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RPT-STMON-010 Rev. 0

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Assessment of the National Research Universal Reactor Proposed New Stack Sampling Probe Location for Compliance with ANSI/HPS N13.1-1999

February 2016

JA Glissmeyer
EJ Antonio
JE Flaherty

U.S. DEPARTMENT OF
ENERGY

Prepared for the Canadian Nuclear Laboratories
under Contract 417887/65167 under an Interagency
Agreement with the U.S. Department of Energy
under Contract DE-AC05-76RL01830

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Pacific Northwest National Laboratory
Richland, Washington 99352

Completeness of Testing

This report describes the results of work and testing specified by test plan TP-STMON-032. The descriptions provided in this test report are an accurate account of both the conduct of the work and the data collected. Test plan results are reported. Also reported are any unusual or anomalous occurrences that are different from expected results. The test results and this report have been reviewed and verified.

Approved:

2/26/2016

Julia E. Flaherty, Manager Date
Stack Monitoring Project

Summary

This document reports on a series of tests conducted to assess the proposed air sampling location for the National Research Universal reactor (NRU) complex exhaust stack, located in Chalk River, Ontario, Canada, with respect to the applicable criteria regarding the placement of an air sampling probe. Due to the age of the equipment in the existing monitoring system, and the increasing difficulty in acquiring replacement parts to maintain this equipment, a more up-to-date system is planned to replace the current effluent monitoring system, and a new monitoring location has been proposed. The new sampling probe should be located within the exhaust stack according to the criteria established by the American National Standards Institute/Health Physics Society (ANSI/HPS) N13.1-1999, *Sampling and Monitoring Releases of Airborne Radioactive Substances from the Stack and Ducts of Nuclear Facilities*.[1] These criteria address the capability of the sampling probe to extract a sample that represents the effluent stream.

The internal Pacific Northwest National Laboratory (PNNL) project for this task was 65167, *Atomic Energy Canada Ltd. Chalk River Effluent Duct Flow Qualification*. The testing described in this document was guided by the Test Plan: Testing of the NRU Stack Air Sampling Position (TP-STMON-032).

PNNL wrote the test plan, test instructions, and trained Canadian Nuclear Laboratories staff to perform the tests conducted during 2015 on the exhaust stacks at the NRU, as described in this report. The series of tests consisted of various measurements taken over a grid of points in the duct cross section at the designated sampling probe locations. The ANSI/HPS N13.1-1999 qualification criteria concern the following properties of the air flowing through the duct where the air sampling probe is to be located:

1. *Uniform Air Velocity* – The gas momentum across the stack cross section where the sample is extracted should be well-mixed or uniform. The uniformity is expressed as the variability of the measurements about the mean, expressed as the percent coefficient of variance (%COV). It is calculated as the standard deviation divided by the mean and expressed as a percentage—the lower the %COV value, the more uniform the velocity.
2. *Angular Flow* – The flow angle test determines whether the mean velocity vector is aligned with the sample nozzle, so that the sampling equipment itself collects a representative sample from the monitoring location.
3. *Uniform Concentration of Tracer Gases* – A uniform contaminant concentration in the sampling plane enables the extraction of gas samples that represent the true concentration.
4. *Uniform Concentration of Tracer Particles* – A uniform contaminant concentration at the sampling probe enables the extraction of particle samples (with particles that are large enough to exhibit inertial effect) that represent the true concentration. Particles of 10-μm aerodynamic diameter were used.

The test results for the test configuration are summarized in Table S.1. The tests were not performed to the quality assurance level prescribed in the test plan and test instructions, so a qualifier must be applied to these results. Based on the results obtained from conducting limited (no test replicates) and partial (no traverse repeats) tests, the location proposed for the air sampling probe in the stack partially meets the requirements of the ANSI/HPS N13.1-1999 Standard for velocity uniformity, flow angle, and gas tracer uniformity, but cannot be reported with high confidence. The velocity uniformity and flow angle tests included traverse repeats, and are therefore of higher quality than the gas tracer uniformity, which had limited traverse repeats and poor instrument calibration check results. Without repeated tests, the

[1] Health Physics Society, McLean, VA 22101. The standard has been reaffirmed in 2011 and is identical to the 1999 version. The regulations have not been updated yet, so the 1999 version is still referenced.

potential variability in test results was not explored, and the result of a single test cannot be used to conclusively determine compliance with the test criteria. However, the stack configuration, geometry, and length point to a high likelihood that the velocity, flow angle, and gaseous tracer uniformity at this location would be compliant with the test criteria. The results of the single particle tracer test were inconclusive because of insufficient particle injection quantity and missing a measurement point (Point 7) needed to compute the center two-thirds concentration uniformity.

To fully demonstrate that the new sampling location meets the criteria set in ANSI/HPS N13.1-1999, PNNL suggests all tests be completed as laid out in the test plan. This would include performing all test repeats, collecting data at all sampling points during a test, and completely filling in data sheets and test instructions. Additional training in the setup of gas analyzer calibration checks or recalibration of the gas analyzer should be addressed. Completion of the particle tracer tests would require the tent structure to be repositioned to allow for sample collection at Point 7 on the South Side traverse.

Table S.1. Summary of Sampling Probe Location Results for the NRU Exhaust Stack

	Acceptance Criteria	Units	Test Result[a]
Velocity Uniformity	≤20	%COV	6.1
Flow Angle	≤20	Degrees	1.3
Gas Tracer Uniformity	≤20	%COV	0.4 – 0.9
	≤30	Maximum % Deviation from Mean	0.9 – 1.4
Particle Tracer Uniformity	≤20	Normalized %COV	Incomplete Test

[a] Insufficient data collected to report results with high confidence.

Acknowledgments

Preparing, executing, and post-processing the measurements described in this report involved a number of Pacific Northwest National Laboratory and Canadian Nuclear Laboratory staff. We would like to particularly acknowledge the support of our quality engineer, Kirsten Meier, and the administrative support from Chrissy Charron and Mona Champion. We also express our appreciation to technical staff members Chris Corrigan and Amelia Shea, who conducted measurements under a variety of conditions. Carmen Arimescu provided technical reviews, and Susan Ennor and Cary Counts, who provided editorial support for this report.

Funding for this effort was provided by Canadian Nuclear Laboratories, Chalk River, Ontario, Canada.

Acronyms and Abbreviations

%COV	percent coefficient of variance
acfm	actual cubic feet per minute
AD	aerodynamic diameter
AECL	Atomic Energy of Canada Limited
afpm	actual feet per minute
ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
atm	atmosphere (unit of pressure)
CCP	computer-assisted calculation package
cfm	cubic feet per minute
CFR	Code of Federal Regulations
CNL	Canadian Nuclear Laboratories
DOE	U.S. Department of Energy
DV	hydraulic diameter × mean velocity
EPA	U.S. Environmental Protection Agency
FA	flow angle test
FIO	For Information Only
GT	gaseous tracer test
HDI	"How Do I…?" (web-based standards system at PNNL)
HPS	Health Physics Society
in.	inch(inches)
µm	micron(s)
m^3/s	cubic meter(s) per second
m/s	meter(s) per second
N_2O	nitrous oxide
NCR	Non-Conformance Report
NESHAP	National Emissions Standards for Hazardous Air Pollutants
NRU	National Research Universal reactor
OPC	optical particle counter
%COV	percent coefficient of variation
PNNL	Pacific Northwest National Laboratory
psig	pounds per square inch gauge
PT	particulate tracer test
QA	quality assurance
R&D	research and development
scfm	standard cubic feet per minute

sfpm	standard feet per minute
STMON	Stack Monitoring Project
VT	velocity uniformity test

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1.0 Introduction

The National Research Universal reactor (NRU) at Chalk River Laboratories, in Ontario, Canada, produces research and medical isotopes, and serves as a test facility for fuels and materials development. As a facility that has the potential to emit radionuclides into the environment, the reactor stack is equipped with an effluent monitoring system to comply with its environmental policy and the Canadian Nuclear Safety Commission license for the NRU facility. This system is located at the base of the stack and the sampling probe is located at the 50-ft elevation level on the stack. Due to the age of the equipment in the existing monitoring system, and the increasing difficulty in acquiring replacement parts to maintain this equipment, a more up-to-date system is planned to replace the current effluent monitoring system, and a new monitoring location has been proposed. The probe for the new monitoring system is expected to be located in an exposed section of the buried exhaust duct, upstream of the stack. Tests were performed to document whether the proposed new air monitoring location in the exhaust stack would meet the applicable criteria governing effluent monitoring systems given in American National Standards Institute/Health Physics Society (ANSI/HPS) N13.1-1999, *Sampling and Monitoring Releases of Airborne Radioactive Substances from the Stack and Ducts of Nuclear Facilities*.

The work documented in this report was performed jointly by Pacific Northwest National Laboratory (PNNL)[1] and Canadian Nuclear Laboratories (CNL) as part of PNNL's Stack Monitoring Program, under a contract with the Atomic Energy of Canada, Ltd (AECL), which is now operated by CNL. PNNL personnel wrote the test plan and the test instructions for this work. PNNL staff also trained CNL technicians in the use of the test plan and test instructions. No PNNL personnel were present during conduct of the tests. CNL management and facility engineers provided the most current engineering input to support the tests. CNL retains responsibility for the technical design of the stack discharge and air monitoring systems. The following sections present the probe location qualification criteria, quality assurance plan, and NRU exhaust system information related to the testing.

1.1 Qualification Criteria

The qualification criteria for the location of a stack air monitoring probe were taken from ANSI/HPS N13.1-1999, Section 5.2.2, and are paraphrased as follows:

1. *Uniform Air Velocity* – It is required that the air velocity be fairly uniform across the stack cross section where the sample is extracted. Consequently, the air velocity is measured at several discrete points in the duct cross section at the proposed location of the sampling nozzle. The uniformity is expressed as the variability of the measurements about the mean. This is expressed using the percent coefficient of variation (%COV),[2] which is the standard deviation divided by the mean and expressed as a percentage—the lower the %COV value, the more uniform the velocity. The qualification criterion is that the %COV of the air velocity must be ≤20% in the center two-thirds of the duct cross section where the sampling probe is to be located.

[1] The internal Pacific Northwest National Laboratory (PNNL) project for this task is 65167, AECL Chalk River Effluent Duct Flow Qualification.

[2] *Coefficient of variation* is considered "dated" terminology. The modern terminology is *percent relative standard deviation*. However, because the standard uses the older terminology, it will likewise be used here.

2. *Angular Flow* – Sampling nozzles are typically aligned with the axis of the stack. If the air travels through the stack in a cyclonic fashion, the air velocity vector approaching a sampling nozzle could be sufficiently misaligned with the nozzle to impair the extraction of particles. Consequently, the flow angle is measured at the proposed location of the sampling probe. The average of the flow angle measurements (made at the same grid of points as the velocity measurements) should not exceed 20° relative to the sampling nozzle axis.

3. *Uniform Concentration of Tracer Gases* – A uniform contaminant concentration in the sampling plane enables the extraction of samples that represent the true concentration within the duct. The uniformity of the concentration is first tested with a tracer gas to represent gaseous effluents. The fan is a good mixer, so injecting the tracer downstream of the fan provides worst-case results. The qualification criteria are that 1) the %COV of the measured tracer gas concentration is ≤20% across the center two-thirds of the duct cross section at the sampling location, and that 2) the concentrations at any of the measurement points cannot deviate from the mean by >30%.

4. *Uniform Concentration of Tracer Particles* – The second set of tests addressing contaminant concentration uniformity at the sampling position uses tracer particles large enough to exhibit inertial effects. Tracer particles of 10 µm aerodynamic diameter (AD) are used by default unless it is known that larger contaminant particles will be present in the airstream. The qualification criterion is that the %COV of particle concentration is ≤20% across the center two-thirds of the duct at the sampling location.

Tests to determine criteria 1 through 4 were met were conducted on the NRU Complex exhaust stack at the new proposed sampling location along the exhaust duct. All of the tracer concentration, velocity, and flow angle measurements were made using the same grid of points in the cross section of the duct.

The following sections of this document present the testing strategy (Section 2), methods (Section 3), and results (Section 4), followed by conclusions and recommendations (Section 5). Appendix A lists the test plan, test instructions, and calculation packages used for the tests documented in this report; and Appendix B contains the data sheets.

2.0 NRU Exhaust System

The NRU exhaust leaves the NRU building and enters Building 160, where it is filtered. Exhaust from two inactive facilities combine with the NRU exhaust, which travels approximately 1 km through an underground duct to a vertical stack. Figure 2.1 is a diagram of the principal parts of the NRU air exhaust system. After exiting Building 160, the airflow undergoes some minor changes in direction until reaching a riser. In the riser, the air ascends vertically, then exits on an angle (to the horizontal), proceeds through the long duct, and gradually ascends up the hill to the base of the vertical stack. Along the run up the hill there are some minor direction changes. Figure 2.2 shows the final 500 ft of the buried duct in profile with labels to indicate the approximate locations of the sampling port and changes in duct slope or direction. Note that in the NRU building there are two fans, one duty and one standby. In Building 160, there are three fans—two duty fans and one standby fan. Under certain emergency conditions, the NRU building fans are bypassed. In that case the total airflow decreases about 7.6%.

