Consumers Energy

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40 CFR Part 60 Subpart JJJJ
40 CFR Part 63 Subpart ZZZZ
Continuous Compliance Test Report

EUENGINE31, EUENGINE32, EUENGINE33, EUENGINE34, and EUENGINE35

Consumers Energy Company
Ray Compressor Station
69333 Omo Road
Armada, Michigan 48005
SRN: B6636

October 27, 2023

Test Dates: August 29 – September 1, 2023

Test Performed by the Consumers Energy Company
Regulatory Compliance Testing Section
Air Emissions Testing Body
Laboratory Services Section
Work Order No. 41252222, 41252223, 41252224, 41252226, 41252227
Version No.: 1

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EXECUTIVE SUMMARY

Consumers Energy Regulatory Compliance Testing Section (RCTS) conducted nitrogen oxides (NO_x), carbon monoxide (CO), and volatile organic compound (VOC) testing upstream and/or downstream of oxidation catalysts installed in the exhausts of five natural gas-fired, reciprocating internal combustion engines (RICE) designated as EUENGINE31, EUENGINE32, EUENGINE33, EUENGINE34, and EUENGINE35, operating at the Ray Compressor Station in Armada, Michigan. Each engine is a four-stroke lean-burn (4SLB); spark ignited 4,735 brake horsepower (BHP) engine operating at a major source of hazardous air pollutant (HAP) emissions. The engines provide mechanical shaft power to compressors maintaining natural gas pipeline pressure for movement in and out of storage reservoirs and along the pipeline system.

The test program was performed on August 29 through September 1, 2023 to satisfy performance test requirements and evaluate continuous compliance with United States Environmental Protection Agency (USEPA) 40 CFR Part 60, Subpart JJJJ, Standards of Performance for Stationary Spark Ignition Internal Combustion Engines, and 40 CFR Part 63, Subpart ZZZZ, National Emission Standards for Hazardous Air Pollutants (NESHAP) for Stationary Reciprocating Internal Combustion Engines, as incorporated in Michigan Department of Environment, Great Lakes, and Energy (EGLE), Renewable Operating Permit (ROP) MI-ROP-B6636-2020b.

A test protocol was submitted to EGLE on April 26, 2023, and subsequently approved by Ms. Regina Angellotti, Environmental Quality Analyst, in a letter dated June 12, 2023. No deviations from the approved test protocol or associated reference methods therein occurred except the proposed test dates were rescheduled from June 26 to August 29, 2023, due to engine availability. EGLE representatives Andrew Riley and Noshin Khan were onsite to witness portions of the testing.

During testing, the engines operated within ± 10 percent of 100 percent peak (or highest achievable) load, as specified in 40 CFR §60.4244(a). Triplicate 60-minute test runs were conducted at each engine following procedures in USEPA Reference Methods (RM) 1, 3A, 7E 10, 18, 19, and 25A in 40 CFR Part 60, Appendix A. The summary of results in Table E-1 indicate each engine and oxidation catalyst complies with applicable percent CO reduction limits.

Table E-1
Summary of Test Results

Parameter	Units	EUENGINE					Emission Limit		
		31	32	33	34	35	40 CFR Part 60, Subpart JJJJ[1, 2, †]	40 CFR Part 63, Subpart ZZZZ	MI-ROP-B6636 2020b
NO_x	g/HP-hr	0.5	0.4	0.4	0.3	0.4	1.0		0.5
	ppmvd at 15% O_2	40	37	32	27	37	82		
CO	g/HP-hr	0.1	0.04	0.04	0.1	0.1	2.0		0.2
	ppmvd at 15% O_2	10	5	5	10	11	270		
	% reduction	96.6	98.2	97.9	96.4	96.0		≥93	≥93
VOC	g/HP-hr	0.1	0.03	0.04	0.03	0.02	0.7		0.19
	ppmvd at 15% O_2	5	3	4	3	1	60		

NO_x nitrogen oxides
CO carbon monoxide
VOC volatile organic compounds (non-methane, non-ethane organic compounds), as propane
g/HP-hr grams per horsepower hour

[1] Owners and operators of stationary non-certified SI engines may choose to comply with the emission standards in units of either g/HP-hr or ppmvd at 15 percent O_2.
[2] Owners and operators of new lean burn SI stationary engines with a site rating ≥250 brake HP located at a major source that are meeting the requirements of 40 CFR Part 63, Subpart ZZZZ, Table 2a do not have to comply with the CO emission standards in 40 CFR Part 60, Subpart JJJJ, Table 1.
[†] 40 CFR Part 60 Subpart JJJJ refers to volatile organic compounds as defined in 40 CFR §51.100(s)(1), which specifies a VOC definition including "*any compound of carbon...other than the following, which have been determined to have negligible photochemical reactivity: methane, ethane...*" Therefore, Subpart JJJJ exhaust gas VOC measurements reported herein include total *non-methane, non-ethane* (C_2H_6) organic compounds only.

Detailed results are presented in Appendix Tables 1 – 5. Sample calculations, field data sheets, engine data and supporting documentation are provided in Appendices A through E.

1.0 INTRODUCTION

This report summarizes compliance air emission results from tests conducted on August 29 through September 1, 2023, at the Consumers Energy Ray Compressor Station (RCS) in Armada, Michigan.

This document follows the November 2019, Michigan Department of Environment, Great Lakes, and Energy (EGLE) *Format for Submittal of Source Emission Test Plans and Reports.* Reproducing only a portion of this report may omit critical substantiating documentation or cause information to be taken out of context. If any portion of this report is reproduced, please exercise due care in this regard.

1.1 Identification, Location, and Dates of Tests

Consumers Energy Regulatory Compliance Testing Section (RCTS) conducted nitrogen oxides (NO_x), carbon monoxide (CO), and volatile organic compound (VOC) tests on emission units (EU) EUENGINE31, EUENGINE32, EUENGINE33, EUENGINE34 and EUENGINE35, operating at the RCS facility, a major source of hazardous air pollutant (HAP) emissions in Armada, Michigan.

A test protocol was submitted to EGLE on April 26, 2023, and subsequently approved by Ms. Regina Angellotti, Environmental Quality Analyst, in a letter dated June 12, 2023. No deviations from the approved test protocol or associated reference methods therein occurred except the proposed test dates were rescheduled from June 26 to August 29, 2023, due to engine availability. EGLE representatives Andrew Riley and Noshin Khan were onsite to witness portions of the testing.

