PNNL-19562
RPT-STMON-005

U.S. DEPARTMENT OF ENERGY

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

Assessment of the 3410 Building Filtered Exhaust Stack Sampling Probe Location

JA Glissmeyer
JE Flaherty

July 2010

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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-001. 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:

John A. Glissmeyer 7/12/10

John A. Glissmeyer
Stack Monitoring Project Manager

Date

Summary

Pacific Northwest National Laboratory performed several tests in the exhaust air discharge from the new 3410 Building Filtered Exhaust Stack to determine whether the location of the air sampling probe for emissions monitoring is acceptable. The method followed involved adopting the results of a previously performed test series from a system with a similar configuration, followed by several tests on the actual system to verify the applicability of the previously performed tests. The qualification criteria for these types of stacks include metrics concerning 1) uniformity of air velocity, 2) sufficiently small flow angle with respect to the axis of the duct, 3) uniformity of tracer gas concentration, and 4) uniformity tracer particle concentration.

Section 1 of this report provides background information concerning the tests for the 3410 Building, while Section 2 describes the testing strategy, including the criteria for the applicability of the model results and the test matrix. Section 3 describes the flow angle and velocity uniformity tests conducted at the 3410 Building Filtered Exhaust Stack. Sections 4 and 5 present the test results and conclusions, respectively. Test data sheets and applicable qualification results from previously tested stack models are included in Appendices.

The testing conducted from the similarly designed scale model stack was determined to be applicable to the current design of the 3410 Building Filtered Exhaust Stack. As a result, this new system also meets the qualification criteria given in the ANSI/HPS N13.1-1999 standard. Changes to the system configuration or operations outside the bounds described in this report (e.g., exhaust stack velocity changes, relocation of sampling probe) will require re-testing or re-evaluation to determine compliance.

Acronyms

acfm	actual cubic feet per minute
AD	aerodynamic diameter
ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
CFR	Code of Federal Regulations
COV	coefficient of variation
DIA	number of duct diameters, distance divided by duct diameter
DOE	U.S. Department of Energy
DV	hydraulic diameter and the mean velocity
EPA	U.S. Environmental Protection Agency
FA	flow angle test run
HDI	"How Do I…?"
HPS	Health Physics Society
M&TE	materials and testing equipment
NQA	National Quality Assurance
PNNL	Pacific Northwest National Laboratory
PSF	Physical Sciences Facility
QA	quality assurance
R&D	research and development
scfm	standard cubic feet per minute
STMON	Stack Monitoring Project
TI	Test Instruction
VT	velocity uniformity test run

Acknowledgments

This work was supported by Project 48043, a Line-Item-funded project to develop, design, and construct the Physical Sciences Facility. Pacific Northwest National Laboratory (PNNL) is operated for the U.S. Department of Energy by Battelle under Contract DE-ACO5-76RL01830.

Preparing and executing these tests involved a number of PNNL staff members. We would like to particularly acknowledge the support of our quality engineer, Kirsten Meier, and administrative support from Mona Champion and Chrissy Charron. Robert Steele, John Hickman, Dan Edwards, and Matthew Barnett provided technical, logistical, and moral support for these tests. In addition, Carmen Arimescu, Matthew Barnett, and Ernest Antonio provided technical reviews. Wayne Cosby provided editorial support for this report.

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1.0 Introduction

The new construction of the Physical Sciences Facility (PSF) at the Pacific Northwest National Laboratory (PNNL) incorporates three laboratory buildings that will house PNNL radiological capabilities. As a result, PNNL has determined that emissions monitoring must be conducted for radionuclides in the exhaust air discharge of these buildings. The air monitoring system is required to conform to applicable federal regulations (Title 40 of the Code of Federal Regulations Part 61 [40 CFR 61], Subpart H), which in turn requires a sampling probe in the exhaust stream to conform to the criteria of ANSI/HPS[a] N13.1 – 1999, *Sampling and Monitoring Releases of Airborne Radioactive Substances from the Stack and Ducts of Nuclear Facilities*. This standard requires that a series of tests be performed to demonstrate the acceptability of the location of the air sampling probe in the system. A facility may choose from one of the three approaches to demonstrate compliance with the federal standards:

1. Perform a full test series on the actual exhaust system
2. Perform the full test series on a scale model of the exhaust system, followed by a partial test of the actual exhaust system to verify the validity of the model results
3. Adopt the results from previously performed full test series for a system with similar configuration, followed by a partial test of the actual exhaust system to verify the applicability of the previous test results.

The third approach was selected to evaluate the acceptability of the location of the air sampling probe in the 3410 Building Filtered Exhaust Stack to monitor discharged air for radionuclides. Consequently, a limited series of tests was performed on the actual exhaust system using the criteria for qualifying the location of a stack monitoring probe and the configuration of the 3410 Building Filtered Exhaust Stack, as described in this report. Also included in this report are the results from the previously performed full test series that serve as the basis for compliance with the standard. Tests on the 3410 Building, also known as the Materials Science and Technology Laboratory, were conducted on May 13 and 14, 2010.

1.1 Qualification Criteria

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

1. Uniform Air Velocity—It is important that the gas velocity across the stack cross-section where the sample is extracted be fairly uniform. Consequently, the velocity is measured at several points in the stack at the position of the sampling nozzle. The uniformity is expressed as the variability of the measurements about the mean. This is expressed using the coefficient of variation (COV),[b] 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 acceptance criterion is that the COV of the air velocity must be ≤20% across the sampling plane.

(a) The American National Standards Institute delegates the writing, publication and maintenance of this standard to the Health Physics Society, McLean, Virginia.

(b) *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 up the stack in 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 in the duct at the location of the sampling probe. The average air-velocity angle must not deviate from the axis of the duct by more than 20°.

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 using 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 acceptance criteria are that 1) the COV of the measured tracer gas concentration is ≤20% across the sampling location, and 2) at no point in the sampling location does the concentration vary 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 acceptance criterion is that the COV of particle concentration is ≤20% across the sampling location.

Glissmeyer and Droppo (2007) conducted tests of a similar stack configuration using a scale model and concluded that the stack was compliant with these criteria. Section 5.2.2.2 of the ANSI/HPS N13.1-1999 standard defines additional criteria for applying the results of the scale model for the actual building stack. A summary of these criteria as applicable for the 3410 Building stack follows:

- The scale model and its sampling location must be geometrically similar to the actual 3410 Building Filtered Exhaust Stack.
- The product of the hydraulic diameter and the mean velocity (DV) of the scale model must be within a factor of six of the DV for the actual 3410 Building Filtered Exhaust Stack.
- The Reynolds number for the model and actual stacks must each be >10,000.

The scale-model results are considered valid if the following are shown by testing on the actual stacks:

- The velocity profile in the actual 3410 Building stack meets the uniformity criterion.
- The velocity uniformity (% COV) values for the model and actual stacks agree to within 5%.
- The flow angle criterion is met on the actual 3410 Building stack.

1.2 Building 3410 Filtered Exhaust Stack Configuration

Figure 1.1 shows a schematic of the plan view of the 3410 Building Filtered Exhaust Stack. Figure 1.2 shows the scale model stack (designated as HV-C2) tested by Glissmeyer and Droppo (2007). The two designs differ in that the model stack (except for the bend upwards at the discharge end) is rotated 90° around its long axis so that the air from the fans enters the straight section from the side rather than from the bottom. This should have no effect on the uniformity of tracers and the air velocity uniformity and flow angles. The model stack was tested with both one and both fans operating, which covers the possible operating modes of the actual stack. Table 1.1 lists key dimensional and flow parameters for both the model stack and the 3410 Building Filtered Exhaust Stack.

