AIR EMISSION TEST REPORT
FOR THE
VERIFICATION OF AIR POLLUTANT EMISSIONS
FROM
NATURAL GAS FIRED ENGINE – GENERATOR SETS

Prepared for:

Toyota Motor North America R&D
SRN N2915

Test Date: July 20, 2022

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IMPACT
COMPLIANCE & TESTING

Report Certification

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Toyota Motor North America R&D
Ann Arbor, MI

Report Certification

The material and data in this document were prepared under the supervision and direction of the undersigned.

Impact Compliance & Testing, Inc.

Tyler J. Wilson
Senior Project Manager

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1.0 Introduction

Toyota Motor North America R&D (TMNA R&D) operates gas-fired reciprocating internal combustion engine (RICE) and electricity generator sets (gensets) at its facility located in Ann Arbor, Washtenaw County, Michigan. The RICE are fueled exclusively with pipeline natural gas.

The State of Michigan Department of Environment, Great Lakes, and Energy – Air Quality Division (EGLE-AQD) has issued to TMNA R&D a Renewable Operating Permit (MI-ROP-N2915-2017c) for operation of the electricity generation facility, which consists of:

- Two (2) Jenbacher (GE®) Model No. JMC 416 GS-N.LC RICE gensets identified as emission units EU-GENSET1 and EU-GENSET2 (Flexible Group ID: FG-GENSETS).

Air emission compliance testing was performed pursuant to MI-ROP-N2915-2017c. Conditions of MI-ROP-N2915-2017c for FG-GENSETS state:

- *Conduct subsequent performance testing every 8,760 hours of engine operation or every three years, whichever comes first, thereafter to demonstrate compliance with the applicable emission standards.*

The compliance testing presented in this report was performed by Impact Compliance & Testing, Inc. (ICT), a Michigan-based environmental consulting and testing company. ICT representatives Tyler Wilson and Andrew Eisenberg performed the field sampling and measurements July 20, 2022.

The engine emission performance tests consisted of triplicate, one-hour sampling periods for nitrogen oxides (NOx), carbon monoxide (CO), and volatile organic compounds (VOC, as non-methane hydrocarbons (NMHC or NMOC)). Exhaust gas velocity, moisture, oxygen (O_2) content, and carbon dioxide (CO_2) content were determined for each test period to calculate pollutant mass emission rates.

The exhaust gas sampling and analysis was performed using procedures specified in the Stack Test Protocol dated May 18, 2022, that was reviewed and approved by EGLE-AQD. Mr. Daniel J Droste of EGLE-AQD observed portions of the compliance testing.

Questions regarding this air emission test report should be directed to:

Tyler J. Wilson
Senior Project Manager
Impact Compliance & Testing, Inc.
37660 Hills Tech Drive
Farmington Hills, MI 48331
(734) 357-8046
Tyler.Wilson@impactCandT.com

John Krocker
Environmental Engineer
Toyota Motor North America R&D
1555 Woodridge Avenue
Ann Arbor, MI 48105
(734) 695-4992
John.Krocker@Toyota.com

2.0 Summary of Test Results and Operating Conditions

2.1 Purpose and Objective of the Tests

Conditions of MI-ROP-N2915-2017c and 40 CFR Part 60, Subpart JJJJ, Standards of Performance for New Stationary Sources for Stationary Spark Ignition Internal Combustion Engines require TMNA R&D to test each engine in FG-GENSETS for CO, NOx, and VOC emissions. Engine Nos. 1 & 2 (EU-GENSET1 & EU-GENSET2, respectively) were tested during this compliance test event.

2.2 Operating Conditions During the Compliance Tests

The testing was performed while the TMNA R&D RICE gensets were operated at maximum operating conditions (within 10% of 1,141-kilowatt (kW) electricity output). TMNA R&D representatives provided kW output in 15-minute increments for each test period.

Fuel flowrate (cubic meters per hour, M3/H) was also recorded by TMNA R&D representatives in 15-minute increments for each test period.