1.2 Purpose of Testing

The purpose of the test program was to satisfy performance test requirements and evaluate continuous compliance with United States Environmental Protection Agency (USEPA) 40 CFR Part 60, Subpart JJJJ, Standards of Performance for Stationary Spark Ignition Internal Combustion Engines, and 40 CFR Part 63, Subpart ZZZZ, National Emission Standards for Hazardous Air Pollutants (NESHAP) for Stationary Reciprocating Internal Combustion Engines, as incorporated in Michigan Department of Environment, Great Lakes, and Energy (EGLE), Renewable Operating Permit (ROP) MI-ROP-B6636-2020b. The engines are subject to federal air emission regulations and collectively grouped as FGENGINES3 within the ROP. The applicable emission limits are presented in Table 1-1:

Table 1-1
FGENGINES3 Emission Limits

Parameter	Emission Limit	Units	Applicable Requirement
NO_x	0.5	g/HP-hr	MI-ROP-B6636-2020b, Flexible Group Conditions: FGENGINES3
	1.0 or 82	g/HP-hr ppmvd at 15% O_2	40 CFR Part 60, Subpart JJJJ, Table 1
CO	0.2	g/HP-hr	MI-ROP-B6636-2020b, Flexible Group Conditions: FGENGINES3
	2.0* or 270*	g/HP-hr ppmvd at 15% O_2	40 CFR Part 60, Subpart JJJJ, Table 1
	93†	% Reduction across oxidation catalyst	MI-ROP-B6636-2020b, Flexible Group Conditions: FGENGINES3 and 40 CFR §63.6300(b) – 40 CFR Part 63, Subpart ZZZZ, Table 2a
VOC‡	0.19	g/HP-hr	MI-ROP-B6636-2020b, Flexible Group Conditions: FGENGINES3
	0.7 or 60	g/HP-hr ppmvd at 15% O_2	40 CFR Part 60, Subpart JJJJ, Table 1

* Owners and operators of new lean burn SI stationary engines with a site rating ≥250 brake HP located at a major source that are meeting the requirements of 40 CFR Part 63, Subpart ZZZZ, Table 2a do not have to comply with the CO emission standards in 40 CFR Part 60, Subpart JJJJ, Table 1.

† 40 CFR Part 63, Subpart ZZZZ, Table 2a allows compliance to be demonstrated by limiting the concentration of formaldehyde in the stationary RICE exhaust to 14 ppmvd or less at 15 percent O_2 or reducing CO emissions by ≥93%. Consumers Energy intends to demonstrate compliance using the CO reduction efficiency emission limit.

‡ 40 CFR Part 60 Subpart JJJJ refers to volatile organic compounds as defined in 40 CFR §51.100(s)(1), which specifies a VOC definition including *"any compound of carbon...other than the following, which have been determined to have negligible photochemical reactivity: methane, ethane..."* Therefore, Subpart JJJJ exhaust gas measurements of VOC will include only the total non-methane, non-ethane organic compounds.

1.3 Brief Description of Source

EUENGINE31, EUENGINE32, EUENGINE33, EUENGINE34 and EUENGINE35 are natural gas-fired, 4SLB spark ignition (SI) RICE coupled to compressors, which are used to transport natural gas into/out of storage fields or along the pipeline system. The engines are collectively grouped as FGENGINES3 within the ROP.

1.4 Contact Information

Table 1-2 contains the test affiliated persons names, addresses and telephone numbers for further information regarding this test program.

Table 1-2
Contact Information

Program Role	Contact	Address
State Regulatory Administrator	Jeremy Howe Technical Programs Unit Supervisor 231-878-6687 howej@michigan.gov	Michigan Department of Environment, Great Lakes and Energy 525 W. Allegan, Constitution Hall, 2nd Floor S Lansing, Michigan 48933
Regulatory Agency Representative	Regina Angellotti Environmental Quality Analyst 313-418-0895 angellottir1@michigan.gov	EGLE – Air Quality Division Detroit District Office Cadillac Place, Suite 2-300 3058 West Grand Boulevard Detroit, Michigan 48202
State District Manager	Joyce Zhu Environmental Manager 586-606-2572 zhuj@michigan.gov	EGLE – Air Quality Division Warren District SE Michigan Office 27700 Donald Court Warren, Michigan 48092
State Regulatory Inspector	Noshin Khan Environmental Engineer 586-536-1197 khann5@michigan.gov	EGLE – Air Quality Division Warren District SE Michigan Office 27700 Donald Court Warren, Michigan 48092
Responsible Official	Avelock Robinson Director of Gas Compression 586-716-3326 avelock.robinson@cmsenergy.com	Consumers Energy Company St. Clair Compressor Station 10021 Marine City Highway Ira, Michigan 48023
Corporate Air Quality Contact	Amy Kapuga Principal Environmental Engineer 517-788-2201 amy.kapuga@cmsenergy.com	Consumers Energy Company Environmental Services Department 1945 West Parnall Road Jackson, Michigan 49201
Field Environmental Coordinator	Thomas Fox Principal Environmental Engineer 989-667-5153 thomas.fox@cmsenergy.com	Consumers Energy Company Bay City Customer Service Center 4141 E. Wilder Road Bay City, MI 48706
Test Facility	William F. Harvey Supervisor Gas Compression 586-784-2096 william.f.harvey@cmsenergy.com	Consumers Energy Company Ray Compressor Station 69333 Omo Road Armada, Michigan 48005
Test Team Representative	Thomas Schmelter, QSTI Sr. Engineering Technical Analyst 616-738-3234 thomas.schmelter@cmsenergy.com	Consumers Energy Company 17010 Croswell Road JHC Training Center / 149-10 West Olive MI 49460

2.0 SUMMARY OF RESULTS

2.1 Operating Data

During the compliance test, the engines fired natural gas, and pursuant to §60.4244(a), operated within 10% of 100 percent peak (or the highest achievable) load based on the maximum manufacturer's design capacity at engine and compressor site conditions. Refer to Appendix D for detailed operating data.

2.2 APPLICABLE PERMIT INFORMATION

RCS operates EUENGINE31, EUENGINE32, EUENGINE33, EUENGINE34 and EUENGINE35 in accordance with the facility ROP, which incorporates 40 CFR Part 60, Subpart JJJJ and 40 CFR Part 63, Subpart ZZZZ requirements specific to FGENGINES3.

2.3 RESULTS

The test results presented in Tables 2-1 and 2-2 indicate each engine and associated oxidation catalyst complies with applicable NO_x, CO, and VOC emission and percent CO reduction limits in 40 CFR Part 60, Subpart JJJJ, 40 CFR Part 63, Subpart ZZZZ, and MI-ROP-B6636-2020b.

