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Physical Sciences Laboratory 1 Rooftop Stack Mixing Study

September 2016

JE Flaherty
EJ Antonio

U.S. DEPARTMENT OF ENERGY

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

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Performing these tests involved significant planning and preparation, and contributions from numerous individuals was necessary to successfully execute this effort. Some of these individuals are acknowledged here. Planning and project oversight was executed by Robert Ford, Jeff Rencken, Gina Wellsfry, Adam Gemmell, Brad Atencio, and Jerry Hall. The crafts support team included John Valdez and Mike Stocke. We particularly appreciate their efforts, working on the rooftop on several particularly hot days. Randy Kirkham assembled and loaned the 2D sonic anemometer used for these tests. We also acknowledge data reviews by Carmen Arimescu and staff with laboratories in the Physical Science Laboratory (PSL) building that accommodated our test equipment. Heather Culley provided editorial support in drafting this report.

Acronyms and Abbreviations

A2LA	American Association for Laboratory Accreditation
cfm	cubic feet per minute
fpm	feet per minute
GM-	Gas Mixing test
HDI	How Do I…? PNNL lab-level requirements, procedures and considerations for conducting work.
LOD	instrument limit of detection
PSL	Physical Sciences Laboratory
mph	miles per hour
PNNL	Pacific Northwest National Laboratory
ppb	parts per billion
ppm	parts per million
SF_6	sulfur hexafluoride
SLPM	standard liters per minute

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1.0 Introduction

To address concerns about potential worker exposures on the Physical Science Laboratory (PSL) rooftop, a tracer study was conducted to measure gaseous tracer concentrations downwind of six stacks on the southern half of the PSL building (PSL-1). These concerns were raised, in part, because the stacks on this building did not meet the current minimum stack height standard of 10 feet. Five of the six stacks were approximately 8 feet tall, with one shorter stack that was essentially level with the roof deck. These stacks were reconfigured in August 2016, and these exhaust points on PSL-1 are now 18 feet tall. This report describes the objectives of the tracer tests performed on PSL-1, provides an overview of how the tests were executed, and presents results of the tests. The tests on the PSL rooftop were a follow-on project from a similar study performed on the LSL2 ventilation exhaust (Flaherty and Antonio, 2016a).

The PSL building is a single-story office and laboratory building with a basement, built in the 1960s. The overall mission of the facility, and the basic types of research performed in the facility (in the areas of energy, materials, and multi-phase systems), has changed little since it was commissioned. The building contains many chemistry, materials, and biology laboratories, with numerous fume hoods and snorkels. The building ventilation is separated between the northern half (PSL-2) and the southern half (PSL-1). In the past, PSL-2 had many short exhaust points; however, these were consolidated into three tall stacks prior to the execution of the study described in this report. PSL-1 still retained non-standard stack heights through July 2016, and therefore, was the focus of this study. The results from PSL-1 may be applied, however, to comment on the historical configuration of emission points on PSL-2.

The basic test elements included a release of tracer gas inside a laboratory fume hood or snorkel and tracer gas measurements at the corresponding stack exit as well as at selected downwind locations on the PSL rooftop. The primary objective of these tests was to experimentally determine the gaseous tracer concentration at rooftop locations relative to the tracer concentration at the exhaust point. This information will be used to contribute to an evaluation of potential worker exposures from routine roof access. Measurements at various rooftop locations were made, typically concurrently with measurements at the exhaust point to evaluate the concentration differences.

A secondary objective of these tests was to experimentally determine the gaseous tracer concentrations entering the PSL-1 and PSL-2 air intakes. This measurement was motivated by odor complaints in the facility, sometimes stemming from concerns that PSL-1 exhaust was entering the PSL-2 supply system.

Figure 1.1 shows a plan view of the PSL building with test measurement locations identified. Note that the legend for this figure is positioned within the building's courtyard. PSL-2 is north of the courtyard, while PSL-1 is south of the courtyard. Tests were performed on the six primary fans for the PSL-1 portion of the facility, as indicated by the colored squares in Figure 1.1.

