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RPT-STMON-008

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

Measurement of the Tracer Gradient and Sampling System Bias of the Hot Fuel Examination Facility Stack Air Monitoring System

JA Glissmeyer
JE Flaherty

July 2011

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Measurement of the Tracer Gradient and Sampling System Bias of the Hot Fuel Examination Facility Stack Air Monitoring System

J. A. Glissmeyer
J. E. Flaherty

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This document was prepared for Battelle Energy Alliance, LLC as part of a Memorandum of Purchase Order (No. 00097184). The testing described in this document was further guided by the Tests of Tracer Gradient and Sampling System Bias in the Hot Fuel Examination Facility Air Exhaust System Test Plan (TP-STMON-022).

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-022. The work and any associated testing followed the quality assurance requirements outlined in the test specification/plan. 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:

_June 14, 2011________
Date

Acronyms

ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
BEA	Battelle Energy Alliance, LLC
BT	Bias test
CFR	Code of Federal Regulations
COV	coefficient of variance
DOE	U.S. Department of Energy
GT	Gradient test
HDI	“How Do I…?”
HFEF	Hot Fuel Examination Facility
HPS	Health Physics Society
INL	Idaho National Laboratory
MPO	Memorandum of Purchase Order
PNNL	Pacific Northwest National Laboratory
ppm	parts per million (by volume)
QA	quality assurance
SF_6	sulfur hexafluoride
SOW	statement of work
STMON	Stack Monitoring Project

Acknowledgments

This work was conducted under a Memorandum of Purchase Order issued by Battelle Energy Alliance, LLC (BEA) to provide funding to Pacific Northwest National Laboratory (PNNL). PNNL is operated for the U.S. Department of Energy by Battelle under Contract DE-AC05-76RL01830.

Preparation and execution of this study involved a number of staff from both PNNL and BEA and its contractors. We would like to particularly acknowledge the support of our quality engineer, Kirsten Meier, our safety and health representative Renee Gray and administrative support from Andrea Boehler, Mona Champion, and Chrissy Charron. We would also like to acknowledge the technical reviews conducted by Rosanne Aaberg, Ernest Antonio, Carmina Arimescu, and Matthew Barnett. Meredith Willingham provided editorial support for this report. The team of support staff at BEA was also integral to the successful completion of the work conducted at the Materials and Fuel Complex (MFC). We especially appreciate the efforts of Micheal Bybee and Tim Solle for arranging training, radiological worker and radiation protection support.

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1.0 BACKGROUND

The objective of additional testing conducted at the Hot Fuel Examination Facility (HFEF) during April 2011 was to follow up on recommendations that resulted from previous stack sampling assessments made during July 2010 and documented in Glissmeyer and Flaherty (2010). The testing described in this report aimed to determine if a stack sampling bias existed and better quantify the concentration gradient within the HFEF stack in further detail to provide a basis for remedial actions on the air sampling system. These stack testing activities were conducted per SOW-8469, Rev 1 and Memorandum Purchase Order No. 00097184, Amendment No. 4 between Battelle Energy Alliance, LLC and Pacific Northwest National Laboratory (PNNL).

2.0 METHODS

The testing described in this document was guided by the test plan titled *Tests of Tracer Gradient and Sampling System Bias in the Hot Fuel Examination Facility Air Exhaust System* (TP-STMON-022). The Test Instructions described the specific steps followed to complete the tests. The Operating Procedure referenced in the Test Instructions contains some general information about how to conduct these types of tests. The test plan and quality-assured data sheets are included as appendices to this report.

Two main types of tests were conducted at HFEF during April 2011:

1. Gradient Tests
2. Bias Tests

Gradient tests measured the concentration of a tracer gas at various points at a fixed elevation in the stack. The aim of the gradient tests was to document the spatial variation of the concentration within the HFEF stack. Although a single point shrouded probe has been installed in this system per the ANSI/HPS N13.1-1999 standard, previous testing showed that the stack is not well-mixed. Therefore, as a mitigation step, measurements to establish the difference between the stack mean concentration and the single-point shrouded probe sampling concentration have been conducted.

Two types of gradient tests were conducted on the HFEF stack. Gradient tests from the north ports measured the concentration on a 4 x 5 two-dimensional grid to estimate the mean concentration in the stack. Gradient tests from the west port measured the concentration on a 20-point one-dimensional grid to document the concentration gradient across the width of the stack. Figure 1 shows the sampling ports used for the gradient tests.

Bias tests measured the concentration of a tracer gas in the stack concurrently with measurements of the tracer concentration as delivered through the stack sampling system. The aim of the bias tests was to document the tracer concentration near the inlet of the shrouded probe in the stack relative to the tracer concentration as measured through the stack sampling system to explore the suspected sampling bias resulting from the July 2010 testing. Figure 2 shows the two sampling locations for the bias tests.

Figure 1. Gradient test sampling locations on the HFEF stack. (a) Four north ports, numbered 1 through 4 from right to left. (b) West port with Plexiglass flange cover and sampling probe installed**.**

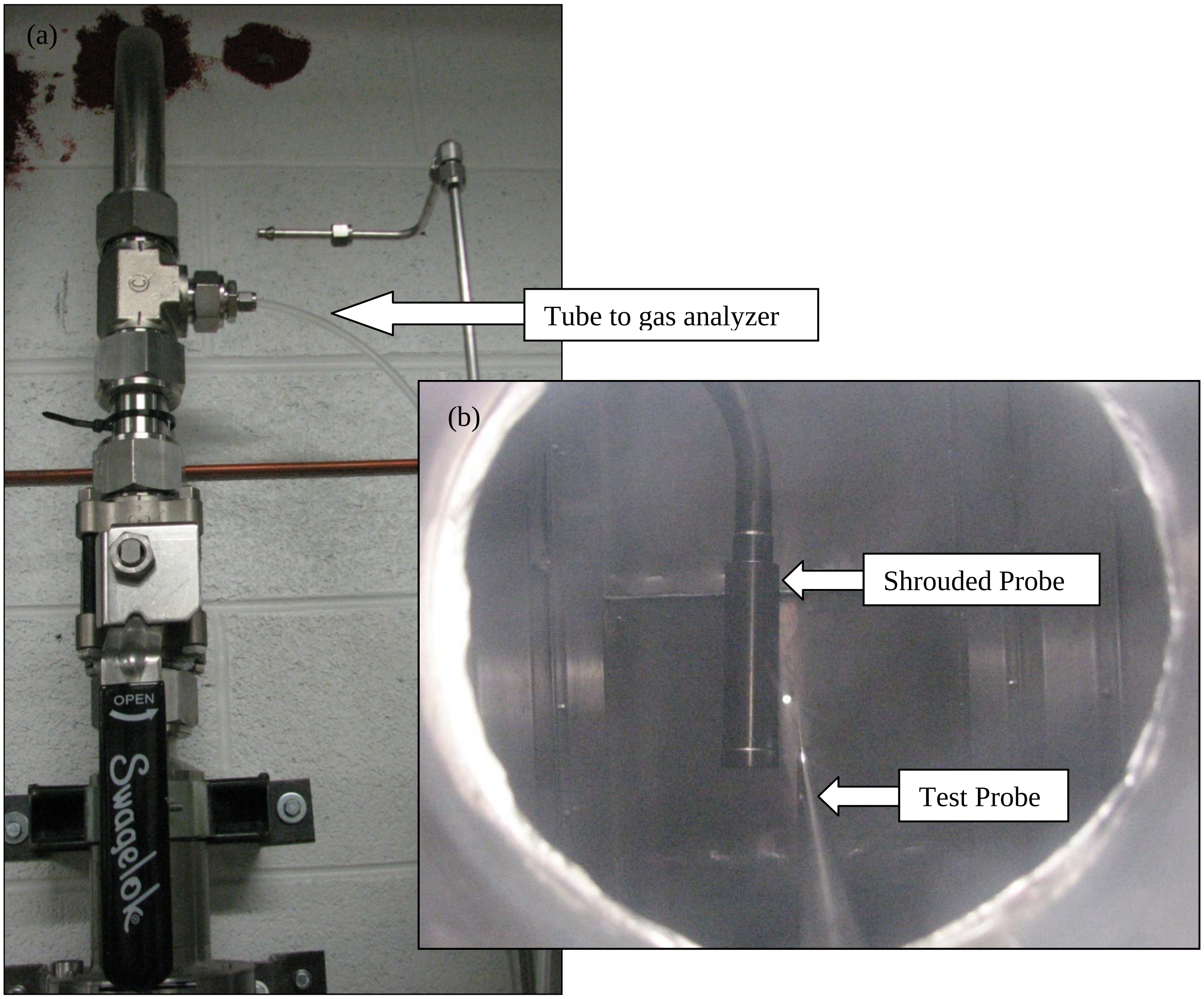

Figure 2. Bias test sampling location on the HFEF stack and on the stack sampling tubing. (a) Stack sampling tubing measurement location at the "big tee." (b) The interior of the HFEF stack showing the shrouded and test probe as observed through the West Port Plexiglas flange cover.

Sulfur hexafluoride (SF_6) tracer gas was used for all of the tests. Pure SF_6 gas was injected at the bottom of the stack into the exhaust air from the process compartments of the building. (See Figure 3.) The injection flowrate was controlled with a mass-flow controller. Tracer gas concentration was measured with photoacoustic gas analyzers (Brüel & Kjær, Model 1302, Ballerup, Denmark). A simple probe was used to extract the sample and deliver it to the gas analyzer, while a small pump drew air from within the stack or sampling tubing. The gas analyzer collected air samples from a tee in the main sample line. Figure 4 shows the equipment set-up (gas analyzer, tee in the sample line, and small pump) used for collecting air samples.

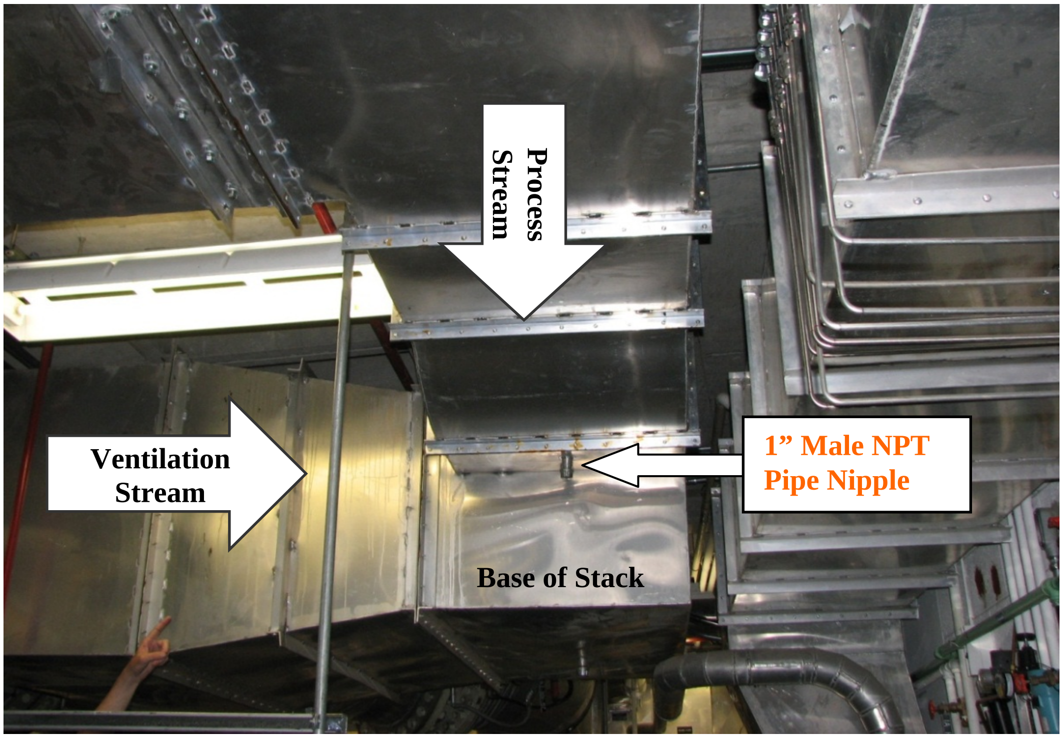

Figure 3. Tracer gas was injected into the process air via the 1" port at the bottom of the stack.

Figure 4. Equipment used for the gaseous tracer sampling. The small air pump (right) draws air through the sample line such that the photoacoustic analyzer (center) can draw air from the line through the tee.

2.1 Quality Assurance

The PNNL Quality Assurance (QA) Program is based upon the requirements defined in the U.S. Department of Energy Order 414.1C, *Quality Assurance*, and 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:

- ASME NQA-1-2000, *Quality Assurance Requirements for Nuclear Facility Applications*, Part 1, Requirements for Quality Assurance Programs for Nuclear Facilities.
- ASME NQA-1-2000, Part II, Subpart 2.7, *Quality Assurance Requirements for Computer Software for Nuclear Facility Applications*.
- ASME NQA-1-2000, Part IV, Subpart 4.2, *Graded Approach Application of Quality Assurance Requirements for Research and Development*.

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

The Stack Monitoring Project (STMON) implements an NQA-1-2000 Quality Assurance Program, graded on the approach presented in NQA-1-2000, Part IV, Subpart 4.2. The STMON Quality Assurance Manual (QA-STMON-0002) describes the technology life cycle stages under the STMON Quality Assurance Plan (QA-STMON-0001). The technology life cycle includes the progression of technology development, commercialization, and retirement in process phases of basic and applied research and development (R&D), engineering and production and operation until process completion. The life cycle is characterized by flexible and informal quality assurance activities in basic research, which becomes more structured and formalized through the applied R&D stages.

The work described in this report has been completed under the QA Technology level of Development Work. 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-601, Document Preparation and Change. This review verifies that the reported results are traceable, that inferences and conclusions are soundly based, and the reported work satisfies the Test Plan objectives.