Table 2-1
Summary of Test Results

Parameter	Units	EUENGINE					Emission Limit		
		31	32	33	34	35	40 CFR Part 60, Subpart JJJJ[1, 2, †]	40 CFR Part 63, Subpart ZZZZ	MI-ROP-B6636 2020b
NO_x	g/HP-hr	0.5	0.4	0.4	0.3	0.4	1.0		0.5
	ppmvd at 15% O_2	40	37	32	27	37	82		
CO	g/HP-hr	0.1	0.04	0.04	0.1	0.1	2.0		0.2
	ppmvd at 15% O_2	10	5	5	10	11	270		
	% reduction	96.6	98.2	97.9	96.4	96.0		≥93	≥93
VOC	g/HP-hr	0.1	0.03	0.04	0.03	0.02	0.7		0.19
	ppmvd at 15% O_2	5	3	4	3	1	60		

NO_x nitrogen oxides
CO carbon monoxide
VOC volatile organic compounds (non-methane, non-ethane organic compounds), as propane
g/HP-hr grams per horsepower hour

[1] Owners and operators of stationary non-certified SI engines may choose to comply with the emission standards in units of either g/HP-hr or ppmvd at 15 percent O_2.
[2] Owners and operators of new lean burn SI stationary engines with a site rating ≥250 brake HP located at a major source that are meeting the requirements of 40 CFR Part 63, Subpart ZZZZ, Table 2a do not have to comply with the CO emission standards in 40 CFR Part 60, Subpart JJJJ, Table 1.
† 40 CFR Part 60 Subpart JJJJ refers to volatile organic compounds as defined in 40 CFR §51.100(s)(1), which specifies a VOC definition including *"any compound of carbon...other than the following, which have been determined to have negligible photochemical reactivity: methane, ethane..."* Therefore, Subpart JJJJ exhaust gas VOC measurements reported herein include total *non-methane, non-ethane* (C_2H_6) organic compounds only.

Table 2-2
Summary of 40 CFR Part 63 Subpart ZZZZ Test Results

Source	Engine Load (%)	CO Reduction Efficiency (%)	Oxidation Catalyst Inlet Temperature[1] (°F)	Oxidation Catalyst Pressure Drop Comparison (Inches Water Gauge)	
				2023 Results	Initial Test
	[Requirement: 100% ± 10%]	[Requirement: ≥93%]	[Requirement: ≥450°F & ≤1350°F]	[Requirement: ±2" from Initial Test]	
EUENGINE31	95.4	96.6	863	2	2.1
EUENGINE32	95.5	98.2	869	2	2.3
EUENGINE33	94.0	97.9	816	1	2.0
EUENGINE34	94.1	96.4	823	2	2.7
EUENGINE35	94.0	96.0	801	2	2.1

[1]Compliance with the catalyst inlet temperature operating range is based on a 4-hour rolling average

Detailed results are presented in Appendix Tables 1 – 5. Section 5.0 contains a discussion of results. Sample calculations and field data sheets are presented in Appendices A and B. Engine operating data and supporting documentation are provided in Appendices C, D, and E.

3.0 SOURCE DESCRIPTION

EUENGINE31, EUENGINE32, EUENGINE33, EUENGINE34 and EUENGINE35 were constructed in 2013. A summary of the engine specifications is presented in Table 3-1.

Table 3-1
Summary of Engine Specifications

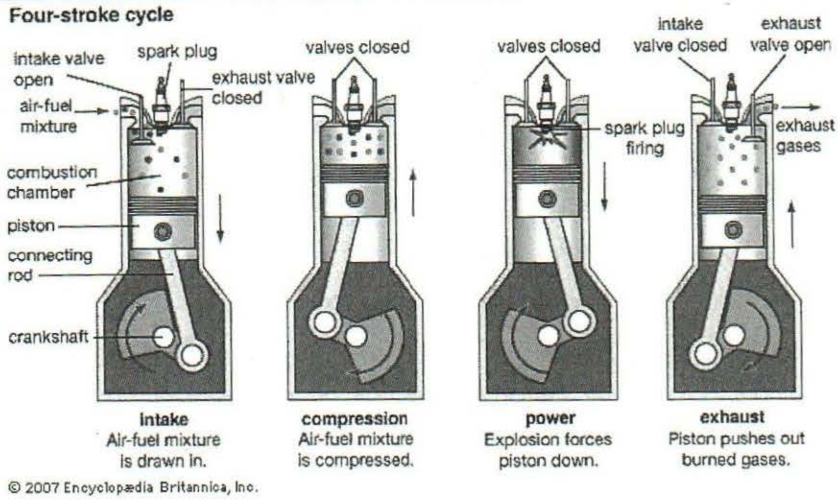
Parameter[1]	EUENGINE31 through EUENGINE35
Make	Caterpillar
Model	G3616
Output (brake-horsepower)	4,735
Heat Input (mmBtu/hr)	32.0
Exhaust Flow Rate (ACFM, wet)	32,100
Exhaust Gas Temp.	856
Engine Outlet O_2 (Vol-%, dry)	12.00
Engine Outlet CO_2 (Vol-%, dry)	5.81
CO, Uncontrolled (ppmv, dry)	572.0
CO, Controlled (ppmv, dry)[2]	40.0

[1] Engine specifications are based upon vendor data for operation at 100% of rated engine capacity.
[2] The controlled CO concentrations are based upon the vendor not to exceed CO concentrations at 100% load, and a reduction 93% by volume for the associated oxidation catalysts.

3.1 PROCESS

The engines utilize the four-stroke engine cycle which starts with the downward air intake piston stroke which aspirates air through intake valves into the combustion chamber (cylinder). When the piston nears the bottom of the cylinder, fuel is injected and the intake valves close. As the piston travels upward, the air/fuel mixture is compressed and ignited, thus forcing the piston downward into the power stroke. At the bottom of the power stroke, exhaust valves open and the piston traveling upward expels the combustion by-products. Significant maintenance has not been performed on the engines or oxidation catalysts within the past three months. Refer to Figure 3-1 for a four-stroke engine process diagram.

Figure 3-1. Four-Stroke Engine Process Diagram



The flue gas generated by natural gas combustion is controlled through parametric controls (i.e., timing and operating at a lean air-to-fuel ratio) and by post-combustion oxidizing catalysts manufactured by EmeraChem, LLC (Part No. 28283.5-300CO). Four catalyst modules installed on each engine exhaust stack use proprietary materials to lower the oxidation temperature of CO and other organic compounds, thus maximizing the catalyst efficiency specific to the exhaust gas temperatures of the engines. As CO passes through the catalytic oxidation system, CO and VOC are oxidized to CO_2 and water, while suppressing the conversion of NO to NO_2.