For testing purposes, the underground duct was partially excavated and exposed. Test ports were installed and a tent/enclosure was erected over the excavation to facilitate testing in the cold weather.

2.1 Flow Parameters

Table 2.1 provides operating information for the NRU exhaust duct. Standard conditions were taken as 1 atmosphere and 21°C (70°F).

Table 2.1. NRU Exhaust Duct Operating Parameters

Operating Parameters	NRU Duct
Duct diameter at sampling probe	120.0 cm (47.25 in.)
No. of operating booster fans (Building 160)	2
Total available booster fans (Building 160)	3
No. of operating NRU fans	1
Total available NRU fans	2
Approx. No. of duct diameters from upstream disturbance (a change in slope) to sampling probe	81
Approx. No. duct diameters from sampling probe to the next disturbance (change in slope and direction) downstream of the sampling probe	6
Normal flow rate[(a)]	14.4 m^3/s (30.5E3 cfm)
Low flow rate[(a)]	12.3 m^3/s (26.1E3 cfm)

(a) Personal communication (K. Dumasia, October 2014)

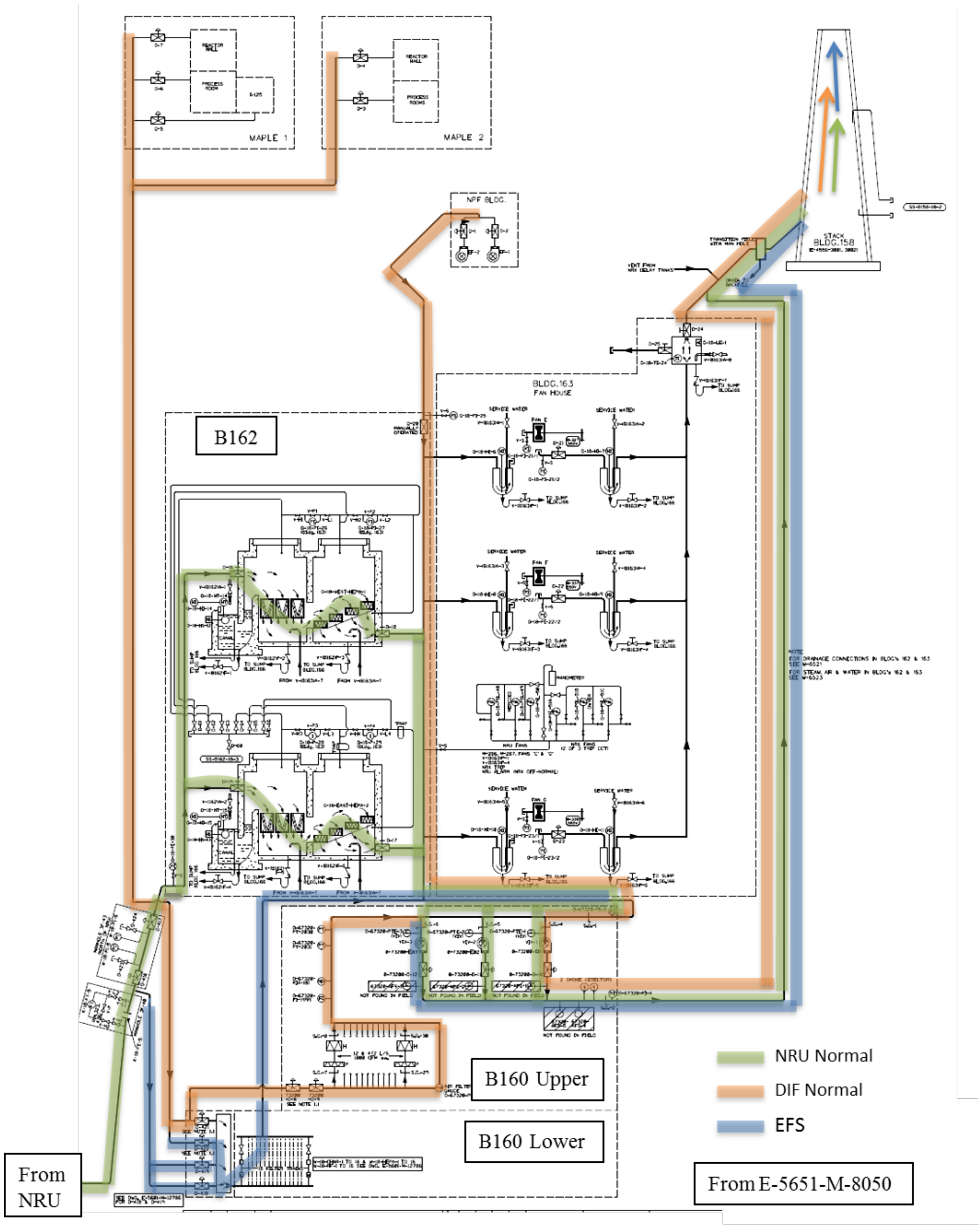


Figure 2.1. Exhaust Air Diagram for the CNL-NRU Complex. (Adapted from CNL DWG E-5651-M-8050)

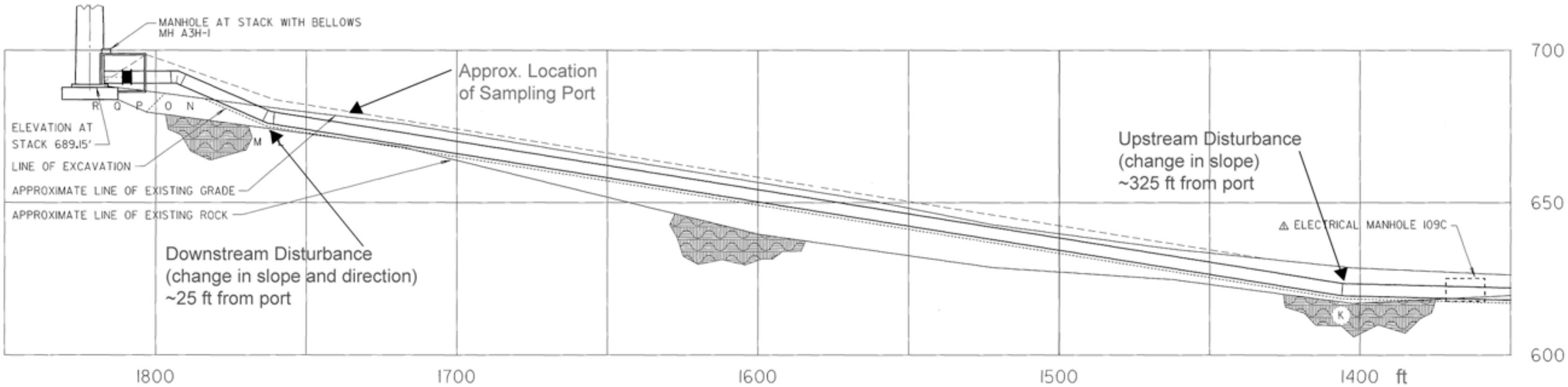


Figure 2.2. NRU Exhaust Duct Profile near the Stack. (Adapted from CNL DWG E-5618-A-792 Rev 2)

3.0 Testing Methods

As described in Section 2.1, PNNL prepared a CNL-approved test plan in accordance with ANS/HPS N13.1-1999 requirements. Test instructions for each test type laid out general procedures as well as specific instructions pertaining to each test, including the following information:

- Layout of measurement points
- Positions of tracer injection points
- List of equipment and instrumentation
- Safety requirements
- List of minimum test runs
- Test description and measurement data sheets for hand entries
- Table of preliminary results.

Because the final data sheets and a description of the test methods are included in this report, the TIs are not included here.

3.1 Quality Assurance

In the absence of specific quality requirements from CNL, the PNNL quality assurance (QA) program was implemented. The PNNL QA program is based on the requirements defined in U.S. Department of Energy (DOE) Order 414.1D, *Quality Assurance*, and Title 10 of the *Code of Federal Regulations* Part 830 (10 CFR 830), *Energy/Nuclear Safety Management*, and Subpart A – *Quality Assurance Requirements* (a.k.a., the Quality Rule). PNNL has chosen to implement the following consensus standards in a graded approach:

- American Society of Mechanical Engineers (ASME) NQA-1-2000, Quality Assurance Requirements for Nuclear Facility Applications, Part I, "Requirements for Quality Assurance Programs for Nuclear Facilities" (ASME 2001).
- ASME NQA-1-2000, Part II, Subpart 2.7, Quality Assurance Requirements for Computer Software for Nuclear Facility Applications (ASME 2001).
- ASME NQA-1-2000, Part IV, Subpart 4.2, Graded Approach Application of Quality Assurance Requirements for Research and Development (ASME 2001).

The procedures necessary to implement the requirements are documented in PNNL's "How Do I…?" (HDI).[1]

The QA plan for the Stack Monitoring Project (STMON) implements the requirements of ASME NQA-1-2000, Part 1: Requirements for Quality Assurance Programs for Nuclear Facilities Applications, presented in two parts. Part 1 of the QA Manual describes the graded approach developed by applying NQA-1-2000, Subpart 4.2, "Guidance on Graded Application of Quality Assurance (QA) for Nuclear-Related Research and Development" to the requirements based on the type of work scope. Part 2 of the QA Manual lists all of the NQA-1-2000 requirements that the project is implementing for the different technology levels of research and development (R&D) work. Requirements are clearly listed for the technology level to which they apply.

[1] HDI is a web-based system for accessing PNNL policies, requirements, and procedures.

This project recognizes that QA applies in varying degrees to a broad spectrum of R&D in the technology life cycle. For this project, the requirements associated with development work apply because the data will be used for application of air discharge permits:

> DEVELOPMENTAL WORK: Development work consists of research tasks moving toward technology commercialization. These tasks still require a degree of flexibility and there is still a degree of uncertainty that exists in many cases. The role of quality on development work is to make sure that adequate controls to support movement into commercialization exist.

STMON addresses internal verification and validation activities by conducting an independent technical review of the final data report in accordance with STMON's procedure QA-STMON-0601, *Document Preparation and Change*. PNNL prepared the test plan and TIs for CNL to perform the tests and collect the data. The data were submitted to PNNL for final review and evaluation.

3.2 Stack Tests

The tests described in the following subsections were conducted under normal flow conditions (listed in Table 2.1) for the NRU stack. The test matrix included with the test plan described the minimum number of tests that were planned for each stack.

The test ports where test measurements were performed were located in the excavated portion of the exhaust duct, downhill and upstream from the vertical exhaust stack. Since the duct is buried, the two test ports were offset by 45° from the vertical air sampling port to minimize the excavation needs (see Figure 3.1). To facilitate cold weather testing, a tent was constructed over the testing area.

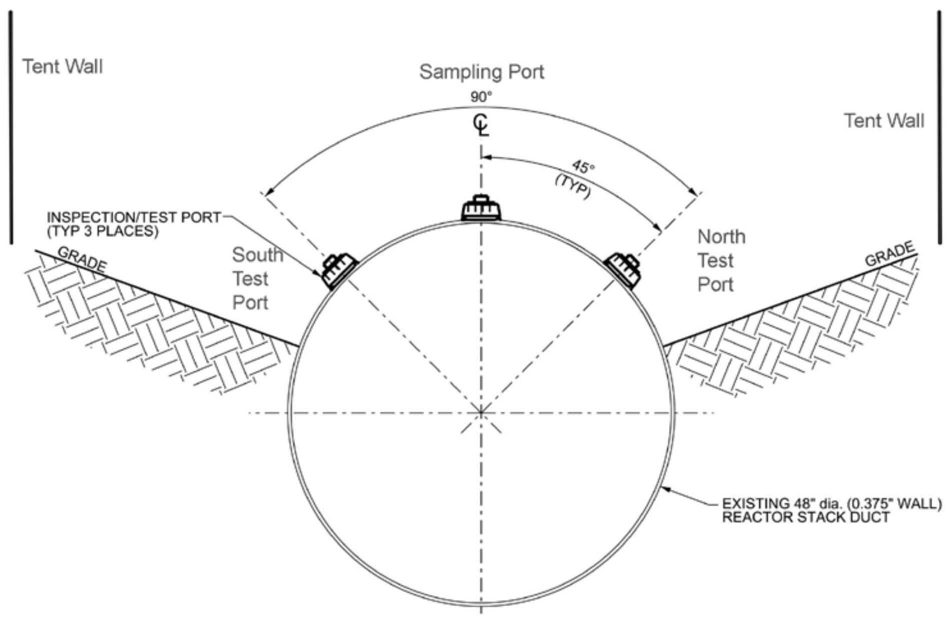


Figure 3.1. Placement of Test Ports in Stack Cross Section. (Adapted from CNL drawing D-212586-MOD-1)

A common grid of measurement points in the duct cross section was used for each of the qualification criteria tests described in the following subsections. The number of and distance between measurement points were based on the ASME PTC 19.5-2004 Standard with the Tchebycheff distribution for circular stacks. For a 47.25 in. (120 cm) duct diameter, eight traverse points were used at the relative positions shown in Figure 3.2. Measurements also were made at the center point. The measurement point closest to the port was Point 1, while the point farthest from the port was Point 8. The stack qualification criteria relate to the measurements within the center two-thirds of the stack, and in this case, points 2 through 7 cover this center two-thirds.

