2 Project Organization

The key parties involved with the tests were:

- Canadian Energy Partnership for Environmental Innovation (CEPEI): The industry association including its member companies which provided funding and overall project direction and coordination;
- Petroleum Technology Alliance of Canada (PTAC): An industry association which provided a portion of the project funding;
- British Columbia Oil and Gas Research and Innovation Society (BC OGRIS): An industry-government collaboration which provided a portion of project funding;
- “Site Alfa” and “Site Buick” (actual company name and site identification are blinded in this test report): The facility owners/operators, responsible for providing access to sample locations and operating the units according to the test plans during the tests;
- Ramboll Environ: Consultant retained by CEPEI responsible for the overall project planning and execution, including test planning, quality assurance oversight, reporting and test results review;
- The Avogadro Group, LLC, a unit of Montrose Environmental Inc.: The test contractor responsible for performing test measurements, test data reduction and preparation of a detailed test report. The test contractor collected all samples and performed laboratory analysis of all liquid samples and 142-mm filter samples;
- Desert Research Institute: Analytical laboratory subcontractor responsible for supplying media and analyzing 47-mm filter samples collected by the test contractor; and
- Clearstone Engineering, Inc.: CEPEI contractor responsible for collection and analysis of natural gas fuel samples during the tests. Key contacts for each organization are provided in Table 1-1.

Table 2-1: Key organizations and contacts for test program.

Organization	Contact name	Contact info
Site Alfa	[withheld]	[withheld]
Site Buick	[withheld]	[withheld]
Ramboll Environ	Glenn England	18100 Von Karman Avenue, Irvine, CA 92612 USA +1 (949) 798-3643 gengland@environcorp.com
CEPEI	Jasmine Urisk	75 Wimbledon Road, Guelph, Ontario N1H 7V7 +1 (519) 836-3739 jtu@sentex.net
Avogadro/Montrose	Kevin Crosby	2825 Verne Roberts Circle, Antioch, CA 94509 USA +1 (925) 680-4337 kcrosby@montrose-env.com
Desert Research Institute	Steve Kohl	2215 Raggio Parkway, Reno, NV 85912 USA (775) 674-7056 Steve.Kohl@dri.edu
Clearstone Engineering	David Picard	700, 900-6th Avenue S.W., Calgary, Alberta, T2P 3K2 (403) 215-2730 dave.picard@clearstone.ca

3. FACILITY DESCRIPTION

3.1 Process Description & Air Pollution Controls

Table 3-1 presents the key characteristics of the units that were tested.

Table 3-1: Process and air pollution control descriptions.

Unit ID	Process Description	Air Pollution Controls
Site Alfa	Natural gas-fired reciprocating internal combustion engine, 4-stroke, lean burn, turbocharged, Waukesha Model 12VAT27GL, 3130 horsepower (2.3 megawatt), commissioned circa 1997. The engine was nearing the end of its major scheduled maintenance cycle at the time of the tests.	Pre-combustion chambers, air/fuel ratio controller
Site Buick	Natural gas-fired gas turbine engine, Rolls Royce model RB211 24DLE, 27.5 megawatt mechanical power output capacity, in service as a natural gas compressor drive.	Dry low emissions (lean premix) combustion system, short can version

3.2 Process Operating Conditions

The engines were operated on natural gas fuel at approximately constant power output, with an engine load of 80% of rated capacity or higher. Process operating conditions for each test run indicate stable operation within the target operating range for each test (Tables 3-2 and 3-3). Note, the fuel gross heat input rate for the reciprocating engine is estimated from other operating parameters because the fuel flow meter was not operating during the tests.

Table 3-2: Reciprocating engine average operating conditions during PM2.5 tests.

Parameter	Units	Run 1	Run 2	Run 3
Date		20 Oct 2015	20 Oct 2015	21 Oct 2015
Fuel heat input (gross)	GJ/hr	20.8	20.5	20.5
Engine speed	RPM	950	950	949

Table 3-3. Gas turbine average operating conditions during PM2.5 tests.

Parameter	Units	Run 1	Run 2	Run 3
Date		15 Oct 2015	16 Oct 2015	17 Oct 2015
Power output	kW	21,000*	23,000*	23,072
Turbine speed	RPM	*	*	4,307
Fuel gas flow rate	kg/s	1.29*	1.39*	1.39
Air inlet temperature	°C	*	*	21.9
Turbine exhaust temperature	°C	*	*	515

*data not available due to data recorder error. Power and fuel flow rates for Runs 1 and 2 estimated from Run 3 data based on measured stack gas flow rates and O_2 concentrations.

4. TEST DESCRIPTION

4.1 Test Design

Modified CTM 39 was selected to measure PM2.5 emissions because it avoids known measurement artifacts and lack of sensitivity inherent in traditional hot filter/cooled impinger methods. After diluting the sample to near ambient conditions with conditioned ambient air, both filterable and condensable PM are collected together on the same filter without distinguishing between them. Modified CTM 39 reproduces conditions present in the stack gas plume which govern condensable PM formation as it mixes and cools in the atmosphere and thus produces results that are representative of a source's true contribution to ambient PM10/2.5 levels. Additional details are provided in Appendix B.

The modifications to CTM 39 in these tests are designed to significantly enhance method sensitivity for gas-fired sources, improve comparability of results with ambient air measurements, and address lessons learned from previous tests.