[1] System for managing the delivery of laboratory-level policies, requirements, and procedures.

3.0 RESULTS

During April 2011, staff from PNNL conducted gradient tests (GT) and bias tests (BT) at the Hot Fuel Examination Facility exhaust stack. A summary of these tests is included in Table 1 and Table 2. The tests are listed in the table in the order in which each test was conducted. GT-1 and GT-2 were conducted first, followed by the BT series, and GT-3N and GT-3W were conducted simultaneously following the BT's.

As established during the July 2010 HFEF stack testing activities, the gaseous emissions from the process ventilation stream is not well-mixed with the building ventilation stream. Test GT-1, which measured concentrations on a 4 x 5 grid of points in the exhaust stream, confirmed that the stack mixing conditions are similar to the previous tests. The coefficient of variance (COV[2]) was 120% during GT-1. GT-2 examined the concentration gradient as the sampling probe was moved along a 20-point, one-dimensional grid from the west wall to the east wall. The COV was 97% during GT-2.

Several bias tests were conducted to determine whether the concentration (measured in parts per million by volume [ppm]) within the stack was accurately sampled by the stack sampling system. Tests were initially conducted with the sampling probe near the shrouded probe. The shrouded probe was not plumb at the start of the tests (see Figure 5), and the probe tip was slightly north of the stack centerline during these tests. Later tests placed the sampling probe directly underneath (and in contact with) the shrouded probe. Several bias tests were conducted, and each resulted in differing concentrations between the two measurement locations.

During the course of bias testing, the impact of sampling line pressures on concentrations was observed. As a result, the final bias test (BT-3b) was conducted using Tedlar® bags (SKC model 232-05, Fullerton, CA) instead of the in-line gas analyzer setup. When the contents of the Tedlar® bags were delivered to the gas analyzer, the concentrations from the two sampling locations matched very well (5.73 vs 5.76 ppm).

Finally, a gradient test was conducted on the 4 x 5 grid (GT-3N) while simultaneously measuring tracer concentration at a single point directly underneath the shrouded probe (GT-3W). Test runs GT-3N and GT-3W determined the stack mean concentration as well as the concentration measured at the entrance to the shrouded probe. Figure 6 shows the mean concentration at each point from these runs; GT-3N is shown by the circular markers while GT-3W is shown by the single diamond marker.

As mentioned previously, the shrouded probe was not plumb at the start of testing activities. To estimate the concentration measured through the shrouded probe relative to the stack mean concentration, the position of the plumb and non-plumb probe in the stack has been plotted on contour plots of the stack concentration in Figure 7. Several tests measured the concentration at the plumb and non-plumb locations; however, measurements made during separate tests cannot be reliably compared, given the pressure effects observed during the bias tests. Therefore, estimates based on contour plots are the only

[2] COV is equivalent to the relative standard deviation. It is calculated as the standard deviation of the concentration measured for each point divided by the mean for all the points, expressed as a percentage. The value should be less than 20% to be considered well mixed. Also, the concentration at any of the measurement points should not differ from the mean by more than 30%.

internally-consistent estimate that can be produced. There are some slight differences in the shape of the contour lines for higher concentrations between GT-1 and GT-3N, which result in some differences in the concentrations at the non-plumb and plumb positions relative to the mean. For GT-1, the approximate concentration at the non-plumb position is 1.25 ppm, compared with 2.00 ppm at the plumb position, while the mean was 1.49 ppm. The approximate concentration at the non-plumb position is 1.40 ppm for GT-3N compared with 2.20 ppm at the plumb position. The stack mean concentration for GT-3N was 1.94 ppm. Therefore, the non-plumb concentration was about 15% and 30% lower than the mean for GT-1 and GT-3N, respectively, while the plumb concentration was about 30% and 15% higher than the mean for the two cases.

Table 1. Summary of Gradient Tests.

Test	Description	Mean Stack (ppm)	COV (%)
GT-1	20-point, 4 x 5 grid through North ports	1.49	120.5
GT-2	20-point, linear grid through West Port	0.58	96.5
GT-3N	20-point, 4 x 5 grid through North ports	1.94	112.0
GT-3W	Single point directly underneath shrouded probe during GT-3N	3.01	6.5

Table 2. Summary of Bias Tests.

Test	Description	Mean Stack (ppm)	Mean Sample Line (ppm)
BT-1	Stack: Same depth as shrouded probe, laterally separated. Shrouded probe is not plumb. Second Floor: “Big Tee” upstream of HOV-004	0.417	0.0061
BT-2a	Stack: Same depth as shrouded probe, laterally separated. Shrouded probe is plumb. Second Floor: “Big Tee” upstream of HOV-004	1.03	0.44
BT-2b	Stack: Directly underneath shrouded probe. Shrouded probe is plumb. Second Floor: “Big Tee” upstream of HOV-004 In-Line filters for gas analyzers are removed.	1.53	0.99
BT-3a	Stack: Directly underneath shrouded probe. Shrouded probe is plumb. Second Floor: “Big Tee” upstream of HOV-004. In-Line filters for gas analyzers are removed. HOV-004 is closed.	3.00	0.95
BT-3b	Stack: Directly underneath shrouded probe. Shrouded probe is plumb. Second Floor: “Big Tee” upstream of HOV-004. HOV-004 is closed. Sampled through Tedlar® bags.	5.73	5.76

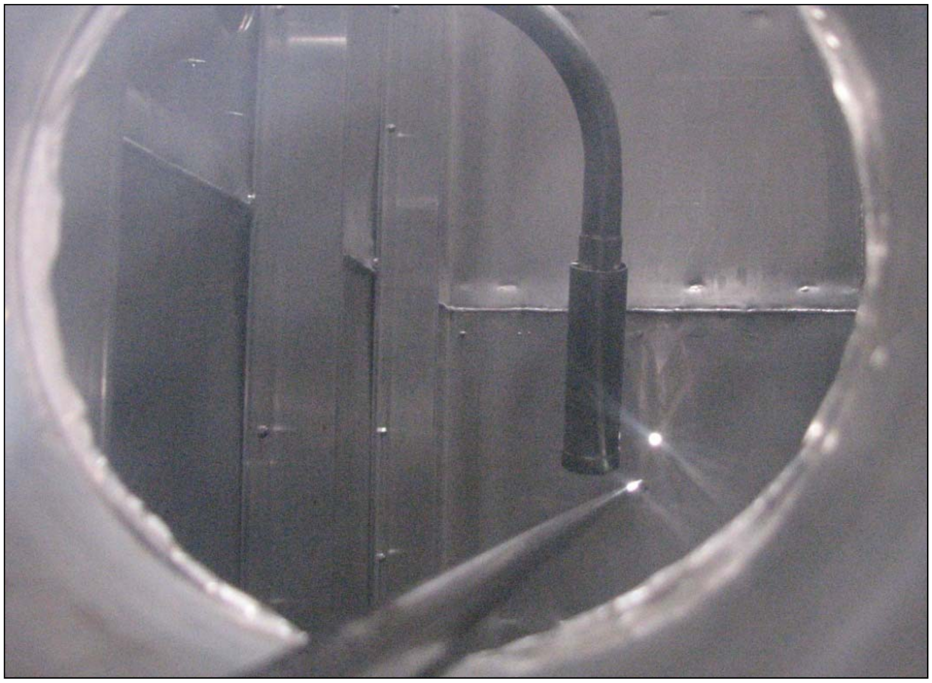

Figure 5. The shrouded probe position as observed at the start of testing activities. The tip was approximately 7 inches further east than plumb.

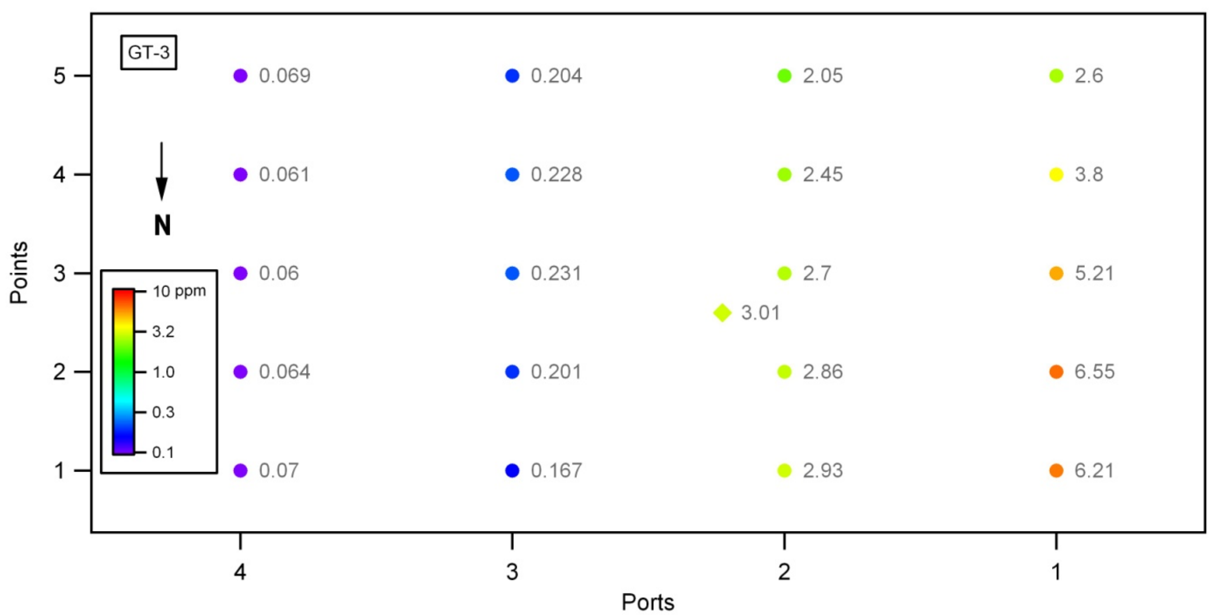

Figure 6. Plan view of SF_6 concentrations within the HFEF stack measured during GT-3N (4 x 5 grid of circular markers) and GT-3W (single diamond marker). The markers are colored according to the concentration as well as labeled with the concentration value. Note that the measurement at GT-3W is 30 inches higher in elevation compared to the measurements made for GT-3N.

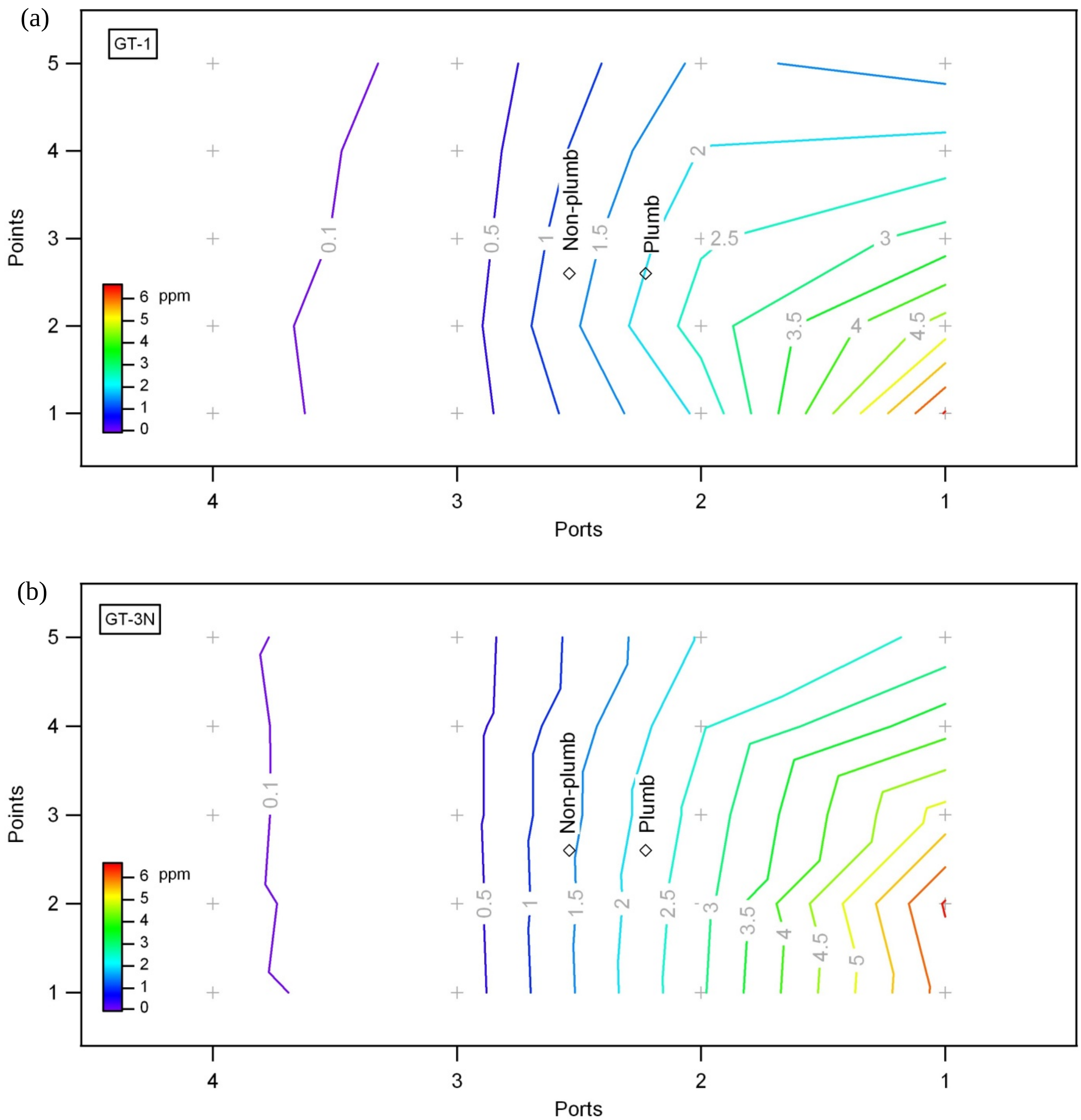

Figure 7. Plan view of SF_6 concentration contours in ppm within the HFEF stack measured during (a) GT-1 and (b) GT-3N. (Note that the line colors are different from the marker colors in Figure 6.) The two diamond markers represent the location of the shrouded probe tip when the probe was found non-plumb, and when it was corrected to plumb.