Nitrogen oxides emissions from the engines are minimized using lean-burn combustion technology. Lean-burn combustion refers to an elevated level of excess air (50% to 100% relative to the stoichiometric amount) in the combustion chamber. The excess air absorbs heat during the combustion process, thereby reducing the combustion temperature and pressure resulting in lower NO_x emissions.

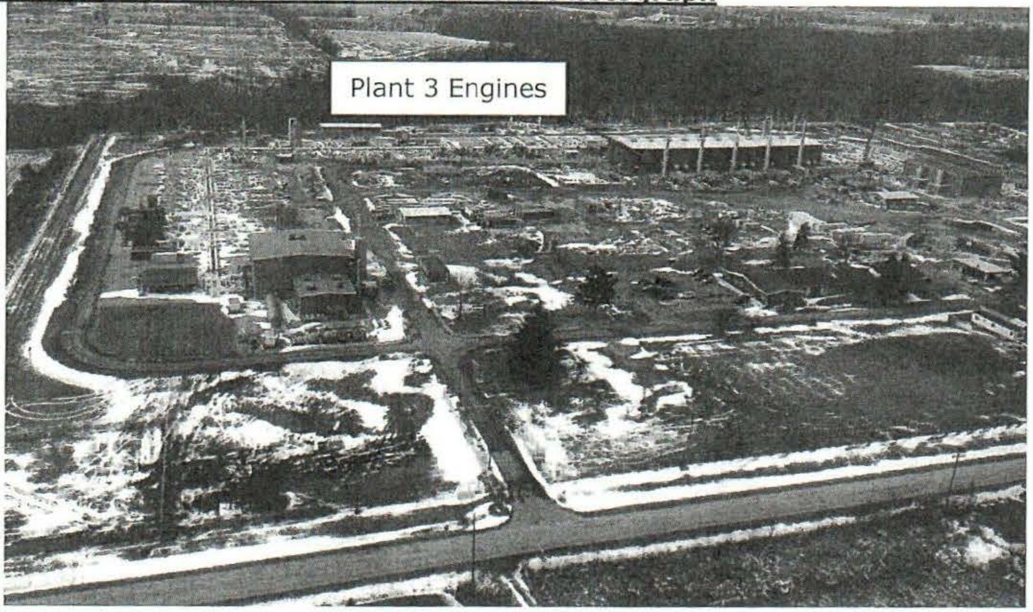
While the catalyst vendor guarantees 93% CO destruction efficiency, the catalyst also controls formaldehyde and non-methane, non-ethane hydrocarbons (NMNEHC). Estimated formaldehyde and NMNEHC destruction efficiencies are 85% and 75%, respectively.

A continuous parameter monitoring system (CPMS) monitors catalyst inlet temperature in accordance with the requirements specified in Table 5 (1) of 40 CFR Part 63, Subpart ZZZZ. This parameter is monitored in accordance with the site-specific preventative maintenance / malfunction and abatement plan to evaluate an efficient catalytic reaction and the performance of the pollution control equipment. Detailed operating data are provided in Appendix D.

3.2 Process Flow

Located in northern Macomb County, the Ray Compressor Station helps maintain natural gas pressure along pipeline systems and for gas injection and withdrawal. An aerial photograph of the Ray Compressor Station is provided in Figure 3-2.

Figure 3-2. Ray Compressor Station Aerial Photograph



The bottom portion of the exhaust stacks contain an outer and an inner circular duct (like a doughnut if viewed from the top of the stack). Engine exhaust gas enters the free-standing outer stack via two horizontal ducts exiting the engine and flows downward through oxidation catalysts in the bottom of the outer stack. The gases are then directed into the inner stack through an opening near the stack base, traveling upwards approximately 95-feet to an unobstructed vertical discharge to atmosphere.

3.3 Materials Processed

The engine fuel fired is exclusively natural gas, as defined in 40 CFR §72.2. Natural gas sample analysis indicates this composition to be approximately 93% methane and 7%.

3.4 Rated Capacity

Each engine has a rated heat input of 32 mmBtu/hr and a maximum output of 4,735 horsepower. These input/output capacities are a function of facility and gas transmission extraction and/or storage demand. During testing, engine operating parameters were recorded and averaged for each test run. Refer to Appendix D for this operating data.

3.5 Process Instrumentation

During testing, engine operating parameters were continuously monitored and collected in one-minute increments, for the following parameters:

- Discharge pressure (psi)
- Engine load as torque share (% max)
- Engine speed (rpm)
- Engine load capacity (%)
- Suction pressure (psi)
- Fuel gas flow (scf/hr)
- Catalyst pressure difference (in. H_2O)
- Catalyst inlet / engine exhaust temperature (°F)
- Power (BHP)

Refer to Appendix D for operating data.

4.0 SAMPLING AND ANALYTICAL PROCEDURES

RCTS measured NO_x, CO, VOC, and O_2 concentrations using the USEPA test methods presented in Table 4-1. The sampling and analytical procedures associated with each are described in the following sections.

Table 4-1
Test Methods

Parameter	Method (USEPA)	Title
Sampling location	1	Sample and Velocity Traverses for Stationary Sources
Oxygen and/or Carbon dioxide	3A	Determination of Oxygen and Carbon Dioxide Concentrations in Emissions from Stationary Sources (Instrumental Analyzer Procedure)
Moisture Content	4 (or ALT-008)	Determination of Moisture Content in Stack Gases
Oxides of Nitrogen	7E	Determination of Nitrogen Oxides Emissions from Stationary Sources (Instrumental Analyzer Procedure)
Carbon monoxide	10	Determination of Carbon Monoxide Emissions from Stationary Sources (Instrumental Analyzer Procedure)
Methane and ethane*	18	Measurement of Gaseous Organic Compound Emissions by Gas Chromatography
Emission Rate	19	Determination of Sulfur Dioxide Removal Efficiency and Particulate Matter, Sulfur Dioxide, and Nitrogen Oxide Emission Rates
Volatile organic compounds	25A	Determination of Total Gaseous Organic Concentration Using a Flame Ionization Analyzer

4.1 Description of Sampling Train and Field Procedures

The test matrix presented in Table 4-2 summarizes the sampling and analytical methods performed for the specified parameters during this test program.