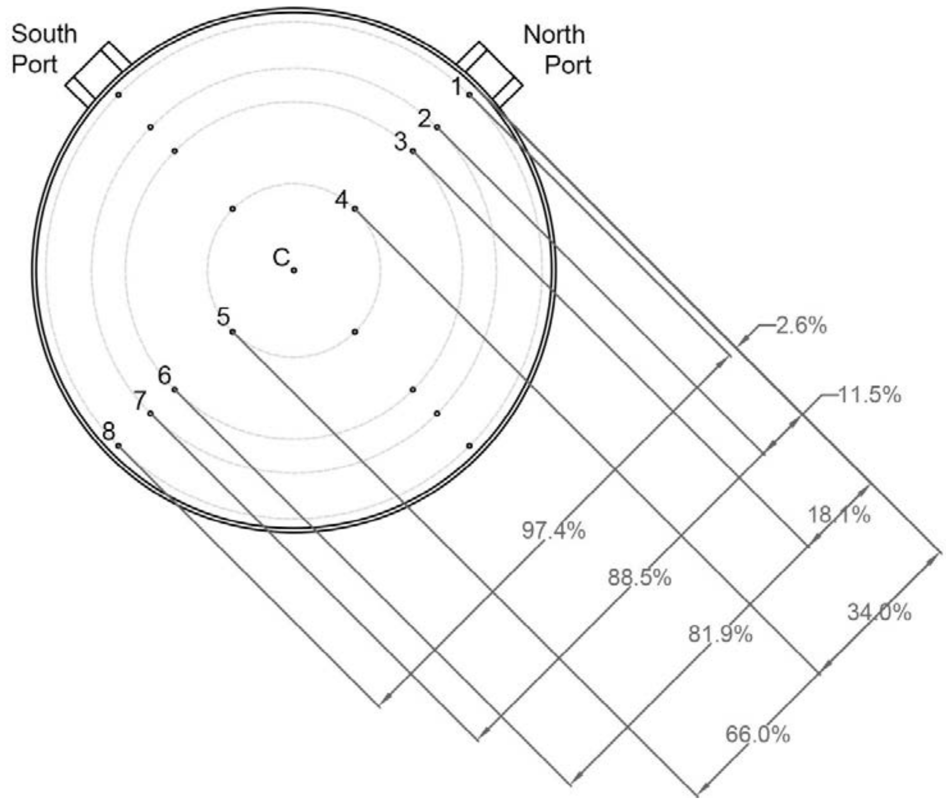


Figure 3.2. Cross Section of the Duct at the Testing Ports with Measurement Points

3.2.1 Velocity Uniformity

The uniformity of air velocity at the stack monitoring location indicates whether the momentum in the stack is well-mixed. The method used to conduct the velocity uniformity tests was based on 40 CFR 60, Appendix A, Method 1. The velocity uniformity criterion is that the %COV should be less than 20% in the center two-thirds of the duct.

Air velocity measurements were made using a TSI Alnor Micromanometer (TSI, Model ETB730, Shoreview, MN). Duct air temperature measurements were made using a TSI thermal anemometer. The micromanometer is capable of reporting velocity in standard meters per second, with standard conditions defined as 1 atm and 70°F, or in actual meters per second. The instrument measures the actual barometric pressure using an internal sensor. The temperature source can be entered manually or taken from a probe that measures temperature and connects at the probe connector. The instrument accuracy for velocity is 3% of the reading plus 0.04 m/s for the range of measurements made for these tests. Figure 3.3 shows the equipment used for this test.

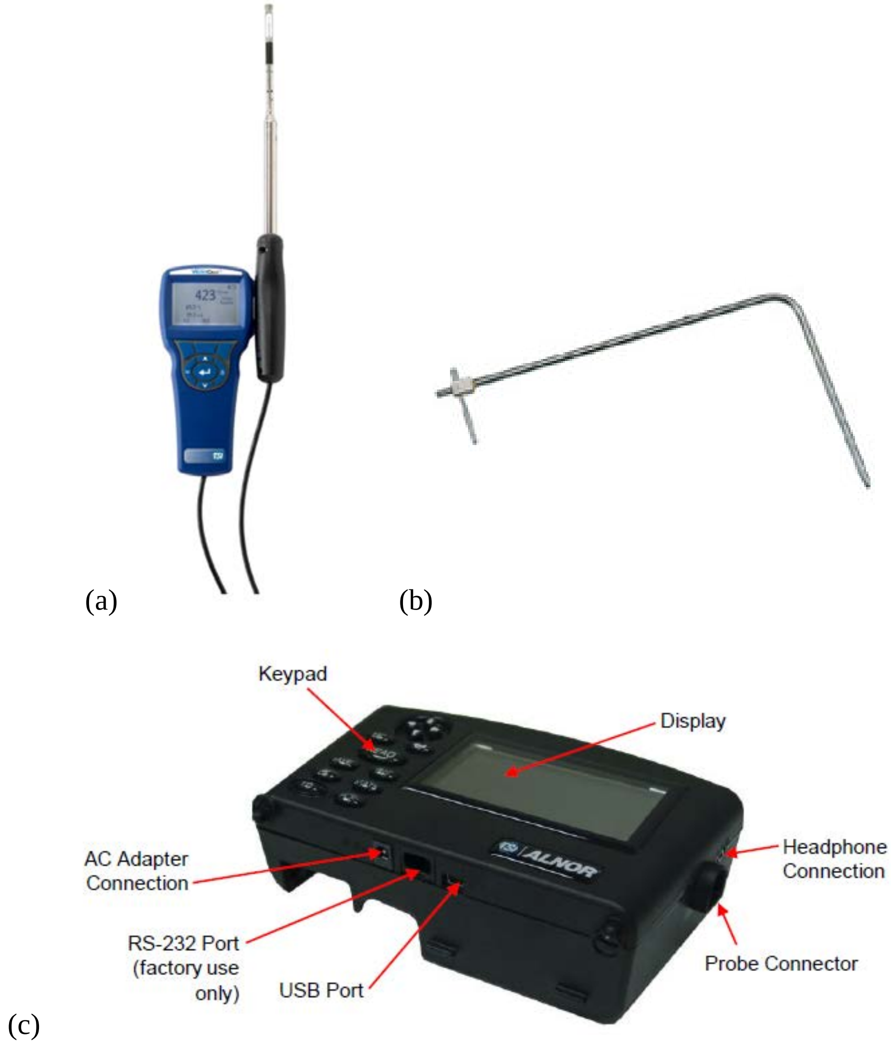


Figure 3.3. Equipment Used for Velocity Uniformity Testing: (a) TSI thermal anemometer, (b) Dwyer standard Pitot tube (the model shown is shorter than the model used for these tests), and (c) Alnor micromanometer

TI-STMON-033 provided specific directions for conducting this test. The velocity readings displayed on the micromanometer were an averaged result of several internal measurements. The velocity at each point was measured three times (with three traverses), and the average of the three readings was computed. The average velocity for each point in the center two-thirds of the duct was used to determine the mean and standard deviation of the velocity across the cross-sectional plane. The %COV (a.k.a. the percent relative standard deviation) was calculated as 100 times the standard deviation divided by the mean. The calculated %COV was then compared to the acceptance criteria.

3.2.2 Flow Angle

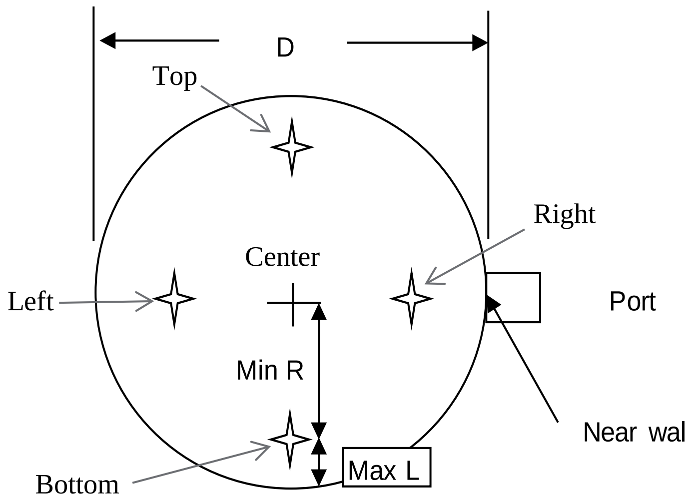
When conducting the flow angle test, the air velocity vector approaching the sample nozzle should be aligned with the axis of the nozzle within an acceptable range so that the sample extraction performance is not degraded. The test method is based on EPA 40 CFR 60, Appendix A, Method 1, Section 11.4, “Verification of the Absence of Cyclonic Flow.” The term “flow angle” refers to the angle between the velocity vector of the flow in the duct and the axis of the sampling nozzle. For the stack testing activities, the flow angle was measured at a grid of nine points across two axes in a cross section of the duct (see Figure 3.1). The qualification criterion for the flow angle test is that the average angle should not exceed 20° within the center two-thirds of the duct.

The flow angle measurements were made using an S-type Pitot tube (Dwyer Instruments, 160S-60PM, Michigan City, IN) attached by flexible tubing to a slant-tube manometer (Dwyer Instruments, 400-5-L, Michigan City, IN) and an angle-indicating device attached to the sampling port as shown in Figure 3.4. For this test, the S-type Pitot tube was rotated so that the planes of the two open ends of the two tubes were parallel to the long axis of the duct. The Pitot tube was then rotated about its long axis until the differential pressure across the open ends of the tubes read zero on the manometer. The rotation angle was read from the angle-indicating device. The measured flow angle for each point was the average of three readings. These measured values were used to calculate the mean absolute value of the flow angle across the duct. TI-STMON-034 provided specific directions for conducting this test.

Figure 3.4. Equipment Used for Flow Angle Testing: (a) TSI Thermal Anemometer, (b) Dwyer Type-S Pitot Tube (the model shown is shorter than the model used for these tests), (c) Dwyer Slant-Tube Manometer, (d) Angle Indicator Plate with Pointer

3.2.3 Gaseous Tracer Uniformity

The gaseous contaminant concentration uniformity was demonstrated using nitrous oxide (N_2O) as the tracer gas. A compressed gas cylinder and a flow controller were used to deliver a constant stream of N_2O into the duct. The gaseous tracer was injected into the duct at a location downstream of the fans. For separate test runs, the injection probe was positioned at one of five different positions in the duct cross section, as illustrated in Figure 3.5 for circular ducts. One position was along the duct centerline, while the remaining four injection positions were within a specified distance of the duct wall. For a nominally 120 cm (47.25 in.) diameter duct, the four "wall" injection locations were located within 9.45 in. (24 cm) of the wall.



Diam., in.	**Max L** Fr. Side	**Min. R** To Point	Max L fr Near Wall	Min L fr Near Wall
47.25	9.45	14.175	9.45	37.8

Figure 3.5. Illustration of Five Injection Points in a Circular Duct. Note: Max L is the maximum distance from the wall, which is 20% of the hydraulic diameter. Therefore, Min R, the minimum radius from the duct center, is 80% of the hydraulic diameter. In the case of a circular duct, the hydraulic diameter is equal to the physical diameter (D).

In the NRU exhaust duct, the tracer injection was located in Building 160, just upstream of a large butterfly valve. An existing smoke detector (red box in Figure 3.6) was removed to reveal two holes in the duct wall. One of these holes was used for tracer injection and the other hole was simply plugged.

A photoacoustic gas analyzer (Innova Gas Analyzer Model 1412i-5, Ballerup, Denmark) was used to measure tracer gas concentrations. The concentration variation was the important result for this test, so calibration bias was not important in the test results. However, the analyzer response was checked with calibration standards before and after conducting the test series to verify an adequate instrument response. The response was considered acceptable if the concentration from the instrument was within 10% of the calibration standard.

Figure 3.6. Location of Tracer Injection in Building 160. The smoke detector (red box) was removed and the existing duct penetration was used for the injection port.