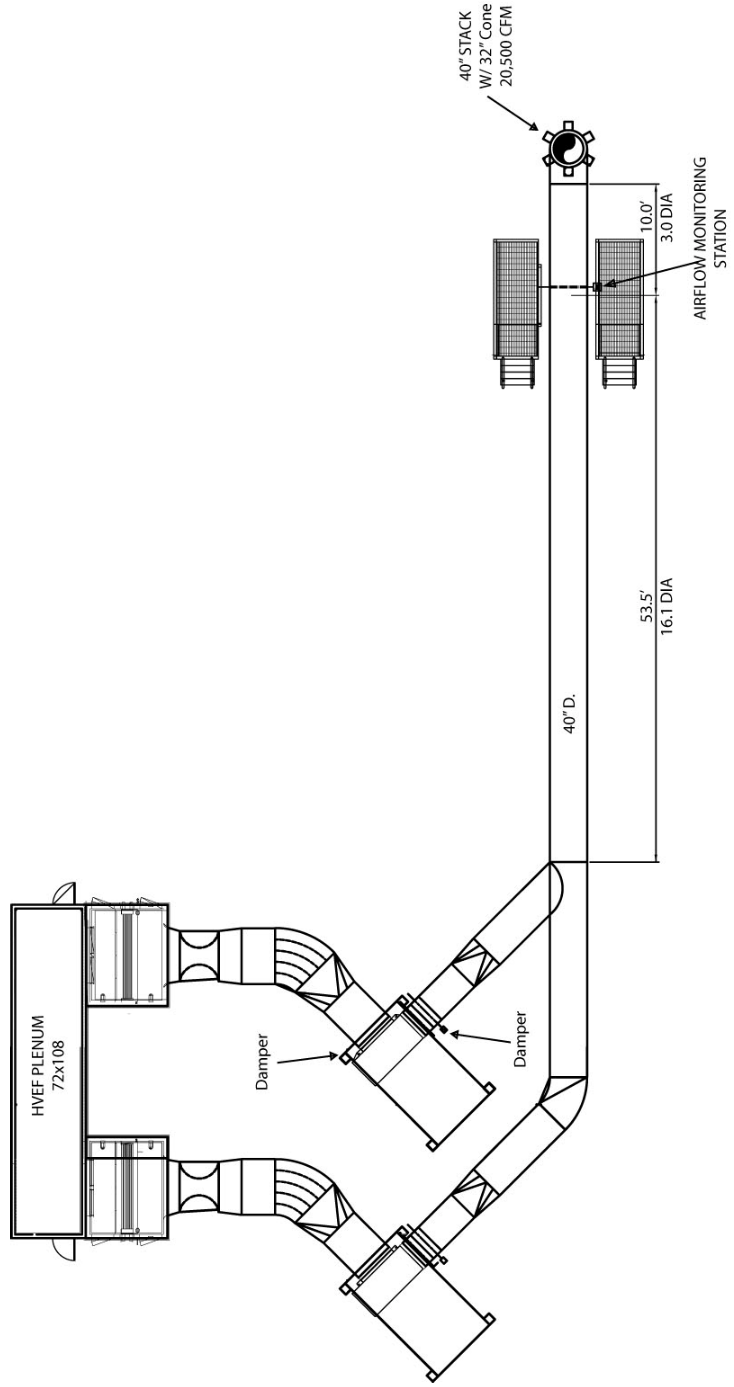

Figure 1.1. Plan View of the 3410 Building Filtered Exhaust Stack

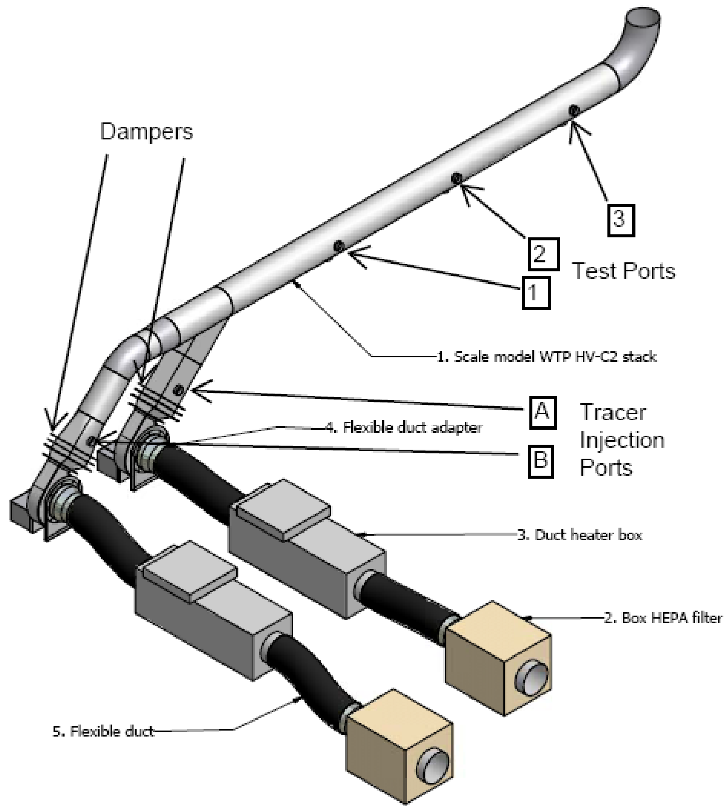

Figure 1.2. Scale Model Tested by Glissmeyer and Droppo (2007)

Table 1.1. Comparison of Model and Actual Stack Dimensions

Operating Parameters	Model	Bldg. 3410
Duct diameter at sampling probe	12 in.	40 in.
Number of duct diameters from upstream duct junction to sampling probe or test ports	Port 1 – 4.5 Port 2 – 9.5 Port 3 – 14.5	16
Number of duct diameters from sampling probe or test ports to downstream bend	Port 3 – 2.25	3
Discharge diameter	12 in.	32 in.
Number of operating fans	1 and 2	2
Total available fans	2	2

2.0 Testing Strategy

The velocity uniformity test results from the model stack are an important factor in the applicability of the model stack results to any other stack. Table 2.1 lists the results from the velocity uniformity test conducted on the model using Test Ports 2 and 3 with both one and two operating fans. The average velocity uniformity (%COV) results were 4.8% COV and 4.9% COV for one and two operating fans, respectively. The most applicable test results for comparison with the 3410 Building exhaust system are the scale model results from Test Port 3 when both fans were running. The average velocity uniformity for these conditions was 4.7% COV. Therefore, the acceptance range for velocity uniformity results for the 3410 Building exhaust is from 0 to 9.7% COV[a] for the results from the HV-C2 scale model to be considered applicable.

Table 2.2 shows calculations of the acceptable range of the diameter × velocity criterion that also determines the applicability of the scale-model results to the actual stacks. The product of duct diameter times air velocity during the tests with typical flow rates (DV=96,000) was within the acceptable factor of six of the scale model's DV product (32,556 × 6 = 195,336) for two operating fans. Table 2.2 also includes the Reynolds number for the scale tests and the building stack tests. In all cases, the Reynolds numbers are greater than 10,000, which is another criterion for applying the scale model results to the building stack.

Table 2.1. List of HV-C2 Velocity Uniformity Test Results with Dampers Installed (from Glissmeyer and Droppo 2007)

Test Port	Operating Fans	Run No.	Control Damper Setting (degrees)	Back Flow Damper Setting (degrees)	Flow Rate cfm	Velocity fpm	% COV
2	A	VT-16	90	70	973	1239	3.6
2	B	VT-19	90	70	977	1244	6
3	A	VT-17	90	70	1002	1276	3.4
3	B	VT-18	90	70	959	1221	6
				Average	977.8	1245.0	4.8
2	A & B	VT-13	90	70	2094	2666	6.1
2	A & B	VT-23	90	70	2132	2715	5.1
2	A & B	VT-24	90	70	2126	2706	4.4
3	A & B	VT-14	90	70	2117	2696	4.4
3	A & B	VT-21	90	70	2136	2720	5.1
3	A & B	VT-22	90	70	2180	2775	4.5
				Average	2130.8	2713.0	4.9

(a) 4.7% +/- 5.0% = 0% - 9.7% (considering only positive values).

Table 2.2. Ranges of Acceptable Diameter × Velocity Values and Reynolds Numbers

Stack	Diameter (in.)	Configuration	Mean Velocity (fpm)	D × V (in. × fpm)	Maximum 6 × (D × V)	Reynolds Number
Model	12	One Fan	1245	14,940	89,640	1.3E+05
Model	12	Two Fans	2713	32,556	195,336	2.8E+05
3410	40	Two Fans	2400	96,000		8.3E+05

Table 2.3 lists the minimum matrix of tests needed for the 3410 Building Filtered Exhaust Stack. Also included in the list are the optional tests that may be required if the applicable criteria for velocity uniformity and diameter/velocity product were not met as presented above.

Table 2.3. Minimum Test Runs for 3410 Building Qualification

Test Configuration				Estimated Number of Test Runs			
Fans	#	Injection Port	Test Port	Flow Angle	Velocity	Gas Tracer (optional)[(a)]	Particle Tracer (optional)
Maximum flow rate	1	Junction	At Probe	2	2	7	2
Minimum flow rate	2	Junction	At Probe	1	1	1	1
Total				3	3	8	3
Grand Total				17			

(a) Five of the seven runs involve injecting the tracer gas in the four corners and center of the cross section at the injection location. The two additional runs are replicates of the test with the worst-case result.

3.0 Testing Methods

The testing methods for the confirmatory tests conducted at the 3410 Building stack are outlined in this section. Per the requirement outlined in Section 1, only the flow angle and velocity uniformity tests were conducted on the actual stack. Tracer testing on the actual stack is not currently anticipated. Figure 3.1 shows the layout of the 3410 duct at the location of the air sampling probe and test ports used in this testing. Figure 3.2 is a photo of the stack interior taken with the inspection hatch removed. The photo is looking downstream in the stack, and shows the shrouded nozzle and flow sensor that make up the sample probe assembly.