The test plan for each unit consisted of three sequential 240-minute CTM 39 test runs, for a total test duration of 720 minutes (12 hours) each. Two complete sample train field blanks (STFBs) also were collected and analyzed for quality assurance purposes.

4.1.1 Preliminary Tests

A preliminary velocity traverse and O_2 concentration measurements were performed prior to the first run at each site to verify the absence of cyclonic flow and determine average velocity for selecting sample nozzle size and target sample train operating conditions.

4.2 Sample Collection and Analysis Methods

Sample collection and analysis methods are briefly summarized below. See Appendices A and B for further details.

4.2.1 Sampling Locations and Traverse Points

The number of traverse points at each sampling location was selected as specified in Environment Canada EPS 1/RM/8, Section A.

Exhaust gas samples for Site Alfa were collected from a horizontal section of round duct between the engine and the exhaust silencer. Two sample ports were installed by the site to facilitate sampling for this project. Because of the CTM 39 sample train configuration, PM2.5 sampling through the vertical port was not feasible; thus, samples were collected from a total of 24 points along a horizontal chord through the center of the duct cross-section rather than from 12 points along each of the horizontal and vertical chords. This is not expected to adversely affect PM2.5 data quality because: the engine exhaust is well mixed at the sampling location; the particles generated from natural gas combustion are very fine and therefore will follow gas streamlines; and the emission factor calculation is based on the measured PM2.5 concentration rather than stack gas flow rate..

Samples for Site Buick were collected from a square vertical exhaust stack through existing sample ports located below the stack exit. Samples were collected from a total of 24 points, eight each through 3 sample ports equally spaced along the width of the stack rather than 25 points through 5 sample ports at the centers of equal areas as specified in the reference method. For the same reasons given above, this is not expected to adversely affect PM2.5 data quality.

4.2.2 Stack gas Velocity and Volumetric Flow Rate

Stack gas velocity was determined following Environment Canada EPS 1/RM/8, Section B. These measurements were used only for characterizing test conditions and determining isokinetic sampling rates, made as part of the CTM 39 measurements, and were not used for determining PM2.5 emission factors (lb/MMBtu).

4.2.3 Stack gas O_2 and CO_2 Concentrations and Molecular Weight

Dry stack gas O_2 and CO_2 concentrations and stack gas molecular weight were determined by direct extraction instrumental methods following U.S. EPA Method 3A.

4.2.4 Stack gas Moisture Concentration

CTM 39 specifies that stack gas moisture must be determined using U.S. EPA Method 4. For these tests, stack gas moisture was determined from CTM 39 instrumentation, using the measured relative humidities, pressures and temperatures of the diluted stack gas sample and dilution air, and the measured volumetric flow rates of the raw sample and dilution air. Calibrated sensors measured the relative humidity and temperature of the dilution air and diluted stack gas sample exhaust. Moisture concentrations in the dilution air and diluted sample were calculated from relative humidity, temperature and pressure. The moisture concentration in the raw stack gas sample was calculated by mass balance using these data with the measured volumetric flow rates of the raw stack gas sample and dilution air.

4.2.5 PM2.5 Concentrations(CTM 39)

The major components of the standard CTM 39 sampling train are: in-stack PM10 and PM2.5 cyclones; a heated sample probe; a pre-dilution tee and mixing cone; a mixing (residence) chamber, two blowers and other ancillary equipment. A modified sampling train (Figure 4-3) and modified procedures were used for these tests.

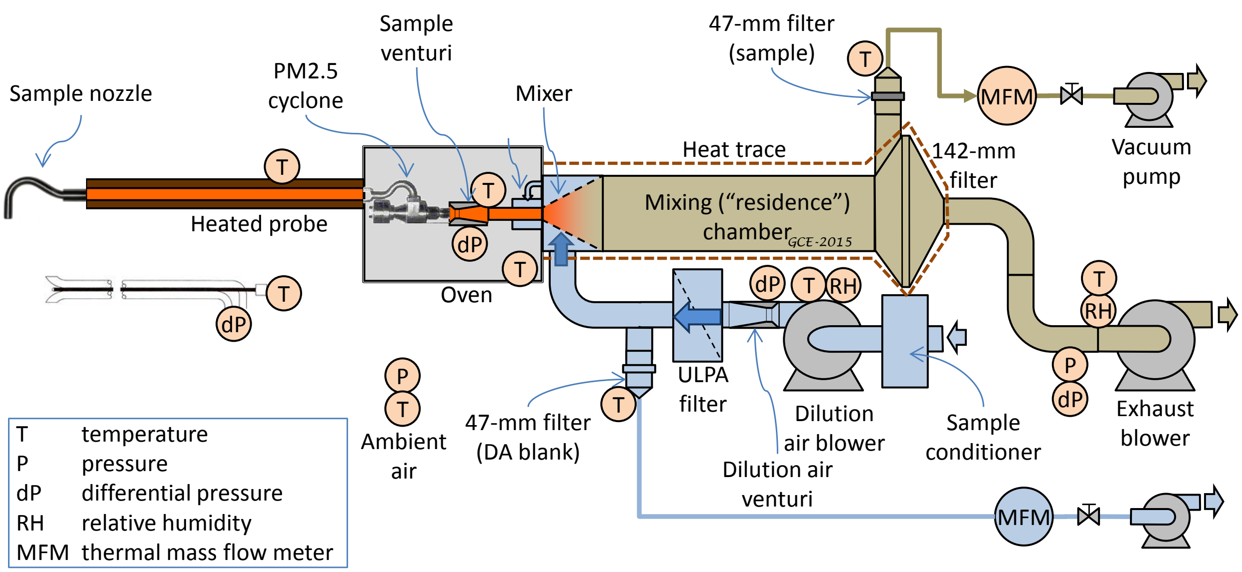

Figure 4-3: Modified U.S. EPA CTM 39 sampler used for CEPEI PM2.5 Emission Factor test program.