A simple probe was used to extract the sample and deliver it to the gas analyzer. A small pump drew air from within the stack through the probe. The gas analyzers then sampled the air from the sample line for analysis (Figure 3.7).

Figure 3.7. Example of Equipment Used for the Gaseous Tracer Sampling: (a) Sampling Probe Installed in a Port, (b) Sampling Pump, and (c) Gas Analyzer (a newer model was used)

TI-STMON-035 provided specific directions for conducting this test. The tracer concentration was to be measured three times at each of the measurement points across the duct. The average of the three measurements was computed, and these values (in the center two-thirds of the duct) were used to calculate the overall mean, standard deviation, and %COV. The qualification criteria for the gaseous tracer test are that 1) the %COV should be ≤20% within the center two-thirds of the duct, and 2) the concentration at any measurement point should not deviate from the overall mean by more than 30%.

3.2.4 Particle Tracer Uniformity

The uniformity of the particulate contaminant concentration was demonstrated using polydisperse vacuum pump oil particles as a particle tracer. The oil was drawn into a spray nozzle (driven by compressed air) housed in a stainless steel chamber. These aerosol particles were injected into the duct air at an injection point downstream of the fans in Building 160 (Figure 3.6). Figure 3.8 shows the equipment used for aerosol injection in the NRU stack. The stainless steel chamber and spray nozzle assembly is also referred to as the aerosol generator. The output from two such aerosol generators was combined to supply sufficient aerosol for the large stack flow rate. The aerosol was injected at the centerline of the duct.

The concentration of the particles was measured at the sampling grid points with a calibrated optical particle counter (OPC) (Hach, Met-One Model 3415, Loveland, CO). A simple probe was used to extract the sample and deliver it to the OPC. Figure 3.9 shows an example setup with the simple probe connected to the OPC. To identify potential inconsistencies in the aerosol output, tests were conducted with a reference instrument measuring the particle concentration at a location downstream of the test port (Sampling Port in Figure 3.1). The OPC sorts the particles into eight size channels. As mentioned in Section 1.1, the particles of interest are10 μm AD. Therefore, only data in the 9 to 11 μm channel of the OPC were used for these tests.

The particle concentration was to be measured three times at each of the measurement points across the cross section of the duct. The average of the three concentrations at each point was computed. From these average values, the overall mean, standard deviation, and %COV were calculated. The qualification criterion for the particle tracer test was that the %COV should be less than or equal to 20% within the center two-thirds of the duct. TI-STMON-036 provided specific directions for conducting this test.

Figure 3.8. Aerosol Generator Used for Particle Injection

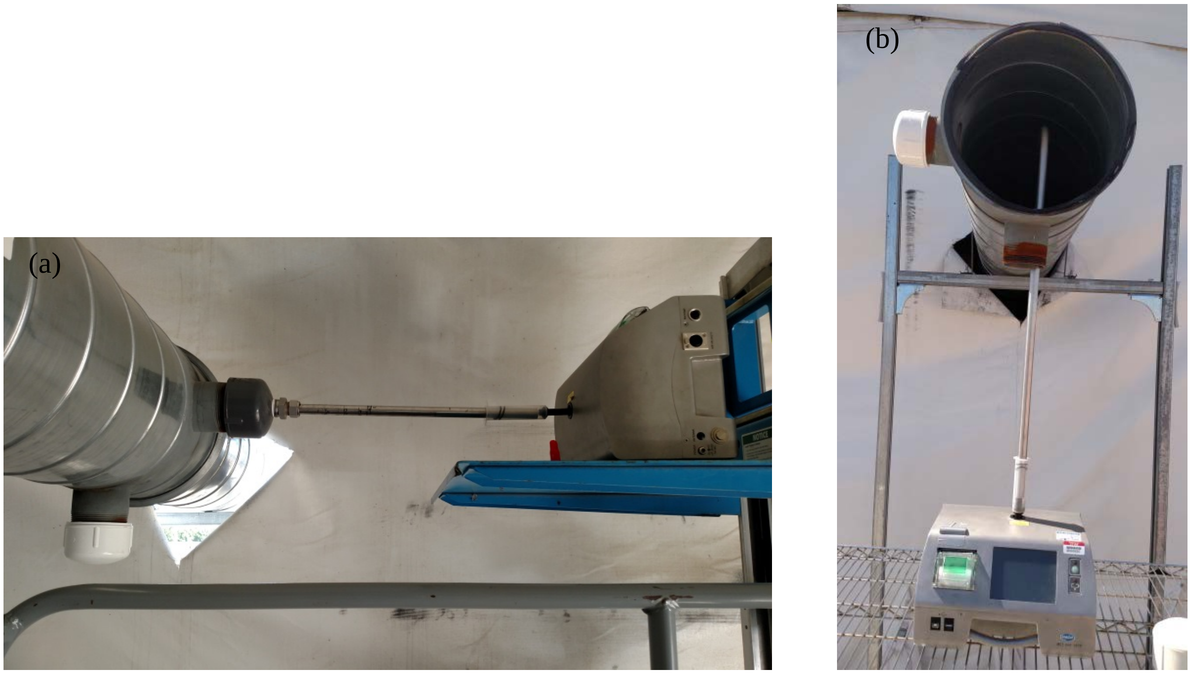


Figure 3.9. Examples of Optical Particle Counters Used for the Particle Sampling. (a) Optical Particle Counter for Measurement Data in Side Port of a Scale Model System; (b) Fixed Position Reference Optical Particle Counter in Bottom of a Reference Port.

4.0 CNL-NRU Stack Testing Results

This section summarizes the results of the stack testing activities conducted by CNL staff at the NRU exhaust stack. The primary, reportable results are the data and data calculations to evaluate the stack results against the requirements of the ANSI/HPS N13.1-1999 standard. Independent reviews were performed by PNNL staff to verify the data transcription and calculations. These calculations were performed using Microsoft Excel™ (2010) and documented in computer-assisted calculation packages (CCPs) in accordance with STMON procedures. Appendix A contains a list of supporting documentation (such as the test plan and TIs) used with this testing effort. The final data sheets for the NRU exhaust tests are included in Appendix B.

The NRU exhaust stack underwent a series of velocity uniformity tests (designated VT), flow angle tests (designated FA), gas tracer tests (designated GT) and particle tracer tests (designated PT). Summary tables of the data from the test ports near the proposed sample location for the new NRU exhaust sample system are presented in the following subsections.

4.1 Test Matrix

The candidate sampling location is located nearly 1 km from the facility, so minor changes in the operating flow conditions were not anticipated to cause any significant variation in the test results. Consequently, the tests focused on the normal flow condition. The test matrix shown in Table 4.1 lists the planned number of test runs by test type and the actual number of tests performed.

Table 4.1. Test Matrix

	Planned Number of Test Runs				
Flow Condition	Velocity	Flow Angle	Gas Tracer	Particle Tracer	Total
	3	3	5 + 1 wc	3	15
Normal	Actual Number of Test Runs Performed				
	1	1	5	1	8
wc = worst case					

A number of replicate tests of each test type were recommended by PNNL; however, due to time and resource constraints, CNL staff performed only single tests. Tests were performed during short duration NRU outages. Because fewer tests were performed than were originally planned, the variability in test results cannot be investigated.

4.2 NRU Air Exhaust Velocity Uniformity

Table 4.2 lists the result for the single velocity uniformity test performed on the CNL-NRU stack. Two planned repeat tests were not performed due to time constraints during the NRU outage. The result of 6.1%COV was well within the criterion of ≤20%COV. However, without the planned repeat tests, this result is un-verified. Although the result of a single test cannot be reported with high confidence, the stack configuration, geometry, and length point to a high likelihood that the velocity at this location would be well-mixed. The completed data sheet from this test is available in Appendix B, Subsection B.1.

Table 4.2. Summary of CNL-NRU Velocity Uniformity Test

Operating Fans	Flow Condition	Run No.	Flow (m^3/s)	Approx. Air Velocity (m/s)	%COV*
A or B and 2 of 3 boosters	Normal	VT-1	13.5	11.9	6.1

* Insufficient data collected to report results with high confidence.

For this test, the additional test uncertainty that would be necessary to end up with a result that is greater than 20%COV (the test criterion) was statistically evaluated. For example, with an additional 12% uncertainty in the test result, there is a 1% probability that the actual result of this test would have been greater than 20%COV (rather than 6.1%COV). Given the level of test uncertainty from the instrument and the measurement technique, 12% additional uncertainty is a relatively high value. Therefore, the likelihood that the uniformity in the stack is actually in excess of 20% is low.

4.3 NRU Air Exhaust Flow Angle

Table 4.3 lists the results for the single flow angle test performed on the CNL-NRU stack. Two planned repeat tests were not performed, again, due to time constraints during the short NRU outage. The result of 1.3 degrees for the test was well within the criterion of flow angle values ≤20°. Without repeated tests, the potential variability in test results was not explored, and the result of a single test cannot be reported with high confidence. However, the stack configuration, geometry, and length point to a high likelihood that the flow angle at this location would be well-aligned with the duct axis. The completed data sheet from this test is available in Appendix B, Subsection B.2.

Table 4.3. Summary of CNL-NRU Flow Angle Tests

Operating Fans	Flow Condition	Run No.	Approx. Air Velocity (m/s)	Flow Angle (Degrees)
A or B and 2 of 3 boosters	Normal	FA-1	13	1.3

* Insufficient data collected to report results with high confidence.

4.4 NRU Air Exhaust Gaseous Tracer Uniformity

During the gas tracer testing, the response of the gas analyzer was checked against calibration standards of appropriate concentrations. The original calibration check performed in April 2015 met the performance requirement of results being within 10% of the calibration standard gas concentration. The results at the time of testing, however, did not meet the requirements of TI-STMON-035, and were 20 and 50% higher than the standard gas concentration. The drift in calibration check data indicated operator inexperience with the equipment, error in setup, or a problem with the gas analyzer. Not meeting test instruction requirements during calibration checks, and in particular, the difference in the calibration check results between the pre-test and post-test check, brings into question the reliability of the test data. The data sheets from all calibration checks can be found in the first portion of Appendix B, Subsection B.3.

The CNL-NRU stack had one injection port and five tracer gas injection locations, as shown in Figure 3.3. Table 4.4 lists the results for all five of the gaseous tracer uniformity tests performed on the CNL-NRU stack. Due to the perceived consistency of the data, only two of three traverses were completed on the North Side and one of three traverses was completed on the South Side for both the Right and Center injection runs (GT-1 and GT-2, see Appendix B, pages B.7 and B.8). In addition, only one traverse was completed in each direction for the Left, Bottom, and Top injection points (GT-3 through GT-5, see Appendix B, pages B.9 through B.11). Collecting fewer data than prescribed decreases the number of data points that the mean, standard deviation, and ultimately the %COV are based on because there is less chance to observe any variability in the tracer gas concentration at a given point.

Table 4.4. Summary of NRU Complex Exhaust Gas Tracer Uniformity Tests

Operating Fans	Flow Condition	Injection Port Location	Run No.	Approx. Air Velocity (m/s)	%COV*	Absolute % Max. Dev. from Mean*
A or B and two of three boosters	Normal	Right	GT-1	11.65	0.5	0.9
		Center	GT-2	11.65	0.9	1.3
		Left	GT-3	11.50	0.5	0.9
		Bottom	GT-4	11.60	0.8	1.4
		Top	GT-5	11.55	0.4	0.7

* Insufficient data collected to report results with high confidence.

Gaseous uniformity tests ranged from 0.4 to 0.9 %COV and the absolute value of the maximum deviation from the mean ranged from 0.7 to 1.4%. In all cases, the gas tracer appeared to be well-mixed, with results well within the qualification criteria of %COV values ≤20% and an absolute value of maximum deviation ≤30%. Unfortunately, due to time constraints during the short NRU outage, the worst-case repeat test was not performed. The lack of repeat tests does not allow for investigation of any possible variability in test results. The completed data sheets are available in Appendix B, Subsection B.3.

4.5 NRU Air Exhaust Particle Tracer Uniformity

The results of the single particle tracer test are not presented here because they were inconclusive for two reasons. First, measurements were not made at all of the test points necessary to cover the center two-thirds of the stack. Because of physical interference with the test port couplings, collecting a sample at Point 8 in both traverse directions was not possible. In addition, interference with the walls of the tent/enclosure (see Figure 3.1) and at an underground conduit prevented readings from being taken at Point 7 on the single South Side traverse. The ANSI Standard requires that the %COV be based on the center two-thirds area of the duct; Point 7 (Figure 3.1) is included in that center two-thirds area, but was not sampled on the South Side traverse. Therefore the %COV could not be determined for the entire center two-thirds area of the duct.