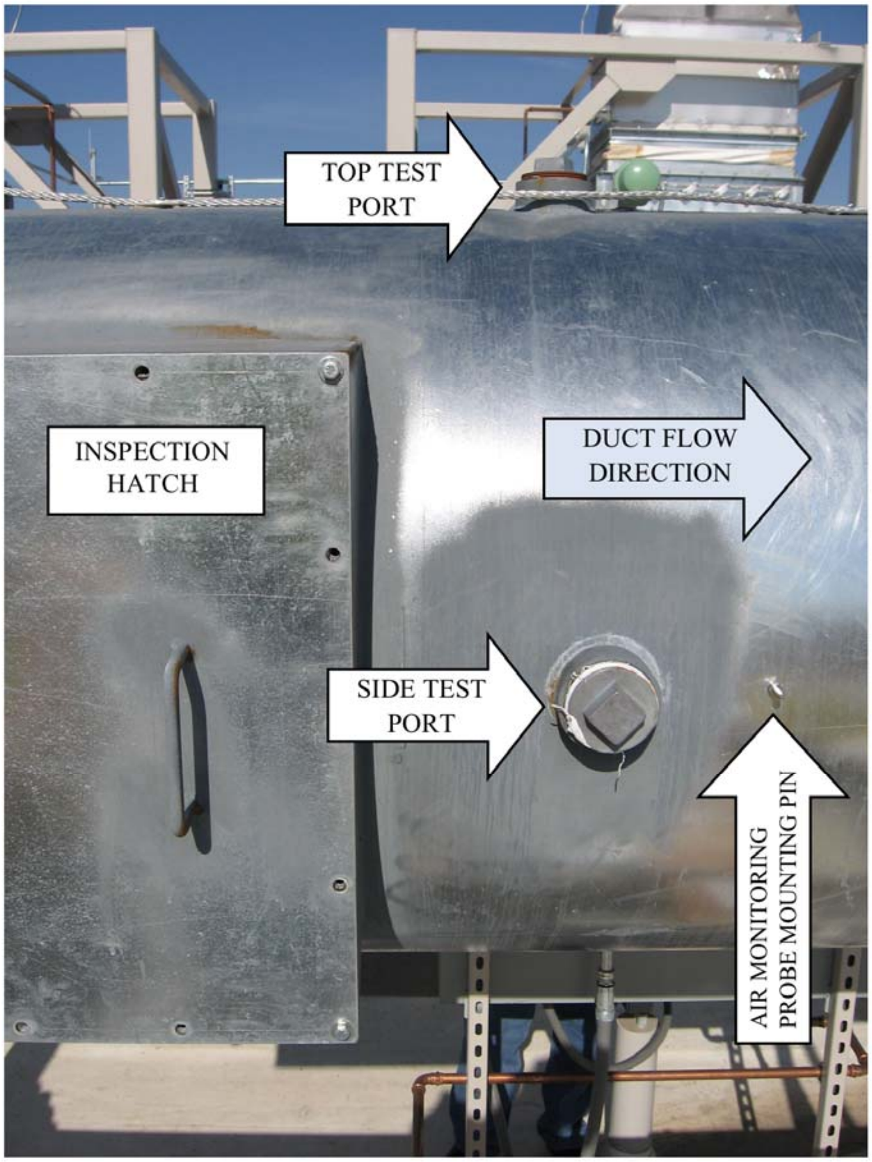

Figure 3.1. Layout of Test Ports and Other Duct Features at the 3410 Stack

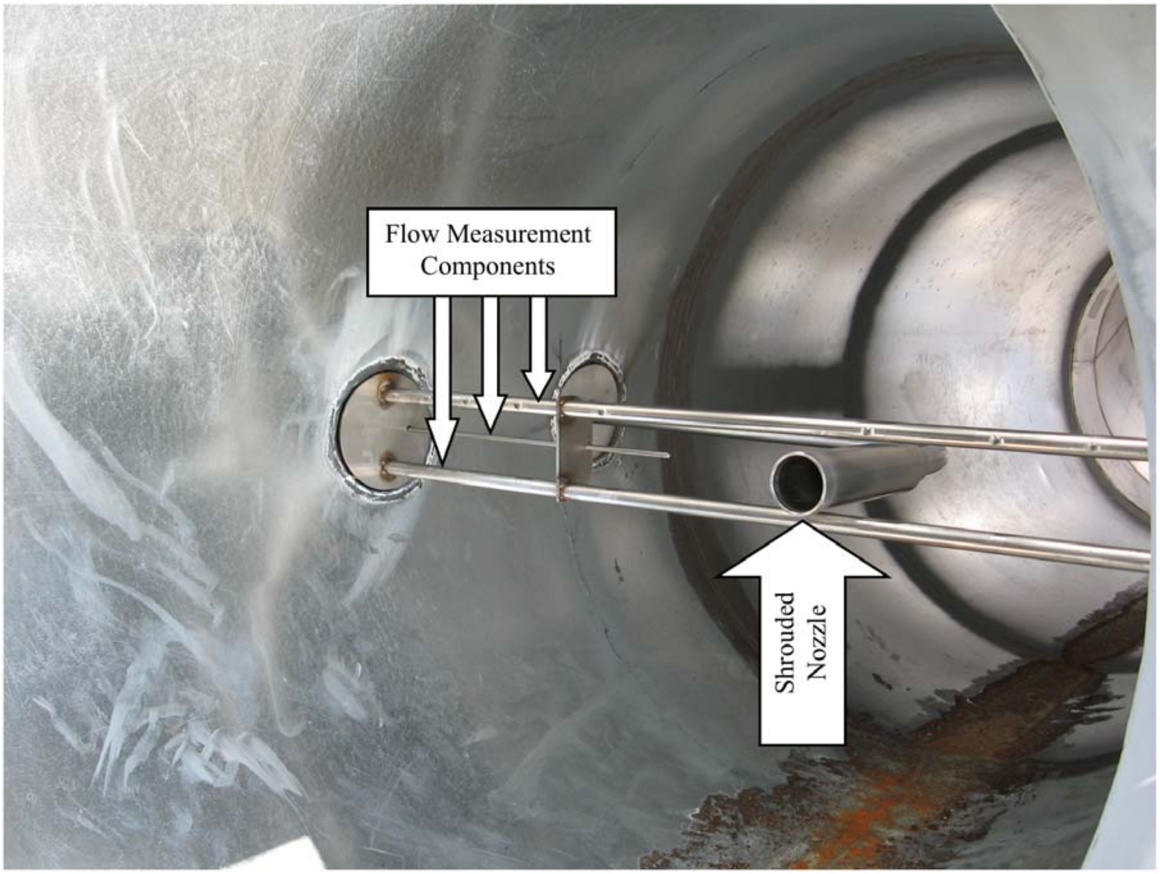

Figure 3.2. Air Monitoring Probe Assembly

3.1 Flow Angle Test

The air velocity vector approaching the sample nozzle should be aligned with the axis of the nozzle within an acceptable deviation angle so that the sample extraction performance is not degraded. The test method to determine the air velocity vector is based on 40 CFR 60, Appendix A, Method 1, Section 11.4, "Verification of the Absence of Cyclonic Flow." The term "flow angle" refers to the average 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 an array of 17 points in a cross pattern in the cross section of the duct. One line of measurement points was aligned with the sampling probe assembly (across the east-west diameter of the duct). The other line of measurement points was perpendicular to the sampling probe assembly (across the top-bottom diameter of the duct). The number and distance between the measurement points is based on the U.S. Environmental Protection Agency's (EPA's) method in 40 CFR 60, Appendix A, Method 1. The criterion for acceptance from the flow angle test is that the average angle must be <20°.

The flow angle measurements were made using an S-type Pitot tube (Dwyer Instruments, 160S-72, Michigan City, IN) attached by flexible tubing to a slant-tube manometer (Dwyer Instruments, 400-5) and an angle-indicating device attached to the sampling port as shown in Figure 3.3 and Figure 3.4. For this test, the S-type Pitot tube was rotated so that the planes of the two openings at the tip of the tube were parallel to the flow in the duct. The Pitot tube is considered perpendicular to the flow in this position.

The large metal plate in Figure 3.3 is the angle-indicating device. It has markings at every degree from -30 degrees to 30 degrees. When the pressures on both tubes of the S-type Pitot tube were equal (as indicated by the manometer), the angle shown on the angle-indicating device is recorded as the reading. Figure 3.4 shows the manometer mounted on the inspection hatch cover at the 3430 Building, which has a configuration similar to the 3410 Building. The PNNL operating procedure EMS-JAG-05 and the Test Instruction TI-STMON-009 were used to conduct this test.