Appendix 2 provides operating records provided by TMNA R&D representatives for the test periods.

Average generator output (kW) and fuel consumption for each RICE is presented in Table 2.1 and Tables 6.1-6.2.

2.3 Summary of Air Pollutant Sampling Results

The gases exhausted from the sampled natural gas fueled RICE (Engine Nos. 1 & 2 / EU-GENSET1 & EU-GENSET2) were each sampled for three (3) one-hour test periods during the compliance testing performed July 20, 2022.

Table 2.2 presents the average measured CO, NO_X, and VOC emission rates for each engine (average of the three test periods).

Test results for each one-hour sampling period and comparison to the permitted emission rates are presented in Section 6.0 of this report.

Table 2.1 Average engine operating conditions during the test periods

Emission Unit	Generator Output (kW)	Fuel Use (M3/H)
Engine No. 1	1,145	233
Engine No. 2	1,147	236

Table 2.2 Average measured emission rates for each engine (three-test average)

	CO	NOx	VOC
Emission Unit	(g/bhp-hr)	(g/bhp-hr)	(g/bhp-hr)
Engine No. 1	0.30	0.41	0.32
Engine No. 2	0.33	0.40	0.30
Permit Limit	*0.9*	*0.5*	*0.35*

3.0 Source and Sampling Location Description

3.1 General Process Description

TMNA R&D is permitted to operate two (2) RICE-generator sets (GE® Model No. JMC 416 GS-N.LC) at its facility. The units are fired exclusively with pipeline natural gas.

3.2 Rated Capacities and Air Emission Controls

The GE® Model No. JMC 416 GS-N.LC RICE gensets each have a rated design capacity of:

- Engine Power: 1,573 brake horsepower (bhp)
- Electricity Generation: 1,141 kW

The GE® JMC 416 GS-N.LC engines are equipped with LEANOX air to fuel controllers (AFC) and an add-on oxidation catalyst for emission reductions. The LEANOX AFC system electronically controls the combustion air and fuel blend to ensures efficient combustion and minimize the nitrogen oxide (NOx) emission rate. The oxidation catalyst primarily reduces carbon monoxide (CO) emissions from the engine in an add-on catalyst chamber.

3.3 Sampling Locations

Each RICE exhaust gas is directed through a muffler and is released to the atmosphere through a dedicated vertical exhaust stack with a vertical release point.

The exhaust stacks for Engine Nos. 1 & 2 / EU-GENSET1 & EU-GENSET2 are identical. The exhaust stack sampling ports are located in individual vertical exhaust ducts, located after each engine muffler, with an inner diameter of 15.0 inches. Each stack is equipped with two (2) sample ports, opposed 90°, that provide a sampling location at least 0.5 duct diameters upstream and at least 2.0 duct diameters downstream from any flow disturbance.

All sample port locations satisfy the USEPA Method 1 criteria for a representative sample location. Individual traverse points were determined in accordance with USEPA Method 1.

Appendix 1 provides a diagram of the emission test sampling locations with actual stack dimension measurements.

4.0 Sampling and Analytical Procedures

A Stack Test Protocol for the air emission testing was reviewed and approved by EGLE-AQD. This section provides a summary of the sampling and analytical procedures that were used during the testing periods.

4.1 Summary of Sampling Methods

USEPA Method 1	Exhaust gas velocity measurement locations were determined based on the physical stack arrangement and requirements in USEPA Method 1.
USEPA Method 2	Exhaust gas velocity pressure was determined using a Type-S Pitot tube connected to a red oil incline manometer; temperature was measured using a K-type thermocouple connected to the Pitot tube.
USEPA Method 4	Exhaust gas moisture was determined based on the water weight gain in chilled impingers.
USEPA Method 3A	Exhaust gas O_2 and CO_2 content was determined using paramagnetic and infrared instrumental analyzers, respectively.
USEPA Method 7E	Exhaust gas NOx concentration was determined using chemiluminescence instrumental analyzers.
USEPA Method 10	Exhaust gas CO concentration was measured using an infrared instrumental analyzer.
USEPA Method 25A / ALT-096	Exhaust gas VOC (as NMHC) concentration was determined using a flame ionization analyzer equipped with methane separation column.