Second, production of tracer particles was inadequate. The measured tracer particle concentrations were generally of the same order as the background concentration taken at the start and end of the test run. The aerosol generator inlet pressure was only 1 psig as noted in the data sheet (Appendix B, page B.12). Experience has shown that a setting of at least 5 psig produces significantly more particles than the lower setting. Increasing the pressure to the regulator's maximum should produce sufficient particles to get at least five times background. However, if increasing the inlet pressure on the aerosol generator is not sufficient to produce particles at least five times background, a larger nozzle for the generator should be installed, or the aerosol injection location should be repositioned and/or relocated.

For completeness, the reviewed data sheet is included in Appendix B, Subsection B.4. A CCP was not produced for this incomplete data set. If the data set obtained through the North and South ports were used, the calculated % COV was about 120% (for indication only). See the special data sheet in Appendix B, page B.13.

5.0 Conclusions

The results of the stack qualification tests performed for the NRU exhaust stack are summarized in Table 5.1. The tests were not performed to the QA level prescribed in the test plan and TIs, so a qualifier must be applied to these results. All tests were performed near normal stack flow rates. The approximate air velocity, which was recorded for each test, is included in Table 5.1. These air velocities, if multiplied by the stack cross-sectional area, correspond to approximate stack flow rates between 13.1 and 14.7 m^3/s.

Table 5.1. Summary of Sampling Probe Location Results for the NRU Exhaust Stack

	Acceptance Criteria	Units	Test Port*	Approx. Air Velocity, m/s
Velocity Uniformity	≤20	%COV	6.1	11.9
Flow Angle	≤20	Degrees	1.3	13.0
Gas Tracer Uniformity	≤20	%COV	0.4 – 0.9	11.6
	≤30	Maximum % Deviation from Mean	0.9 – 1.4	
Particle Tracer Uniformity	≤20	Normalized %COV	Incomplete Test	Incomplete Test

* Insufficient data collected to report results with high confidence.

Based on the results obtained from conducting limited (no test replicates) and partial (no traverse repeats) tests, the location proposed for the air sampling probe in the stack partially meets the requirements of the ANSI/HPS N13.1-1999 Standard for velocity uniformity, flow angle, and gas tracer uniformity, but cannot be reported with high confidence. The velocity uniformity and flow angle tests included traverse repeats, and are therefore of higher quality than the gas tracer uniformity, which had limited traverse repeats and poor instrument calibration check results. Without repeated tests, the potential variability in test results was not explored, and the result of a single test cannot be used to conclusively determine compliance with the test criteria. However, the stack configuration, geometry, and length point to a high likelihood that the velocity, flow angle, and gaseous tracer uniformity at this location would be compliant with the test criteria. In addition, for the velocity uniformity tests, statistical calculations showed that an additional 12% uncertainty in the test result would only achieve a 1% probability that the test result was actually greater than 20%COV. This analysis also points to the high likelihood that the single test demonstrates compliance with the test criteria. The results of the single particle tracer test were inconclusive for the reasons described in Section 4.5.

To fully demonstrate that the new sampling location meets the criteria set in ANSI/HPS N13.1-1999, PNNL suggests all tests be completed as laid out in the test plan. This would include performing all test repeats, collecting data at all sampling points during a test, and completely filling in data sheets and TIs. Additional training in the setup of gas analyzer calibration checks or recalibration of the gas analyzer should be addressed. To complete the particle tracer tests this would require the tent structure and/or the sampling ports be repositioned to allow for sample collection at Point 7 on the South Side traverse. Adequate particle production would also need to be addressed by both proper setup of the aerosol generators with appropriate sized nozzles installed, and sufficient air pressure supplied to the generators, relocating the aerosol injection position, or modification of the particle generators themselves.

6.0 References

10 CFR 830, Subpart A. "Quality Assurance Requirements." *Code of Federal Regulations,* U.S. Department of Energy.

40 CFR 60, Appendix A, Method 1. "Method 1—Sample and Velocity Traverses for Stationary Sources." *Code of Federal Regulations*, U.S. Environmental Protection Agency.

40 CFR 61, Subpart H. "National Emission Standard for Emissions of Radionuclides Other than Radon from Department of Energy Facilities." *Code of Federal Regulations,* U.S. Environmental Protection Agency.

American National Standards Institute and the Health Physics Society (ANSI/HPS). 1999. *Sampling and Monitoring Releases of Airborne Radioactive Substances from the Stacks and ducts of Nuclear Facilities*. ANSI/HPS N13.1-1999, McLean, Virginia (reaffirmed in 2011 as ANSI/HPS N13.1-2011).

American Society of Mechanical Engineers (ASME). 2005. *Flow Measurement Performance Test Codes*. ASME PTC 19.5-2004. New York.

American Society of Mechanical Engineers (ASME). 2000. *Quality Assurance Requirements for Nuclear Facility Applications*. NQA-1-2000, New York.

DOE (U.S. Department of Energy). 2011. "Quality Assurance." Order 414.1D, Washington, D.C.

Appendix A

CNL-NRU Scale Model Testing Supporting Documents List

Appendix A

CNL-NRU Scale Model Testing Supporting Documents List

Test Plan	TP-STMON-032 Rev 0.0	Testing of the NRU Complex Stack Air Sampling Position
Test Instructions	TI-STMON-033	Velocity Uniformity Test at the NRU/DIF Duct
	TI- STMON-034	Flow Angle Test at the NRU/DIF Duct
	TI- STMON-035	Gas Tracer Mixing Test at the NRU/DIF Duct
	TI- STMON-036	Particle Tracer Mixing Test at the NRU/DIF Duct
Calculation Packages	CCP-STMON-030	Determine Air Velocity Uniformity in CNL-NRU Stack
	CCP-STMON-031	Determine Flow Angle in CNL-NRU Stack
	CCP-STMON-032	Determine Gas Tracer Mixing in CNL-NRU Stack

Appendix B

CNL-NRU Data Sheets

B.1 Velocity Uniformity

VELOCITY TRAVERSE DATA FORM

Site	**CNL-NRU**	Run No.	**VT-1**
Date	**2015 July 15**	Fan Configuration	**Fan A or B and 2/3 Booster Fans**
Testers	CC / AS	Start/End Time	**10:32 / 12:01**
Stack Dia.	120 cm (47.25 in)	Stack Temp	24 deg C
Stack X-Area	1.13 m^2 (12.2 ft^2)	Center 2/3 from	11.0 cm to: 109.0
Test Port	North/South	Points in Center 2/3	2 to: 7
Dist. to disturbance	meters	Velocity units	m/s 12.2

Order -->		First				Second			
Traverse-->		North Side				South Side			
Trial ---->		1	2	3	Mean	1	2	3	Mean
Point	Depth, cm	Velocity				Velocity			
1	3.2	10.1	10.6	10.7	10.5	10.2	10.1	10.3	10.2
2	13.8	12.6	12.5	12.6	12.6	12.2	12.4	12.3	12.3
3	21.7	13.0	13.4	13.2	13.2	13.1	13.2	13.1	13.1
4	40.8	13.8	13.7	13.7	13.7	13.6	13.7	13.7	13.7
Center	60.0	13.2	13.0	13.1	13.1	13.3	13.2	13.3	13.3
5	79.2	12.6	12.4	12.6	12.5	12.7	12.5	12.4	12.5
6	98.3	11.7	11.7	11.8	11.7	11.8	12.0	11.8	11.9
7	106.2	11.5	11.4	11.4	11.4	11.5	11.6	11.4	11.5
8	116.9	9.9	10.0	10.0	9.9	10.0	9.6	9.9	9.8
Averages ---------->		12.0	12.1	12.1	12.1	12.0	12.0	12.0	12.0

All	m/s	Dev. from mean	***Center 2/3***	North Side	South Side	All
Mean	12.1		Mean	12.6	12.6	12.6
Min Point	9.8	-18.5%	Std. Dev.	0.8	0.8	0.8
Max Point	13.7	13.9%	COV as %	6.5	6.2	**6.1**

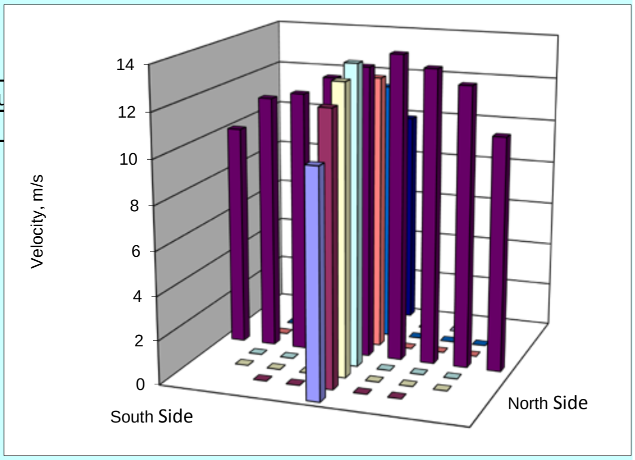
Flow w/o C-Pt 13.5 m3/s

Vel Avg w/o C-Pt 11.9 m/s

	Start	Finish	
Stack temp	22.6	26.2	C
Ambient temp	24.7	28.6	C
Ambient pressure	989	989	mbars

Instuments Used:	Cal Due
TSI/Alnor Micromanometer EBT730	10/15/15
TSI 9545 Digital Velocity Meter, S/N	9/24/2015
Handheld Digital Manometer, S/N	8/12/2016

Notes: Distance to Disturbance was requested but not given to u
Fan configuration was all the detail we were given.



Entries made by:	ChrissCorrigan/ Amelia Shea	Technical Data Review performed by:	Carmen Arimescu
Signature/date	15/11/19	Signature/date	on file with TI-STMON-033 12/7/2015

B.2 Flow Angle

FLOW ANGLE DATA FORM

Site	CNL-NRU	Run No.	FA-1
Date	2015 July 15	Fan Configuration	of A or B and 2 of 3 Booster Fans
Testers	C.C. / A. S.	Start/End Time	14:00 / 17:00
Stack Dia.	120 cm (47.25 in)	Approx. air vel.	13 m/s at point >> Center
Stack X-Area	1.13 m^2 (12.2 ft^2)	Units	degrees (clockwise > pos. nos.)
Elevation	149 meters	Test Port	N / S
Dist to disturbance	NA meters	Stack Temp	26.4 °C

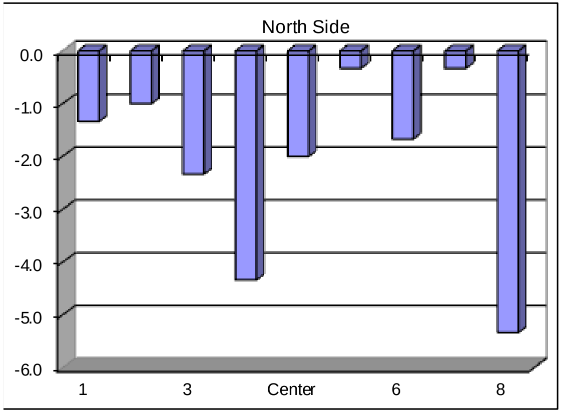
Order -->		First				Second			
Traverse-->		North Side				South Side			
Trial ---->		1	2	3		1	2	3	
Point	Depth, cm	deg. cw	deg. cw	deg. cw	Avg.	deg. cw	deg. cw	deg. cw	Avg.
1	3.2	1	-2	-3	-1.3	-2	-2	2	-0.7
2	13.8	1	-1	-3	-1.0	0	-1	4	1.0
3	21.7	-1	-2	-4	-2.3	0	0	4	1.3
4	40.8	-7	-2	-4	-4.3	0	1	0	0.3
Center	60.0	-1	-4	-1	-2.0	-2	2	0	0.0
5	79.2	1	0	-2	-0.3	0	-1	-1	-0.7
6	98.3	0	-2	-3	-1.7	2	2	0	1.3
7	106.2	0	-1	0	-0.3	0	0	0	0.0
8	116.9	-4	-15	3	-5.3	3	-12	9	0.0
Mean of absolute values:					2.1				0.6
" " w/o points by wall:					1.7				0.7
								Grand mean ABS	1.3
								" " w/o wall pts	1.2

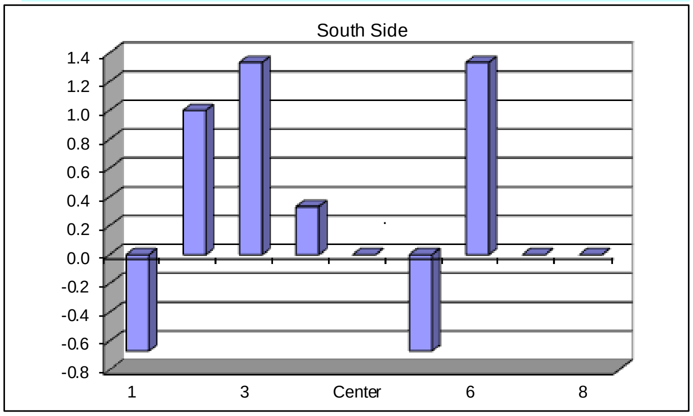
Note:
To assure similar hose connections between the manometer and pitot tube, rotating the pitot tube assembly clockwise drives the meniscus to the right (to higher pos. numbers).