Table 4-2
Test Matrix

Date (2023)	Run	Sample Type	Start Time (EDT)	Stop Time (EDT)	Test Duration (min)	USEPA Test Method	Comment
EUENGINE31							
August 29	1	O_2 CO NO_x VOC	12:30	13:29	60	1 3A 7E 10 18 19 25A	A 3-point traverse (16.7, 50.0 & 83.3% of the measurement line) conducted at each location during Run 1. Single point sampling thereafter.
	2		14:05	15:04	60		
	3		15:40	16:39	60		
EUENGINE32							
August 30	1	O_2 CO NO_x VOC	08:40	09:39	60	1 3A 7E 10 18 19 25A	A 3-point traverse (16.7, 50.0 & 83.3% of the measurement line) conducted at each location during Run 1. Single point sampling thereafter.
	2		10:10	11:09	60		
	3		11:40	12:39	60		
EUENGINE33							
August 30	1	O_2 CO NO_x VOC	15:10	11:10	60	1 3A 7E 10 18 19 25A	A 3-point traverse (16.7, 50.0 & 83.3% of the measurement line) conducted at each location during Run 1. Single point sampling thereafter.
August 31	2		08:45	09:44	60		
	3		10:20	11:19	60		
EUENGINE34							
August 31	1	O_2 CO NO_x VOC	12:30	13:29	60	1 3A 7E 10 18 19 25A	A 3-point traverse conducted at each location during Run 1. Single point sampling thereafter. Run 3 paused 16:23-16:38 due to open valve.
	2		14:05	15:04	60		
	3		15:35	16:50	60		
EUENGINE35							
September 1	1	O_2 CO NO_x VOC	10:25	11:24	60	1 3A 7E 10 18 19 25A	A 3-point traverse (16.7, 50.0 & 83.3% of the measurement line) conducted at each location during Run 1. Single point sampling thereafter.
	2		11:55	12:54	60		
	3		13:20	14:19	60		

4.2 Sample Location and Traverse Points (USEPA Method 1)

The number and location of traverse points for each engine was evaluated according to the requirements in Table 4 of 40 CFR Part 63 and USEPA Method 1, *Sample and Velocity Traverses for Stationary Sources*.

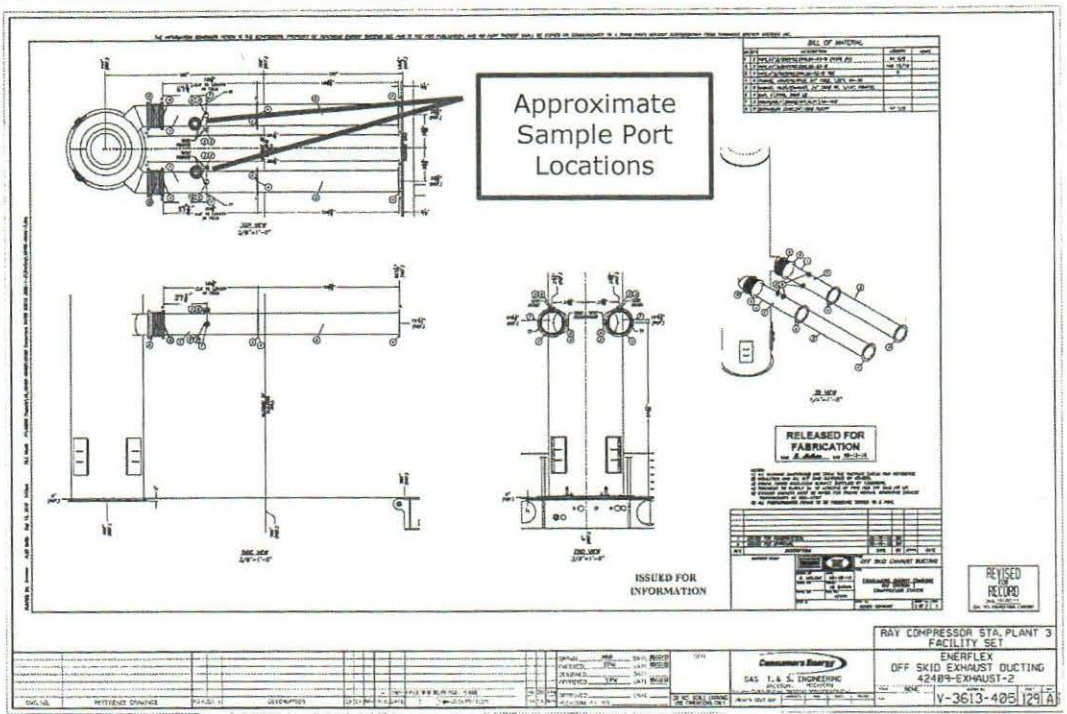
Pre-catalyst Sampling Ports

Each engine is equipped with sample ports located upstream of the oxidation catalyst in (two) horizontal 24-inch diameter ducts exiting the engine and building. The ports are:

- At least 208 inches (8.7 duct diameters) downstream of a duct bend disturbance at the engine exhaust, and
- At least 57 inches (2.4 duct diameters) upstream of flow disturbance caused by a change in duct diameter and flow direction as it enters the oxidation catalyst.

The pre-catalyst sample ports are 4-inch in diameter and extend 2-inches beyond the stack wall (Figure 4-1).

Figure 4-1. Pre-Catalyst Sampling Port Location



Post-catalyst Sampling Ports

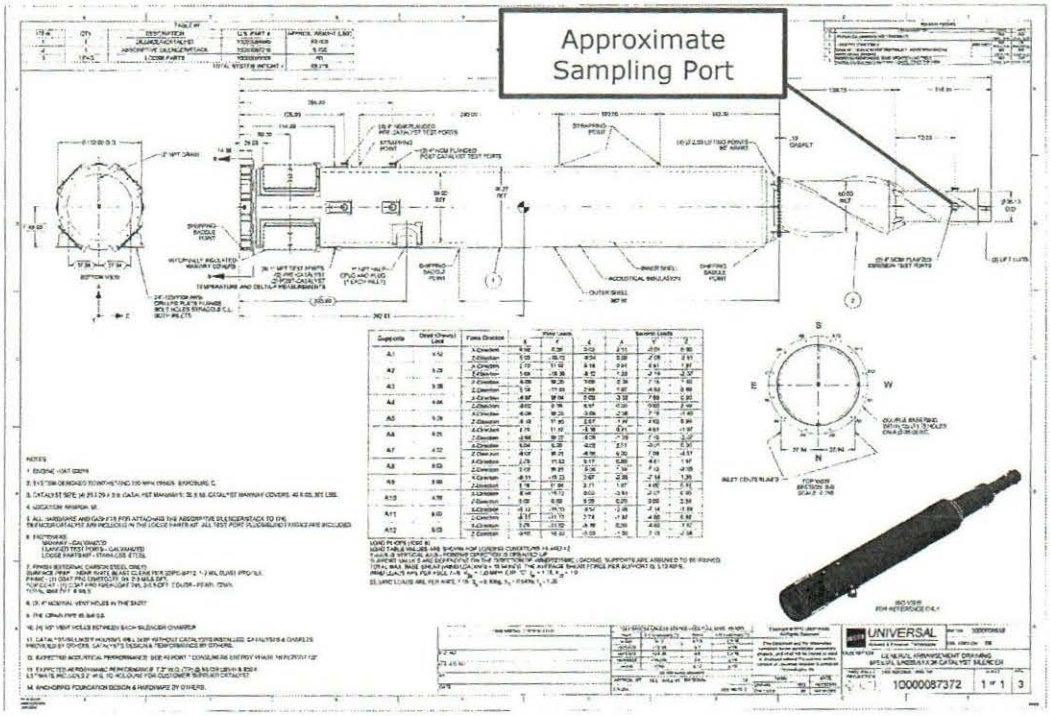
Each engine is also equipped with sample ports located downstream of the oxidation catalyst in (one) vertical 36-inch diameter stack at:

- 72-inches (2 stack diameters) downstream of a flow disturbance, and
- 43-inches (1.2 stack diameters) upstream of the stack exit.

The post-catalyst sample ports are 4-inch in diameter and extend 4-inches beyond the stack wall (Figure 4-2).

Since each exhaust duct or stack is >12 inches in diameter and the sample port locations meet the two and one-half diameter criterion in Section 11.1.1 of Method 1, exhaust gas was sampled at equal time intervals from each of three traverse points located at 16.7, 50.0, and 83.3% of the measurement line during Run 1. Stratification data obtained during Run 1 revealed each location was unstratified, therefore sampling was conducted at a single sample point which most closely matched the mean concentration.

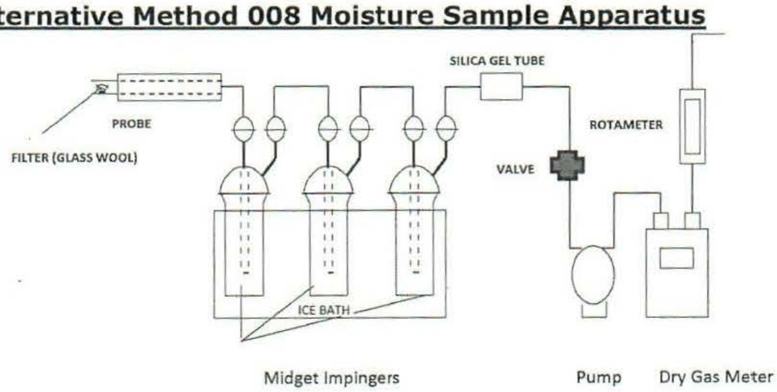
Figure 4-2. Post-Catalyst Sampling Port Location



4.3 Moisture Content (USEPA ALT-008)

Exhaust gas moisture content was determined at each engine following specifications in USEPA Method 4, *Determination of Moisture Content in Stack Gases*, or equivalent alternate moisture methodology, such as ALT - 008, to convert wet-basis volatile organic compound measurements to a dry basis. Exhaust gas was drawn from the stack into impingers immersed in an ice-bath, condensing any water therein, after which the condensed water was measured gravimetrically to calculate the percent moisture content (Figure 4-3).

Figure 4-3. Alternative Method 008 Moisture Sample Apparatus



The silica gel tube depicted in this figure was replaced with a midget impinger (bubbler) with a straight tube insert, as allowed in ALT-008, §1.

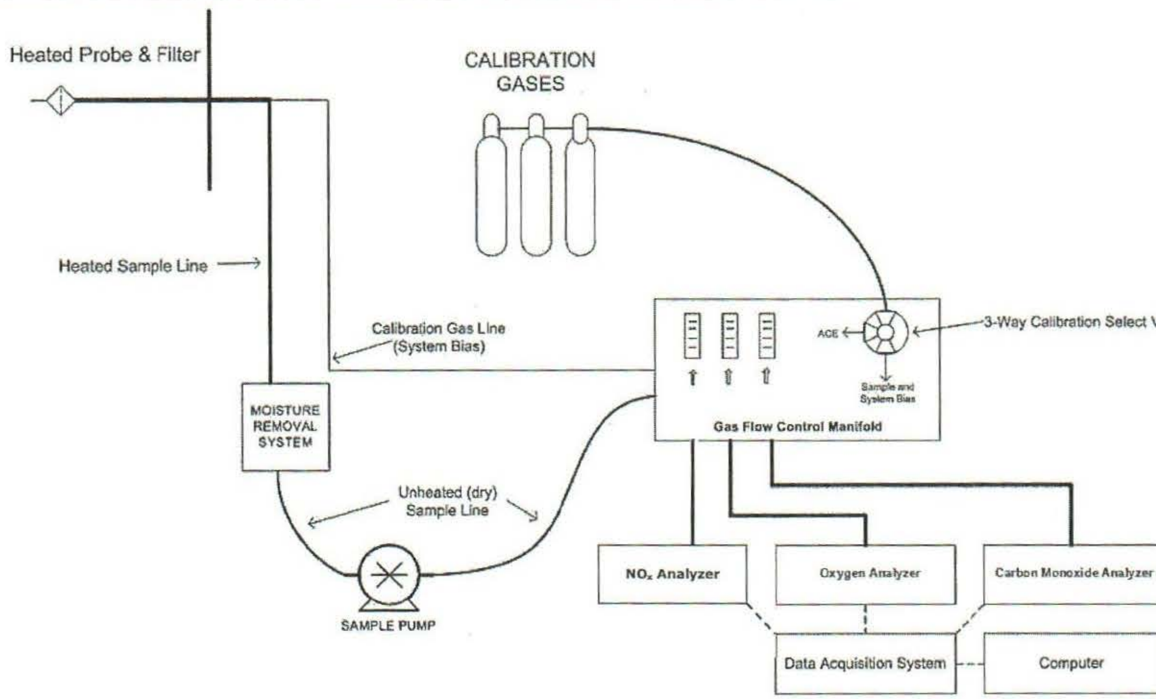
4.4 O_2, NO_X, AND CO (USEPA METHODS 3A, 7E, AND 10)

Oxygen, nitrogen oxides, and carbon monoxide concentrations were measured using the following sampling and analytical procedures:

- USEPA Method 3A, *Determination of Oxygen and Carbon Dioxide Concentrations in Emissions from Stationary Sources (Instrumental Analyzer Procedure),*
- USEPA Method 7E, *Determination of Nitrogen Oxides Emissions from Stationary Sources (Instrumental Analyzer Procedure)*, and
- USEPA Method 10, *Determination of Carbon Monoxide Emissions from Stationary Sources (Instrumental Analyzer Procedure).*

Each cited method sampling is procedurally similar apart from the analyzer and analytical technique used. Engine exhaust gas was extracted from the stacks or ducts through a stainless-steel probe, heated Teflon® sample line, and through a gas conditioning system to remove water and dry the sample before entering a sample pump, flow control manifold, and gas analyzers (Figure 4-4).