4.0 CONCLUSIONS

This report describes tracer gas gradient and bias measurements made in the exhaust air discharge of the Hot Fuel Examination Facility at Idaho National Laboratory. These measurements were conducted to follow up on measurements made at this facility during July 2010. During the July testing, measurements revealed that there is little mixing between the process and building ventilation streams. A single point shrouded probe has been installed in this system per the ANSI/HPS N13.1-1999 standard. The airstream must be well-mixed for a single point sampling probe to extract a representative sample of the entire stream. Therefore, additional measurements were made to characterize the concentrations in the stack with respect to the current probe location.

When the west port was first opened, we observed that the shrouded probe located in the HFEF stack was not pointed directly into the flow. The probe was about 20 degrees from plumb at the start of our testing activities, and was corrected during the tests. Re-positioning the shrouded probe by moving the tip approximately 7 inches toward the west wall of the stack improves the measurement through the sampling system relative to the stack mean concentration. Based on the gradient testing, we estimate that the previous probe position sampled concentrations that were about 15 to 30% lower than the stack mean concentration, while the current probe position samples concentrations that are about 15 to 30% higher than the stack mean concentration. Environmental conditions as well as changes in building ventilation conditions may impact the actual concentration gradient within the exhaust stack. Although a well-mixed stack is needed for single point sampling, the existing sampling probe configuration at HFEF extracts a conservative sample of the process air effluent. Particle line-loss and non-process effluent sampling were not addressed in these tests.

The PNNL-provided sampling system utilized for these measurements has some previously-unidentified pressure effects that impact the instrument analysis for SF_6 concentration. The suspected bias between the stack concentration and the sampling system concentration resulting from the July 2010 tests was a consequence of this pressure effect, and was not a true bias in the system. For typical tracer uniformity testing applications, where only the relative concentration is needed, the systematic error in concentration due to pressure effects does not impact the mixing results. However, absolute concentration values are not reliable between measurements made under different pressure conditions. Until the effects of pressure on the gas analyzer are fully understood and quantified, Tedlar® bags should be used when the absolute (vs relative) concentration of a tracer is necessary.

5.0 REFERENCES

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APPENDIX 1: Test Plan

Stack Monitoring Project Test Plan	**Document No.: TP-STMON-022** Rev. No.: 0.0
Title: Tests of Tracer Gradient and Sampling System Bias in the Hot Fuel Examination Facility Air Exhaust System	
Technology Level: ☐ Basic Research ☐ Applied Research ☒ Developmental Work	
Effective Date: Upon Final Signature	Page 1 of 15
Work Location (Building/Room or "General"):	**Hot Fuel Examination Facility, Idaho National Laboratory**

Signatures:

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Program QE Kirsten Meier Kirsten Meier (Print/Sign) 3/14/11 (Date)

Client Tim Solle Tim Solle (Print/Sign) 3/15/11 (Date)

Concurrence:

Project Manager John Glissmeyer John Glissmeyer (Print/Sign) 3/14/11 (Date)

REVISION HISTORY

Revision Number	Interim Change No.	Effective Date	Description of Change
0	0	Upon Final Signature	Initial issue.

Definitions/Acronyms

ANSI American National Standards Institute

ASME American Society of Mechanical Engineers

CFR Code of Federal Regulations

DOE U.S. Department of Energy

HPS Health Physics Society

M&TE measuring and test equipment

NQA Nuclear Quality Assurance

PNNL Pacific Northwest National Laboratory

QA quality assurance

QAP quality assurance plan

R&D research and development

TRIM PNNL'S electronic Total Records Information Management system

STMON Stack Monitoring Project

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1.0 Purpose

The purpose of this series of tests is to document the concentration gradient and potential sampling system bias in the stack sampling probe located in the air exhaust stack of the Hot Fuel Examination Facility (HFEF). During previous testing to evaluate the HFEF exhaust stack, a significant concentration gradient was observed in the stack at a plane approximately 20 ft from the base of the stack. Additionally, when the tracer gas concentration was measured through the existing stack sampling system (from the sample canister connected to the sampling line; see Figure 4b), the concentration was an order of magnitude lower than expected from the measurements made in the stack. The tests conducted under this test plan will explore these issues further and document the characteristics of the tracer mixing and measurements. These data will be used to support the air emissions permit for the HFEF.

This work is performed by Pacific Northwest National Laboratory (PNNL) for Idaho National Laboratory (INL) under Memorandum Purchase Order No. 00097184 and under Contract No. DE-AC05-76RL01830 according to the statement of work SOW-8469 Revision 1 issued by INL.

The tests will be conducted by PNNL personnel at the HFEF and in observance of INL safety and radiation protection requirements. Assistance will be provided by INL staff.

Section 6 of this test plan details the quality program that is followed for this project and testing. Work will be performed to the quality requirements of American Society of Mechanical Engineers (ASME) NQA-1-2000, *Quality Assurance Requirements for Nuclear Facility Applications*, Part 1, *Requirements for Quality Assurance Programs for Nuclear Facilities*, and ASME NQA-1-2000, Part IV, Subpart 4.2, *Graded Approach Application of Quality Assurance Requirements for Research and Development*. These quality requirements are implemented through the *Stack Monitoring Project (STMON) QA Plan* (QA-STMON-0001, QAP). This project is graded as technology level “Development Work” in accordance with the quality assurance (QA) program.

2.0 Objectives

The objective of this test plan is to describe testing that will be conducted to document the concentration gradient in the HFEF stack near the location of the stack sampling system, and to determine whether the current stack sampling system has a measurement bias that results in reported concentrations that are significantly lower than the concentrations within the stack at the sample inlet position. This determination requires a series of tests that are described below under Section 4.0, “Test Conditions.”

This test plan outlines the testing that will be conducted at the HFEF. The test conditions described in this test plan are assumed to represent the normal operating condition of the air exhaust system. Consideration will be given to tests runs at alternate operating conditions as they are identified. Typically, the tests are conducted at flowrates that bracket the range of expected flowrates or fan operating conditions.

3.0 Success Criteria

Completion of the work described in the test plan will document the gaseous tracer concentration gradient in the stack near the sampling probe position, and determine whether there is a bias in the concentrations measured by the air sampling system.

4.0 Test Conditions

A specific test procedure and test instructions will be followed to complete the tests to measure the gradient across a cross-section and to determine stack sampling system bias. The basic series of tests include the following:

- Measurement of gas tracer concentration gradient
- Measurement of sampling system bias

These tests are described in sub-sections to this section. The details concerning the constraints for conducting the basic tests, and an initial outline of the number and type of tests to be conducted on the HFEF stack are also included.

4.1. Gas Tracer Measurements

The approach to assessing the tracer gradient and sampling system bias is outlined below.

1. Measure the SF_6 gradient
    a. Inject a regulated amount of tracer at one of the points indicated by the arrows in Figure 1
    b. Measure average concentration using the standard procedure described by Glissmeyer and Flaherty (2010)
        i. Make measurements from the four ports on North side of stack
        ii. Use five points per port so one of the points is at the same depth as the E/W traverse. (Ports on the north are not co-planar with the port on the west, so the measurement locations will not be coincident.)
    c. Measure the SF_6 concentration gradient near the sampling nozzle
        i. This may be done using either the 1-inch port or the 6-inch flanged pipe on the West side of the stack. The 1-inch port is less than 6 inches below the inlet of the shrouded nozzle. The flanged pipe is about even with the bottom of the shrouded nozzle (See Figure 2)
        ii. Space measurement points to include the points that nearly align with the center points from the measurement grid used for the four North ports and with the inlet of the shrouded nozzle. (Preliminary sampling grid is shown in Figure 3)
2. Measure the sampling system bias
    a. Measure SF_6 concentration near the sampling nozzle via one of the test ports used above. (We expect that will be the 1-inch port on the West side of the stack.) The results of Step 1c will provide guidance on whether the sampling location is fixed or moving to cover a small span of points near the shrouded nozzle.
    b. Simultaneously measure SF_6 concentrations through the sampling system at one of the locations shown in Figure 4.
3. Repeat tests #1 and #2 as needed (assumed to include as many runs as can be done in two days).

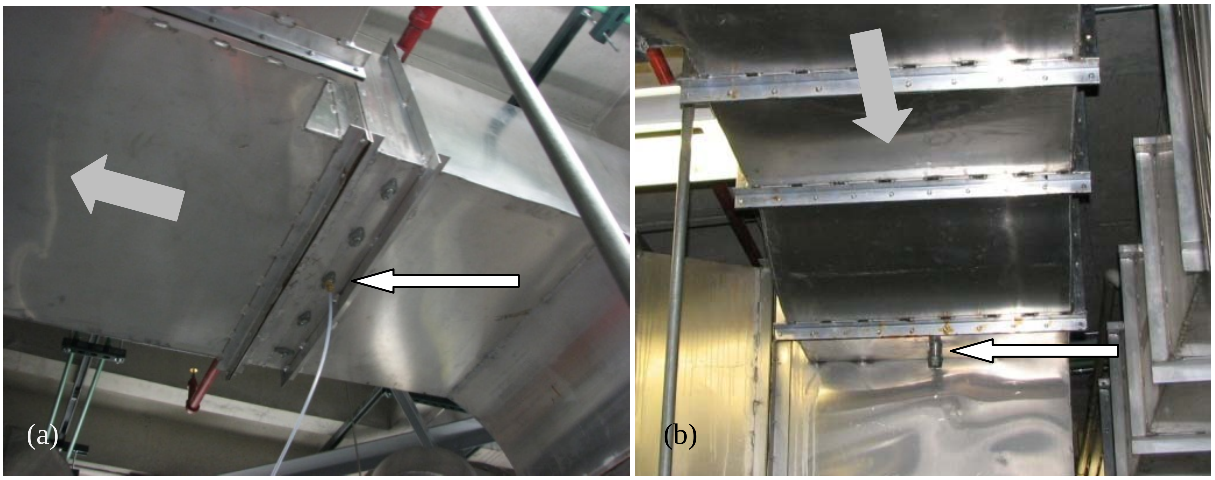


Figure 8 Tracer injection locations in the process duct in Room 209. The wide, grey arrows indicate the direction of air flow in the duct.

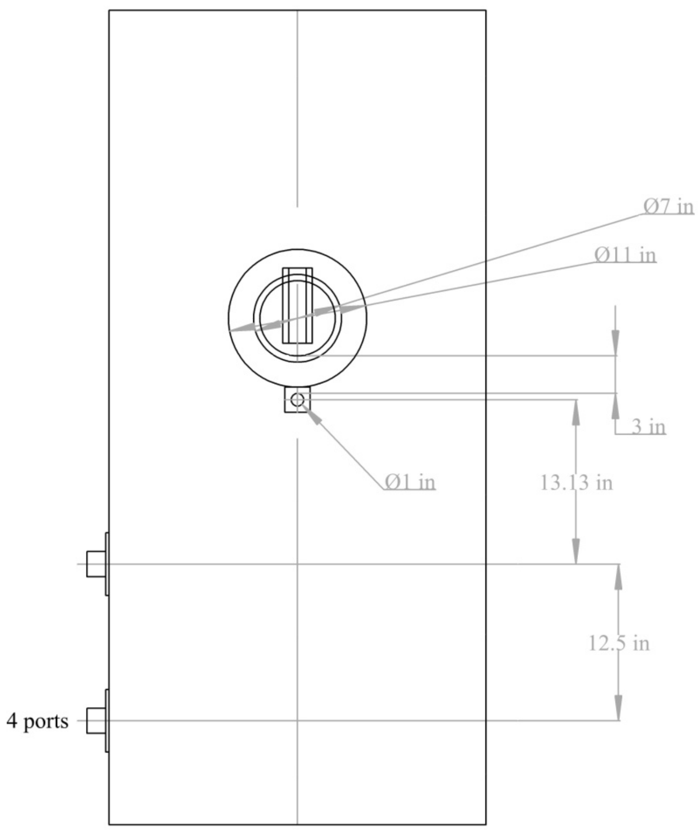


Figure 9 Two ports on the West side of the HFEF stack.

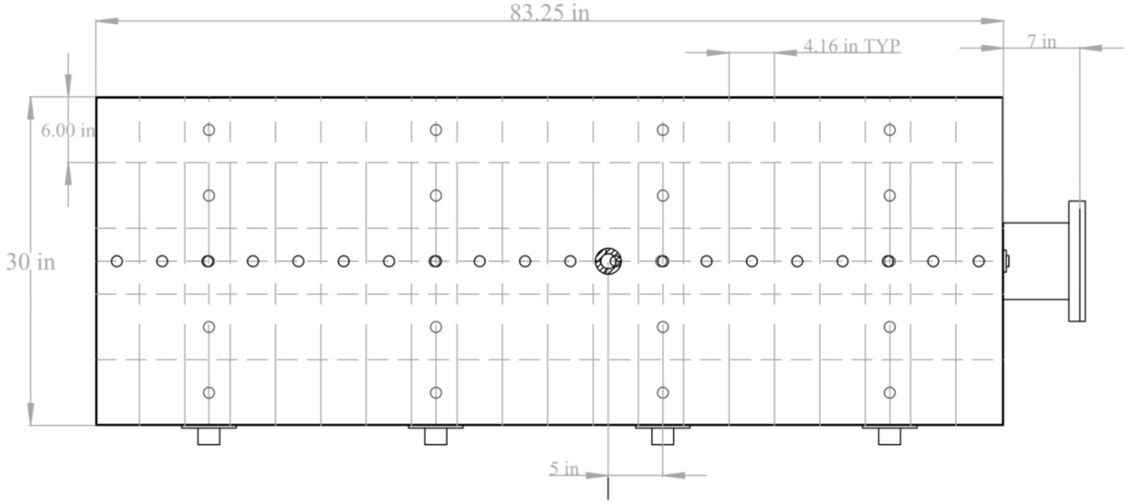


Figure 10 Preliminary sampling grid through the four ports on the North side of the HFEF stack and through the West side port.