Instuments Used:	Cal. Due
S-type pitot	Cert. of conformance
TSI 9545 Digital Velocity Meter, S/N	9/24/2015
Shop built Angle indicator	N/A
Dwyer Slant-Tube Manometer	Cert. of conformance

	Start	Finish	
Stack temp	26.4	26.1	C
Ambient temp	27.7	27.5	C
Ambient pressure	989	989	mbars

Notes:
When taking angle measurements note orientation of angle indicator at north and south ports.
Fan configuration is all the detail we were given
Distance to Disturbance was requested but not provided.





Entries made by:	Chris Corrigan	Technical Data Review performed by:	Carmen Arimescu
Signature/date	Amelia Shea 15/11/19	Signature/date	on file with TI-STMON-034 12/2/2015

Section B.3 Gas Tracer Uniformity

GAS ANALYZER CALIBRATION

Site	**CNL-NRU**	Instrument	Innova Model 1412i-5
Date	4/23/2015	Serial No.	713-006
Testers	EA & JAG	Property No.	N/A

Setup:

6.5	ft	sample inlet tube length
986.8	mbar	station pressure
23.52	deg C ambient temp	analyzer corrects to 20 deg C
35.9	percent RH	

Pre-Test background, ppb
Compensating for water vapor
484, 478, 455, 464, 459, 437, 446, 423, 433, 432, 417

	2.0 ppm		59.7 ppm
Cylinder	CAL8557	Cylinder	CAL10610
start P =	1950 psi	start P =	1950 psi
end P =	1600 psi	end P =	1800 psi

	Calibration readings: (ppm)		Calibration readings: (ppm)
1	2.14	1	62.9
2	2.12	2	63.0
3	2.13	3	63.0
4	2.13	4	63.1
5	2.12	5	63.2
6	2.13	6	63.0
7	2.11	7	63.1
8	2.12	8	63.3
9	2.12	9	63.2
10	2.12	10	63.4
= avg	**2.12**	= avg	**63.1**
=avg/std	**1.062**	=avg/std	**1.057**

Standards Used:		Expiration date:
Air Liquide 2.0 ppm N2O in air	CAL8557	11/5/2017
Air Liquide 59.7 ppm N2O in air	CAL10610	11/5/2017
Weather Station Used:		**Cal.Date**
~~Handheld Traceable Digital Barometer SN#140544586~~		~~8/12/2016~~ JAG 4/23/15

Notes: Onsite Cal Lab barometer in Bldg 409
Barometer: DHI-ppc2+ Due 2/6/16 SN 422
Temp & Humidity Fluke 1620A Due 5/12/15 SN A84609 Thernohygrometere
Calibration check location Bldg 409 Rm. 132

Entries made by:	J Glissmeyer	Technical Data Review performed by:	Carmen Arimescu
Signature/date:	4/23/2015	Signature/date	on file with TI-STMON-035
	Signature on file with original		12/2/2015

GAS ANALYZER CALIBRATION

Site	**CNL-NRU**	Instrument	Innova Model 1412i-5
Date	7/14/2015	Serial No.	713-006
Testers	CC : AS	Property No.	N/A

Setup:

6.5	ft	sample inlet tube length	
982	mbar	station pressure	
23	deg C ambient temp		analyzer corrects to 20 deg C
49.2	percent RH		

Pre-Test background, ppb
Compensating for water vapor
274, 244, 290, 284, 265, 255, 276, 251, 247, 280

	2.0 ppm		59.7 ppm
Cylinder	CAL8557	Cylinder	CAL10610
start P =	1600 psi	start P =	1700 psi
end P =	1550 psi	end P =	1600 psi

	Calibration readings: (ppm)		Calibration readings: (ppm)
1	2.40	1	73.6
2	2.44	2	74.7
3	2.55	3	73.4
4	2.60	4	73.5
5	2.65	5	73.6
6	2.52	6	73.8
7	2.50	7	73.7
8	2.53	8	73.8
9	2.80	9	73.9
10	2.52	10	74.1
= avg	**2.55**	= avg	**73.8**
=avg/std	**1.276**	=avg/std	**1.236**

Standards Used:			Expiration date:
Air Liquide	2.0 ppm N2O in air	CAL8557	11/5/2017
Air Liquide	59.7 ppm N2O in air	CAL10610	11/5/2017
Weather Station Used:			Cal.Date
Handheld Traceable Digital Barometer SN#140544586			8/12/2016

Notes: Low flow relief valve passing on regulator.

Entries made by: Signature/date: *Chris Corrigan/Amelia Shea*	Technical Data Review performed by: Carmen Arimescu Signature/date on file with TI-STMON-035 12/2/2015

GAS ANALYZER CALIBRATION

Site	**CNL-NRU**	Instrument	Innova Model 1412i-5
Date	2015 July 22	Serial No.	713-006
Testers	CC / AS	Property No.	N/A

Setup:

10.5	ft	sample inlet tube length	
997	mbar	station pressure	
22	deg C ambient temp		analyzer corrects to 20 deg C
53.5	percent RH		

Pre-Test background, ppb
Compensating for water vapor
325, 343, 318, 343, 330, 329, 307, 318, 334, 302

	2.0 ppm		59.7 ppm
Cylinder	CAL8557	Cylinder	CAL10610
start P =	1200 psi	start P =	950 psi
end P =	1000 psi	end P =	750 psi

	Calibration readings: (ppm)		Calibration readings: (ppm)
1	3.11	1	89.4
2	3.15	2	89.5
3	3.17	3	90.2
4	3.16	4	86.5
5	3.17	5	88.0
6	3.15	6	87.8
7	3.16	7	87.7
8	3.15	8	88.0
9	3.15	9	87.8
10	3.11	10	87.9
= avg	**3.15**	= avg	**88.3**
=avg/std	**1.574**	=avg/std	**1.479**

Standards Used:			Expiration date:
Air Liquide	2.0 ppm N2O in air	CAL8557	11/5/2017
Air Liquide	59.7 ppm N2O in air	CAL10610	11/5/2017
Weather Station Used:			**Cal.Date**
Handheld Traceable Digital Barometer SN#140544586			8/12/2016

Notes: PRV's liking at 10psi, boarder line low flow.

Entries made by: Signature/date: *Chris Corrigan/Amelia Shea* 2015 July 22	Technical Data Review performed by: Carmen Arimescu Signature/date on file with TI-STMON-035 12/2/2015

TRACER GAS TRAVERSE DATA FORM

Site	**CNL-NRU**	Run No.	**GT-1**
Date	2015 July 16	Fan Configuration	**1 of Fan A or B and 2/3 Booster Fans**
Testers	C. C. / A. S.	Start/End Time	13:30 / 17:00
Stack Dia.	120 cm (45.25 ft)	Stack Temp	27.8 deg C
Stack X-Area	1.13 m^2 (12.2 ft^2)	Center 2/3 from	11.0 cm to: 109.0 cm
Test Port	North and South	Points in Center 2/3	2 to: 7
Distance to disturbance	N/A meters	Injection Point	**Right**
Measurement units	ppm N2O		

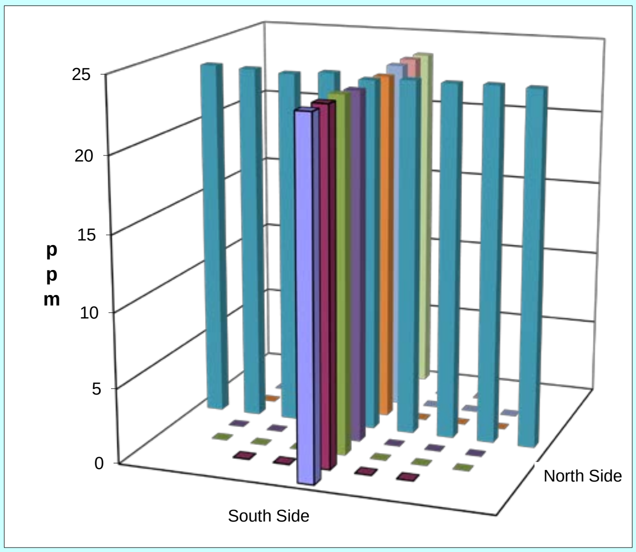
Order -->		First				Second			
Traverse-->		North Side				South Side			
Trial ---->		1	2	3	Mean	1	2	3	Mean
Point	Depth, cm	ppm				ppm			
1	3.2	23.2	23.4	N/A	23.3	23.4	N/A	N/A	23.4
2	13.8	23.3	23.4	N/A	23.4	23.4	N/A	N/A	23.4
3	21.7	23.3	23.3	N/A	23.3	23.5	N/A	N/A	23.5
4	40.8	23.5	23.2	N/A	23.4	23.3	N/A	N/A	23.3
Center	60.0	23.1	23.3	N/A	23.2	23.5	N/A	N/A	23.5
5	79.2	23.6	23.4	N/A	23.5	23.3	N/A	N/A	23.3
6	98.3	23.3	23.3	N/A	23.3	23.6	N/A	N/A	23.6
7	106.2	23.4	23.5	N/A	23.5	23.6	N/A	N/A	23.6
8	116.9	23.5	23.6	N/A	23.6	23.5	N/A	N/A	23.5
Averages ---------->		23.4	23.4	#DIV/0!	23.4	23.5	#DIV/0!	#DIV/0!	23.5

All	ppm	Dev. from mean	***Center 2/3***	North Side	South Side	All
Mean	23.41		Mean	23.35	23.46	23.40
Min Point	23.20	-0.9%	Std. Dev.	0.10	0.13	0.12
Max Point	23.60	0.8%	COV as %	0.4	0.5	**0.5**

Avg. Conc. 23.419 ppm

Instuments Used:	**Cal Due:**
Innova 1412i-5 Gas Analyzer SN 713-006	Cat2 M&TE
TSI 9545 Digital Velocity Meter SN T95451439005	9/24/2015
Handheld Traceable Digital Barometer SN#140544586	8/12/2016

	Start	Finish	
Tracer tank pressure	62.1	55.2	bar
Injection flowmeter	14.7	14.84	slpm
Stack Temp	27.5	28.1	°C
Mean stack velocity	11.5	11.8	m/s
Sampling flowmeter	5	5	lpm
Ambient pressure	993	991	mbar
Ambient Temp	30.6	30.8	°C
B&K vapor correction	Y	Y	Y/N
Back-Gd gas	340	411	ppm
No. Bk-Gd samples	2	2	n



Gas analyzer check date: 2015 July 14

Notes: Only preformed 2 runs on North Side and 1 run on
on South due to consistency of readings.
Fan configuration is what was provided to us from project lead.
Distance to disturbance was not provided (we requested it).