4.2 Exhaust Gas Velocity Determination (USEPA Method 2)

The RICE exhaust stack gas velocities and volumetric flow rates were determined using USEPA Method 2 once during each test period. An S-type Pitot tube connected to a red-oil manometer was used to determine velocity pressure at each traverse point across the stack cross section. Gas temperature was measured using a K-type thermocouple mounted to the Pitot tube. The Pitot tube and connective tubing were leak-checked periodically throughout the test periods to verify the integrity of the measurement system.

The absence of significant cyclonic flow at the sampling location was verified using an S-type Pitot tube and oil manometer. The Pitot tube was positioned at each velocity traverse point with the planes of the face openings of the Pitot tube perpendicular to the stack cross-sectional plane. The Pitot tube was then rotated to determine the null angle (rotational angle as measured from the perpendicular, or reference, position at which the differential pressure is equal to zero).

Appendix 3 provides exhaust gas flowrate calculations and field data sheets.

4.3 Exhaust Gas Molecular Weight Determination (USEPA Method 3A)

CO_2 and O_2 content in each RICE exhaust gas stream were measured continuously throughout each test period in accordance with USEPA Method 3A. The CO_2 content of the exhaust was monitored using a Servomex 1440D infrared gas analyzer. The O_2 content of the exhaust was monitored using a Servomex 1440D gas analyzer that uses a paramagnetic sensor.

During each sampling period, a continuous sample of the RICE exhaust gas stream was extracted from the stack using a stainless-steel probe connected to a Teflon® heated sample line. The sampled gas was conditioned by removing moisture prior to being introduced to the analyzers; therefore, measurement of O_2 and CO_2 concentrations correspond to standard dry gas conditions. Instrument response data were recorded using an ESC Model 8816 data acquisition system that monitored the analog output of the instrumental analyzers continuously and logged data as one-minute averages.

Prior to, and at the conclusion of each test, the instruments were calibrated using upscale calibration and zero gas to determine analyzer calibration error and system bias (described in Section 5.0 of this document). Sampling times were recorded on field data sheets.

Appendix 4 provides O_2 and CO_2 calculation sheets. Raw instrument response data are provided in Appendix 5.

4.4 Exhaust Gas Moisture Content (USEPA Method 4)

Moisture content of each RICE exhaust gas was determined in accordance with USEPA Method 4 using a chilled impinger sampling train. Exhaust gas moisture content measurements were performed concurrently with the instrumental analyzer sampling periods. At the conclusion of each sampling period the moisture gain in the impingers was determined gravimetrically by weighing each impinger to determine net weight gain.

4.5 NO_x and CO Concentration Measurements (USEPA Methods 7E and 10)

NO_X and CO pollutant concentrations in the RICE exhaust gas streams were determined using a Thermo Environmental Instruments, Inc. (TEI) Model 42i High Level chemiluminescence NO_X analyzer and a TEI Model 48i infrared CO analyzer.

Throughout each test period, a continuous sample of the engine exhaust gas was extracted from the stack using the Teflon® heated sample line and gas conditioning system and delivered to the instrumental analyzers. Instrument response for each analyzer was recorded on an ESC Model 8816 data acquisition system that logged data as one-minute averages. Prior to, and at the conclusion of each test, the instruments were calibrated using upscale calibration and zero gas to determine analyzer calibration error and system bias.

Appendix 4 provides CO and NO_X calculation sheets. Raw instrument response data are provided in Appendix 5.

4.6 Measurement of VOC (USEPA Method 25A / ALT-096)

The VOC emission rates were determined by measuring the nonmethane hydrocarbon (NMHC or NMOC) concentration in each engine exhaust gas. NMHC pollutant concentration was determined using a TEI Model 55i Methane / Nonmethane hydrocarbon analyzer. The TEI 55i analyzer contains an internal gas chromatograph column that separates methane from non-methane components. The concentration of NMHC in the sampled gas stream, after separation from methane, is determined relative to a propane standard using a flame ionization detector in accordance with USEPA Method 25A.