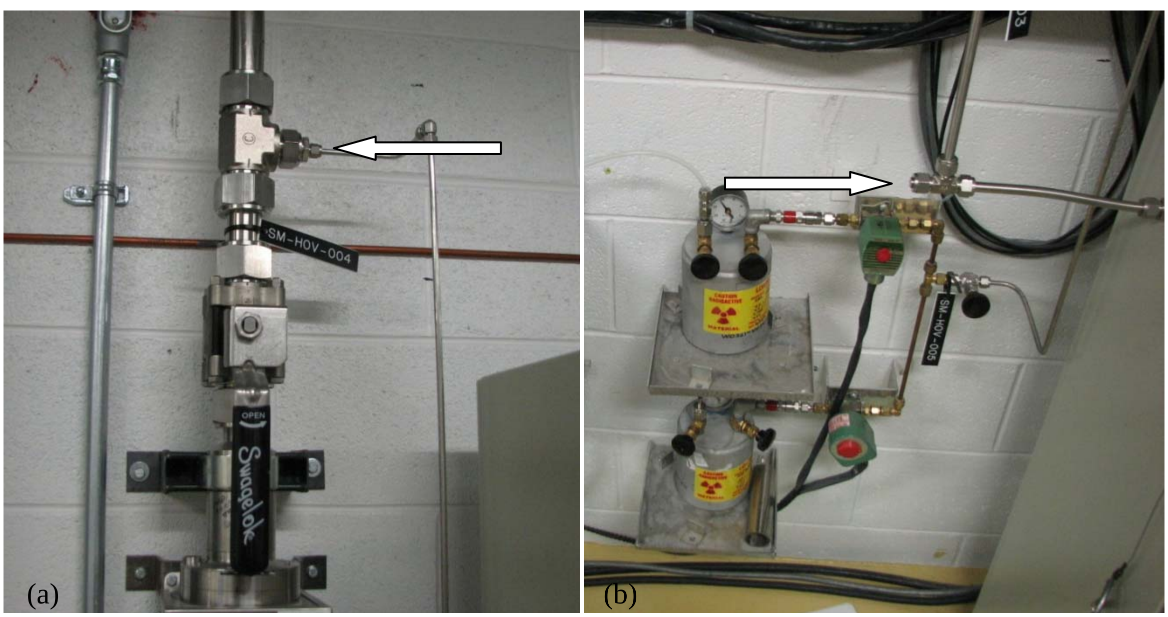


Figure 11 Sampling system tracer measurement locations in hall outside Room 209.

A uniform contaminant concentration at the sampling plane enables the extraction of a sample that represents the mean concentration of the stack effluent. Sulfur hexafluoride is used as a tracer gas injected into the air downstream of the fan. The tracer concentration is then measured at the sampling location using a photoacoustic gas analyzer.[3] For the SF_6 gradient measurements, the tracer concentration is measured three times at each grid point, and each measurement is recorded. The measurements at each grid point are averaged and are used to calculate the mean and standard deviation of concentration for the

[3] Photoacoustic Gas Monitor Model 1302, Innova AirTech Instruments A/S, Energivej 30, 2750 Ballerup, Denmark, Tel. +45 44 20 01 01, www.innova.dk.

sampling location. Previous testing indicated that there is a strong gradient across the East-West width of the stack. Therefore, the tests to measure the SF_6 gradient will document the gradient that exists in the stack as a reference for the facility to use in computing the difference between the concentration measured by the stack sampling system and the stack mean concentration.

For the sampling system bias measurements, the SF_6 concentration will be measured concurrently at a single point in the stack and from a single point along the sampling system line. Each measurement will be made about 10 times to establish a statistically sound mean concentration for comparison between the two locations. The sampling system bias measurements will document whether there is a difference between the concentration measured by the stack sampling system and the concentration in the stack at the sampling system probe location. The 6-inch flanged pipe may be equipped with a Plexiglas cover for visual inspection of the sampling system probe. A video camera may also be utilized to evaluate the shrouded probe condition as necessary.

The SF_6 analyzer response is checked with calibration standards before conducting the test series to verify that the instrument responds adequately to changes in concentration. Typically, the tests use a single instrument, and systematic bias in the instrument response has no effect on the uniformity measurements. Under these testing conditions, if the indicated concentration is within 20% of the standard, the response is acceptable. For the sampling system bias tests, two instruments will be utilized concurrently. As a result, it will be important to also recognize any systematic instrument biases between the two instruments when reporting the differences between the two sampling locations.

PNNL procedure EMS-JAG-01, *Test to Determine Uniformity of a Tracer Gas at a Sampler Probe*, is used for this test. Each gradient test run will take about 90 minutes, while the bias test will take about 30 minutes. A test instruction will be issued specifically for each of these tests. Table 3 lists the planned tests to accomplish the goals of this work. Field observations may inform the execution of these tests.

Table 3. Planned Test Runs

Test Prefix	Test Objective	Test Port	Nr. Measurement Points
GT-	Planar mean concentration	4 North Ports	20
GT-	E-W concentration gradient	1 West Port	15
BT-	Sample System Bias	1” West Port and Sample System Line (2^{nd} Floor)	2 (1 in the stack, 1 from the line)

4.2. Exhaust System Geometry and Flow

Figure 5 is a plan view diagram of the air exhaust system provided by INL. The airflow is comprised of the filtered process off-gas and the filtered ventilation off-gas. These two streams join at the bottom of the stack. Figure 6 (also provided by INL) is a diagram of the side view of the stack.

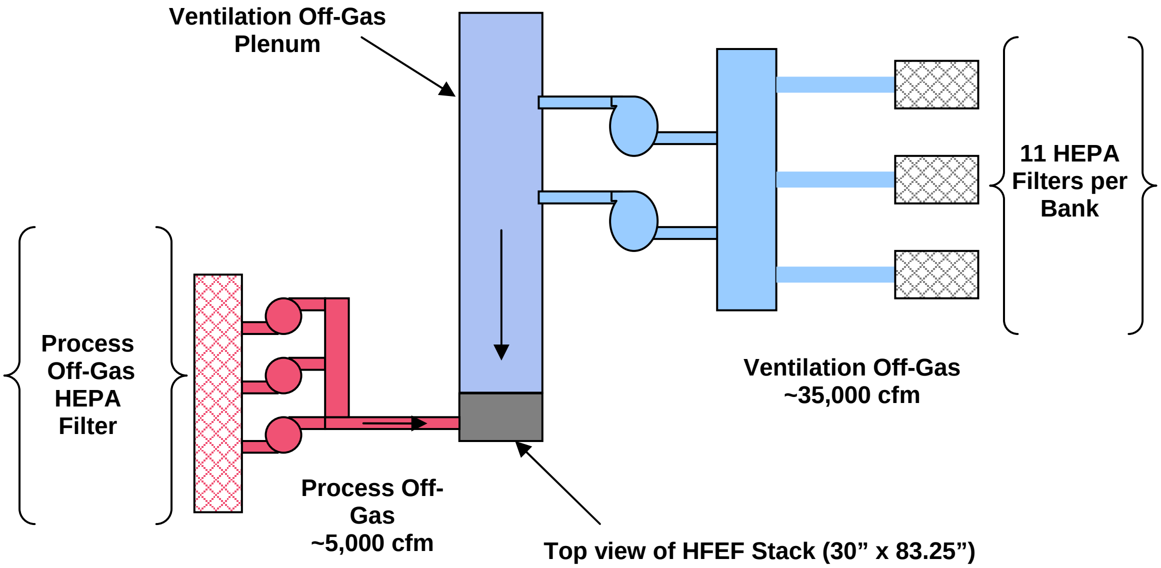


Figure 12 Plan view diagram of the HFEF air exhaust system

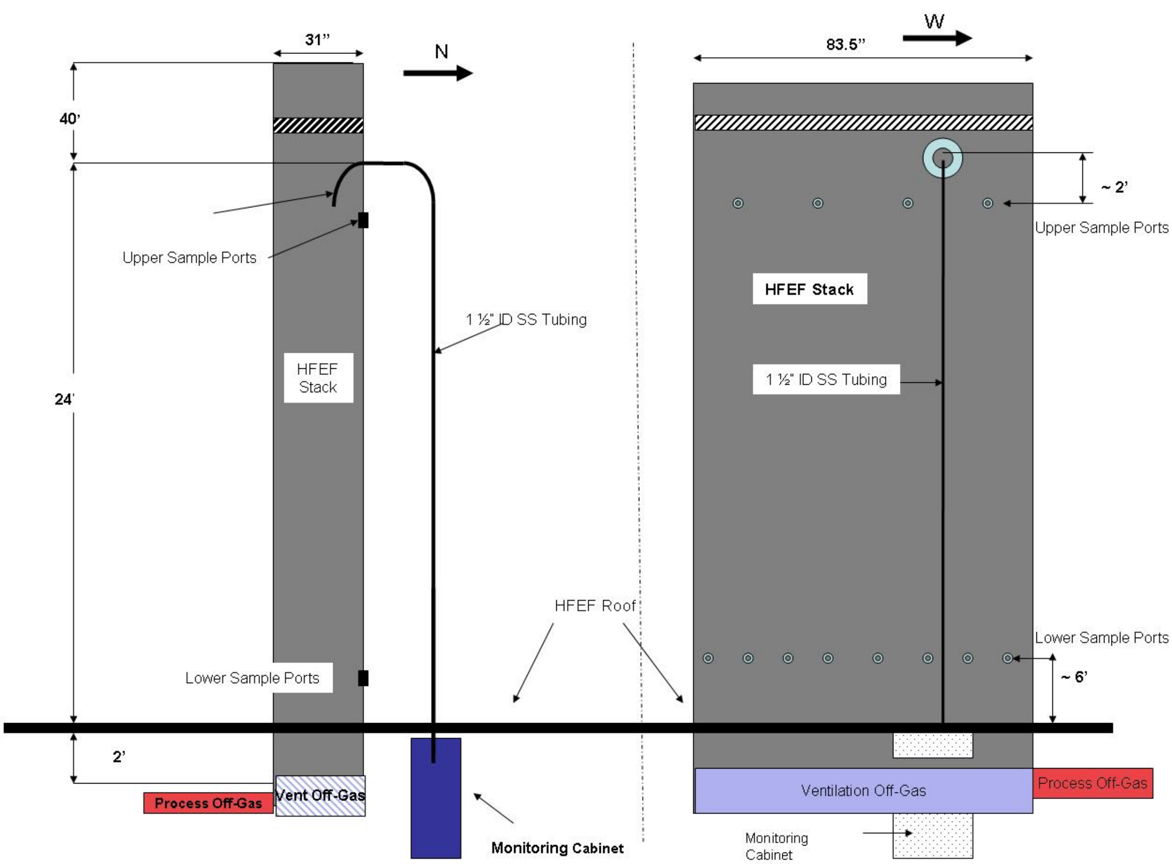


Figure 13 Side view diagram of the HFEF air exhaust system

Table 4 lists the duct dimensions, approximate airflows and average air velocity for the building ventilation (clean) and process (potentially contaminated) streams. At the junction where the ventilation and process streams meet, the process air velocity is about 33% less than the velocity of the ventilation air. The two streams are physically separated as they turn upwards into the base of the stack, and combine as two parallel (rather than orthogonal) flows. Figure 7 shows how the ducts for the two streams meet at the base of the HFEF stack. The large difference in air velocities, in conjunction with the geometry of the flow junction, results in poor mixing of the two air streams as observed in the July stack tests (Glissmeyer and Flaherty, 2010).

Table 4 Duct dimensions and flow parameters

Duct	Width in.	Depth in.	Area sq. in.	Area sq. ft.	Flow cfm	Mean Velocity fpm
Ventilation	76	30	2280	15.83	35000	2211
Process	30	18	486	3.38	5000	1481

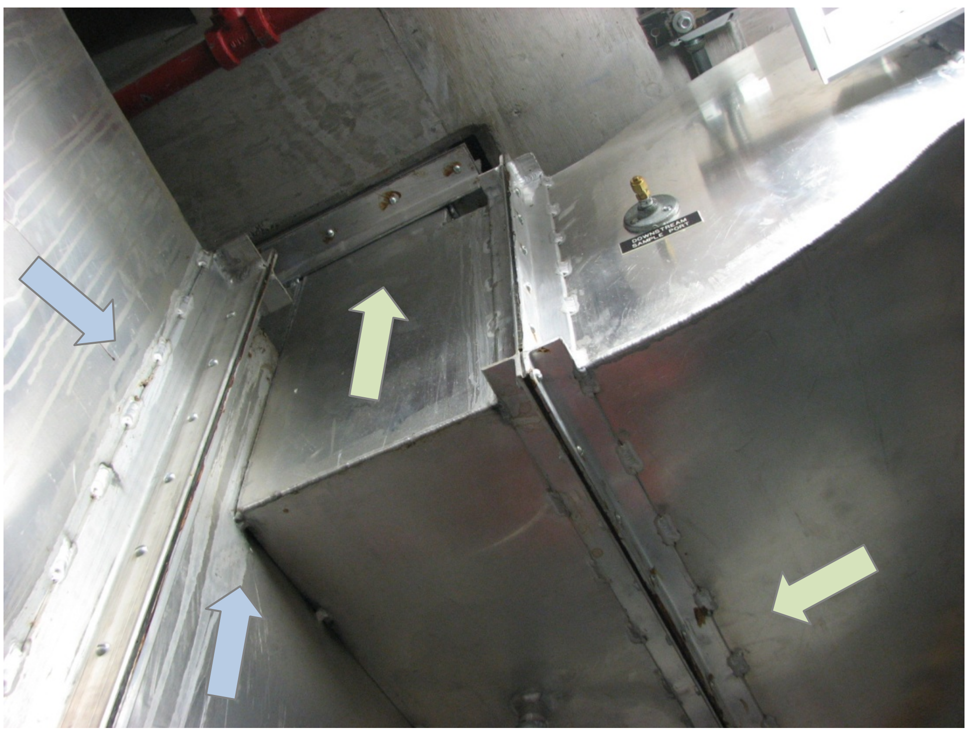


Figure 14 The ventilation and process flows meet at the bases of the HFEF stack in Room 209. The blue arrows represent the flow direction of the ventilation stream, while the green arrows represent the process stream. The process stream duct is separated from the ventilation stream by the duct wall (seen as the seam between the upward-pointing green arrow and the duct stiffener to its left).