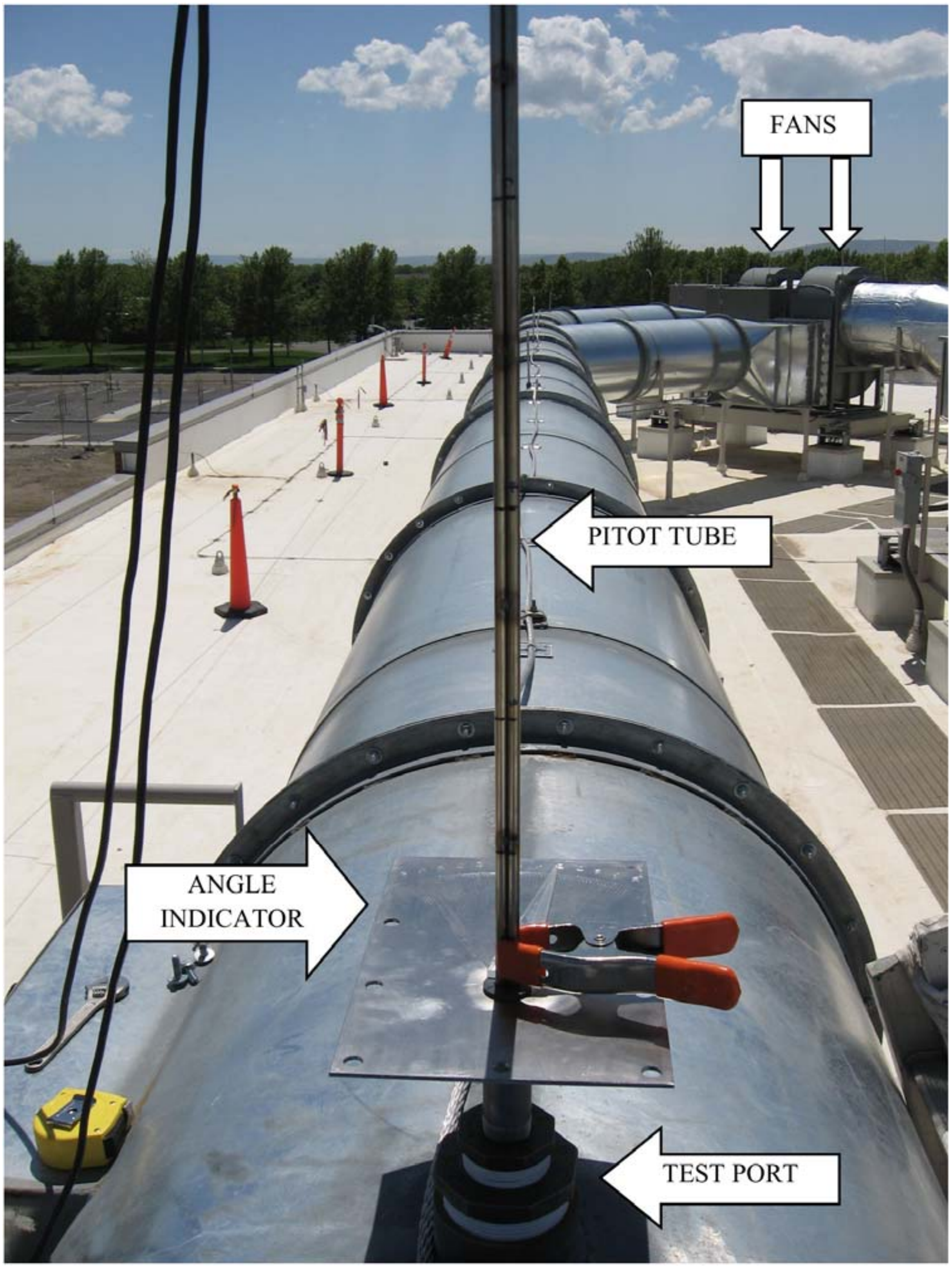

Figure 3.3. Flow Angle Indicator and Pitot Tube Installed on 3410 Stack

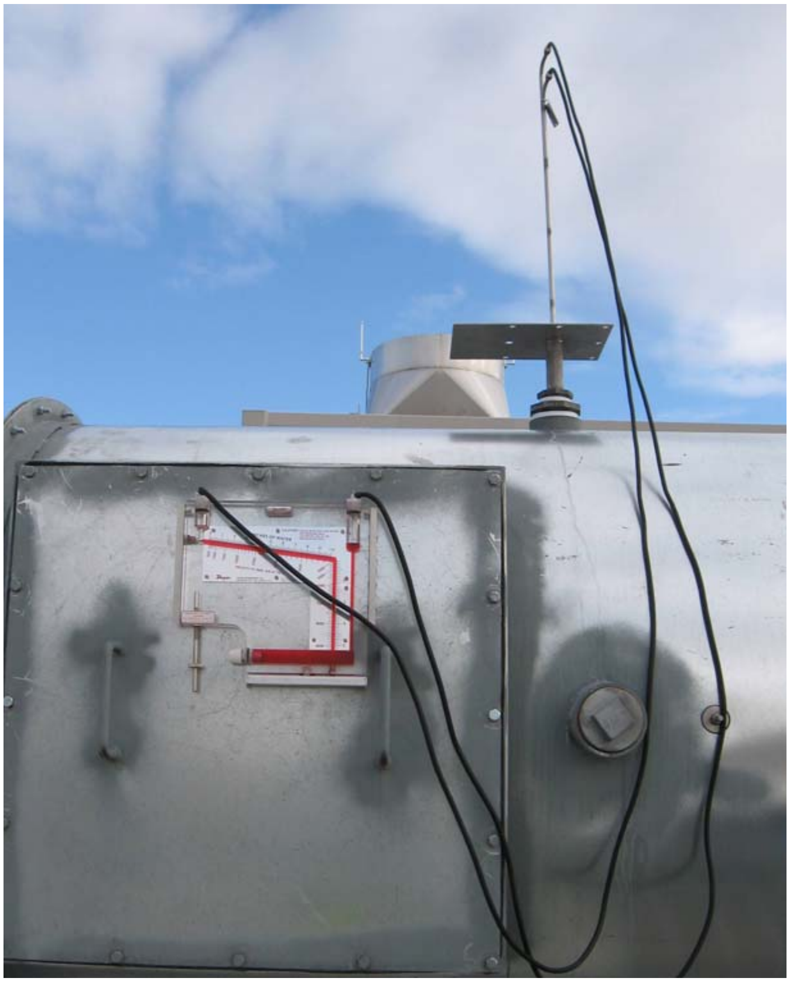

Figure 3.4. Slant Tube Manometer on 3430 Inspection Hatch Cover

3.2 Velocity Uniformity Test

The uniformity of air velocity at the stack monitoring location indicates the degree to which 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 measurement grid used in the velocity uniformity tests was the same as the grid used for the flow angle test. In general, the criterion for acceptance from the velocity uniformity test is that the COV should be less than 20%.

The air velocity was measured three times at each of the 17 grid points across the cross-section of the duct. The average of the three measurements for the center two thirds of the stack was used to determine the mean and standard deviation of the velocity across the cross-sectional plane. The coefficient of variance (also known as the percent relative standard deviation) was calculated as 100 times the standard deviation divided by the mean. For the previously conducted tests to be applicable to the 3410 Building exhaust stack, the %COV from the 3410 velocity tests must be between 0 and 9.7% COV.

Each air velocity measurement was made using an S-type Pitot tube connected to a calibrated electronic manometer (GrayWolf, Zephyr II+, Shelton, CT) by flexible tubing. Duct air temperature measurements were made with a handheld thermal anemometer (TSI, Model 8360, Shoreview, MN).

Figure 3.5 shows the equipment used for this test. In this test, the S-type Pitot tube was positioned so that the normal vector to one of the two openings at the tip was pointing in the same direction as the axis of the duct. The procedure EMS-JAG-04 and the test instruction TI-STMON-008 were followed to conduct this test.

Figure 3.5. Electronic Manometer Connected to Pitot Tube

3.3 Quality Assurance

The Pacific Northwest National Laboratory Quality Assurance (QA) Program is based upon the requirements as 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:

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

The procedures necessary to implement the requirements are documented in PNNL's standards-based management system called "How Do I…?" (HDI).[a]

The Stack Monitoring Project (STMON) implements a National Quality Assurance (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[b]) describes the technology life-cycle stages under the STMON Quality Assurance Plan (QA-STMON-0001[c]). 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 QA activities in basic research, which becomes more structured and formalized through the applied R&D stages.

- BASIC RESEARCH—Basic research consists of research tasks that are conducted to acquire and disseminate new scientific knowledge. During basic research, maximum flexibility is desired to allow the researcher the necessary latitude to conduct the research.
- APPLIED RESEARCH—Applied research consists of research tasks that acquire data and documentation necessary to make sure that results can be satisfactorily reproduced. The emphasis during this stage of a research task is on achieving adequate documentation and controls necessary to be able to reproduce results.
- DEVELOPMENTAL WORK—Developmental 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 Developmental Work is to make sure that adequate controls to support movement into commercialization exist.
- RESEARCH AND DEVELOPMENT SUPPORT ACTIVITIES—Support activities are those that are conventional and secondary in nature to the advancement of knowledge or development of technology, but allow the primary purpose of the work to be accomplished in a credible manner. An example of a support activity is controlling and maintaining documents and records. The level of quality for these activities is the same as for developmental work.

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,[d] *Document Preparation and Change*. This review verifies that the reported results are traceable, that inferences and conclusions are soundly based, and that the reported work satisfies the Test Plan objectives.

The tests were conducted according to an approved Test Plan and Test Instructions. Data transcription and calculations were independently reviewed.

(a) System for managing the delivery of laboratory-level policies, requirements, and procedures.

(b) QA-STMON-0002, Rev. 0. January 2, 2010. "Pacific Northwest National Laboratory Stack Monitoring Project Quality Assurance Manual," Pacific Northwest National Laboratory, Richland, Washington.

(c) QA-STMON-0001, Rev. 0. January 2, 2010. "Pacific Northwest National Laboratory Stack Monitoring Project Quality Assurance Plan," Pacific Northwest National Laboratory, Richland, Washington.

(d) QA-STMON-0601, Rev. 0. January 2, 2010. "Document Preparation and Change," Pacific Northwest National Laboratory, Richland, Washington.

4.0 Stack Testing Results

Independent reviews were performed to verify the data transcription and calculations. The final data sheets are included in Appendix A.