The USEPA Office of Air Quality Planning and Standards (OAQPS) has issued an alternate test method approving the use of the TEI 55i-series analyzer as an effective instrument for measuring VOC from gas-fueled RICE (ALT-096).

Samples of the exhaust gas were delivered directly to the instrumental analyzer using the Teflon® heated sample line to prevent condensation. The sample to the NHMC analyzer was not conditioned to remove moisture. Therefore, VOC measurements correspond to standard conditions with no moisture correction (wet basis).

Prior to, and at the conclusion of each test, the instrument was calibrated using mid-range calibration (propane) and zero gas to determine analyzer calibration error and system bias (described in Section 5.0 of this document).

Appendix 4 provides VOC calculation sheets. Raw instrument response data for the NMHC analyzer is provided in Appendix 5.

5.0 QA/QC Activities

5.1 Flow Measurement Equipment

Prior to arriving onsite (or onsite prior to beginning compliance testing), the instruments used during the source test to measure exhaust gas properties and velocity (pyrometer, Pitot tube, and scale) were calibrated to specifications in the sampling methods.

5.2 NO_x Converter Efficiency Test

The NO_2 – NO conversion efficiency of the Model 42i analyzer was verified prior to the testing program. A USEPA Protocol 1 certified concentration of NO_2 was injected directly into the analyzer, following the initial three-point calibration, to verify the analyzer's conversion efficiency. The analyzer's NO_2 – NO converter uses a catalyst at high temperatures to convert the NO_2 to NO for measurement. The conversion efficiency of the instrumental analyzer will be deemed acceptable if the measured NOx concentration is at least 90% of the expected value (within 10%).

The NO_2 – NO conversion efficiency test satisfied the USEPA Method 7E criteria (measured NO_x concentration was 100.5% of the expected value).

5.3 Gas Divider Certification (USEPA Method 205)

A STEC Model SGD-710C 10-step gas divider was used to obtain appropriate calibration span gases. The ten-step STEC gas divider was NIST certified (within the last 12 months) with a primary flow standard in accordance with Method 205. When cut with an appropriate zero gas, the ten-step STEC gas divider delivered calibration gas values ranging from 0% to 100% (in 10% step increments) of the USEPA Protocol 1 calibration gas that was introduced into the system. The field evaluation procedures presented in Section 3.2 of Method 205 were followed prior to use of gas divider. The field evaluation yielded no errors greater than 2% of the triplicate measured average and no errors greater than 2% from the expected values.

5.4 Instrumental Analyzer Interference Check

The instrumental analyzers used to measure NO_X, CO, O_2, and CO_2 have had an interference response test preformed prior to their use in the field, pursuant to the interference response test procedures specified in USEPA Method 7E. The appropriate interference test gases (i.e., gases that would be encountered in the exhaust gas stream) were introduced into each analyzer, separately and as a mixture with the analyte that each analyzer is designed to measure. All of analyzers exhibited a composite deviation of less than 2.5% of the span for all measured interferent gases. No major analytical components of the analyzers have been replaced since performing the original interference tests.

5.5 Instrument Calibration and System Bias Checks

At the beginning of each day of the testing program, initial three-point instrument calibrations were performed for the NO_x, CO, CO_2, and O_2 analyzers by injecting calibration gas directly into the inlet sample port for each instrument. System bias checks were performed prior to and at the conclusion of each sampling period by introducing the upscale calibration gas and zero gas into the sampling system (at the base of the stainless steel sampling probe prior to the particulate filter and Teflon® heated sample line) and determining the instrument response against the initial instrument calibration readings.

At the beginning of each test day, appropriate high-range, mid-range, and low-range span gases followed by a zero gas were introduced to the NMHC analyzer, in series at a tee connection, which is installed between the sample probe and the particulate filter, through a poppet check valve. After each one-hour test period, mid-range and zero gases were re-introduced in series at the tee connection in the sampling system to check against the method's performance specifications for calibration drift and zero drift error.