Table 5 lists key air flow parameters for the exhaust stack. The flow conditions are typically constant, with a brief (<5minute) drop in flow rate during planned monthly tests of auxiliary power. There should be no fan changes or maintenance during the conduct of these tests. Figure 8 shows a portion of the stack with the sampling platform (for measurements from the four North ports) as well as the two West ports.

Table 5 HFEF Flow Characteristics

Characteristic	HFEF Stack
Stack Cross-sectional Length x Width	30 x 83.25 in
Effective Diameter 2(L*W)/(L+W)	3.78 ft
Reynolds Number	>1.0 E+6
Shrouded Probe distance to nearest upstream disturbance	6.9 duct dia.
Shrouded Probe distance to nearest downstream disturbance	10.6 duct dia.

Figure 15 The HFEF stack

4.3. Measuring and Testing Equipment

The equipment needed to perform the testing is listed in Table 6.

Table 6 Summary of Measurement and Test Equipment (M&TE)

M&TE	Application	Range	Tolerance
Electronic air velocity meter and thermometer	Single point measurement	0–8000 ft/min	Greater of ±3% of reading or 3 ft/min
		32–140 °F	±2°F
SF_6 Tracer gas analyzer	Gas tracer uniformity	See below	See below
SF_6 calibration standards	Gas tracer uniformity	0.1 ppm	±20%
		5 ppm	±10%
Tape measure, caliper and ruler	Stack dimensions, tracer injection position	N.A.	± 0.125 in.
Portable weather station	Environmental conditions (barometric pressure, temperature and humidity)	23.45–31.01 in Hg 800–1050 mbar	± 0.1477 in. Hg ± 5 mbar
		0–55˚C 32–131˚F	± 1.8˚F/ ± 1˚C

5.0 Data Records and Reporting

The data from each test run will be recorded in a data sheet. The data reduction will be performed by PNNL using Microsoft Excel with a worksheet for each data sheet. The data transfers into the worksheet will be independently verified. The worksheet will be independently verified to ensure that it correctly performs its calculations in accordance with the QA procedures described in Section 6. Each completed and quality-assured worksheet will be included in the final letter report and data package. The hand-recorded work sheets become part of the Test Instruction record.

Equipment operational data may be collected electronically or by hand to monitor or evaluate the test equipment. These operational data are not quality-affecting data and may not be included in the data package. A letter report and data package will be prepared and provided at the conclusion of the current project.

6.0 Application of Quality Assurance Requirements

The Pacific Northwest National Laboratory QA program is based upon the requirements as defined in the U.S. Department of Energy (DOE) Order 414.1C, *Quality Assurance* and 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:

- ASME NQA-1-2000, *Quality Assurance Requirements for Nuclear Facility Applications*, Part 1, *Requirements for Quality Assurance Programs for Nuclear Facilities*.
- ASME NQA-1-2000, Part II, Subpart 2.7, *Quality Assurance Requirements for Computer Software for Nuclear Facility Applications.*
- ASME NQA-1-2000, Part IV, Subpart 4.2, *Graded Approach Application of Quality Assurance Requirements for Research and Development.*

The QA plan for the STMON implements the requirements of ASME NQA-1-2000, Part 1: "Requirements for Quality Assurance Programs for Nuclear Facilities," which is 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 they apply to.

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 as the data will be used for applying 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.

Records can be stored as hardcopy records in a 1-hour fire-rated container. A copy of the hardcopy record can be stored in two separate locations (dual storage) or as a scanned electronic copy in the PNNL electronic records management system (Training Requirements and Information Management System—TRIM) (the original can be destroyed after the electronic copy has been verified). Electronic files of testing data will be retained until report publication. At that time, data files can be requested by the client before they are removed from storage.

6.1. Conduct of Experimental and Analytical Work

Experiments that are not method-specific are performed in accordance with QA-STMON-1103 “Scientific Investigations—Development Work” and QA-STMON-1201 “Calibration and Control of M&TE.” Properly calibrated measuring and test equipment is used to acquire sufficient data to produce quality results. Testing will be performed to the requirements of ANSI/HPS N13.1-1999, *Sampling and Monitoring Releases of Airborne Radioactive Substances from the Stack and Ducts of Nuclear Facilities.*

6.2. Internal Data Verification and Validation

The Stack Monitoring Project addresses internal verification and validation activities by conducting an independent technical review of the final data report in accordance with the project’s procedure QA-STMON-1702, “Data Entry and Data Review.” This review verifies that the reported results are traceable, that inferences and conclusions are soundly based, and the reported work satisfies the Test Plan objectives. This review procedure is part of the STMON *Quality Assurance Manual*.

7.0 Deviation from Statement of Work

There are no current deviations from the Statement of Work.

8.0 References

1. 40 CFR 60, Appendix A, Method 1, Section 2.4, “Sample and Velocity Traverses for Stationary Sources.”

2. ANSI/HPS N13.1-1999, *Sampling and Monitoring Releases of Airborne Radioactive Substances from the Stack and Ducts of Nuclear Facilities*. Health Physics Society, McLean, VA 22101.

3. Glissmeyer, J.A., 2009. EMS-JAG-01, *Test to Determine Uniformity of a Tracer Gas at a Sampler Probe.*

4. Glissmeyer, J.A., and J.E. Flaherty, 2010. Assessment of the Idaho National Laboratory Hot Fuel Examination Facility Stack Monitoring Site for Compliance with ANSI/HPS N13.1 1999. PNNL-19659, RPT-STMON-007, Pacific Northwest National Laboratory, Richland, WA 99352.

5. Idaho National Laboratory. 2011. Statement of Work: Tracer Gradient and Sampling System Bias of the HFEF Stack Air Monitoring System. Pacific Northwest National Laboratory. SOW 8469, Rev 1.

APPENDIX 2: Data Sheets

TRACER GAS GRADIENT DATA FORM

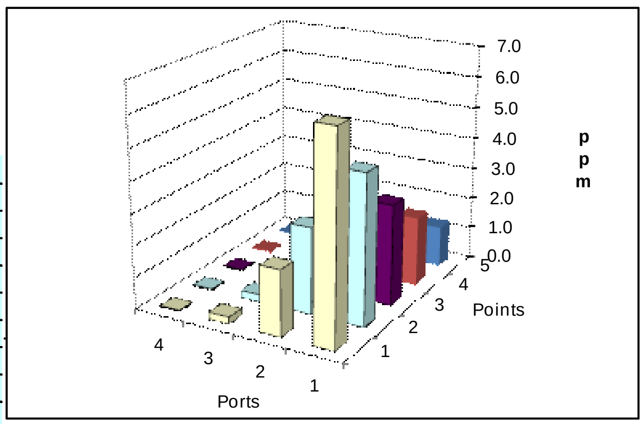
Site	INL HFEF	Run No.	GT-1
Date	4/12/2011	Start/End Time	1615 / 1750
Testers	JAG, JEF	Fan Configuration	Both Fans
Duct Width	83.175 in.	Stack Temp	78 deg F
Duct Depth	30.2 in.	Injection Point	Pipe Nipple
Stack X-Area	17.4 ft2	Measurement Loc.	North Ports

		Trial---->	1	2	3	Mean
Port	Point	Depth, in.	ppm SF6			
1	1	3.02	6.57	6.68	6.37	6.54
1	2	9.06	4.77	4.62	4.78	4.72
1	3	15.09	3.05	3.11	3.40	3.19
1	4	21.13	1.74	2.28	2.55	2.19
1	5	27.17	1.10	1.44	1.33	1.29
2	1	3.02	2.00	2.10	2.16	2.09
2	2	9.06	2.64	2.76	2.82	2.74
2	3	15.09	2.26	2.65	2.37	2.43
2	4	21.13	2.01	2.20	1.86	2.02
2	5	27.17	1.44	1.59	1.76	1.60
3	1	3.02	0.287	0.169	0.211	0.222
3	2	9.06	0.352	0.175	0.183	0.237
3	3	15.09	0.184	0.181	0.166	0.177
3	4	21.13	0.129	0.132	0.217	0.159
3	5	27.17	0.151	0.135	0.109	0.132
4	1	3.02	0.0181	0.0311	0.0287	0.026
4	2	9.06	0.0394	0.0246	0.0316	0.032
4	3	15.09	0.0277	0.0451	0.0164	0.030
4	4	21.13	0.0356	0.0324	0.0325	0.034
4	5	27.17	0.0415	0.0316	0.0254	0.033
	Averages ---------->		1.442	1.519	1.521	1.494

	Start	Finish	
Stack Flow (Control Rm)	63%	63%	% of 51,900
Stack Flow (KURZ)	32,406	32,426	cfm
Tracer tank pressure	250	300	psig
Injection flowmeter	3.75	3.75	lpm as CO2
Stack Temp	78	78	ºF
Center Pt. air vel.	1400	1470.0	fpm
Sampling flowmeter	10	10	lpm
Ambient pressure	834.00	834.00	mbar
Ambient humidity	32	32	RH
Ambient Temp	51	53	ºF
B&K vapor correction	Y	Y	Y/N
Back-Gd gas	26,2,22,17	40,61,59,21	ppb
No. Bk-Gd samples	4	4	n

	ppm	Deviation from mean		
Mean	1.49			
Min Point	0.03	-98.3%	Std. Dev.	1.80
Max Point	6.54	337.7%	COV as %	120.5

Instruments Used:	Cal Due / Check
B&K 1302 Gas Analyzer SN 1804888	4/12/2011
TSI VelociCalc SN 209060	6/25/2011
Omega FMA-2606A flowmeter SN 27708	N/A
Fisher Weather Station SN 61876141	5/17/2011



Notes: 32,300 - 32,600 cfm on CMS2000/KURZ.
Can't reach point 5 due to cross-beam.
32,406 on CMS2000/KURZ during Port 2 measurements at 16:57.
32,426 on CMS2000/KURZ at the end of the test.

Background measurements at Port 1, Point 1.
Stack air velocity & temperature at Port 2 near center. Avg 5 readings.

Hi-Q #1 pump.

Entries made by:	Julia Flaherty	4/12/2011	Technical Data Review performed by:		Carmina Arimescu
Signature/date	*On File with Original*		Signature/date	*Via Email*	5/9/2011

TRACER GAS GRADIENT DATA FORM

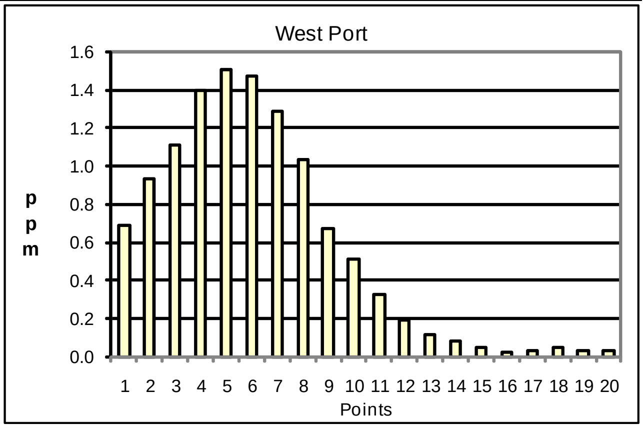
Site	**INL HFEF**	Run No.	**GT-2**
Date	4/13/2011	Start/End Time	**10:00 / 11:31**
Testers	JAG, JEF	Fan Configuration	**Both Fans**
Duct Width	83.175 in.	Stack Temp	77.5 deg F
Duct Depth	30.2 in.	Injection Point	Pipe Nipple
Stack X-Area	17.4 ft2	Measurement Loc.	**West Port**

Port	Point	Depth, in.	Trial----> 1	2	3	Mean
			ppm SF6			
W	1	2.08	0.659	0.564	0.841	0.69
W	2	6.24	0.916	0.890	0.994	0.93
W	3	10.40	1.09	0.928	1.31	1.11
W	4	14.56	1.28	1.40	1.51	1.40
W	5	18.71	1.48	1.48	1.56	1.51
W	6	22.87	1.32	1.54	1.55	1.47
W	7	27.03	1.23	1.26	1.37	1.29
W	8	31.19	1.04	0.956	1.12	1.04
W	9	35.35	0.604	0.592	0.815	0.67
W	10	39.51	0.480	0.491	0.558	0.51
W	11	43.67	0.309	0.293	0.375	0.326
W	12	47.83	0.230	0.196	0.151	0.192
W	13	51.98	0.0941	0.166	0.102	0.121
W	14	56.14	0.0831	0.0832	0.0699	0.079
W	15	60.30	0.0336	0.0457	0.0581	0.046
W	16	64.46	0.0289	0.0208	0.0339	0.028
W	17	68.62	0.0218	0.0372	0.0270	0.029
W	18	72.78	0.0348	0.0777	0.0375	0.050
W	19	76.94	0.0233	0.0439	0.0293	0.032
W	20	81.10	0.0315	0.0352	0.0428	0.037
	Averages ---------->		0.549	0.555	0.628	0.577

	Start	Finish	
Stack Flow (Control Rm)	N/A	N/A	% of 51,900
Stack Flow (KURZ)	32,370	32,209	cfm
Tracer tank pressure	250	300	psig
Injection flowmeter	3.75	3.75	lpm as CO2
Stack Temp	77	78	ºF
Center Pt. air vel.	1440	1490.0	fpm
Sampling flowmeter	10	10	lpm as CO2
Ambient pressure	832.00	831.00	mbar
Ambient humidity	51	38	RH
Ambient Temp	44	53	ºF
B&K vapor correction	Y	Y	Y/N
Back-Gd gas	41, 27, 22, 48	21, 43, 29, 38	ppb
No. Bk-Gd samples	4	4	n

	ppm	Deviation from mean		
Mean	0.58			
Min Point	0.03	-95.2%	Std. Dev.	0.56
Max Point	1.51	160.9%	COV as %	96.6

Instruments Used:	Cal Due / Check
B&K 1302 Gas Analyzer SN 1804888	4/12/2011
TSI VelociCalc SN 209060	6/25/2011
Omega FMA-2606A flowmeter SN 27708	N/A
Fisher Weather Station SN 61876141	5/17/2011



Notes: Hi-Q #1 Pump
~11" between Port 1 centerline and West edge of stack.
So, West Port, Point 3 should match North Port 1, Point 3.
Shrouded probe expected to be near Point 8 on this grid;
actual location is near Point 11.