The key modifications and clarifications to the published test method were:

- Because the objective of these tests is to characterize PM2.5 emissions and particles produced via natural gas combustion are understood to be much smaller than 1 micrometer, the in-stack PM10 cyclone was not considered necessary and was not used. A PM2.5 cyclone was used as a precaution to remove spurious large particles not associated with normal combustion that may be present in the stack gas (e.g., due to metal corrosion/scaling, debris, etc.).

- The PM2.5 cyclones could not be used in-stack due to high stack gas temperatures which precluded the use of conventional threaded stainless steel cyclone components. All particulate matter produced from gaseous fuels combustion is estimated to be smaller than 2.5 micrometers in diameter, except for occasional spurious larger particles that do not originate from the combustion process. Therefore, the in-stack cyclone was replaced by a buttonhook sampling nozzle and an external heated PM2.5 cyclone was added between the probe and the sample venturi;
- To minimize particle deposition in the sample train due to electrostatic charge, the probe liner was constructed from Hastelloy C276, which is electrically conductive and high temperature corrosion resistant. The mixing cone, mixing ("residence") chamber and 142-millimeter (mm) filter holder were electropolished rather than Teflon-coated as specified in CTM 39 to provide an electrically-conductive surface.
- Borosilicate glass probe nozzles were used due to the high stack gas temperatures. Probe heaters were set to approximately 160 degrees centigrade (°C). However, probe temperature was generally higher than this due to the hot stack gas. The probe temperature could not be maintained at least 5 °C above stack gas temperature for minimizing deposition due to thermophoresis as specified in CTM 39 due to the high stack gas temperature and limitations of the heated probe assembly;
- Samples were collected on two 47-mm filter packs attached to the CTM 39 sample train at the 142-mm filter holder inlet:
  - The first filter pack consisted of a 47-mm Teflon® membrane filter (TMF, Gelman No. RPJ047), directly exposed to the diluted stack gas sample for determination of mass and elements, followed by a pre-fired 47-mm quartz fiber filter (QFF) in series downstream of the TMF for determination of potential volatile organic compound (VOC) artifact contribution to OC. The QFFs were heated in air for at least three hours at approximately 900 °C prior to use;
  - The second filter pack consisted of a pre-fired 47-mm QFF only, directly exposed to the diluted stack gas sample, for determination of water-soluble ions, organic carbon (OC) and elemental carbon (EC).
  - Sample flow rate to each 47-mm filter was measured using a thermal mass flow meter and was manually controlled to a nominal target sample flow rate of 35-37 sL/min using a needle valve. The mass flow meter sample flow rate and temperature signals were recorded electronically via datalogger.
- A ultra-low particulate air (ULPA) filter (≥99.999% removal of 100 nanometers (0.1 micrometer) or larger particles) was used for the dilution air supply conditioning rather than a high efficiency particulate arrest (HEPA) filter as specified in CTM 39 to reduce background PM2.5 levels in the dilution air. A dilution air blank was collected on a 47-mm filter added to the dilution air supply downstream of the ULPA filter for each test run;
- The CTM 39 dilution cone holder, mixing chamber, 142-mm filter holder inlet and 1.5-inch 47-mm filter nozzles were heat traced and insulated to avoid water condensation on the interior surfaces;
- The acetone and water recovery rinses were collected and analyzed as specified in CTM 39. The recovery rinse results are not included in the final results because previous tests demonstrate that levels in recovery rinses can't be distinguished from levels in recovery

rinses from replicate sample train field blanks at low particulate matter concentrations characteristic of natural gas combustion. The results were used for evaluating method performance, to be summarized in separate report addendum.

- Calculations were modified to accommodate the modified sample collection approach. The modified calculation approach was drawn from another similar stationary source PM10/2.5 dilution test method, ISO 25597:13.

47-mm filters were analyzed as follows

- For analysis, each QFF was cut in half. One QFF half was extracted with water and analyzed for ions, ammonium (NH_4^+) by colorimetry and chloride (Cl-), sulfate ($SO_4^=$), nitrate (NO_3^-), potassium (K^+), phosphate (PO_4^+), magnesium (Mg^+) and soluble sodium (Na^+) by ion chromatography. The other QFF half was analyzed by thermal/optical reflectance to determine OC and EC.
- PM2.5 mass was determined gravimetrically by equilibrating 47-mm TMFs at 20-23°C and 30-40% relative humidity followed by weighing on an electro-microbalance with 1 microgram resolution;
- After gravimetric analysis, 47-mm TMFs also were analyzed by energy dispersive x-ray fluorescence analysis for the following elements: aluminum (Al), silver (Ag), arsenic (As), gold (Au), barium (Ba), bromine (Br), calcium (Ca), cadmium (Cd), cerium (Ce), chlorine (Cl), cobalt (Co), chromium (Cr), cesium (Cs), copper (Cu), europium (Eu), iron (Fe), gallium (Ga), hafnium (Hf), mercury (Hg), indium (In), iridium (Ir), potassium (K), lanthanum (La), magnesium (Mg), manganese (Mn), molybdenum (Mo), sodium (Na), niobium (Nb), nickel (Ni), phosphorus (P), lead (Pb), palladium (Pd), rubidium (Rb), sulfur (S), antimony (Sb), scandium (Sc), selenium (Se), silicon (Si), samarium (Sm), tin (Sn), strontium (Sr), tantalum (Ta), terbium (Tb), titanium (Ti), thallium (Tl), uranium (U), vanadium (V), wolfram (W, also tungsten), yttrium (Y), zinc (Zn), and zirconium (Zr). Mg and Na results are considered semi-quantitative because of analytical technique limitations.