Figure 4-4. USEPA Methods 3A, 7E, and 10 Sampling System



Prior to sampling engine exhaust gas, the analyzers were calibrated by performing a calibration error test where zero-, mid-, and high-level calibration gases were introduced directly to the back of the analyzers. The calibration error check was performed to evaluate if the analyzers response was within ±2.0% of the calibration gas span or high calibration gas concentration. An initial system-bias test was then performed where the zero- and mid- or high- calibration gases were introduced at the sample probe to measure the ability of the system to respond accurately to within ±5.0% of span.

A NO_2 to NO conversion efficiency test was performed on the NO_X analyzer prior to beginning the test program to evaluate the ability of the instrument to convert NO_2 to NO before analyzing for NO_X.

Upon successful completion of the calibration error and initial system bias tests, sample flow rate and component temperatures were verified, and the probes inserted into the ducts at the appropriate traverse point. After confirming the engine was operating at established conditions, the test run was initiated. Gas concentrations were recorded at 1-minute intervals throughout each 60-minute test run. Oxygen concentrations were measured to adjust the pollutant concentrations to 15% O_2 and calculate pollutant emission rates.

At the conclusion of each test run, a post-test system bias check was performed to compare analyzer bias and drift relative to pre-test system bias checks, ensuring analyzer bias was within ±5.0% of span and drift was within ±3.0%. The analyzer response was used to correct measured gas concentrations for analyzer drift.

4.5 Emission Rates (USEPA Method 19)

USEPA Method 19, *Determination of Sulfur Dioxide Removal Efficiency and Particulate Matter, Sulfur Dioxide, and Nitrogen Oxide Emission Rates*, was used to calculate emission rates (lb/mmBtu). Measured oxygen concentrations and F-factors (ratios of combustion gas volumes to heat inputs) were used to calculate emission rates using equation 19-1 from the method:

Figure 4-5. USEPA Method 19 Equation 19-1

$$E = C_d F_d \frac{20.9}{(20.9 - \%O_{2d})}$$

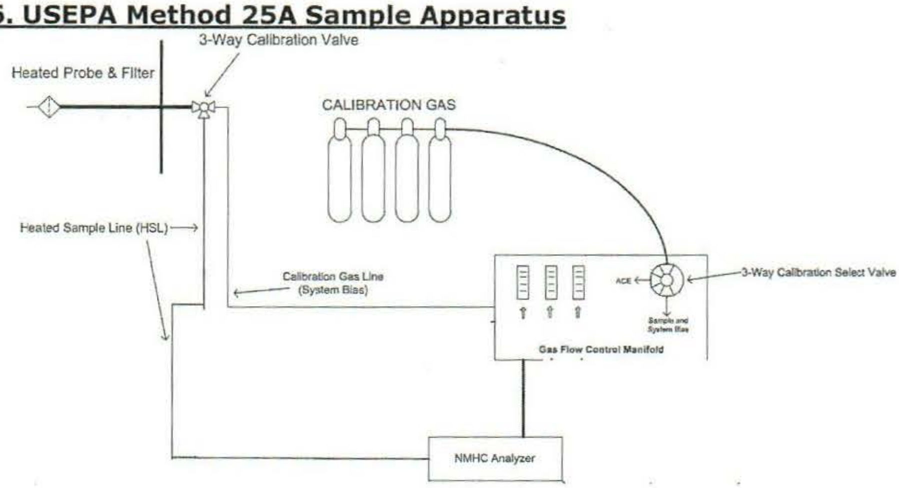
Where:

E	=	Pollutant emission rate (lb/mmBtu)
C_d	=	Pollutant concentration, dry basis (lb/dscf)
F_d	=	Volumes of combustion components per unit of heat content
$\%O_{2d}$	=	Concentration of oxygen on a dry basis (%, dry)

4.6 Volatile Organic Compounds (ALT-096: USEPA Methods 18/25A)

VOC concentrations were measured using a Thermo Model 55i Direct Methane and Non-methane Analyzer as approved in alternative test method (ALT)-096, following the procedures of USEPA Method 25A, *Determination of Total Gaseous Organic Concentration Using a Flame Ionization Analyzer (FIA)* (Figure 4-6).

Figure 4-6. USEPA Method 25A Sample Apparatus



The instrument uses a flame ionization detector (FID) to measure the exhaust gas total hydrocarbon concentration in conjunction with a gas chromatography column that separates methane from other organic compounds. The instrument measures on a wet basis, and 40 CFR Subpart JJJJ requires VOC reporting on a dry basis. Therefore, the exhaust gas moisture content was determined to convert VOC measurements to a dry basis.

The components of the extractive sample interface apparatus are constructed of Type 316 stainless steel and Teflon. Flue gas was sampled from the stack via a sample probe and heated sample line and into the analyzer, which communicates with data acquisition handling systems (DAHS) via output signal cables. The analyzer uses a rotary valve and gas chromatograph column to separate methane from hydrocarbons in the sample and quantifies these components using a flame ionization detector.

The instrument is calibrated with USEPA Protocol Gases consisting of zero air and three propane/methane blends in air, following USEPA Method 25A procedures at the zero level, low (25 to 35 percent of calibration span), mid (45 to 55 percent of calibration span) and high (equivalent to 80 to 90 percent of instrument span).

Sample gas is injected into the column and due to methane's low molecular weight and high volatility, the compound moves through the column more quickly than other organic compounds that may be present and is quantified by the FID. The column is then flushed with inert carrier gas and the remaining non-methane organic compounds are analyzed in the FID. This analytical technique allows separate measurements for methane and non-methane organic compounds via the use of a single FID.