Entries made by:	Julia Flaherty	4/13/2011	Technical Data Review performed by:	Carmina Arimescu	
Signature/date	*On File with Original*		Signature/date	*Via Email*	5/9/2011

TRACER GAS GRADIENT DATA FORM

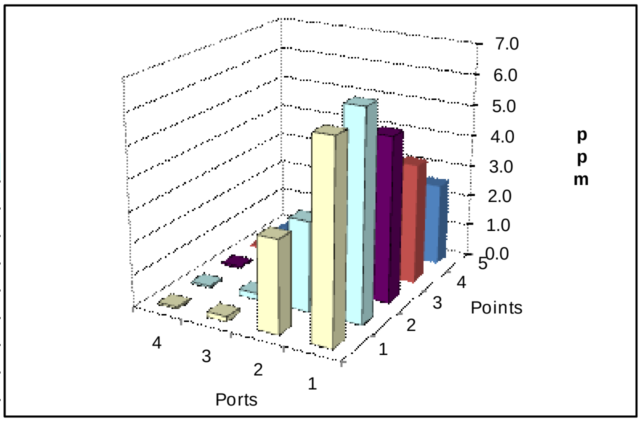
Site	**INL HFEF**	Run No.	**GT-3N**
Date	4/14/2011	Start/End Time	**15:00 / 16:35**
Testers	JEF	Fan Configuration	**Both Fans**
Duct Width	83.175 in.	Stack Temp	78 deg F
Duct Depth	30.2 in.	Injection Point	Pipe Nipple
Stack X-Area	17.4 ft2	Measurement Loc.	**North Ports**

Port	Point	Depth, in.	Trial 1 (ppm SF6)	Trial 2 (ppm SF6)	Trial 3 (ppm SF6)	Mean
1	1	3.02	7.22	5.60	5.81	6.21
1	2	9.06	6.86	6.31	6.48	6.55
1	3	15.09	5.68	5.52	4.44	5.21
1	4	21.13	3.85	4.25	3.30	3.80
1	5	27.17	2.22	3.25	2.34	2.60
2	1	3.02	3.59	2.73	2.48	2.93
2	2	9.06	2.61	3.14	2.84	2.86
2	3	15.09	2.45	3.17	2.48	2.70
2	4	21.13	2.32	2.65	2.38	2.45
2	5	27.17	2.00	2.07	2.07	2.05
3	1	3.02	0.108	0.223	0.169	0.167
3	2	9.06	0.204	0.249	0.150	0.201
3	3	15.09	0.230	0.264	0.198	0.231
3	4	21.13	0.203	0.270	0.212	0.228
3	5	27.17	0.185	0.228	0.200	0.204
4	1	3.02	0.0612	0.0672	0.0829	0.070
4	2	9.06	0.0547	0.0700	0.0661	0.064
4	3	15.09	0.0465	0.0635	0.0686	0.060
4	4	21.13	0.0539	0.0688	0.0598	0.061
4	5	27.17	0.0640	0.0731	-	0.069
	Averages --------->		2.001	2.013	1.886	1.936

	Start	Finish	
Stack Flow (Control Rm)	N/A	N/A	% of 51,900
Stack Flow (KURZ)	~32000	32281	cfm
Tracer tank pressure	300	300	psig
Injection flowmeter	3.75	3.75	lpm as CO2
Stack Temp	78	77	ºF
Center Pt. air vel.	1640	1490	fpm
Sampling flowmeter	10	10	lpm
Ambient pressure	837	838	mbar
Ambient humidity	30	29	RH
Ambient Temp	47	45	ºF
B&K vapor correction	Y	Y	Y/N
Back-Gd gas	15, 39, 13, 20	37, 27, 30, 37	ppb
No. Bk-Gd samples	4	4	n

	ppm	Deviation from mean		
Mean	1.94			
Min Point	0.06	-96.9%	Std. Dev.	2.17
Max Point	6.55	238.3%	COV as %	112.0

Instruments Used:	Cal Due / Check
B&K 1302 Gas Analyzer SN 1804888	4/12/2011
TSI VelociCalc SN 209060	6/25/2011
Omega FMA-2606A flowmeter SN 27708	N/A
Fisher Weather Station SN 61876141	5/17/2011



Notes: Hi-Q # 2

Measurements made concurently with a probe under the shrouded probe and at the north ports. At start of test, Port 2, Point 3 was 3.11 vs 3.37 ppm at shroud.

Entries made by:	Julia Flaherty	4/14/2011	Technical Data Review performed by:	Carmina Arimescu	
Signature/date	*On File w/ Original*		Signature/date	*Via Email*	5/9/2011

TRACER GAS GRADIENT DATA FORM

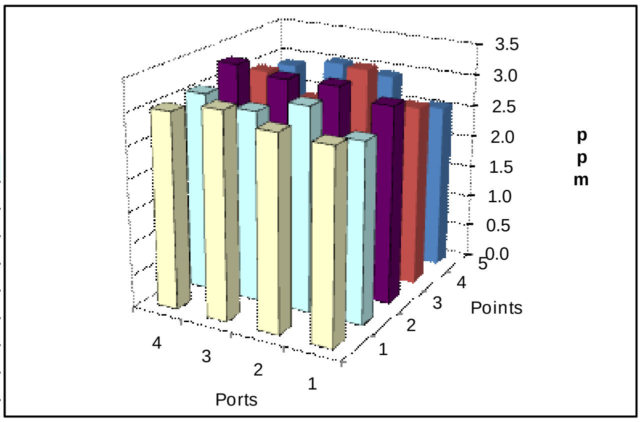
Site	**INL HFEF**	Run No.	**GT-3W**
Date	4/14/2011	Start/End Time	**15:00 / 16:35**
Testers	JEF	Fan Configuration	**Both Fans**
Duct Width	83.175 in.	Stack Temp	78 deg F
Duct Depth	30.2 in.	Injection Point	Pipe Nipple
Stack X-Area	17.4 ft2	Measurement Loc.	**West Port - UNDER SHROUDED PROBE**

Simultaneous North Port Trial and Points---->			1	2	3	Mean
Port	North Point	W Depth, in.	ppm SF6			
W	Port 1, 1	35.43	3.16	2.57	3.18	2.97
W	Port 1, 2	35.43	2.62	3.14	2.60	2.79
W	Port 1, 3	35.43	3.33	3.20	2.65	3.06
W	Port 1,4	35.43	3.00	3.11	2.29	2.80
W	Port 1, 5	35.43	2.21	2.73	2.78	2.57
W	Port 2, 1	35.43	3.59	2.65	2.81	3.02
W	Port 2, 2	35.43	3.06	2.93	3.48	3.16
W	Port 2, 3	35.43	3.64	2.79	3.25	3.23
W	Port 2, 4	35.43	3.50	3.41	2.89	3.27
W	Port 2, 5	35.43	3.19	3.53	2.14	2.95
W	Port 3, 1	35.43	3.52	3.28	2.79	3.20
W	Port 3, 2	35.43	2.94	2.47	3.44	2.95
W	Port 3, 3	35.43	2.97	2.59	4.08	3.21
W	Port 3, 4	35.43	2.55	2.59	2.88	2.67
W	Port 3, 5	35.43	2.59	2.76	3.79	3.05
W	Port 4, 1	35.43	3.30	3.21	2.62	3.04
W	Port 4, 2	35.43	2.85	3.44	2.96	3.08
W	Port 4, 3	35.43	3.63	3.44	2.91	3.33
W	Port 4, 4	35.43	2.74	3.06	3.23	3.01
W	Port 4, 5	35.43	2.94	2.87	2.90	2.90
	Averages ---------->		3.07	2.99	2.98	3.01

	Start	Finish	
Stack Flow (Control Rm)	N/A	N/A	% of 51,900
Stack Flow (KURZ)	~32000	32281	cfm
Tracer tank pressure	300	300	psig
Injection flowmeter	3.75	3.75	lpm as CO2
Stack Temp	78	77	ºF
Center Pt. air vel.	1640	1490	fpm
Sampling flowmeter	10	10	lpm
Ambient pressure	837	838	mbar
Ambient humidity	30	29	RH
Ambient Temp	47	45	ºF
B&K vapor correction	Y	Y	Y/N
Back-Gd gas	9, -.9, -.9, 7	38, 32, 31, 24	ppb
No. Bk-Gd samples	4	4	n

	ppm	Deviation from mean		
Mean	3.01			
Min Point	2.57	-14.6%	Std. Dev.	0.20
Max Point	3.33	10.4%	COV as %	6.5

Instruments Used:	Cal Due / Check
B&K 1302 Gas Analyzer SN 1765299	4/12/2011
TSI VelociCalc SN 209060	6/25/2011
Omega FMA-2606A flowmeter SN 27708	N/A
Fisher Weather Station SN 61876141	5/17/2011



Notes: Hi-Q # 1

Measurements made concurently with a probe under the shrouded probe and at the north ports. At start of test, Port 2, Point 3 was 3.11 vs 3.37 ppm at shroud.

Entries made by:	Julia Flaherty	4/14/2011	Technical Data Review performed by:		Carmina Arimescu
Signature/date	*On File w/ Original*		Signature/date	*Via Email*	5/9/2011

SAMPLING SYSTEM GAS BIAS DATA FORM

Site	**INL HFEF**	Run No.	**BT-1**
Date	4/13/2011	Start/End Time	13:53 / 14:40
Testers	JAG, JEF	Fan Configuration	**Both Fans**
Duct Width	83.175 in.	Stack Temp	78 deg F
Duct Depth	30.2 in.	Injection Point	Pipe Nipple
Stack X-Area	17.4 ft2	Measurement Loc.	2 inches S of Shrouded Probe

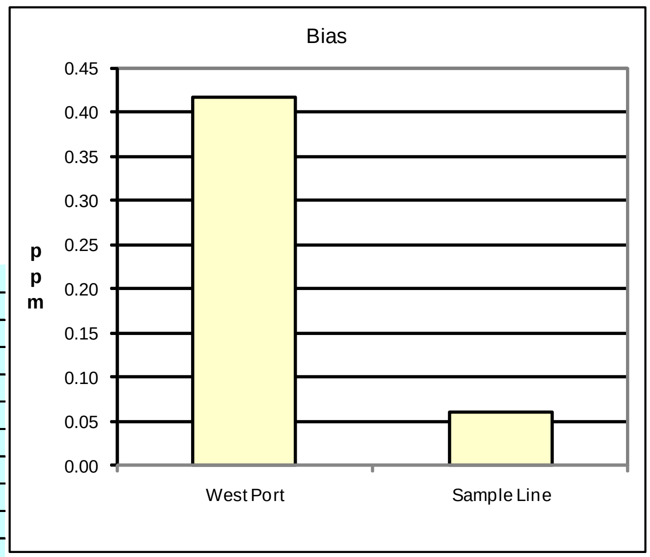
General Info	Start	Finish	
Stack Flow (Control Rm)	N/A	N/A	% of 51,900
Stack Flow (KURZ)	32,212	31,800	cfm
Tracer tank pressure	300	300	psig
Injection flowmeter	3.75	3.75	lpm as CO2
Stack Temp	78	78	ºF
Center Pt. air vel.	1410	1450	fpm

West Port	Start	Finish	
Sampling flowmeter	10	10	lpm
Ambient pressure	828	828	mbar
Ambient humidity	26	36	RH
Ambient Temp	59	60	ºF
B&K vapor correction	Y	Y	Y/N
Back-Gd gas	16, 18, 8, 18	13, 16, 20, 19	ppb
No. Bk-Gd samples	4	4	n

Sample Line	Start	Finish	
cabinet flow rate	1.04	1.04	
Sampling flowmeter	10	10	lpm
Ambient pressure	840	840	mbar
Ambient humidity	28	27	RH
Ambient Temp	74	75	ºF
B&K vapor correction	Y	Y	Y/N
Back-Gd gas	34, 23, 21, 21	3.2, 1.8, -1.8, -1.8	ppb
No. Bk-Gd samples	4	4	n

Trial	West Port	Sample Line
	ppm SF6	
1	0.430	0.0604
2	0.380	0.0538
3	0.313	0.0564
4	0.445	0.0536
5	0.354	0.0797
6	0.423	0.0633
7	0.429	0.0640
8	0.427	0.0590
9	0.483	0.0590
10	0.487	0.0632
MEAN	0.417	0.061
W/S RATIO:	6.81	

Instruments Used:	**Cal Due / Check**
West Port B&K 1302 Gas Analyzer SN 1804888	4/12/2011
Sample Line B&K 1302 Gas Analyzer SN 1765299	4/12/2011
TSI VelociCalc SN 209060	6/25/2011
Omega FMA-2606A flowmeter SN 27708	N/A
West Port Fisher Weather Station SN 61876141	5/17/2011
Sample Line Fisher Weather Station SN 90936818	10/20/2011



Notes: Shrouded probe is not plumb.
Second floor sampling accomplished with 1/4" tubing connected to the big tee upstream of the CMS2000 box.