4.2.6 Natural Gas Composition and Heating Value

Natural gas fuel samples were collected from a sample tap in the natural gas supply line upstream of gas conditioning equipment (by Clearstone Engineering). Natural gas sample collection procedures and analytical results are provided in Appendix C.

Natural gas samples were analyzed for hydrocarbons and diluents by gas chromatography with flame ionization and thermal conductivity detection, heating value by calculation from composition following ASTM International standard D3588 (ASTM D3588); sulfur content by gas chromatography with sulfur chemiluminescence detection, generally following ASTM D5504.

Carbon, hydrogen, oxygen and nitrogen content and higher (gross) heating value were calculated based on fuel hydrocarbon and inert gas composition.

4.2.7 PM2.5 Emission Factor (lb/MMBtu)

PM2.5 emission factors in lb/MMBtu were calculated from PM2.5 concentration (dry basis) and stack gas O_2 concentration using fuel factors (“F-factors”) following U.S. EPA Method 19. The results of the fuel gas sample analysis were used to calculate a dry oxygen-based F-factor (Fd) which, along with the measured PM2.5 concentration and stack gas O_2 concentration, was used to calculate PM2.5 emission rate for each test run in lb/MMBtu.

5. QUALITY ASSURANCE/QUALITY CONTROL

5.1 Internal QA Activities

5.1.1 Blanks

The following blanks were collected during the test program.

- Sample train field blanks (STFBs):
  - STFBs are complete sample trains that have been cleaned, charged with sample media, heated and leak checked at the sampling location, recovered and analyzed in the same manner as actual samples – all steps except introducing the sample probe to the stack gas and collecting samples;
  - One STFB was collected prior to the first run for each unit;
  - A second STFB was collected after the first or second sample;
  - All STFB sample fractions were analyzed;
  - STFB results were used to compare sample results. Sample results are flagged "FB" (field blank) if the ratio of exhaust gas sample filter mass (net weight for gravimetric results) to STFB sample filter mass is less than 5, using the average of the two STFB results.
- Dilution air blanks (47-mm filters)
  - Dilution air blanks are based on dilution air particles collected on 47-mm filters (TMF followed by QFF) placed in the dilution air supply between the dilution air conditioning and filtration equipment and the mixing cone holder air inlet;
  - One dilution air blank was collected for every test run;
  - All dilution air blanks were analyzed;
  - If dilution air blank result exceeds the analytical reporting limit, the measured dilution air blank concentration (mass/volume) was subtracted from the diluted sample concentration (mass/volume). If the blank-corrected diluted sample result is less than the dilution air blank concentration, the result is flagged "BBL" (below dilution blank level) and the dilution air blank concentration is reported. If the diluted sample concentration is less than 5 times the dilution air blank concentration, the result also is flagged "B".

6. RESULTS

A detailed test report is provided in Appendix A. Ramboll Environ verified or recalculated all results for consistency with calculation methods provided in the test protocol and subsequent revisions (Appendix A.1). All results are corrected for dilution air blanks. Reference temperature for volumetric concentrations in mg/dscm is 20 °C[1], except were noted.

Test results are summarized in Tables 6-1 to 6-8 below. The following data qualifiers are shown as appropriate:

- ADL: sample result is above the analytical reporting limit. The sample result is shown.
- BDL: sample result is below the analytical reporting limit. The reporting limit is shown.
- DLL: result is detection level limited. Some results are ADL and some are BDL.
- BBL: sample result is ADL but concentration in the dilution air blank is greater than in the sample. The dilution blank concentration is shown.
- B: the result is less than five times the dilution air blank result.
- FB: the result is less than five times the STFB result.

Carbon results are provided for both the 47-mm quartz fiber filters exposed directly to the sample and for the quartz fiber filters placed behind the Teflon membrane filters (backup filter). The backup filter results indicate the amount of potential artifact present in the directly exposed filter results due to adsorption of VOCs on the quartz fiber filters.

The reconstructed PM2.5 mass was calculated as the sum of the individual species measured plus corrections for element oxidation (each element was divided by its element atomic weight and multiplied by the molecular weight of its highest stable oxide) and organic carbon hydrocarbon speciation (OC was multiplied by 1.08). The reconstructed PM2.5 mass and measured PM2.5 mass agree well for the reciprocating engine (within ±6%) test runs. For the gas turbine engine, the measured PM2.5 mass for Run 1 is very high relative to Runs 2 and 3. This is accounted for primarily by silicon. This strongly suggests sample contamination for Run 1, which may have been introduced during sample train operation troubleshooting prior to starting the run. The measured mass is much lower than the reconstructed mass for gas turbine Runs 2 and 3. However, the average measured and reconstructed masses for all three test runs are nearly the same (0.278 and 0.276 milligrams per dry standard cubic meter, mg/dscm, respectively, excluding silicon from the reconstructed mass for Run 1). Because the reconstructed masses are more consistent from run to run, excluding silicon in Run 1 due to likely contamination, these are believed to be more representative of actual normal emissions. Therefore, the reconstructed masses for all three test runs (excluding silicon from reconstructed mass for Run 1) were used for emission factor calculations.