The duct diameters that were field measured at the test ports were found to be 40.0 in as listed in Table 4.1. The distance from the test ports to the nearest upstream disturbance (the junction of the ducts from the two fans) was 53.5 ft. The tests were conducted at 16 duct diameters (DIA = linear distance divided by duct diameter) downstream of the duct junction. In comparison, the scale model tests were conducted at ports located 4.45 DIA, 9.47 DIA, and 14.5 DIA.

Table 4.1. 3410 Duct Depth Measurements

Direction across duct	Measured Duct Diameter, in.
Vertical	40.0
Horizontal	40.0

4.1 Velocity Uniformity

Table 4.2 lists the results for the velocity uniformity tests performed on the 3410 Building exhaust duct. The conditions for the velocity uniformity test runs (VTs) included a typical low-flow condition with all fume hood sashes closed and a typical high-flow condition with all fume hood sashes open as well as a condition in which the fans were manually set to a low flow. The flow rate was measured with the Zephyr II+ results in actual cubic feet per minute (acfm) whereas the airflow displayed in the air sampling cabinet is in standard cubic feet per minute (scfm). In all cases tested, the results were well within the general criterion of COV values less than 20%. The average of the four tests was 3.9% COV, which compares well with the 4.7% COV measured for the most similar (geometric and operational) condition represented by the model test. COV values were within the acceptance criterion derived in Section 2 (<9.7% COV) for verifying that the 3410 Building Filtered Exhaust Stack configuration is represented by the model tests of Glissmeyer and Droppo (2007). The completed data sheets from these three tests are available in Appendix A.

Table 4.2. Summary of Velocity Uniformity Tests

Fan Operating Configuration	Run Nos.	Measured acfm	Airflow Displayed in Sampling Cabinet scfm	% COV
2 Fans, Lab hood sashes closed	VT-1	19,759	17,910	3.6
2 Fans, Lab hood sashes open	VT-2	21,136	19,325	4.3
2 Fans, Lab hood sashes open	VT-3	20,451	19,050	4.1
2 Fans, manually set to low rpm	VT-4	12,351	10,800	3.4

4.2 Flow Angle

Table 4.2 lists the results for the flow angle test runs (FAs) performed on the 3410 Building exhaust duct. The average flow angle of 2.8° is acceptable as it is well within the criterion of average flow angle values less than 20°. The completed data sheets from these three tests are available in Appendix A.

Table 4.3. Summary of Flow Angle Tests

Fan Operating Configuration	Run Nos.	Airflow Displayed in Sampling Cabinet scfm	Mean Absolute Flow Angle
2 Fans, Lab hood sashes closed	FA-1	17,975	3.1
2 Fans, Lab hood sashes open	FA-2	18,350	2.7
2 Fans, manually set to low rpm	FA-3	10,800	2.6

5.0 Conclusions

Velocity uniformity tests were performed on the 3410 Building Filtered Exhaust Stack during May 2010 and show an acceptable level of agreement with the results of the scale-model tests performed previously (Glissmeyer and Droppo 2007). The previous tests of velocity uniformity had COV values of 4.7% COV, which allows the results of the actual stack to be up to 9.7% COV. The 3410 velocity tests compared well with the scale-model results with an average value of 3.9% COV. Consequently, the location of the air sampling probe meets the qualification criteria given in ANSI/HPS-1999. The gas and particle tracer qualification results of the scale model apply equally to the full-sized stack. The results from Glissmeyer and Droppo (2007) are included in Appendix B of this report. The results for the flow angle test on the 3410 Building Filtered Exhaust Stack also show compliance with the flow angle criterion.

6.0 References

10 CFR 830, Subpart A. 2008. "Quality Assurance Requirements." *Code of Federal Regulations*, U.S. Department of Energy.

40 CFR 60, Appendix A, Method 1. 2008. "Sample and Velocity Traverses for Stationary Sources." *Code of Federal Regulations,* U.S. Environmental Protection Agency.

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TI-STMON-009. 2009. *Flow Angle Test of Filtered Exhaust at 3410 Building*. Pacific Northwest National Laboratory, Richland, Washington.

TI-STMON-008. 2009. *Velocity Uniformity Test of Filtered Exhaust at 3410 Building*. Pacific Northwest National Laboratory, Richland, Washington.

Appendix A

Data Sheets

Appendix A: Data Sheets

FLOW ANGLE DATA FORM

FlowAngleRev0.xls — 4-Aug-06 Based on ---- CCP-WTPSP-178

Site	**EP-3410--01-S**	Run No.	**FA-1**
Date	5/13/2010	Fan Setting	**sashes closed**
Tester	JAG & JEF	Fan configuration	**2 fans**
Stack Dia.	40 in	Approx. air vel.	2450 fpm at side center
Stack X-Area	1256.6 in2	Units	degrees (clockwise > pos. nos.)
Elevation	N.A. ft	Port	nearest to probe
Distance to disturbance	53.5 ft.	Stack Temp	79 F
Start/End Time	1230/1315		

Order -->		1				2			
Traverse-->		Side				Top			
Trial ---->		1	2	3		1	2	3	
Point	Depth, in.	deg. cw	deg. cw	deg. cw	Avg.	deg. cw	deg. cw	deg. cw	Avg.
1	1.00	-4	-2	0	-2.0	-11	-11	-11	-11.0
2	4.17	0	0	0	0.0	0	-2	-1	-1.0
3	7.71	4	3	3	3.3	6	3	2	3.7
4	12.84	2	0	-1	0.3	-1	-1	-1	-1.0
Center	19.875	-2	0	-1	-1.0	1	-1	-1	-0.3
5	26.91	-5	-1	-1	-2.3	-2	-2	-2	-2.0
6	32.04	-3	-3	0	-2.0	-4	-3	-5	-4.0
7	35.58	-4	-3	-3	-3.3	-5	-5	-7	-5.7
8	38.75	-4	-4	-2	-3.3	-8	-9	-9	-8.7
Mean of absolute values of all data:					2.0				4.1
w/o points by wall:					1.8				2.5
								all	3.1
								w/o wall pts	2.1

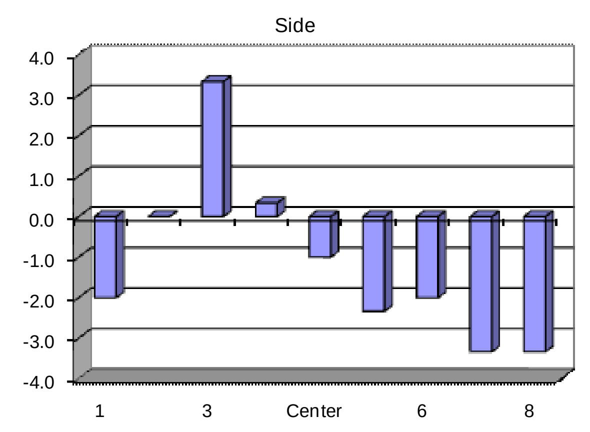
Instuments Used:

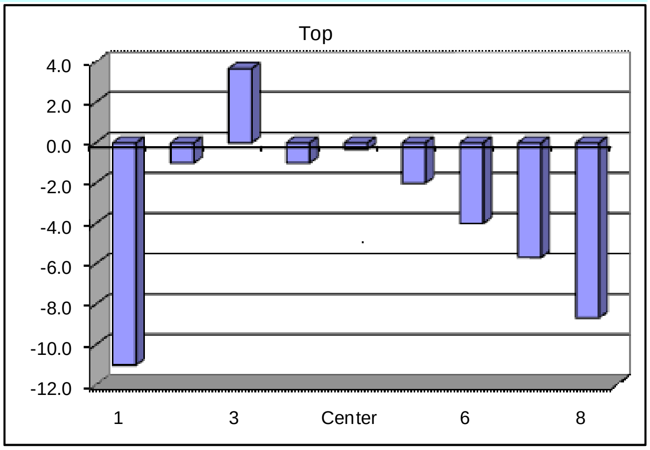
			Cal. Due
S-type pitot	Dwyer 72-inch S-type Pitot#11		Cert. of conformance
Velocity sensor	TSI VelociCalc	SN 305039	6/23/2010
Angle indicator	Shop built	Cat. 3	
Manometer	Dwyer 400-5, S36N	Cat. 3	Man-3

Notes: RAES reading, scfm

start	17900
end	18050

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).