Entries made by:	Julia Flaherty	4/13/2011	Technical Data Review performed by:	Carmina Arimescu	
Signature/date	*On File w/ Original*		Signature/date	*Via Email*	5/17/2011

SAMPLING SYSTEM GAS BIAS DATA FORM

Site	**INL HFEF**	Run No.	**BT-2a**
Date	4/14/2011	Start/End Time	10:27 / 11:28
Testers	JAG, JEF	Fan Configuration	**Both Fans**
Duct Width	83.175 in.	Stack Temp	77.5 deg F
Duct Depth	30.2 in.	Injection Point	Pipe Nipple
Stack X-Area	17.4 ft2	Measurement Loc.	2 inches S of Shrouded Probe

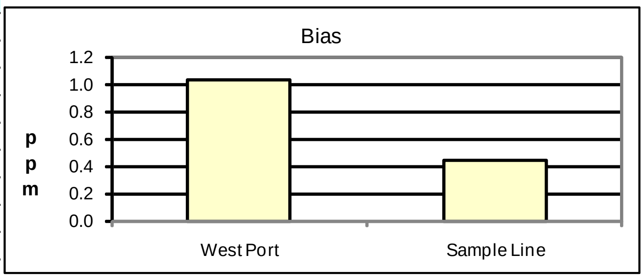
General Info	Start	Finish	
Stack Flow (Control Rm)	N/A	N/A	% of 51,900
Stack Flow (KURZ)	32,235	24,900	cfm
Tracer tank pressure	300	300	psig
Injection flowmeter	3.75	3.75	lpm as CO2
Stack Temp	78	77	ºF
Center Pt. air vel.	1430	1090	fpm

West Port	Start	Finish	
Sampling flowmeter	10	10	lpm
Ambient pressure	837	838	mbar
Ambient humidity	36	40	RH
Ambient Temp	43	42	ºF
B&K vapor correction	Y	Y	Y/N
Back-Gd gas	7, 8, 1, 10	63, 71, 52, 39	ppb
No. Bk-Gd samples	4	4	n

Sample Line	Start	Finish	
cabinet flow rate	1.05	0.84	
Sampling flowmeter	10	10	lpm
Ambient pressure	844	844	mbar
Ambient humidity	26	23	RH
Ambient Temp	75	77	ºF
B&K vapor correction	Y	Y	Y/N
Back-Gd gas	15, 17, 16, 18, 14	26, 31, 26, 28	ppb
No. Bk-Gd samples	5	4	n

	West Port	Sample Line
Trial	ppm SF6	
1	0.895	0.431
2	0.895	0.441
3	1.10	0.436
4	0.906	0.381
5	0.834	0.428
6	0.900	0.423
7	1.07	0.457
8	1.16	0.461
9	0.938	0.475
10	1.15	0.448
11	1.03	0.434
12	1.24	0.408
13	1.04	0.385
14	0.943	0.449
15	1.14	0.437
16	1.17	0.447
17	0.979	0.493
18	1.09	0.464
19	0.948	0.450
20	1.18	0.432
MEAN	1.03	0.44
W/S RATIO:	2.35	

Instruments Used:	**Cal Due / Check**
West Port B&K 1302 Gas Analyzer SN 1765299	4/12/2011
Sample Line B&K 1302 Gas Analyzer SN 1804888	4/12/2011
TSI VelociCalc SN 209060	6/25/2011
Omega FMA-2606A flowmeter SN 27708	N/A
West Port Fisher Weather Station SN 61876141	5/17/2011
Sample Line Fisher Weather Station SN 90936818	10/20/2011



Notes: Started BT-2 on 4/13/2011, but had to quit due to thunder, lightning, rain and snow. Re-start test on 4/14/2011.
Our sampling probe is at the same E-W position as the shrouded probe, but 1-2 inches south (in the centerline).

Hi-Q #2 was used on second floor, Hi-Q #1 was used on stack.

Observed positive pressure from the big tee.

Prior to run, shrouded probe repositioned to plumb.

Entries made by:	Julia Flaherty	4/14/2011
Signature/date	*On File w/ Original*	
Technical Data Review performed by:	Carmina Arimescu	
Signature/date	*Via Email*	5/17/2011

SAMPLING SYSTEM GAS BIAS DATA FORM

Site	**INL HFEF**	Run No.	**BT-2b**
Date	4/14/2011	Start/End Time	10:27 / 11:28
Testers	JAG, JEF	Fan Configuration	**Both Fans**
Duct Width	83.175 in.	Stack Temp	77.5 deg F
Duct Depth	30.2 in.	Injection Point	Pipe Nipple
Stack X-Area	17.4 ft2	Measurement Loc.	2 inches S of Shrouded Probe

General Info	Start	Finish	
Stack Flow (Control Rm)	N/A	N/A	% of 51,900
Stack Flow (KURZ)	32,235	24,900	cfm
Tracer tank pressure	300	300	psig
Injection flowmeter	3.75	3.75	lpm as CO2
Stack Temp	78	77	ºF
Center Pt. air vel.	1430	1090	fpm

West Port	Start	Finish	
Sampling flowmeter	10	10	lpm
Ambient pressure	837	838	mbar
Ambient humidity	36	40	RH
Ambient Temp	43	42	ºF
B&K vapor correction	Y	Y	Y/N
Back-Gd gas	7, 8, 1, 10	63, 71, 52, 39	ppb
No. Bk-Gd samples	4	4	n

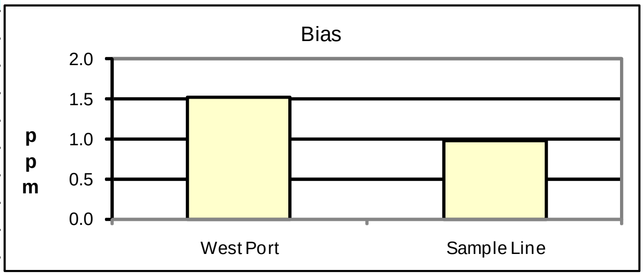
Sample Line	Start	Finish	
cabinet flow rate	1.05	0.84	
Sampling flowmeter	10	10	lpm
Ambient pressure	844	844	mbar
Ambient humidity	26	23	RH
Ambient Temp	75	77	ºF
B&K vapor correction	Y	Y	Y/N
Back-Gd gas	15, 17, 16, 18, 14	26, 32, 26, 28	ppb
No. Bk-Gd samples	5	4	n

Trial	West Port (ppm SF6)	Sample Line (ppm SF6)
1	1.22	1.06
2	1.30	1.03
3	0.996	0.903
4	1.01	0.927
5	1.30	1.13
6	1.20	0.997
7	1.11	0.887
8	1.30	0.937
9	1.13	0.989
10	1.27	0.984
11	1.08	1.06
12	1.67	0.988
13	1.86	0.930
14	1.90	0.962
15	1.87	0.974
16	1.96	0.974
17	1.96	0.921
18	2.17	1.01
19	2.10	1.09
20	2.23	0.974
MEAN	1.53	0.99
W/S RATIO:	1.55	

Instruments Used:	**Cal Due / Check**
West Port B&K 1302 Gas Analyzer SN 1765299	4/12/2011
Sample Line B&K 1302 Gas Analyzer SN 1804888	4/12/2011
TSI VelociCalc SN 209060	6/25/2011
Omega FMA-2606A flowmeter SN 27708	N/A
West Port Fisher Weather Station SN 61876141	5/17/2011
Sample Line Fisher Weather Station SN 90936818	10/20/2011

Notes: Started BT-2 on 4/13/2011, but had to quit due to thunder, lightning, rain and snow. Re-start test on 4/14/2011.
Our sampling probe is at the same E-W position as the shrouded probe, but 1-2 inches south (in the centerline).

BT-2b tested the effect of removing the in-line filter holder.
For the first 10 measurements, the downstairs system had no filter holder. For the second 10 measurements, both systems had no filter holder.
At end of testing, discovered that filter holder on the scaffold did not contain a filter.



Entries made by:	Julia Flaherty	4/14/2011	
Signature/date	*On File w/ Original*		
Technical Data Review performed by:	Carmina Arimescu		
Signature/date	*Via Email*	5/17/2011	

SAMPLING SYSTEM GAS BIAS DATA FORM

Site	INL HFEF		Run No.	BT-3a
Date	4/14/2011		Start/End Time	12:50 / 14:29
Testers	JAG, JEF		Fan Configuration	Both Fans
Duct Width	83.175	in.	Stack Temp	78 deg F
Duct Depth	30.2	in.	Injection Point	Pipe Nipple
Stack X-Area	17.4	ft2	Measurement Loc.	2 inches S of / Under Shrouded Probe

General Info	Start	Finish	
Stack Flow (Control Rm)	N/A	N/A	% of 51,900
Stack Flow (KURZ)	32,516	32,700	cfm
Tracer tank pressure	300	300	psig
Injection flowmeter	3.75	3.75	lpm as CO2
Stack Temp	78	78	ºF
Center Pt. air vel.	1620	1640	fpm

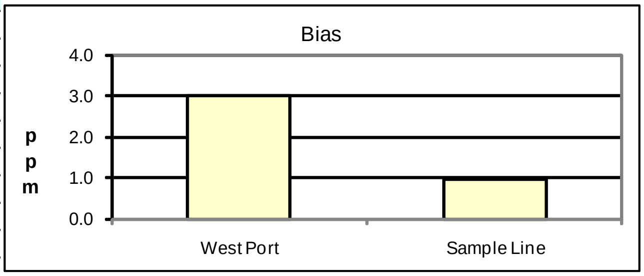
West Port	Start	Finish	
Sampling flowmeter	10	10	lpm
Ambient pressure	838	837	mbar
Ambient humidity	32	30	RH
Ambient Temp	46	47	ºF
B&K vapor correction	Y	Y	Y/N
Back-Gd gas	.3, -10, 19, 6	36, 27, 31, 25	ppb
No. Bk-Gd samples	4	4	n

Sample Line	Start	Finish	
cabinet flow rate	0	1.06	scfm
Sampling flowmeter	10	10	lpm
Ambient pressure	846	847	mbar
Ambient humidity	22	22	RH
Ambient Temp	79	79	ºF
B&K vapor correction	Y	Y	Y/N
Back-Gd gas	16, 12, 13, 17	4, 5, 7, 4	ppb
No. Bk-Gd samples	4	4	n

	West Port	Sample Line
Trial	ppm SF6	
1	2.08	0.955
2	2.06	0.968
3	2.92	0.984
4	2.39	0.979
5	2.86	0.938
6	2.81	0.979
7	3.03	0.993
8	2.34	0.982
9	2.44	0.974
10	3.37	0.947
11	2.91	0.931
12	3.30	0.926
13	3.53	0.920
14	3.46	0.932
15	3.46	0.941
16	3.13	0.940
17	3.53	0.922
18	3.54	0.948
19	3.03	0.934
20	3.73	0.985
MEAN	3.00	0.95
W/S RATIO:	3.14	

Instruments Used:	Cal Due / Check
West Port B&K 1302 Gas Analyzer SN 1765299	4/12/2011
Sample Line B&K 1302 Gas Analyzer SN 1804888	4/12/2011
TSI VelociCalc SN 209060	6/25/2011
Omega FMA-2606A flowmeter SN 27708	N/A
West Port Fisher Weather Station SN 61876141	5/17/2011
Sample Line Fisher Weather Station SN 90936818	10/20/2011

Notes: Our probe is at the same E-W position as the shrouded probe, and is about 1.5 inches south for the first 10 readings.
1650 fpm, 79 deg F in stack after sampling.
~14:13 back up scaffold to fill tedlar bag (sample line has been done). ~8 min to fill.
~50deg F in the shelter box.
At start, sampling cablinet flow is off and ball valve is closed.
For readings 11 - 20, our probe was positioned directly below the shrouded probe nozzle.
Hi-Q #2 used on 2nd floor, Hi-Q #1 used on scaffold.