In Run 3 of the gas turbine tests, a temperature anomaly in the exhaust blower inlet gas temperature sensor resulted in a calculated water vapor concentration of 35%, which is much greater than theoretically possible based on natural gas combustion and measured stack conditions. It is believed the exhaust blower inlet gas temperature sensor may have been dislodged from its normal position or failed during the test, resulting in incorrect temperature measurements. Therefore, the exhaust

[1] Note, the reference temperature for U.S. EPA CTM 39 and other U.S. EPA source test methods is 20 °C while reference temperature for Environment Canada test methods is 25 °C. The results are reported at 20 °C reference temperature for simplicity given the test methods used, except where noted.

temperature is estimated based on the upstream CTM 39 train temperature measured upstream of the exhaust blower at the exit of the 142-mm filter housing (assuming the same temperature difference between these locations – 4 °F (2 °C) - that was measured in Run 2). The water vapor concentration for this run shown in Table 6-5 is based on the estimated exhaust blower inlet gas temperature. Any difference between the actual and estimated temperature values will produce a small difference in calculated dry gas sample volumes and therefore also the PM2.5 and species concentrations for Run 3. The potential difference is not considered significant relative to the overall magnitude of the results.

For the gas turbine tests, the diluted sample gas temperature exceeded the maximum temperature of 85 °F specified in CTM 39 in all three runs, ranging from 92 to 103 °F (33-39 °C), due to the very high stack gas temperature and limitations in the dilution air flow capacity of the CTM 39 apparatus. This may result in a degree of low bias in the mass of condensable PM2.5 collected on the sample filters. The difference in saturated vapor pressures at these slightly elevated temperatures compared with the maximum CTM 39 specification is very small for most condensable species of interest (e.g., sulfuric acid) and therefore the difference in condensed PM2.5 mass also is expected to be small.

Table 6-1: Summary of reciprocating engine (Site Alfa) test results for stack conditions and PM2.5 mass (47mm and 142 mm filters).

Parameter		Run 1		Run 2		Run 3		Average
Exhaust temperature, °F		749		751		751		750
O_2, %vd		11.31		11.22		11.09		11.21
CO_2, %vd		5.53		5.74		5.56		5.61
Water, %v		5.9		5.9		6.0		6.0
PM2.5, mg/dscm	ADL	3.21	ADL	2.11	ADL	4.09	ADL	3.14
Fd, dscf/MMBtu		8618.8		8618.8		8618.8		8618.8
PM2.5, kg/GJ	ADL	1.62E-03	ADL	1.05E-03	ADL	2.02E-03	ADL	1.56E-03

Table 6-2: Summary of reciprocating engine (Site Alfa) test results for particulate carbon (mg/dscm).

Parameter			Run 1			Run 2			Run 3			Average
OC		ADL	1.14E+00		ADL	1.36E+00		ADL	1.23E+00		ADL	1.24E+00
EC		ADL	1.19E-02		ADL	2.82E-02		ADL	2.11E-02		ADL	2.04E-02
Total C		ADL	1.15E+00		ADL	1.39E+00		ADL	1.26E+00		ADL	1.26E+00
OC Backup		ADL	1.77E-01		ADL	2.29E-01		ADL	1.76E-01		ADL	1.94E-01
EC Backup	B	ADL	4.13E-04		BDL	1.01E-04	FB B	ADL	1.87E-04	FB B	DLL	2.34E-04

Table 6-3: Summary of reciprocating engine (Site Alfa) test results for elements (mg/dscm).