The instruments were calibrated with USEPA Protocol 1 certified concentrations of CO_2, O_2, NO_x, and CO in nitrogen and zeroed using hydrocarbon free nitrogen. The NMHC (VOC) instrument was calibrated with USEPA Protocol 1 certified concentrations of propane in air and zeroed using hydrocarbon-free air. A STEC Model SGD-710C ten-step gas divider was used to obtain intermediate calibration gas concentrations as needed.

5.6 Determination of Exhaust Gas Stratification

A stratification test was performed for each RICE exhaust stack. The stainless-steel sample probe was positioned at sample points correlating to 16.7, 50.0 (centroid), and 83.3% of the stack diameter. Pollutant concentration data were recorded at each sample point for a minimum of twice the maximum system response time.

The recorded concentration data for the RICE exhaust stacks indicated that the measured O_2 and CO_2 concentrations did not vary by more than 5% of the mean across the stack diameter. Therefore, the RICE exhaust gas was considered to be unstratified and the compliance test sampling was performed at a single sampling location within each RICE exhaust stack.

5.7 System Response Time

The response time of the sampling system was determined prior to the compliance test program by introducing upscale gas and zero gas, in series, into the sampling system using a tee connection at the base of the sample probe. The elapsed time for the analyzer to display a reading of 95% of the expected concentration was determined using a stopwatch.

Sampling periods did not commence until the sampling probe had been in place for at least twice the greatest system response time.

5.8 Meter Box Calibrations

The dry gas meter sampling console used for moisture testing was calibrated prior to and after the testing program. This calibration uses the critical orifice calibration technique presented in USEPA Method 5. The metering console calibration exhibited no data outside the acceptable ranges presented in USEPA Method 5.

The digital pyrometer in the metering console was calibrated using a NIST traceable Omega® Model CL 23A temperature calibrator.

Appendix 6 presents test equipment quality assurance data (NO_2 – NO conversion efficiency test data, instrument calibration and system bias check records, calibration gas certifications, interference test results, meter box calibration records, and field equipment calibration records).

6.0 Results

6.1 Test Results and Allowable Emission Limits

Engine operating data and air pollutant emission measurement results for each one-hour test period are presented in Tables 6.1 through 6.2.

Engine Nos. 1 & 2 / EU-GENSET1 & EU-GENSET2 each have the following allowable emission limits specified in MI-ROP-N2915-2017c:

- 0.9 grams per brake horsepower hour (g/bhp-hr) for CO;
- 0.5 g/bhp-hr for NOx; and
- 0.35 g/bhp-hr for VOC.

The measured air pollutant concentrations and emission rates for Engine Nos. 1 & 2 / EU-GENSET1 & EU-GENSET2 are less than the allowable limits specified in MI-ROP-N2915-2017c and 40 CFR Part 60, Subpart JJJJ, Standards of Performance for New Stationary Sources for Stationary Spark Ignition Internal Combustion Engines.

6.2 Variations from Normal Sampling Procedures or Operating Conditions

The testing for all pollutants was performed in accordance with USEPA methods and the approved Stack Test Protocol. The engine-generator sets were operated within 10% of maximum output (1,141 kW generator output for GE® JMC 416 GS-N.LC RICE) and no variations from normal operating conditions occurred during the engine test periods.