Entries made by:	John Glissmeyer		Technical Data Review performed by:	Carmen Arimescu	
Signature/date	*On File with Original*	5/13/2010	Signature/date	*On File with Original*	6/24/2010

FLOW ANGLE DATA FORM FlowAngleRev0.xls 4-Aug-06 Based on ---- CCP-WTPSP-178

Site	**EP-3410--01-S**	Run No.	**FA-2**
Date	5/14/2010	Fan Setting	**sashes open**
Tester	JAG & JEF	Fan configuration	**2 fans**
Stack Dia.	40 in	Approx. air vel.	2630 fpm at top center
Stack X-Area	1256.6 in2	Units	degrees (clockwise > pos. nos.)
Elevation	N.A. ft	Port	nearest to probe
Distance to disturbance	53.5 ft.	Stack Temp	79
Start/End Time	1015/1100		

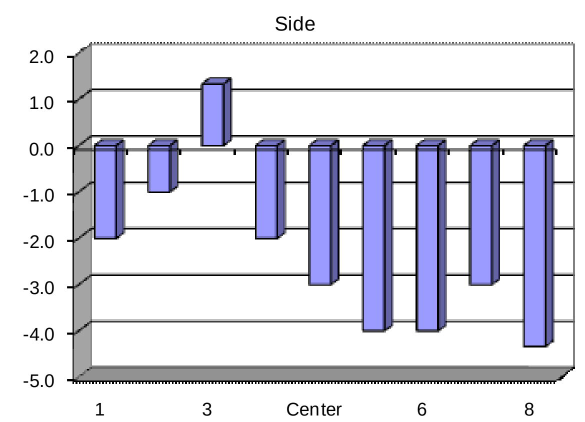
Order -->		2nd				1st			
Traverse-->		Side				Top			
Trial ---->		1	2	3		1	2	3	
Point	Depth, in.	deg. cw	deg. cw	deg. cw	Avg.	deg. cw	deg. cw	deg. cw	Avg.
1	1.00	4	-5	-5	-2.0	10	-14	-13	-5.7
2	4.17	0	-3	0	-1.0	2	2	4	2.7
3	7.71	2	2	0	1.3	2	0	-1	0.3
4	12.84	-2	-2	-2	-2.0	-1	-1	-2	-1.3
Center	19.875	-4	-3	-2	-3.0	0	-1	-1	-0.7
5	26.91	-4	-3	-5	-4.0	-1	-2	-2	-1.7
6	32.04	-5	-3	-4	-4.0	-4	-3	-4	-3.7
7	35.58	-3	-3	-3	-3.0	-4	-5	-5	-4.7
8	38.75	-4	-4	-5	-4.3	-3	-4	-3	-3.3
Mean of absolute values of all data:					2.7				2.7
w/o points by wall:					2.6				2.1
								all	2.7
								w/o wall pts	2.4

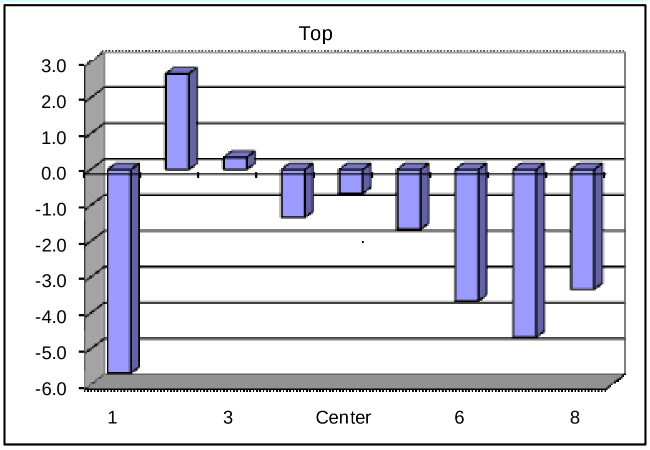
Instuments Used:		**Cal. Due**	
S-type pitot	Dwyer 72-inch S-type Pitot#11		Cert. of conformance
Velocity sensor	TSI VelociCalc	SN 305039	6/23/2010
Angle indicator	Shop built	Cat. 3	
Manometer	Dwyer 400-5, S36N	Cat. 3	Man-3

Notes: RAES reading, scfm

start	18900
end	17800

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).





Entries made by:	John Glissmeyer		Technical Data Review performed by:	Carmen Arimescu	
Signature/date	5/14/2010	5/14/2010	Signature/date	*On File with Original*	6/24/2010

FLOW ANGLE DATA FORM

FlowAngleRev0.xls | 4-Aug-06 Based on ---- CCP-WTPSP-178

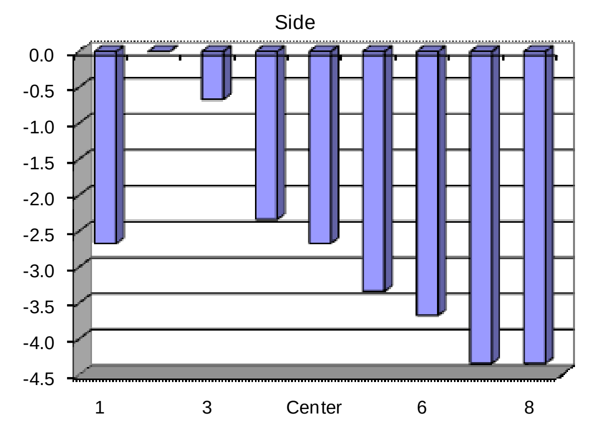
Site	**EP-3410--01-S**	Run No.	**FA-3**
Date	5/14/2010	Fan Setting	**manual low**
Tester	JAG & JEF	Fan configuration	**2 fans**
Stack Dia.	40 in	Approx. air vel.	1450 fpm at side center
Stack X-Area	1256.6 in2	Units	degrees (clockwise > pos. nos.)
Elevation	N.A. ft	Port	nearest to probe
Distance to disturbance	53.5 ft.	Stack Temp	81
Start/End Time	1205/1225		

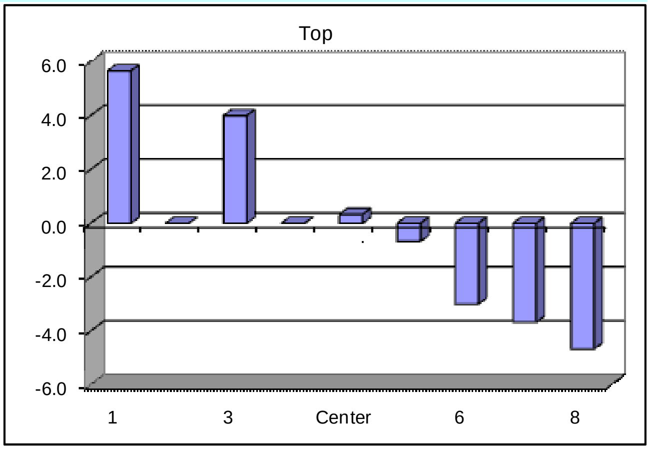
Order -->		1st				2nd			
Traverse-->		Side				Top			
Trial ---->		1	2	3		1	2	3	
Point	Depth, in.	deg. cw	deg. cw	deg. cw	Avg.	deg. cw	deg. cw	deg. cw	Avg.
1	1.00	-5	-1	-2	-2.7	4	6	7	5.7
2	4.17	0	0	0	0.0	0	0	0	0.0
3	7.71	1	-2	-1	-0.7	1	5	6	4.0
4	12.84	-2	-3	-2	-2.3	-1	1	0	0.0
Center	19.875	-2	-3	-3	-2.7	1	0	0	0.3
5	26.91	-2	-4	-4	-3.3	-2	0	0	-0.7
6	32.04	-2	-4	-5	-3.7	-4	-2	-3	-3.0
7	35.58	-4	-5	-4	-4.3	-4	-4	-3	-3.7
8	38.75	-5	-4	-4	-4.3	-5	-4	-5	-4.7
Mean of absolute values of all data:					2.7				2.4
w/o points by wall:					2.4				1.7
								all	2.6
								w/o wall pts	2.0

Instuments Used:		**Cal. Due**	
S-type pitot	Dwyer 72-inch S-type Pitot#11		Cert. of conformance
Velocity sensor	TSI VelociCalc	SN 305039	6/23/2010
Angle indicator	Shop built	Cat. 3	
Manometer	Dwyer 400-5, S36N	Cat. 3	Man-3

Notes:	RAES reading, scfm
start	10800
end	10800

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).





Entries made by:	John Glissmeyer		Technical Data Review performed by:	Carmen Arimescu	
Signature/date	*On File with Original*	5/14/2010	Signature/date	*On File with Original*	6/24/2010

VELOCITY TRAVERSE DATA FORM

Site	**EP-3410-01-S**	Run No.	**VT-1**
Date	**5/13/10**	Fan Configuration	**2 fans**
Testers	**JAG & JEF**	Fan Setting	**sashes closed**
Stack Dia.	40 in.	Stack Temp	81.4 deg F
Stack X-Area	1256.6 in.2	Start/End Time	1320/1505
Test Port	NEAREST TO PROBE	Center 2/3 from	3.67 to: 36.33
Distance to disturbance	53.5 ft.	Points in Center 2/3	2 to: 7
Velocity units	ft/min	Pitot correction:	0.84

Order -->		2nd				1st			
Traverse-->		Side				Top			
Trial ---->		1	2	3	Mean	1	2	3	Mean
Point	Depth, in.	Velocity				Velocity			
1	1.00	1705	1705	1772	1727.6	1880	1987	1898	1921.6
2	4.17	2253	2240	2251	2248.1	2365	2335	2372	2357.6
3	7.71	2370	2330	2358	2352.6	2495	2479	2478	2483.9
4	12.84	2381	2376	2428	2394.8	2518	2507	2539	2521.7
Center	19.875	2414	2432	2454	2433.5	2465	2487	2465	2472.7
5	26.91	2439	2446	2470	2451.7	2413	2442	2420	2425.1
6	32.04	2358	2349	2342	2349.5	2386	2394	2373	2384.5
7	35.58	2232	2244	2258	2244.8	2286	2321	2248	2285.1
8	38.75	1900	1971	1992	1954.7	2150	2140	2085	2125.2
Averages ---------->		2228.0	2232.6	2258.5	2239.7	2328.9	2343.7	2319.8	2330.8