The Thermo 55i analyzer measures methane and non-methane organic compounds (NMOC) separately, however ethane is a component of the NMOC measurement. Since 40 CFR Part 60, Subpart JJJJ defaults to 40 CFR, Part 51.100(s)(1) VOC definitions classifying VOC as *any compound of carbon...other than the following, which have been determined to have negligible photochemical reactivity: methane, ethane...,* exhaust gas samples were collected from each engine exhaust to quantify the ethane fraction of the NMOC concentration using USEPA Method 18, *Measurement of Gaseous Organic Compound Emissions by Gas Chromatography*.

These exhaust gas samples were collected in bags manufactured from polyvinyl fluoride (PVF) film, also known as Tedlar film, and sent to an outside contracted laboratory for analysis. The ethane concentrations in each bag were measured by separating the major organic components using a gas chromatograph (GC) column and measuring them with a suitable detector. The retention times of each separated component were compared with those of known compounds under identical conditions to identify and quantify the major components. The approximate concentrations were estimated before analysis and standard mixtures prepared so the GC/detector was calibrated under physical conditions identical to those used for the samples.

Method 18 requires the sample results be adjusted to results obtained from a spike recovery study. For the bag sampling technique to be considered valid, the spike recovery must be between 70% $<R<$ 130%. The recovery study performed on the RCS engine Tedlar bag samples successfully achieved the R value requirement and that value was applied to the reported ethane concentrations as propane. The USEPA Method 18 laboratory report is presented in Appendix C.

5.0 TEST RESULTS AND DISCUSSION

The test program conducted August 29 through September 1, 2023, satisfies the performance testing and compliance evaluation requirements in 40 CFR Part 60, Subpart JJJJ, *Standards of Performance for Stationary Spark Ignition Internal Combustion Engines*, 40 CFR Part 63, Subpart ZZZZ, *National Emission Standards for Hazardous Air Pollutants for Reciprocating Internal Combustion Engines* and MI-ROP-B6636-2020b. The test results also indicate the NO_x, CO, and VOC engine emissions are compliant with the applicable emissions limits summarized in Table 2-1 of this report.

5.1 Tabulation of Results

Appendix Tables 1 through 5 contain detailed tabulation of results, process operating conditions, and exhaust gas conditions for each respective RICE.

5.2 Significance of Results

The test results indicate each engine is achieving continuous compliance requirements and meeting applicable emissions limits.

5.3 Variations from Sampling or Operating Conditions

No sampling or operating condition variations occurred during the test event.

5.4 Process or Control Equipment Upset Conditions

Each engine and gas compressor were operating under maximum routine conditions and no upsets were encountered during testing.

5.5 Air Pollution Control Device Maintenance

No major air pollution control device maintenance was performed during the three-month period prior to the test event. Engine optimization is continuously performed to ensure lean-burn combustion and ongoing compliance with regulatory emission limits.

5.6 Re-Test Discussion

Based on the test program results, a re-test is not required. Subsequent air emissions testing on the engines will be performed:

40 CFR Part 63, Subpart ZZZZ
- annually to evaluate the reduction of CO emissions across the oxidation catalyst

40 CFR Part 60, Subpart JJJJ
- every 8,760 engine operating hours, or 3 years, whichever comes first
  - EUENGINE31: August 29, 2026 or 27,800 hours
  - EUENGINE32: August 30, 2026 or 27,800 hours
  - EUENGINE33: August 31, 2026 or 29,200 hours
  - EUENGINE34: August 31, 2026 or 27,600 hours
  - EUENGINE35: September 1, 2026 or 27,400 hours

5.7 Results of Audit Samples

Audit samples for the reference methods utilized during this test program are not available from USEPA Stationary Source Audit Sample Program providers.

The USEPA reference methods performed state reliable results are obtained by persons equipped with a thorough knowledge of the techniques associated with each method. Factors with the potential to cause measurement errors are minimized by implementing quality control (QC) and assurance (QA) programs into the applicable components of field testing. QA/QC components were included in this test program. Table 5-1 summarizes the primary field quality assurance and quality control activities that were performed. Refer to Appendix D for supporting documentation.

Table 5-1
QA/QC Procedures

QA/QC Activity	Purpose	Procedure	Frequency	Acceptance Criteria
M1: Sampling Location	Evaluates sampling location suitability for sampling	Measure distance from ports to downstream and upstream flow disturbances	Pre-test	≥2 diameters downstream; ≥0.5 diameter upstream.
M1: Duct diameter/ dimensions	Verifies area of stack is accurately measured	Review as-built drawings and field measurement	Pre-test	Field measurement agreement with as-built drawings
M3A, M7E, M10: Calibration gas standards	Ensures accurate calibration standards	Traceability protocol of calibration gases	Pre-test	Calibration gas uncertainty ≤2.0%
M3A, M7E, M10: Calibration Error	Evaluates analyzer operation	Calibration gases introduced directly into analyzers	Pre-test	±2.0% of calibration span
M3A, M7E, M10: System Bias and Analyzer Drift	Evaluates analyzer/sample system integrity and accuracy over test duration	Calibration gas introduced at sample probe tip, HSL, and into analyzers	Pre-test and Post-test	Bias: ±5.0% of calibration span Drift: ±3.0% of calibration span
M4 (ALT-008): Field balance calibration	Verifies moisture measurement accuracy	Class 6 weight used to check balance accuracy	Daily before use	Balance must measure weight within ±0.5 gram of certified mass
M7E: NO_2-NO converter efficiency	Evaluates NO_2-NO converter operation	NO_2 calibration gas introduced directly into analyzer	Pre-test or Post-test	NO_x response ≥90% of certified NO_2 calibration gas
M25A/ALT096: Calibration Error	Evaluates operation of analyzer and sample system	Cal gas introduced through sample system	Pre-test	±5.0% of calibration gas value
M25A/ALT096: Zero and Calibration Drift	Evaluates analyzer and sample system integrity/accuracy over test duration	Cal gas introduced through sample system	Pre and Post-test	±3.0% of analyzer span

5.8 Calibration Sheets

Calibration sheets, including gas protocol sheets and analyzer quality control and assurance checks are presented in Appendix E.

5.9 Sample Calculations

Sample calculations and formulas used to compute emissions data are presented in Appendix A.

5.10 Field Data Sheets

Field data sheets are presented in Appendix B.

5.11 Laboratory Quality Assurance / Quality Control Procedures

The method specific quality assurance and quality control procedures in each method employed during this test program were followed, without deviation. Refer to Appendix C for the laboratory data sheets associated with the natural gas fuel samples collected during the test program.

5.12 QA/QC Blanks

The Method 3A, 7E, 10, and 25A calibration gases described in Table 5-1 above were the only QA/QC media employed during the test event. QA/QC data are shown in Appendix E.