Table 6.1 Measured exhaust gas conditions and air pollutant emission rates for Engine No. 1 (EU-GENSET1)

Test No. **Test date** **Test period (24-hr clock)**	**1** **7/20/2022** **1225-1325**	**2** **7/20/2022** **1347-1447**	**3** **7/20/2022** **1507-1607**	**Three Test Average**
Fuel flowrate (M3/H)	234	233	231	233
Generator output (kW)	1,145	1,145	1,144	1,145
Engine output (bhp)	1,582	1,584	1,582	1,583
Exhaust Gas Composition				
CO_2 content (% vol)	6.38	6.39	6.40	6.39
O_2 content (% vol)	10.7	10.7	10.7	10.7
Moisture (% vol)	12.4	12.3	14.1	12.9
Exhaust gas temperature (°F)	740	733	733	735
Exhaust gas flowrate (dscfm)	2,870	2,812	2,782	2,821
Exhaust gas flowrate (scfm)	3,276	3,206	3,238	3,240
Nitrogen Oxides				
NO_X conc. (ppmvd)	71.4	69.9	72.4	71.2
NO_X emissions (lb/hr)	1.47	1.41	1.44	1.44
NO_X emissions (g/bhp-hr)	0.42	0.40	0.41	0.41
NO_X permit limit (g/bhp-hr)	-	-	-	*0.5*
Carbon Monoxide				
CO conc. (ppmvd)	86.0	86.2	85.0	85.7
CO emissions (lb/hr)	1.08	1.06	1.03	1.06
CO emissions (g/bhp-hr)	0.31	0.30	0.30	0.30
CO permit limit (g/bhp-hr)	-	-	-	*0.9*
Volatile Organic Compounds				
VOC conc. (ppmv)	49.3	49.7	49.4	49.5
VOC emissions (lb/hr)	1.11	1.10	1.10	1.10
VOC emissions (g/bhp-hr)	0.32	0.31	0.32	0.32
VOC permit limit (g/bhp-hr)	-	-	-	*0.35*

Table 6.2 Measured exhaust gas conditions and air pollutant emission rates for Engine No. 2 (EU-GENSET2)

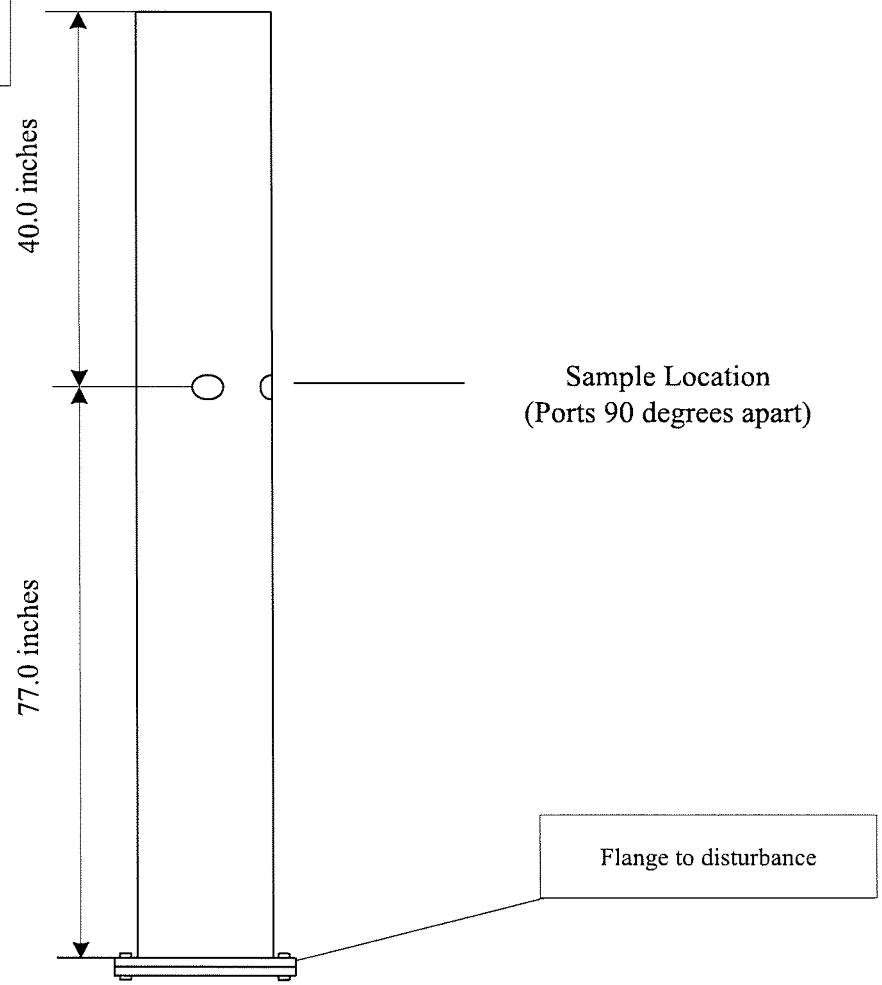
Test No. **Test date** **Test period (24-hr clock)**	**1** **7/20/2022** **815-915**	**2** **7/20/2022** **937-1037**	**3** **7/20/2022** **1057-1157**	**Three Test Average**
Fuel flowrate (M3/H)	235	236	237	236
Generator output (kW)	1,148	1,145	1,147	1,147
Engine output (bhp)	1,587	1,584	1,585	1,585
Exhaust Gas Composition				
CO_2 content (% vol)	6.34	6.33	6.35	6.34
O_2 content (% vol)	10.8	10.8	10.8	10.8
Moisture (% vol)	13.0	13.6	13.4	13.3
Exhaust gas temperature (°F)	743	744	744	744
Exhaust gas flowrate (dscfm)	2,886	2,792	2,854	2,844
Exhaust gas flowrate (scfm)	3,319	3,230	3,297	3,282
Nitrogen Oxides				
NO_X conc. (ppmvd)	69.1	69.2	69.7	69.3
NO_X emissions (lb/hr)	1.43	1.38	1.43	1.41
NO_X emissions (g/bhp-hr)	0.41	0.40	0.41	0.40
NO_X permit limit (g/bhp-hr)	-	-	-	*0.5*
Carbon Monoxide				
CO conc. (ppmvd)	92.9	91.7	91.6	92.1
CO emissions (lb/hr)	1.17	1.12	1.14	1.14
CO emissions (g/bhp-hr)	0.33	0.32	0.33	0.33
CO permit limit (g/bhp-hr)	-	-	-	*0.9*
Volatile Organic Compounds				
VOC conc. (ppmv)	46.3	45.9	45.8	46.0
VOC emissions (lb/hr)	1.06	1.02	1.04	1.04
VOC emissions (g/bhp-hr)	0.30	0.29	0.30	0.30
VOC permit limit (g/bhp-hr)	-	-	-	*0.35*