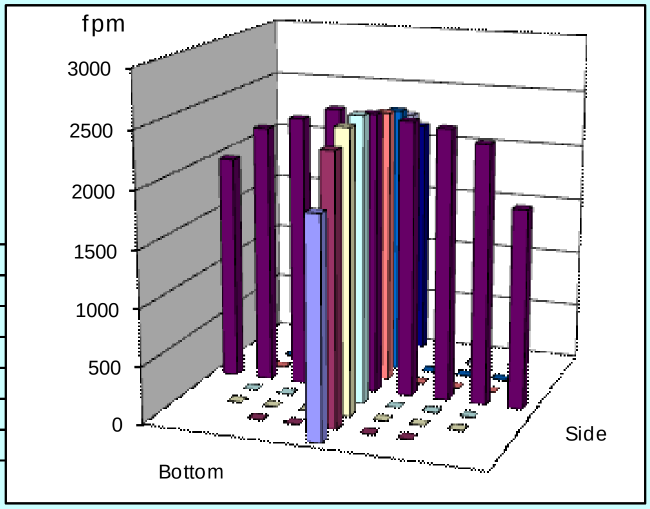
All	ft/min	Dev. from mean	***Center 2/3***	Side	Top	All
Mean	2285.3		Mean	2353.6	2418.6	2386.1
Min Point	1727.6	-24.4%	Std. Dev.	82.4	82.2	86.0
Max Point	2521.7	10.3%	COV as %	3.5	3.4	**3.6**

Flow w/o C-Pt 19760 acfm

Vel Avg w/o C-Pt 2264 fpm

	Start	Finish	
Stack temp	80.7	82	F
Equipment temp	N.A.	N.A.	F
Ambient temp	80	85	F
Stack static	0.80	0.70	mbars
Ambient pressure	1006	1005	mbars
Total Stack pressure	1007	1006	mbars
Ambient humidity	25%	21%	RH

Instuments Used:		Cal Due
Fisher Scientific	SN 90936818	9/29/2010
Zephyr II+	SN 80355	9/18/2010
TSI Velocicalc	SN 305039	6/23/2010
Dwyer Pitot Tube	PN 1605-72 A304	Cert. of Conf.



Notes: RAES readings, scfm

start 17870

end 17950

Entries made by:	Julia Flaherty		Technical Data Review performed by:	Carmen Arimescu
Signature/date	*On File with Original*	5/13/2010	Signature/date	6/24/2010

VELOCITY TRAVERSE DATA FORM

Site	**EP-3410-01-S**	Run No.	**VT-2**
Date	**5/13/10**	Fan Configuration	**2 fans**
Testers	**JAG & JEF**	Fan Setting	**sashes open**
Stack Dia.	40 in.	Stack Temp	82.2 deg F
Stack X-Area	1256.6 in.2	Start/End Time	1520/1650
Test Port	NEAREST TO PROBE	Center 2/3 from	3.67 to: 36.33
Distance to disturbance	53.5 ft.	Points in Center 2/3	2 to: 7
Velocity units	ft/min	Pitot correction:	0.84

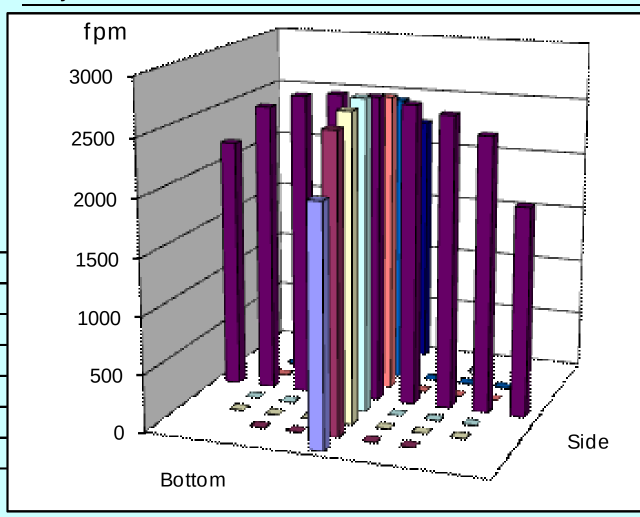
Order -->		1st				2nd			
Traverse-->		Side				Top			
Trial ---->		1	2	3	Mean	1	2	3	Mean
Point	Depth, in.	Velocity				Velocity			
1	1.00	1764	1772	1772	1769.6	2088	2106	2065	2086.3
2	4.17	2314	2348	2314	2325.4	2570	2610	2586	2588.9
3	7.71	2461	2474	2486	2473.8	2663	2707	2674	2681.3
4	12.84	2523	2538	2552	2537.9	2699	2744	2755	2732.8
Center	19.875	2568	2584	2591	2581.0	2661	2686	2712	2686.3
5	26.91	2586	2560	2606	2583.8	2597	2645	2653	2631.7
6	32.04	2539	2569	2545	2551.1	2547	2496	2601	2548.3
7	35.58	2446	2423	2449	2439.1	2464	2395	2515	2457.8
8	38.75	2127	2108	2111	2115.4	2206	2250	2233	2229.4
Averages ---------->		2369.8	2375.1	2380.7	2375.2	2499.5	2515.5	2532.6	2515.9

All	ft/min	Dev. from mean	***Center 2/3***	Side	Top	All
Mean	2445.6		Mean	2498.9	2618.2	2558.5
Min Point	1769.6	-27.6%	Std. Dev.	93.6	94.3	109.4
Max Point	2732.8	11.7%	COV as %	3.7	3.6	**4.3**

Flow w/o C-Pt 21136 acfm
Vel Avg w/o C-Pt 2422 fpm

	Start	Finish	
Stack temp	82.2	82.2	F
Equipment temp	N.A.	N.A.	F
Ambient temp	85.1	83.3	F
Stack static	1.30	0.70	mbars
Ambient pressure	1005	1005	mbars
Total Stack pressure	1006	1006	mbars
Ambient humidity	21%	22%	RH

Instuments Used:		Cal Due
Fisher Scientific	SN 90936818	9/29/2010
Zephyr II+	SN 80355	9/18/2010
TSI Velocicalc	SN 305039	6/23/2010
Dwyer Pitot Tube	PN 1605-72 A304	Cert. of Conf.



Notes: RAES readings, scfm

start	18900
end	19750

Entries made by:	John Glissmeyer		Technical Data Review performed by:	Carmen Arimescu
Signature/date	*On File with Original*	5/13/2010	Signature/date	6/24/2010

VELOCITY TRAVERSE DATA FORM

Site	EP-3410-01-S	Run No.	VT-3
Date	5/14/10	Fan Configuration	2 fans
Testers	JAG & JEF	Fan Setting	sashes open
Stack Dia.	40 in.	Stack Temp	77.8 deg F
Stack X-Area	1256.6 in.2	Start/End Time	0830/1010
Test Port	NEAREST TO PROBE	Center 2/3 from	3.67 to: 36.33
Distance to disturbance	53.5 ft.	Points in Center 2/3	2 to: 7
Velocity units	ft/min	Pitot correction:	0.84

Order -->		1st				2nd			
Traverse-->		Side				Top			
Trial ---->		1	2	3	Mean	1	2	3	Mean
Point	Depth, in.	Velocity				Velocity			
1	1.00	1743	1715	1763	1740.5	2029	2041	2088	2053.0
2	4.17	2231	2209	2293	2244.5	2493	2467	2486	2482.2
3	7.71	2403	2407	2418	2409.7	2574	2584	2584	2580.5
4	12.84	2444	2481	2486	2470.4	2628	2633	2629	2630.0
Center	19.875	2513	2506	2548	2522.2	2583	2586	2529	2566.2
5	26.91	2521	2527	2555	2534.3	2530	2477	2474	2493.7
6	32.04	2489	2495	2526	2503.2	2470	2451	2407	2442.4
7	35.58	2328	2344	2399	2357.0	2389	2364	2342	2364.9
8	38.75	2013	2057	2058	2042.6	2153	2168	2117	2145.9
Averages ---------->		2298.4	2304.6	2338.5	2313.8	2427.6	2419.1	2406.2	2417.6

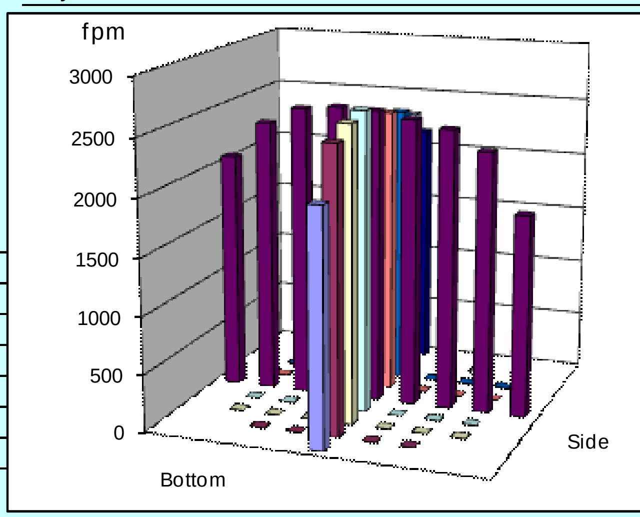
All	ft/min	Dev. from mean	***Center 2/3***	Side	Top	All
Mean	2365.7		Mean	2434.5	2508.6	2471.5
Min Point	1740.5	-26.4%	Std. Dev.	105.2	90.5	101.8
Max Point	2630.0	11.2%	COV as %	4.3	3.6	**4.1**

Flow w/o C-Pt 20450 acfm

Vel Avg w/o C-Pt 2343 fpm

	Start	Finish	
Stack temp	76.5	79	F
Equipment temp	N.A.	N.A.	F
Ambient temp	68	80	F
Stack static	0.80	0.60	mbars
Ambient pressure	1007	1005	mbars
Total Stack pressure	1008	1006	mbars
Ambient humidity	35%	29%	RH

Instuments Used:		Cal Due
Fisher Scientific	SN 90936818	9/29/2010
Zephyr II+	SN 80355	9/18/2010
TSI Velocicalc	SN 305039	6/23/2010
Dwyer Pitot Tube	PN 1605-72 A304	Cert. of Conf.