Entries made by:	Chris Corrigan		Technical Data Review performed by:	Carmen Arimescu
Signature/date	Amelia Shea	15/11/19	Signature/date	on file with TI-STMON-035 12/2/2015

TRACER GAS TRAVERSE DATA FORM

Site	**CNL-NRU**	Run No.	**GT-2**
Date	2015 July 16	Fan Configuration	**1 of Fan A or B and 2/3 Booster Fans**
Testers	C. C. / A. S.	Start/End Time	13:30 / 17:00
Stack Dia.	120 cm (45.25 ft)	Stack Temp	27.8 deg C
Stack X-Area	1.13 m^2 (12.2 ft^2)	Center 2/3 from	11.0 cm to: 109.0 cm
Test Port	North and South	Points in Center 2/3	2 to: 7
Distance to disturbance	N/A meters	Injection Point	**Center**
Measurement units	ppm N2O		

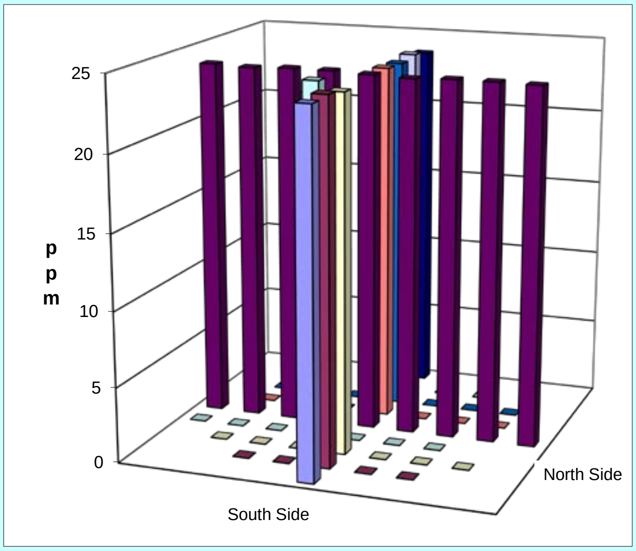
Order -->		First				Second			
Traverse-->		North Side				South Side			
Trial ---->		1	2	3	Mean	1	2	3	Mean
Point	Depth, cm	ppm				ppm			
1	3.2	23.3	23.4	N/A	23.4	23.8	N/A	N/A	23.8
2	13.8	23.2	23.6	N/A	23.4	23.9	N/A	N/A	23.9
3	21.7	23.3	23.5	N/A	23.4	23.6	N/A	N/A	23.6
4	40.8	23.2	23.4	N/A	23.3	23.7	N/A	N/A	23.7
Center	60.0	23.5	23.3	N/A	23.4	23.8	N/A	N/A	23.8
5	79.2	23.3	23.7	N/A	23.5	23.8	N/A	N/A	23.8
6	98.3	23.6	23.4	N/A	23.5	23.7	N/A	N/A	23.7
7	106.2	23.3	23.5	N/A	23.4	23.9	N/A	N/A	23.9
8	116.9	23.5	23.5	N/A	23.5	23.6	N/A	N/A	23.6
Averages ---------->		23.4	23.5	#DIV/0!	23.4	23.8	#DIV/0!	#DIV/0!	23.8

All	ppm	Dev. from mean	***Center 2/3***	North Side	South Side	All
Mean	23.59		Mean	23.41	23.77	23.59
Min Point	23.30	-1.2%	Std. Dev.	0.07	0.11	0.21
Max Point	23.90	1.3%	COV as %	0.3	0.5	**0.9**

Avg. Conc. 23.584 ppm

	Start	Finish	
Tracer tank pressure	55.2	48.3	bar
Injection flowmeter	14.6	14.74	slpm
Stack Temp	27.5	28.1	°C
Mean stack velocity	11.7	11.6	m/s
Sampling flowmeter	5	5	lpm
Ambient pressure	993	992	mbar
Ambient Temp	30.8	30.8	°C
B&K vapor correction	Y	Y	Y/N
Back-Gd gas	340	411	ppm
No. Bk-Gd samples	2	2	n

Instuments Used:	**Cal Due:**
Innova 1412i-5 Gas Analyzer SN 713-006	Cat2 M&TE
TSI 9545 Digital Velocity Meter SN T95451439005	9/24/2015
Handheld Traceable Digital Barometer SN#140544586	8/12/2016



Gas analyzer check date: 2015 July 14

Notes: Performed only 2 of 3 runs on North Side and 1 of 3 runs on South side due to consistency of readings.
Fan configuration is what was provided to us from project lead.
Distance to disturbance was not provided.

Entries made by:	Chris Corrigan		Technical Data Review performed by:	Carmen Arimescu
Signature/date	Amelia Shea	15/11/19	Signature/date	on file with TI-STMON-035 12/2/2015

TRACER GAS TRAVERSE DATA FORM

Site	**CNL-NRU**	Run No.	**GT-3**
Date	2015 July 16	Fan Configuration	**1 ofFan A or B and 2/3 Booster Fans**
Testers	C.C. / A. S.	Start/End Time	13:30 / 17:00
Stack Dia.	120 cm (45.25 ft)	Stack Temp	27.8 deg C
Stack X-Area	1.13 m^2 (12.2 ft^2)	Center 2/3 from	11.0 cm to: 109.0 cm
Test Port	North and South	Points in Center 2/3	2 to: 7
Distance to disturbance	N/A meters	Injection Point	**Left**
Measurement units	ppm N2O		

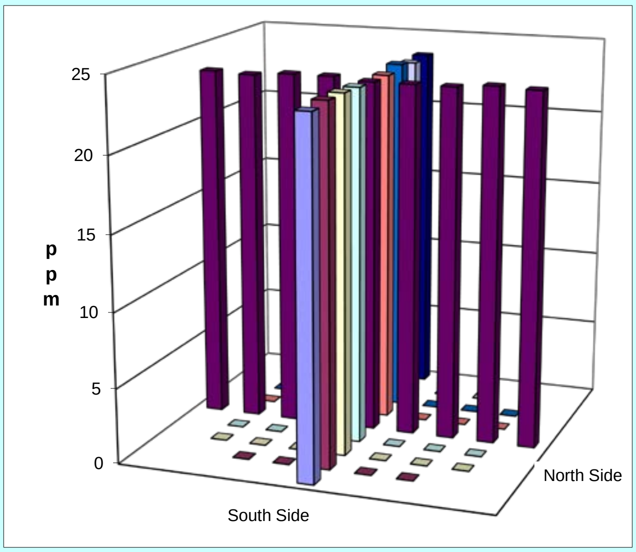
Order -->		First				Second			
Traverse-->		North Side				South Side			
Trial ---->		1	2	3	Mean	1	2	3	Mean
Point	Depth, cm	ppm				ppm			
1	3.2	23.5	N/A	N/A	23.5	23.4	N/A	N/A	23.4
2	13.8	23.6	N/A	N/A	23.6	23.6	N/A	N/A	23.6
3	21.7	23.4	N/A	N/A	23.4	23.6	N/A	N/A	23.6
4	40.8	23.4	N/A	N/A	23.4	23.5	N/A	N/A	23.5
Center	60.0	23.4	N/A	N/A	23.4	23.4	N/A	N/A	23.4
5	79.2	23.6	N/A	N/A	23.6	23.4	N/A	N/A	23.4
6	98.3	23.6	N/A	N/A	23.6	23.7	N/A	N/A	23.7
7	106.2	23.4	N/A	N/A	23.4	23.4	N/A	N/A	23.4
8	116.9	23.5	N/A	N/A	23.5	23.5	N/A	N/A	23.5
Averages ---------->		23.5	#DIV/0!	#DIV/0!	23.5	23.5	#DIV/0!	#DIV/0!	23.5

All	ppm	Dev. from mean	***Center 2/3***	North Side	South Side	All
Mean	23.49		Mean	23.49	23.51	23.50
Min Point	23.40	-0.4%	Std. Dev.	0.11	0.12	0.11
Max Point	23.70	0.9%	COV as %	0.5	0.5	**0.5**

Avg. Conc. 23.506 ppm

	Start	Finish	
Tracer tank pressure	48.3	41.4	bar
Injection flowmeter	14.54	14.7	slpm
Stack Temp	27.5	28.1	°C
Mean stack velocity	11.4	11.6	m/s
Sampling flowmeter	5	5	lpm
Ambient pressure	992	992	mbar
Ambient Temp	30.8	30.9	°C
B&K vapor correction	Y	Y	Y/N
Back-Gd gas	340	411	ppm
No. Bk-Gd samples	2	2	n

Instuments Used:	**Cal Due:**
Innova 1412i-5 Gas Analyzer SN 713-006	Cat2 M&TE
TSI 9545 Digital Velocity Meter SN T95451439005	9/24/2015
Handheld Traceable Digital Barometer SN#140544586	8/12/2016



Gas analyzer check date: 2015 July 14

Notes: Ferformed only 1 of 3 runs on both North and South side due to consistency of readings.
Fan configuration is what was provided to us.
Distance to disturbance was not provided to us.

Entries made by:	Chris Corrigan	
Signature/date	Amelia Shea	15/11/19
Technical Data Review performed by:	Carmen Arimescu	
Signature/date	on file with TI-STMON-035	12/2/2015

TRACER GAS TRAVERSE DATA FORM

Site	**CNL-NRU**	Run No.	**GT-4**		
Date	2015 July 16	Fan Configuration	**1 of Fan A or B and 2/3 Booster Fans**		
Testers	C. C. / A. S.	Start/End Time	13.30/17:00		
Stack Dia.	120 cm (45.25 ft)	Stack Temp	27.8 deg C		
Stack X-Area	1.13 m^2 (12.2 ft^2)	Center 2/3 from	11.0 cm	to:	109.0 cm
Test Port	North and South	Points in Center 2/3	2	to:	7
Distance to disturbance	N/A meters	Injection Point	**Bottom**		
Measurement units	ppm N2O				

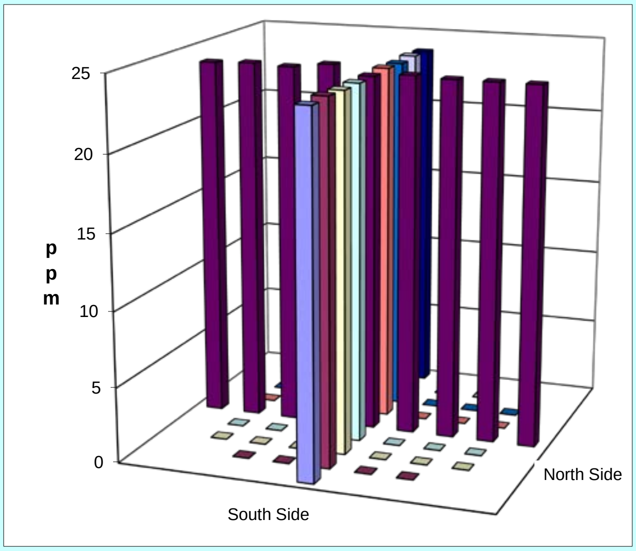
Order -->		First				Second			
Traverse-->		North Side				South Side			
Trial ---->		1	2	3	Mean	1	2	3	Mean
Point	Depth, cm	ppm				ppm			
1	3.2	23.4	N/A	N/A	23.4	23.7	N/A	N/A	23.7
2	13.8	23.4	N/A	N/A	23.4	23.8	N/A	N/A	23.8
3	21.7	23.4	N/A	N/A	23.4	23.7	N/A	N/A	23.7
4	40.8	23.5	N/A	N/A	23.5	23.7	N/A	N/A	23.7
Center	60.0	23.3	N/A	N/A	23.3	23.7	N/A	N/A	23.7
5	79.2	23.9	N/A	N/A	23.9	23.8	N/A	N/A	23.8
6	98.3	23.6	N/A	N/A	23.6	23.7	N/A	N/A	23.7
7	106.2	23.7	N/A	N/A	23.7	23.8	N/A	N/A	23.8
8	116.9	23.6	N/A	N/A	23.6	23.7	N/A	N/A	23.7
Averages ---------->		23.5	#DIV/0!	#DIV/0!	23.5	23.7	#DIV/0!	#DIV/0!	23.7

All	ppm	Dev. from mean	***Center 2/3***	North Side	South Side	All
Mean	23.63		Mean	23.54	23.74	23.64
Min Point	23.30	-1.4%	Std. Dev.	0.21	0.05	0.18
Max Point	23.90	1.1%	COV as %	0.9	0.2	**0.8**

Avg. Conc. 23.650 ppm

Instuments Used:	**Cal Due:**
Innova 1412i-5 Gas Analyzer SN 713-006	Cat2 M&TE
TSI 9545 Digital Velocity Meter SN T95451439005	9/24/2015
Handheld Traceable Digital Barometer SN#140544586	8/12/2016

	Start	Finish	
Tracer tank pressure	41.4	34.5	bar
Injection flowmeter	14.56	14.65	slpm
Stack Temp	27.5	28.1	°C
Mean stack velocity	11.8	11.4	m/s
Sampling flowmeter	5	5	lpm
Ambient pressure	992	991	mbar
Ambient Temp	30.9	31.0	°C
B&K vapor correction	Y	Y	Y/N
Back-Gd gas	340	411	ppm
No. Bk-Gd samples	2	2	n



Gas analyzer check date: 2015 July 14

Notes: Fan configuration is all we were provided.
Performed only 1 of 3 runs on North and South side due to consistency of readings.
Distance to disturbance not provided to us.