Parameter				Run 1				Run 2				Run 3				Average
Ag			ADL	5.54E-05			BDL	5.12E-06			BDL	4.34E-06			DLL	2.16E-05
Al			BDL	3.59E-04	FB		BBL	9.38E-04			BDL	5.73E-05	FB	B	DLL	4.52E-04
As			BDL	1.76E-06			BDL	2.04E-06			BDL	1.73E-06			BDL	1.84E-06
Au			BDL	4.85E-06	FB		BBL	7.44E-05	FB	B	ADL	2.96E-05	FB	B	DLL	3.63E-05
Ba			BDL	2.03E-05			ADL	9.00E-04			BDL	2.00E-05	FB		DLL	3.14E-04
Br	FB		ADL	5.51E-05	FB		ADL	1.91E-05	FB	B	BBL	3.52E-05	FB	B	DLL	3.64E-05
Ca			ADL	7.97E-03			ADL	8.94E-03			ADL	5.98E-03			ADL	7.63E-03
Cd			BDL	8.83E-06	FB		BBL	1.35E-04			BDL	8.65E-06	FB		DLL	5.10E-05
Ce	FB	B	BBL	3.49E-04			BDL	5.10E-04			BDL	6.48E-05	FB	B	DLL	3.08E-04
Cl			ADL	5.37E-04			ADL	1.40E-03	FB	B	ADL	4.70E-05			ADL	6.61E-04
Co			BDL	4.51E-07			BDL	5.22E-07			BDL	4.42E-07			BDL	4.71E-07
Cr	FB		ADL	7.29E-05			BDL	9.77E-06	FB	B	BBL	3.44E-05	FB	B	DLL	3.90E-05
Cs	FB		BBL	2.79E-04	FB	B	ADL	2.67E-04			BDL	1.22E-04	FB	B	DLL	2.23E-04
Cu		B	BBL	2.56E-05			BDL	1.78E-06			BDL	1.51E-06		B	DLL	9.61E-06
Eu			BDL	9.45E-04		B	ADL	1.45E-03			BDL	1.43E-04		B	DLL	8.47E-04
Fe			ADL	4.58E-04	FB	B	ADL	1.58E-04			ADL	9.22E-05		B	ADL	2.36E-04
Ga			BDL	1.54E-06			BDL	1.78E-06			BDL	1.51E-06			BDL	1.61E-06
Hf			BDL	2.21E-05			BDL	2.56E-05			BDL	2.17E-05			BDL	2.31E-05
Hg			BDL	4.46E-05			BDL	5.25E-05			BDL	3.25E-06			BDL	3.34E-05
In			BDL	4.20E-06			BDL	6.08E-05			BDL	4.12E-06			BDL	2.30E-05
Ir			BDL	4.85E-06			BDL	5.62E-06			BDL	4.76E-06			BDL	5.08E-06
K			ADL	2.40E-04			ADL	1.34E-04		B	ADL	4.61E-05			ADL	1.40E-04
La	FB	B	ADL	6.07E-05	FB		ADL	3.10E-04			BDL	2.86E-05	FB	B	DLL	1.33E-04
Mg			BDL	3.05E-03			BDL	2.50E-04			BDL	2.36E-04			BDL	1.18E-03
Mn			BDL	4.43E-06			BDL	5.12E-06	FB		BBL	5.40E-05	FB		DLL	2.12E-05
Mo			BDL	2.44E-06			BDL	2.82E-06			BDL	2.39E-06			BDL	2.55E-06
Na			BDL	1.55E-03			BDL	1.17E-03			BDL	1.64E-03			BDL	1.45E-03
Nb			BDL	9.95E-06			BDL	1.53E-06			BDL	1.36E-05			BDL	8.36E-06
Ni	FB		ADL	1.45E-05			BDL	1.01E-06			BDL	8.58E-07	FB		DLL	5.45E-06
Pb	FB	B	ADL	6.33E-06	FB		ADL	4.98E-05	FB	B	BBL	7.61E-05	FB	B	DLL	4.41E-05
Pd			BDL	7.96E-06			BDL	9.21E-06			BDL	7.80E-06			BDL	8.32E-06
P			ADL	4.38E-04			ADL	6.13E-04			ADL	8.22E-04			ADL	6.24E-04
Rb			BDL	5.97E-06	FB	B	BBL	1.93E-05	FB	B	BBL	1.34E-05	FB	B	DLL	1.29E-05
S			ADL	1.09E-02			ADL	6.36E-03			ADL	4.79E-03			ADL	7.34E-03
Sb			BDL	1.31E-04	FB	B	ADL	4.88E-05	FB	B	ADL	1.36E-05	FB	B	DLL	6.44E-05
Sc			BDL	6.24E-04			BDL	5.67E-05			BDL	5.01E-04			BDL	3.94E-04
Se			BDL	1.99E-06			BDL	1.96E-05			BDL	1.95E-06			BDL	7.84E-06

Table 6-3: Summary of reciprocating engine (Site Alfa) test results for elements (mg/dscm).

Parameter	Run 1				Run 2				Run 3				Average			
Si	FB	B	ADL	4.13E-04	FB		ADL	3.63E-04			ADL	1.40E-03	FB	B	ADL	7.26E-04
Sm	FB	B	ADL	1.65E-04			BDL	1.05E-04			BDL	8.70E-05	FB	B	DLL	1.19E-04
Sn	FB		BBL	9.95E-05	FB		BBL	1.22E-04			BDL	1.70E-05	FB	B	DLL	7.95E-05
Sr			ADL	1.66E-05			ADL	1.75E-05			ADL	2.93E-05		B	ADL	2.11E-05
Ta			BDL	2.21E-05			BDL	2.56E-05			BDL	2.17E-05			BDL	2.31E-05
Tb			BDL	6.44E-05			BDL	4.06E-04			BDL	6.08E-05			BDL	1.77E-04
Ti			ADL	2.05E-04			ADL	2.47E-04	FB		ADL	6.58E-05			ADL	1.73E-04
Tl	FB		BBL	2.21E-05	FB		BBL	2.70E-05	FB	B	BBL	1.24E-05	FB	B	BBL	2.05E-05
U			BDL	4.63E-06			BBL	7.10E-05			BBL	5.64E-05			DLL	4.40E-05
V			BDL	2.11E-06			BDL	5.22E-07			BDL	4.42E-07			BDL	1.02E-06
W	FB		ADL	1.90E-04	FB		BBL	3.39E-04	FB	B	BBL	8.76E-05	FB	B	DLL	2.05E-04
Y			ADL	1.89E-05	FB	B	BBL	9.76E-06			BDL	3.81E-05	FB	B	DLL	2.23E-05
Zn			ADL	1.30E-03			ADL	1.46E-03			ADL	8.81E-04			ADL	1.21E-03
Zr			BDL	4.60E-05			BDL	2.30E-06			BDL	1.57E-05			BDL	2.13E-05

Table 6-4: Summary of reciprocating engine (Site Alfa) test results for ions (mg/dscm).