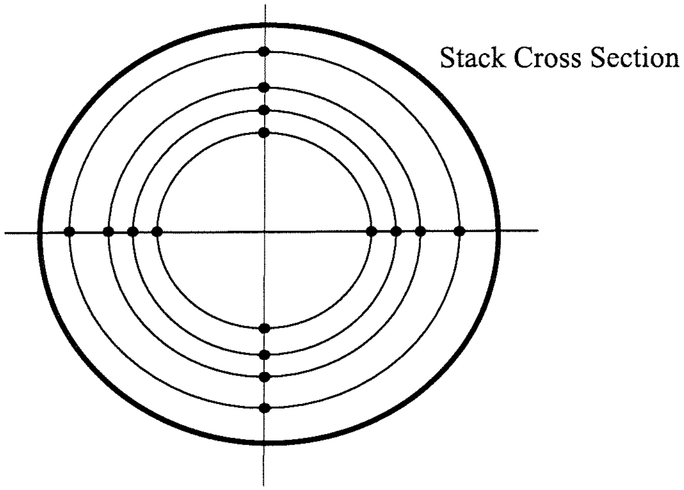
APPENDIX 1

- RICE Engine Sample Port Diagram

Exhaust
Stack (15.0
inch diameter)

EU-GENSET1 & EU-GENSET2





Velocity sample locations (not including sample port)

Sample Port	
Pt. #	in.
1	0.50
2	1.58
3	2.91
4	4.83
5	10.16
6	12.09
7	13.43
8	14.50

12/15/17 ALR
3/29/18 TJW
11/01/18 BMT

Toyota Motor North America
R&D Generator Sets

Scale
None

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