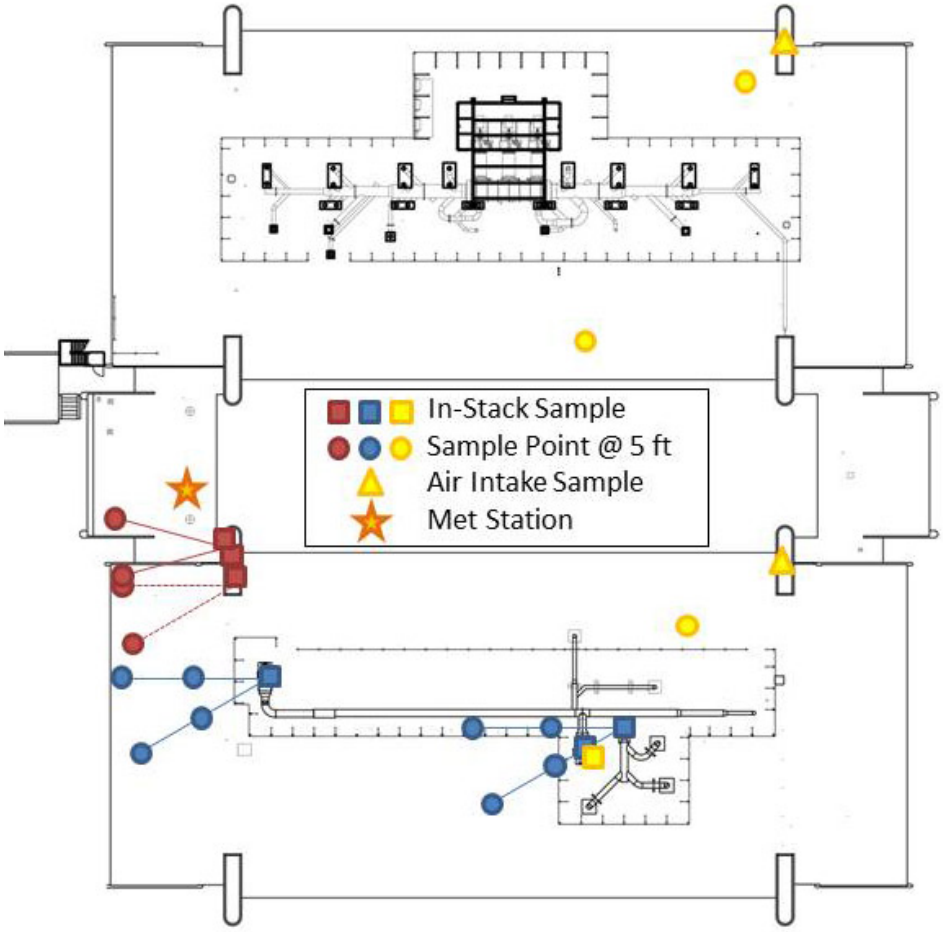

Figure 1.1. Plan View of the PSL Building Rooftop with Test Equipment Locations

2.0 Methods

To support the assessment of potential worker exposures from the PSL exhaust, a tracer study was performed to experimentally determine concentrations at selected downwind locations compared with the exhaust concentration. This section describes the ventilation system, in general, and the testing methods employed in this study. Some of the specific steps employed in executing the test may be found in the test plan for this work (Flaherty and Antonio, 2016b).

2.1 PSL-1 Exhaust Configuration

The PSL-1 exhaust system described in this report ventilates first floor and basement spaces (primarily laboratories, but also a machine shop and other spaces) in the southern half of the PSL building. Figure 2.1, Figure 2.2, and Figure 2.3 show diagrams of the PSL-1 rooftop fans, first floor exhaust routing with fume hood and snorkel locations, and basement exhaust routing with fume hood and snorkel locations. The fans for the three pylon stacks are located in the basement. Table 2.1 lists the fan number, along with the common fan name that will be used in this report. A summary of the spaces ventilated by each fan is also included in this table. Note that there are at least two other exhaust points on the PSL-1 rooftop; however, these ventilation exhausts service general office and non-laboratory spaces without chemical emissions concerns.

A photograph of the PSL-1 rooftop with all of the exhaust stacks, focusing on the pylon, is shown in Figure 2.4. The Pylon North stack exit is located below the grate and ventilates Lab 242 in the basement. The Pylon Middle stack ventilates the machine shop and Lab 242 enclosures within the basement. The Pylon South stack ventilates a canopy and snorkel in Lab 247, as well as a laser and calorimeter in Lab 429, which are located in the basement. Photographs expressly focused on the East, 1300, and West Fans are included in Figure 2.5. The East Fan and West Fan are connected by 24 in. diameter ducting than runs east-west on the rooftop. The system of ducting has feeder ducts ranging in size from 8 in. to 24 in. diameter, which pull air from labs located on the first floor and basement. Finally, the 1300 Fan ventilates Lab 1300 on the first floor.