Entries made by:	Chris Corrigan		Technical Data Review performed by:	Carmen Arimescu
Signature/date	Amelia Shea	15/11/19	Signature/date	on file with TI-STMON-035 12/2/2015

TRACER GAS TRAVERSE DATA FORM

Site	**CNL-NRU**	Run No.	**GT-5**
Date	2015 July 16	Fan Configuration	**1 of Fan A or B and 2/3 Booster Fans**
Testers	C. C. / A. S.	Start/End Time	13:30/17:00
Stack Dia.	120 cm (45.25 ft)	Stack Temp	27.8 deg C
Stack X-Area	1.13 m^2 (12.2 ft^2)	Center 2/3 from	11.0 cm to: 109.0 cm
Test Port	North and South	Points in Center 2/3	2 to: 7
Distance to disturbance	meters	Injection Point	**Top**
Measurement units	ppm N2O		

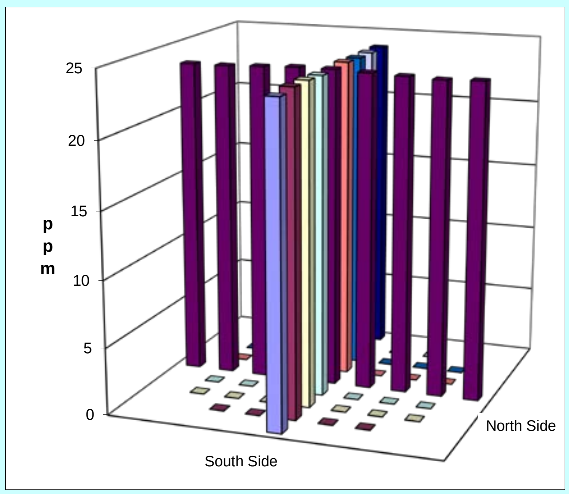
Order -->		First				Second			
Traverse-->		North Side				South Side			
Trial ---->		1	2	3	Mean	1	2	3	Mean
Point	Depth, cm	ppm				ppm			
1	3.2	23.6	N/A	N/A	23.6	23.5	N/A	N/A	23.5
2	13.8	23.5	N/A	N/A	23.5	23.7	N/A	N/A	23.7
3	21.7	23.6	N/A	N/A	23.6	23.7	N/A	N/A	23.7
4	40.8	23.7	N/A	N/A	23.7	23.6	N/A	N/A	23.6
Center	60.0	23.8	N/A	N/A	23.8	23.6	N/A	N/A	23.6
5	79.2	23.8	N/A	N/A	23.8	23.7	N/A	N/A	23.7
6	98.3	23.7	N/A	N/A	23.7	23.6	N/A	N/A	23.6
7	106.2	23.6	N/A	N/A	23.6	23.6	N/A	N/A	23.6
8	116.9	23.6	N/A	N/A	23.6	23.6	N/A	N/A	23.6
Averages ---------->		23.7	#DIV/0!	#DIV/0!	23.7	23.6	#DIV/0!	#DIV/0!	23.6

All	ppm	Dev. from mean	***Center 2/3***	North Side	South Side	All
Mean	23.64		Mean	23.67	23.64	23.66
Min Point	23.50	-0.6%	Std. Dev.	0.11	0.05	0.09
Max Point	23.80	0.7%	COV as %	0.5	0.2	**0.4**

Avg. Conc. 23.631 ppm

Instuments Used:		**Cal Due:**
Innova 1412i-5 Gas Analyzer	SN 713-006	Cat2 M&TE
TSI 9545 Digital Velocity Meter	SN T95451439005	9/24/2015
Handheld Traceable Digital Barometer SN#140544586		8/12/2016

	Start	Finish	
Tracer tank pressure	34.5	27.6	bar
Injection flowmeter	14.58	14.61	slpm
Stack Temp	27.5	28.1	°C
Mean stack velocity	11.5	11.6	m/s
Sampling flowmeter	5	5	lpm
Ambient pressure	991	991	mbar
Ambient Temp	31.8	30.9	°C
B&K vapor correction	Y	Y	Y/N
Back-Gd gas	340	411	ppm
No. Bk-Gd samples	2	2	n



Gas analyzer check date: 2015 July 14

Notes: Fan configuration is all that was provided to us.
Performed only 1 of 3 runs on North and South side due to consistency of readings.
Distance to disturbance was not provided to us.

Entries made by:	Chris Corrigan		Technical Data Review performed by:	Carmen Arimescu
Signature/date	Amelia Shea	15/11/19	Signature/date	on file with TI-STMON-035 12/2/2015

Section B.4 Particle Tracer Uniformity

PARTICLE TRACER TRAVERSE DATA FORM

Site	**CNL-NRU**	Run No.	**PT-1**
Date	**2015 October 21**	Fan configuration	**one of Fan A or B & 2 of 3 booster fans**
Testers	CC, AS, TS	Stack Temp	22.4 deg F
Stack Dia.	120 cm (3.94 ft)	Start/End Time	10:14 am / 12:37 pm
Stack X-Area	1.13 m^2 (12.2 ft^2)	Center 2/3 from	11.0 cm to: 109.0 cm
Test Port	North, SouthCenter	Points in Center 2/3	2 to: 7
Distance to disturbance	N/A meters	Injection Point	**B160**
Measurement units	particles/ft3		

Order ----->		First				Second			
Traverse-->		North Side				South Side			
Trial ---->		1	2	3	Mean	1	2	3	Mean
Point	Depth, cm	particles/ft3				particles/ft3			
1	3.2	6.0	6.0	1.0	4.3	20.0	NA	NA	20.0
2	13.8	6.0	7.0	8.0	7.0	57.1	NA	NA	57.1
3	21.7	5.0	10.0	9.0	8.0	3.0	NA	NA	3.0
4	40.8	9.0	4.0	9.0	7.3	9.0	NA	NA	9.0
Center	60.0	5.0	4.0	1.0	3.3	5.0	NA	NA	5.0
5	79.2	2.0	5.0	5.0	4.0	9.0	NA	NA	9.0
6	98.3	2.0	4.0	6.0	4.0	11.0	NA	NA	11.0
7	106.2	6.0	4.0	2.0	4.0	NA	NA	NA	#DIV/0!
8	116.9	NA	NA	NA	#DIV/0!	NA	NA	NA	#DIV/0!
Averages ---------->		5.1	5.5	5.1	#DIV/0!	16.3	#DIV/0!	#DIV/0!	#DIV/0!

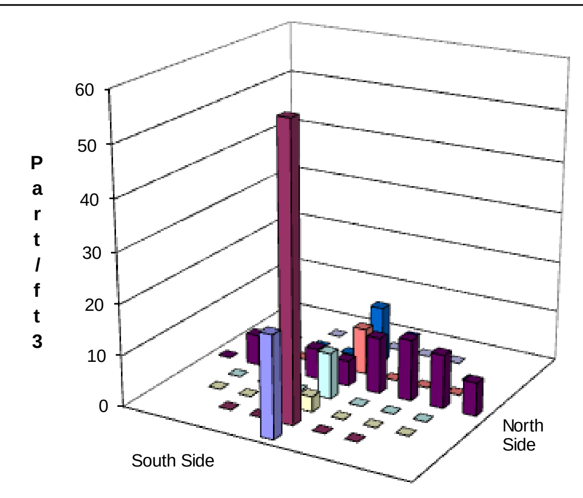
All	pt/ft3	Dev. from mean
Mean	#DIV/0!	
Min Point	#DIV/0!	#DIV/0!
Max Point	#DIV/0!	#DIV/0!

Center 2/3	North	South	All	Normlzd
Mean	5.4	#DIV/0!	#DIV/0!	#DIV/0!
Std. Dev.	2.0	#DIV/0!	#DIV/0!	#DIV/0!
COV as %	36.5	#DIV/0!	**#DIV/0!**	**#DIV/0!**

Avg Conc #DIV/0! pt/ft3

	Start	Finish	
Stack Temp	22.4	22.4	C
Mean Velocity	3.7	12.4	m/s
Ambient pressure	998	1000	mbar
Ambient temp	7.9	12.3	C
Back-Gd aerosol	3.0	4.0	pt/ft3
No. Bk-Gd samples	2	2	
Compressor output	50.0	50.0	psig
Generator Inlet Press	1	1	psig
Purge Flow Rate	35	35	LPM

Instuments Used:		Cal. Due
TSI 9545 Digital Velocity Meter SN T95451439005		9/24/2015
Handheld Traceable Digital Barometer SN140544586		8/12/2016
Met One OPC S/N 1411529001	ref	11/4/2015
Met One OPC S/N 1411529002	sample	11/4/2015



Notes: Fan configuration is what was provided from project leader.
Weldolet coupling hindered us from taking readings at point 8 N & S.
Tent hindered our reading at point 7 on south side.
Only one run preformed on south side .
South side run 3 actually run done on center weldolet.
(South side run 3 not entered in spreadsheet).

Oil Used:

Ref. Probe Location: Ref port downstream of Port 1

Probe Type / Configuration: L-Shape probe

Entries made by: Chris Corrigan
Signature/date Amelia Shea 15/11/19

Technical Data Review performed by: Carmen Arimescu
Signature/date on file with TI-STMON-036
12/14/2015

PARTICLE TRACER TRAVERSE DATA FORM

Site	**CNL-NRU**	Run No.	**PT-1 FORCED**
Date	**2015 October 21**	Fan configuration	**one of Fan A or B & 2 of 3 booster fans**
Testers	CC, AS, TS	Stack Temp	22.4 deg F
Stack Dia.	120 cm (3.94 ft)	Start/End Time	10:14 am / 12:37 pm
Stack X-Area	1.13 m^2 (12.2 ft^2)	Center 2/3 from	11.0 cm to: 109.0 cm
Test Port	North, SouthCenter	Points in Center 2/3	2 to: 7
Distance to disturbance	N/A meters	Injection Point	**B160**
Measurement units	particles/ft3		

Order ----->		First				Second			
Traverse-->		North Side				South Side			
Trial ---->		1	2	3	Mean	1	2	3	Mean
Point	Depth, cm	particles/ft3				particles/ft3			
1	3.2	6.0	6.0	1.0	4.3	20.0	NA	NA	20.0
2	13.8	6.0	7.0	8.0	7.0	57.1	NA	NA	57.1
3	21.7	5.0	10.0	9.0	8.0	3.0	NA	NA	3.0
4	40.8	9.0	4.0	9.0	7.3	9.0	NA	NA	9.0
Center	60.0	5.0	4.0	1.0	3.3	5.0	NA	NA	5.0
5	79.2	2.0	5.0	5.0	4.0	9.0	NA	NA	9.0
6	98.3	2.0	4.0	6.0	4.0	11.0	NA	NA	11.0
7	106.2	6.0	4.0	2.0	4.0	NA	NA	NA	#DIV/0!
8	116.9	NA	NA	NA	#DIV/0!	NA	NA	NA	#DIV/0!
Averages ---------->		5.1	5.5	5.1	#DIV/0!	16.3	#DIV/0!	#DIV/0!	#DIV/0!

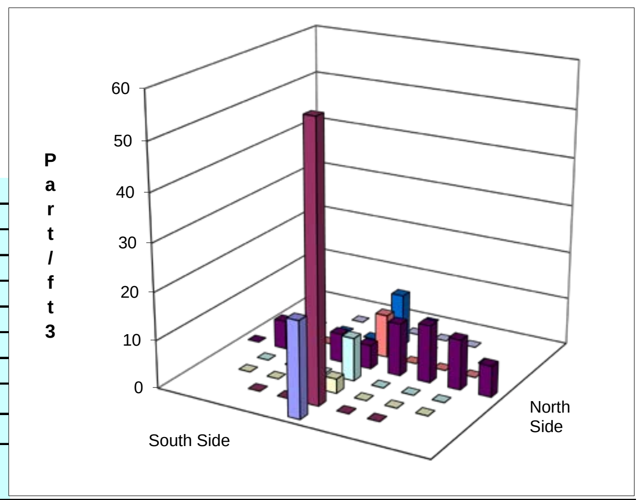
All	pt/ft3	Dev. from mean
Mean	#DIV/0!	
Min Point	#DIV/0!	#DIV/0!
Max Point	#DIV/0!	#DIV/0!

Center 2/3	North	South	All	Normlzd
Mean	5.4	15.7	10.1	11.58
Std. Dev.	2.0	20.5	14.3	13.97
COV as %	36.5	130.7	**141.5**	**120.57**

Avg Conc #DIV/0! pt/ft3

Instuments Used:		Cal. Due
TSI 9545 Digital Velocity Meter SN T95451439005		9/24/2015
Handheld Traceable Digital Barometer SN140544586		8/12/2016
Met One OPC S/N 1411529001	ref	11/4/2015
Met One OPC S/N 1411529002	sample	11/4/2015

	Start	Finish	
Stack Temp	22.4	22.4	C
Mean Velocity	3.7	12.4	m/s
Ambient pressure	998	1000	mbar
Ambient temp	7.9	12.3	C
Back-Gd aerosol	3.0	4.0	pt/ft3
No. Bk-Gd samples	2	2	
Compressor output	50.0	50.0	psig
Generator Inlet Press	1	1	psig
Purge Flow Rate	35	35	LPM



Notes: Fan configuration is what was provided from project leader. Weldolet hindered us from taking readings at point 8 N & S.
Tent hindered our reading at point 7 on south side.
Only one run preformed on south side .
South side run 3 actually run done on center weldolet.
(South side run 3 not entered in spreadsheet).
Spreadsheet forced to calculate %COV without pt 7 data.

Oil Used:

Ref. Probe Location: Ref port downstream of Port 1

Probe Type / Configuration: L-Shape probe

Entries made by:	Chris Corrigan	Technical Data Review performed by:
Signature/date	Amelia Shea 15/11/19	Signature/date

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