Entries made by:	Julia Flaherty	4/14/2011	Technical Data Review performed by:		Carmina Arimescu
Signature/date	*On File w/ Original*		Signature/date	*Via Email*	5/17/2011

SAMPLING SYSTEM GAS BIAS DATA FORM

Site	**INL HFEF**		Run No.	**BT-3b**	
Date	4/14/2011		Start/End Time	15:00	
Testers	JAG, JEF		Fan Configuration	**Both Fans**	
Duct Width	83.175	in.	Stack Temp	78	deg F
Duct Depth	30.2	in.	Injection Point	Pipe Nipple	
Stack X-Area	17.4	ft2	Measurement Loc.	Under Shrouded Probe	

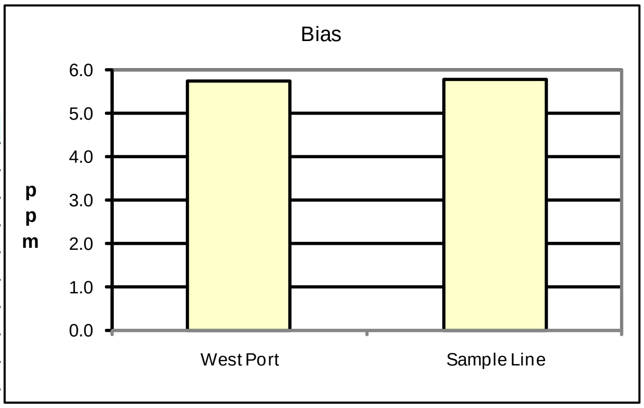
General Info	Start	Finish	
Stack Flow (Control Rm)	N/A	N/A	% of 51,900
Stack Flow (KURZ)	32,516	32,700	cfm
Tracer tank pressure	300	300	psig
Injection flowmeter	3.75	3.75	lpm as CO2
Stack Temp	78	78	ºF
Center Pt. air vel.	1620	1640	fpm

	West Port	Sample Line
Trial	ppm SF6	
1	5.76	5.76
2	5.75	5.78
3	5.75	5.79
4	5.73	5.77
5	5.74	5.77
6	5.75	5.79
7	5.75	5.78
8	5.72	5.78
9	5.70	5.78
10	5.72	5.79
11	5.73	5.71
12	5.71	5.69
13	5.71	5.70
MEAN	5.73	5.76
W/S RATIO:	1.00	

West Port	Start	Finish	
Sampling flowmeter	10	10	lpm
Ambient pressure	838	837	mbar
Ambient humidity	32	30	RH
Ambient Temp	46	47	ºF
B&K vapor correction	Y	Y	Y/N
Back-Gd gas	.3, -10, 19, 6	36, 27, 31, 25	ppb
No. Bk-Gd samples	4	4	n

Sample Line	Start	Finish	
cabinet flow rate	0	1.06	
Sampling flowmeter	10	10	lpm
Ambient pressure	846	847	mbar
Ambient humidity	22	22	RH
Ambient Temp	79	79	ºF
B&K vapor correction	Y	Y	Y/N
Back-Gd gas	16, 12, 13, 17	4, 5, 7, 4	ppb
No. Bk-Gd samples	4	4	n

Instruments Used:	**Cal Due / Check**
B&K 1302 Gas Analyzer SN 1804888	4/12/2011
B&K 1302 Gas Analyzer SN 1788615	4/13/2011
TSI VelociCalc SN 209060	6/25/2011
Omega FMA-2606A flowmeter SN 27708	N/A
West Port Fisher Weather Station SN 61876141	5/17/2011
Sample Line Fisher Weather Station SN 90936818	10/20/2011



Notes: At the end of BT-3, tedlar bags were filled in place of real-time analysis using the B&K analyzer. This data sheet contains the results of the analysis of the contents of the Tedlar bags using two different B&K analyzers.
Tedlar bag analysis was conducted with B&K SN 1804888 for trial 1-8. Tedlar bag analysis was conducted with B&K SN 1788615 for trial 9-13.

Entries made by:	John Glissmeyer	4/14/2011	Technical Data Review performed by:		Carmina Arimescu
Signature/date	*On File w/ Original*		Signature/date	*Via Email*	5/17/2011

SULFUR HEXAFLUORIDE GAS INSTRUMENT CALIBRATION

Site	INL HFEF	Instrument	B&K Model 1302
Date/Time	4/12/11 / 1300	Serial No.	1765299
Testers	JAG	Property No.	WD17210

Setup:	6.33	ft B&K sample inlet tube length
	836	mbar station pressure
	64	deg F ambient temp analyzer corrects to 20 deg C
	33	percent RH

Pre-Test background, ppb

Not compensating for water vapor, monitoring task 2

85.4, 76.6, 76.9, 78.7, 71.9

Compensating for water vapor, monitoring task 1

65.1, 66.5, 58.8, 65.7, 61.2

	0.1 ppm		5.01 ppm
Cylinder	CLM002314	Cylinder	CAL011887
start P =	1900 psi	start P =	2000 psi
end P =	1900 psi	end P =	2000 psi

B&K Calibration readings: (ppm)

	0.1 ppm	5.01 ppm
Compensating for water vapor		
	0.108	5.52
	0.114	5.50
	0.109	5.50
	0.112	5.51
	0.0992	5.49
Not compensating for water vapor		
	0.110	5.47
	0.111	5.46
	0.113	5.46
	0.111	5.47
	0.110	5.46
= avg	**0.110**	**5.48**
= avg/standard	**1.097**	**1.095**

Standards Used:	Expiration date:
Scott Specialty Gas 0.1 ppm SF6 in air, CLM002314	3/3/2012
Scott Specialty Gas 5.01 ppm SF6 in air, CAL011887	3/3/2013
Fisher Scientific SN 61876141 ID# WSFI1-0005	5/17/2011

Entries made by: John Glissmeyer 4/12/2011	Technical Data Review performed by:
Signature/date *On File with Original*	Signature/date Carmina Arimescu
	Via Email 5/9/2011

SULFUR HEXAFLUORIDE GAS INSTRUMENT CALIBRATION

Site	INL HFEF	Instrument	B&K Model 1302
Date/Time	4/12/11 / 1405	Serial No.	1804888
Testers	JEF / JAG	Property No.	WD54623

Setup:	6.33	ft B&K sample inlet tube length
	836	mbar station pressure
	67	deg F ambient temp analyzer corrects to 20 deg C
	30	percent RH

Pre-Test background, ppb

Not compensating for water vapor, monitoring task 2

59.9, 58.4, 57.8, 58.5, 53.3

Compensating for water vapor, monitoring task 1

34.8, 32.4, 32.4, 32.2, 29.0

	0.1 ppm		5.01 ppm
Cylinder	CLM002314	Cylinder	CAL011887
start P =	1900 psi	start P =	2000 psi
end P =	1800 psi	end P =	1900 psi

B&K Calibration readings: (ppm)

	0.1 ppm	5.01 ppm	
Compensating for water vapor			
	0.107	5.37	
	0.107	5.37	
	0.110	5.19	
	0.110	5.20	
	0.110	5.17	
Not compensating for water vapor			
	0.108	5.15	
	0.106	5.12	
	0.113	5.15	
	0.107	5.27	
	0.107	5.34	
	0.109	**5.23**	= avg
	1.085	**1.045**	= avg/standard

Standards Used:	Expiration date:
Scott Specialty Gas 0.1 ppm SF6 in air, CLM002314	3/3/2012
Scott Specialty Gas 5.01 ppm SF6 in air, CAL011887	3/3/2013
Fisher Scientific SN 61876141 ID# WSFI1-0005	5/17/2011

Entries made by: John Glissmeyer 4/12/2011	Technical Data Review performed by:
Signature/date *On File with Original*	Signature/date Carmina Arimescu *Via Email* 5/9/2011

SULFUR HEXAFLUORIDE GAS INSTRUMENT CALIBRATION

Site	INL HFEF	Instrument	B&K Model 1302
Date/Time	4/13/2011	Serial No.	1788615
Testers	JAG	Property No.	WD54624

Setup:

7.5	ft	B&K sample inlet tube length
840	mbar station pressure	
63	deg F ambient temp	analyzer corrects to 20 deg C
33	percent RH	

Pre-Test background, ppb

Not compensating for water vapor, monitoring task 2

14.6, 10.8, 13.4, 9.05, 7.48

Compensating for water vapor, monitoring task 1

48.6, 37.7, 35.3, 31.0, 33.6

	0.1 ppm		5.01 ppm
Cylinder	CLM002314	Cylinder	CAL011887
start P =	1800 psi	start P =	1800 psi
end P =	1700 psi	end P =	1800 psi

B&K Calibration readings: (ppm)

0.1 ppm standard	5.01 ppm standard
Compensating for water vapor	**Compensating for water vapor**
0.108	5.32
0.102	5.35
0.104	5.34
0.101	5.33
0.103	5.32
Not compensating for water vapor	**Not compensating for water vapor**
0.103	5.42
0.102	5.42
0.102	5.20
0.102	5.35
0.102	5.41
0.103 = avg	**5.35** = avg
1.029 = avg/standard	**1.067** = avg/standard

Standards Used:	Expiration date:
Scott Specialty Gas 0.1 ppm SF6 in air, CLM002314	3/3/2012
Scott Specialty Gas 5.01 ppm SF6 in air, CAL011887	3/3/2013
Fisher Scientific SN 90936818 ID# WSFI1-0006	10/20/2011

Entries made by: John Glissmeyer 4/13/2011	Technical Data Review performed by:
Signature/date *On File with Original*	Signature/date Carmina Arimescu
	Via Email 5/17/2011

SULFUR HEXAFLUORIDE GAS INSTRUMENT CALIBRATION

Site	INL HFEF	Instrument	B&K Model 1302
Date/Time	4/14/2011	Serial No.	1765299
Testers	JEF / JAG	Property No.	WD17210

Setup:	7.5	ft	B&K sample inlet tube length
	848	mbar station pressure	
	66.2	deg F ambient temp	analyzer corrects to 20 deg C
	24	percent RH	

Pre-Test background, ppb

Not compensating for water vapor, monitoring task 2

33, 35, 28, 24, 24

Compensating for water vapor, monitoring task 1

64, 52, 34, 35, 35

	0.1 ppm		5.01 ppm
Cylinder	CLM002314	Cylinder	CAL011887
start P =	1800 psi	start P =	1300 psi
end P =	1800 psi	end P =	1300 psi

B&K Calibration readings: (ppm)

0.1 ppm	5.01 ppm
Compensating for water vapor	**Compensating for water vapor**
0.106	5.16
0.107	5.17
0.102	5.16
0.102	5.15
0.1030	5.16
Not compensating for water vapor	**Not compensating for water vapor**
0.101	5.17
0.107	5.17
0.103	5.16
0.102	5.16
0.103	5.16
0.104 = avg	**5.16** = avg
1.036 = avg/standard	**1.030** = avg/standard

Standards Used:	Expiration date:
Scott Specialty Gas 0.1 ppm SF6 in air, CLM002314	3/3/2012
Scott Specialty Gas 5.01 ppm SF6 in air, CAL011887	3/3/2013
Fisher Scientific SN 90936818	10/20/2011

Entries made by: John Glissmeyer 4/14/2011	Technical Data Review performed by:
Signature/date *On File with Original*	Signature/date Carmina Arimescu *Via Email* 5/9/2011

SULFUR HEXAFLUORIDE GAS INSTRUMENT CALIBRATION

Site	INL HFEF	Instrument	B&K Model 1302
Date/Time	4/14/11 / 16:50	Serial No.	1804888
Testers	JEF / JAG	Property No.	WD54623

Setup:	7.5	ft	B&K sample inlet tube length
	848	mbar station pressure	
	66.2	deg F ambient temp	analyzer corrects to 20 deg C
	24	percent RH	

Pre-Test background, ppb

Not compensating for water vapor, monitoring task 2

21.0, 19.7, 18.9, 8.95, 22.1

Compensating for water vapor, monitoring task 1

12.0, 7.35, 8.97, 7.00, 5.34

	0.1 ppm		5.01 ppm
Cylinder	CLM002314	Cylinder	CAL011887
start P =	1700 psi	start P =	1600 psi
end P =	1700 psi	end P =	1500 psi

B&K Calibration readings: (ppm)

	0.1 ppm	5.01 ppm
Compensating for water vapor		
	0.113	5.13
	0.110	5.15
	0.108	5.12
	0.109	5.14
	0.108	5.13
Not compensating for water vapor		
	0.111	5.13
	0.109	5.11
	0.108	5.18
	0.106	5.14
	0.108	5.16
= avg	**0.109**	**5.14**
= avg/standard	**1.09**	**1.026**

Standards Used:	Expiration date:
Scott Specialty Gas 0.1 ppm SF6 in air, CLM002314	3/3/2012
Scott Specialty Gas 5.01 ppm SF6 in air, CAL011887	3/3/2013
Fisher Scientific SN 90936818	10/20/2011

Entries made by: John Glissmeyer 4/14/2011	Technical Data Review performed by:
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SULFUR HEXAFLUORIDE GAS INSTRUMENT CALIBRATION

Site	INL HFEF	Instrument	B&K Model 1302
Date/Time	4/14/2011	Serial No.	1788615
Testers	JAG	Property No.	WD54624

Setup:	7.5	ft B&K sample inlet tube length
	848	mbar station pressure
	64	deg F ambient temp analyzer corrects to 20 deg C
	26	percent RH

Pre-Test background, ppb

Not compensating for water vapor, monitoring task 2

13, 17, 12, 18, 13

Compensating for water vapor, monitoring task 1

16, 14, 7, 7, <0

	0.1 ppm		5.01 ppm
Cylinder	CLM002314	Cylinder	CAL011887
start P =	1800 psi	start P =	1750 psi
end P =	1800 psi	end P =	1650 psi

B&K Calibration readings: (ppm)

	0.1 ppm	5.01 ppm
Compensating for water vapor		
	0.103	5.09
	0.102	5.09
	0.102	5.09
	0.104	5.08
	0.1070	5.09
Not compensating for water vapor		
	0.106	5.11
	0.106	5.10
	0.104	5.09
	0.104	5.09
	0.104	5.08
= avg	**0.104**	**5.09**
= avg/standard	**1.042**	**1.016**

Standards Used:	Expiration date:
Scott Specialty Gas 0.1 ppm SF6 in air, CLM002314	3/3/2012
Scott Specialty Gas 5.01 ppm SF6 in air, CAL011887	3/3/2013
Fisher Scientific SN 90936818	10/20/2011

Entries made by: John Glissmeyer 4/14/2011	Technical Data Review performed by:
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