Parameter	Run 1		Run 2		Run 3		Average	
NH_4^+	BDL	2.99E-05	BDL	3.62E-05	BDL	2.92E-05	BDL	3.17E-05
Cl^-	BDL	2.99E-05	BDL	3.62E-05	BDL	2.92E-05	BDL	3.17E-05
NO_3^-	ADL	3.67E-03	ADL	6.02E-03	ADL	2.19E-03	ADL	3.96E-03
K^+	BDL	8.96E-04	BDL	1.09E-03	BDL	8.75E-04	BDL	9.52E-04
Na^+	ADL	6.11E-04	ADL	1.34E-04	BDL	2.92E-05	DLL	2.58E-04
SO_4^{2-}	ADL	7.13E-03	ADL	8.50E-03	ADL	6.21E-03	ADL	7.28E-03

Table 6-5: Summary of gas turbine engine (Site Buick) test results for PM2.5 (47-mm filter only).

Parameter		Run 1		Run 2		Run 3		Average
Exhaust Temperature, °F		884		928		942		918
O_2, %vd		15.34		15.15		15.24		15.24
CO_2, %vd		3.94		3.94		3.98		3.95
Water, %v		8.2		11.7		6.2		8.7
Fd, dscf/MMBtu		8615.0		8615.0		8615.0		8615.0
Measured PM2.5 mass:								
PM2.5, mg/dscm	ADL	0..819	FB B ADL	0.00878	FB B ADL	0.00636	ADL	0.278
PM2.5, kg/GJ	ADL	7.12E-04	FB B ADL	7.38E-06	FB B ADL	5.43E-06		2.42E-04
Reconstructed PM2.5 mass (excluding silicon in Run 1):								
PM2.5, mg/dscm	DLL	0.440	FB DLL	0.265	FB DLL	0.123	FB DLL	0.276
PM2.5, kg/GJ	DLL	3.82E-04	FB DLL	2.22E-04	FB DLL	1.05E-04	FB DLL	2.36E-04

Table 6-6: Summary of gas turbine engine (Site Buick) test results for particulate carbon (mg/dscm).

Parameter		Run 1		Run 2		Run 3		Average
OC	ADL	4.22E-01	ADL	1.77E-01	ADL	1.52E-01	ADL	2.51E-01
EC	ADL	2.72E-02	FB ADL	6.43E-03	BDL	2.03E-03	DLL	1.19E-02
Total C	ADL	4.49E-01	ADL	1.84E-01	ADL	1.52E-01	ADL	2.62E-01
OC Backup	B ADL	5.84E-02	B ADL	2.49E-02	B ADL	5.32E-02	B ADL	4.55E-02
EC Backup	B ADL	1.76E-03	B ADL	5.11E-05	B ADL	2.99E-05	B ADL	6.13E-04

Table 6-7: Summary of gas turbine engine (Site Buick) test results for elements (mg/dscm).

Parameter				Run 1				Run 2				Run 3				Average
Ag			BDL	4.72E-06			BDL	6.45E-06			BDL	4.89E-06			BDL	5.35E-06
Al			BDL	5.99E-05			BDL	9.81E-04			BDL	6.95E-05			BDL	3.70E-04
As			BDL	1.88E-06			BDL	2.57E-06			BDL	1.95E-06			BDL	2.13E-06
Au			BDL	1.54E-05			BDL	7.06E-06			BDL	5.90E-05			BDL	2.72E-05
Ba	FB	B	BBL	6.35E-05			BDL	4.11E-04			BDL	1.72E-05	FB	B	DLL	1.64E-04
Br			ADL	7.38E-04	FB		ADL	1.07E-04	FB		BBL	2.92E-05			DLL	2.91E-04
Ca		B	ADL	7.19E-05			BBL	4.56E-05			BDL	3.35E-05		B	DLL	5.03E-05
Cd	FB		BBL	6.35E-05			BDL	1.89E-04	FB		BBL	1.68E-04	FB	B	DLL	1.40E-04
Ce			BDL	1.26E-04			BDL	6.90E-04	FB		BBL	1.18E-03	FB	B	DLL	6.64E-04
Cl		B	ADL	4.90E-05	FB	B	ADL	3.14E-05	FB	B	BBL	8.16E-05		B	DLL	5.40E-05
Co			BDL	4.80E-07			BDL	6.56E-07			BDL	4.97E-07			BDL	5.45E-07
Cr	FB		BBL	1.27E-05			BDL	5.69E-05			ADL	2.94E-05	FB	B	DLL	3.30E-05
Cs			BDL	2.23E-05			BDL	3.54E-05	FB		ADL	3.52E-04	FB	B	DLL	1.37E-04
Cu		B	BBL	2.29E-06			BDL	2.91E-04			BDL	1.70E-06		B	DLL	9.83E-05
Eu			BDL	1.06E-03	FB	B	BBL	2.68E-03			BDL	1.48E-04	FB	B	DLL	1.30E-03
Fe			ADL	7.68E-05	FB	B	ADL	4.44E-06		B	ADL	5.40E-05	FB	B	ADL	4.51E-05
Ga			BDL	1.64E-06			BDL	2.24E-06			BDL	1.70E-06			BDL	1.86E-06
Hf			BDL	2.35E-05			BDL	3.21E-05			BDL	2.44E-05			BDL	2.67E-05
Hg			BBL	2.38E-05			BDL	7.02E-05			BBL	6.30E-05		B	DLL	5.24E-05
In	FB		BBL	3.02E-05			BDL	6.12E-06			BDL	4.64E-06	FB		DLL	1.37E-05
Ir			BDL	5.17E-06			BDL	7.06E-06			BDL	5.36E-06			BDL	5.86E-06
K			ADL	1.74E-04	FB	B	ADL	4.50E-05			BDL	5.15E-05			DLL	9.03E-05
La			BDL	1.58E-04			BDL	3.23E-04			BDL	2.46E-05			BDL	1.68E-04
Mg			BDL	2.30E-04		B	BBL	6.12E-03			BDL	3.67E-03		B	DLL	3.34E-03
Mn			BBL	3.18E-05			BBL	1.14E-04			BBL	8.42E-05			BBL	7.68E-05
Mo			BDL	2.60E-06			BDL	5.25E-05			BDL	2.69E-06			BDL	1.93E-05
Na			BDL	7.14E-03	FB		BBL	2.64E-02			BDL	1.83E-03	FB		DLL	1.18E-02
Nb			BDL	7.51E-06			BDL	1.93E-06			BDL	1.46E-06			BDL	3.63E-06
Ni			BDL	9.33E-07			BBL	2.26E-05			BDL	9.66E-07			DLL	8.17E-06
Pb	FB	B	BBL	3.59E-05			BDL	1.37E-04	FB	B	ADL	2.03E-05	FB	B	DLL	6.45E-05
Pd			BDL	8.48E-06			BDL	2.17E-04			BDL	8.78E-06			BDL	7.80E-05
P			ADL	2.65E-03	FB		ADL	4.75E-05	FB	B	BBL	5.49E-05			DLL	9.16E-04
Rb			BDL	2.58E-06			BDL	6.56E-07	FB		ADL	6.15E-06	FB	B	DLL	3.13E-06
S			BDL	2.36E-06			BDL	3.22E-06			BDL	2.44E-06			BDL	2.68E-06
Sb			BDL	1.18E-05			BDL	8.53E-05	FB	B	BBL	1.59E-04	FB	B	DLL	8.53E-05
Sc			BDL	4.96E-05			BDL	8.18E-04			BDL	5.22E-05			BDL	3.07E-04
Se			BDL	2.12E-06			BBL	5.14E-05			BDL	2.19E-06			DLL	1.86E-05