Notes: RAES readings, scfm

start	19300
end	18800

Entries made by:	John Glissmeyer		Technical Data Review performed by:	Carmen Arimescu
Signature/date	*On File with Original*	5/14/2010	Signature/date	6/24/2010

VELOCITY TRAVERSE DATA FORM

Site	**EP-3410-01-S**	Run No.	**VT-4**	
Date	**5/14/10**	Fan Configuration	**2 fans**	
Testers	**JAG & JEF**	Fan Setting	**manual low**	
Stack Dia.	40 in.	Stack Temp	81.8	deg F
Stack X-Area	1256.6 in.2	Start/End Time	1230/1355	
Test Port	NEAREST TO PROBE	Center 2/3 from	3.67	to: 36.33
Distance to disturbance	53.5 ft.	Points in Center 2/3	2	to: 7
Velocity units	ft/min	Pitot correction:	0.84	

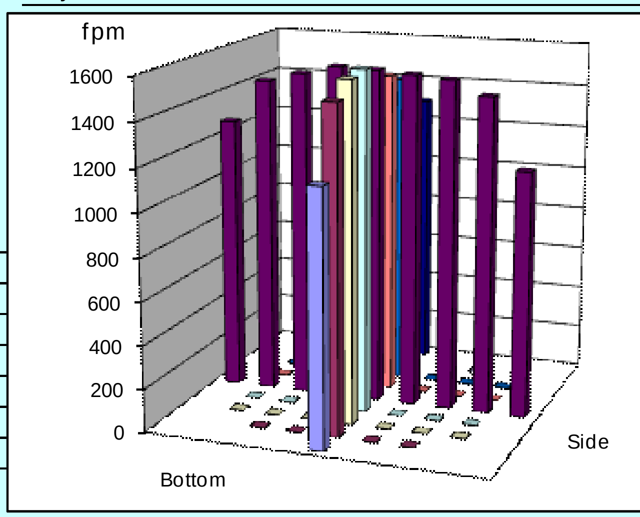
Order -->		2nd				1st			
Traverse-->		Side				Top			
Trial ---->		1	2	3	Mean	1	2	3	Mean
Point	Depth, in.	Velocity				Velocity			
1	1.00	1079	1106	1127	1104.3	1168	1195	1165	1176.0
2	4.17	1441	1370	1439	1416.8	1498	1487	1514	1499.4
3	7.71	1509	1461	1465	1478.4	1560	1574	1570	1568.0
4	12.84	1522	1472	1480	1491.3	1567	1602	1588	1585.4
Center	19.875	1528	1483	1497	1502.5	1541	1562	1562	1554.6
5	26.91	1525	1490	1505	1506.7	1495	1497	1513	1501.6
6	32.04	1460	1485	1462	1468.9	1473	1478	1418	1456.3
7	35.58	1424	1428	1425	1425.5	1414	1467	1432	1437.8
8	38.75	1246	1204	1250	1233.1	1293	1266	1328	1295.6
Averages ---------->		1414.9	1388.7	1405.5	1403.0	1445.2	1458.7	1454.3	1452.7

All	ft/min	Dev. from mean	***Center 2/3***	Side	Top	All
Mean	1427.9		Mean	1470.0	1514.7	1492.4
Min Point	1104.3	-22.7%	Std. Dev.	35.9	56.5	51.1
Max Point	1585.4	11.0%	COV as %	2.4	3.7	**3.4**

Flow w/o C-Pt	12351	acfm
Vel Avg w/o C-Pt	1415	fpm

	Start	Finish	
Stack temp	81.5	82	F
Equipment temp	N.A.	N.A.	F
Ambient temp	82.4	94	F
Stack static	0.20	0.40	mbars
Ambient pressure	1004	1003	mbars
Total Stack pressure	1004	1003	mbars
Ambient humidity	27%	17%	RH

Instuments Used:		Cal Due
Fisher Scientific	SN 90936818	9/29/2010
Zephyr II+	SN 80355	9/18/2010
TSI Velocicalc	SN 305039	6/23/2010
Dwyer Pitot Tube	PN 1605-72 A304	Cert. of Conf.



Notes: RAES readings, scfm

start	10800
end	10800

Entries made by:	Julia Flaherty		Technical Data Review performed by:	Carmen Arimescu	
Signature/date	*On File with Original*	5/14/2010	Signature/date	*On File with Original*	6/24/2010

Appendix B

Applicable Qualification Results from the Model Stack

Appendix B: Applicable Qualification Results from the Model Stack

These data are extracted from the report by Glissmeyer and Droppo (2007).

Table B.1 lists the gas-tracer uniformity tests conducted on the scale model with the dampers installed at the fan outlets. Only the data for Test Ports 2 and 3 are shown. The model Test Port 3 was just 1.5 duct diameters closer to the nearest upstream disturbance than the test ports on the 3410 Building Filtered Exhaust Stack. Therefore, the tracer uniformity results for the 3410 Building Filtered Exhaust Stack would likely be slightly more favorable relative to the acceptance criteria.

The % COV was calculated for the measured gas concentration at the points in the center two-thirds area of the scale model stack. The percent deviation from the mean concentration was also calculated for any point in the measurement grid.

Table B.1. Summarized Results of Gas-Tracer Uniformity Tests with Dampers

Injection Port		Operating Fans	Test Port	Run No.	Control Damper Setting (degrees)	Back Flow Damper Setting (degrees)	Center $^2/_3$% COV	% Deviation from Mean
B	Center	A & B	2	GT-49	45.0	45.0	1.7	4.4
B	Center	A & B	3	GT-48	45.0	45.0	1.3	2.6
A	Center	A	2	GT-38	90.0	70.0	1.3	2.6
A	Center	A	3	GT-37	90.0	70.0	2.3	5.3
A	Center	A & B	2	GT-27	90.0	70.0	7.2	13.8
A	Center	A & B	3	GT-34	90.0	70.0	3.2	7.9
B	Center	B	2	GT-46	90.0	70.0	1.1	1.9
B	Center	B	3	GT-47	90.0	70.0	1.7	2.9
B	Center	A & B	2	GT-52	90.0	70.0	6.3	12.3
B	Center	A & B	3	GT-54	90.0	70.0	3.9	9.1
A	Far Left	A & B	2	GT-28	90.0	70.0	5.2	9.8
A	Far Left	A & B	2	GT-31	90.0	70.0	4.5	13.1
A	Far Left	A & B	3	GT-32	90.0	70.0	3.2	6.6
A	Far Right	A & B	2	GT-29	90.0	70.0	10.0	28.3
A	Far Right	A & B	3	GT-33	90.0	70.0	2.8	5.8
A	Near Left	A & B	2	GT-51	90.0	70.0	2.0	4.5
A	Near Left	A & B	3	GT-36	90.0	70.0	2.9	5.5
A	Near Right	A & B	2	GT-30	90.0	70.0	5.7	9.6
A	Near Right	A & B	3	GT-35	90.0	70.0	3.5	7.9

Table B.2 lists the particle tracer uniformity results for the model stack. Only the data for Test Ports 2 and 3 are shown. The model Test Port 3 was just 1.5 DIA closer to the nearest upstream disturbance than the test ports on the 3410 Building Filtered Exhaust Stack. The last column shows the uniformity results for the combination of operating parameters tested.

Table B.2. Particle-Tracer Uniformity Tests with Dampers

Injection Port	Operating Fans	Test Port	Run No.	Control Damper Setting (degrees)	Back Flow Damper Setting (degrees)	Normalized % COV
A	A & B	2	PT-12	90	70	13.75
A	A & B	2	PT-21	90	70	7.41
A	A & B	3	PT-13	90	70	9.72
A	A & B	3	PT-20	90	70	8.12
A	A	2	PT-15	90	70	2.46
A	A	3	PT-14	90	70	3.73
B	B	2	PT-18	90	70	3.02
B	B	3	PT-19	90	70	3.61

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