Table 6-7: Summary of gas turbine engine (Site Buick) test results for elements (mg/dscm).

Parameter				Run 1				Run 2				Run 3				Average
Si			ADL	1.35E-01	FB	B	ADL	7.31E-04	FB	B	BBL	3.25E-04			DLL	4.55E-02
Sm			BBL	6.29E-04			BBL	2.28E-03			BDL	1.75E-03		B	DLL	1.55E-03
Sn	FB		BBL	5.72E-05			BDL	1.36E-04			BDL	1.09E-04	FB	B	DLL	1.01E-04
Sr		B	BBL	5.62E-06			BDL	2.24E-06			BDL	2.97E-05		B	DLL	1.25E-05
Ta			BDL	2.35E-05			BDL	3.21E-05			BDL	2.44E-05			BDL	2.67E-05
Tb			BDL	8.06E-05			BBL	1.65E-03			BDL	1.22E-03		B	DLL	9.82E-04
Ti	FB	B	BBL	8.48E-06	FB		ADL	9.86E-05			BDL	1.21E-06	FB	B	DLL	3.61E-05
Tl	FB		BBL	1.27E-05	FB		BBL	4.56E-05			BDL	1.95E-06	FB		DLL	2.01E-05
U			BDL	4.93E-06		B	ADL	1.01E-05			BBL	8.79E-05		B	DLL	3.43E-05
V			BDL	8.96E-06	FB	B	BBL	3.22E-05			BDL	3.02E-06	FB	B	DLL	1.47E-05
W			BDL	1.65E-04		B	BBL	2.71E-04			BBL	4.20E-04		B	DLL	2.85E-04
Y	FB	B	ADL	2.07E-05			BDL	2.24E-06	FB	B	BBL	2.39E-05	FB	B	DLL	1.56E-05
Zn	FB	B	BBL	1.69E-05			BDL	8.05E-05	FB		BBL	5.01E-05	FB	B	DLL	4.92E-05
Zr			BDL	1.24E-05	FB		BBL	5.14E-05	FB	B	ADL	1.64E-06	FB	B	DLL	2.18E-05

Table 6-8: Summary of gas turbine engine (Site Buick) test results for ions (mg/dscm).

Parameter		Run 1			Run 2			Run 3			Average	
NH_4^+		BDL	1.82E-05		BDL	6.02E-05		BDL	4.44E-05		BDL	4.09E-05
Cl^-		BDL	1.82E-05		BDL	6.02E-05		BDL	4.44E-05		BDL	4.09E-05
NO_3^-	FB	ADL	4.57E-04	FB	ADL	3.62E-04	FB	ADL	6.65E-04	FB	ADL	4.95E-04
K^+		BDL	5.48E-04		BDL	1.81E-03		BDL	1.33E-03		BDL	1.23E-03
Na^+	FB	ADL	1.74E-04		BDL	2.05E-03		BDL	1.53E-03	FB	DLL	1.25E-03
SO_4^{2-}		BDL	1.82E-05		BDL	6.02E-05		BDL	4.44E-05		BDL	4.09E-05