Table 2.1. Fan Name, Number, and Ventilation Source for PSL-1 Fans

Fan Name	Fan Number	Ventilation Space Location	Test Injection Location
Pylon North	HVE-081-F	Basement	Lab 242 - Snorkel
Pylon Middle	HVE-082-F	Basement	Room 201 Machine Shop - Snorkel
Pylon South	HVE-299-F	Basement	Lab 247 - Snorkel
West Fan	HVE-014-F (previously HVE-274-F)	First Floor	Lab 1425 - Hood #1
East Fan	HVE-013-F	First Floor, Basement	Lab 1401 - Hood #4
1300 Fan	HVE-348-F	First Floor	Lab 1300 – Hood HVE-349-FH

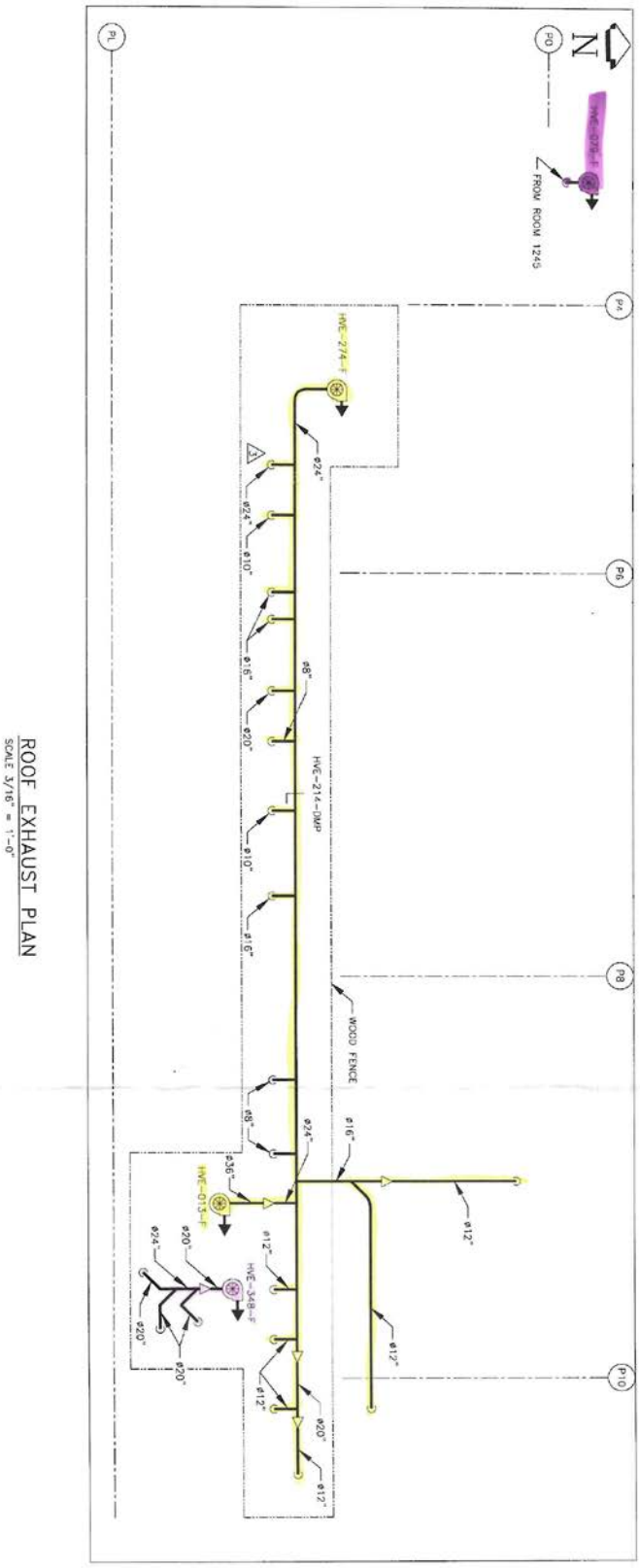

Figure 2.1. PSL-1 Rooftop Exhaust Diagram for the West, East, and 1300 Fans. Note: the West Fan, labeled here as HVE-274-F, has since been re-numbered as HVE-014-F.

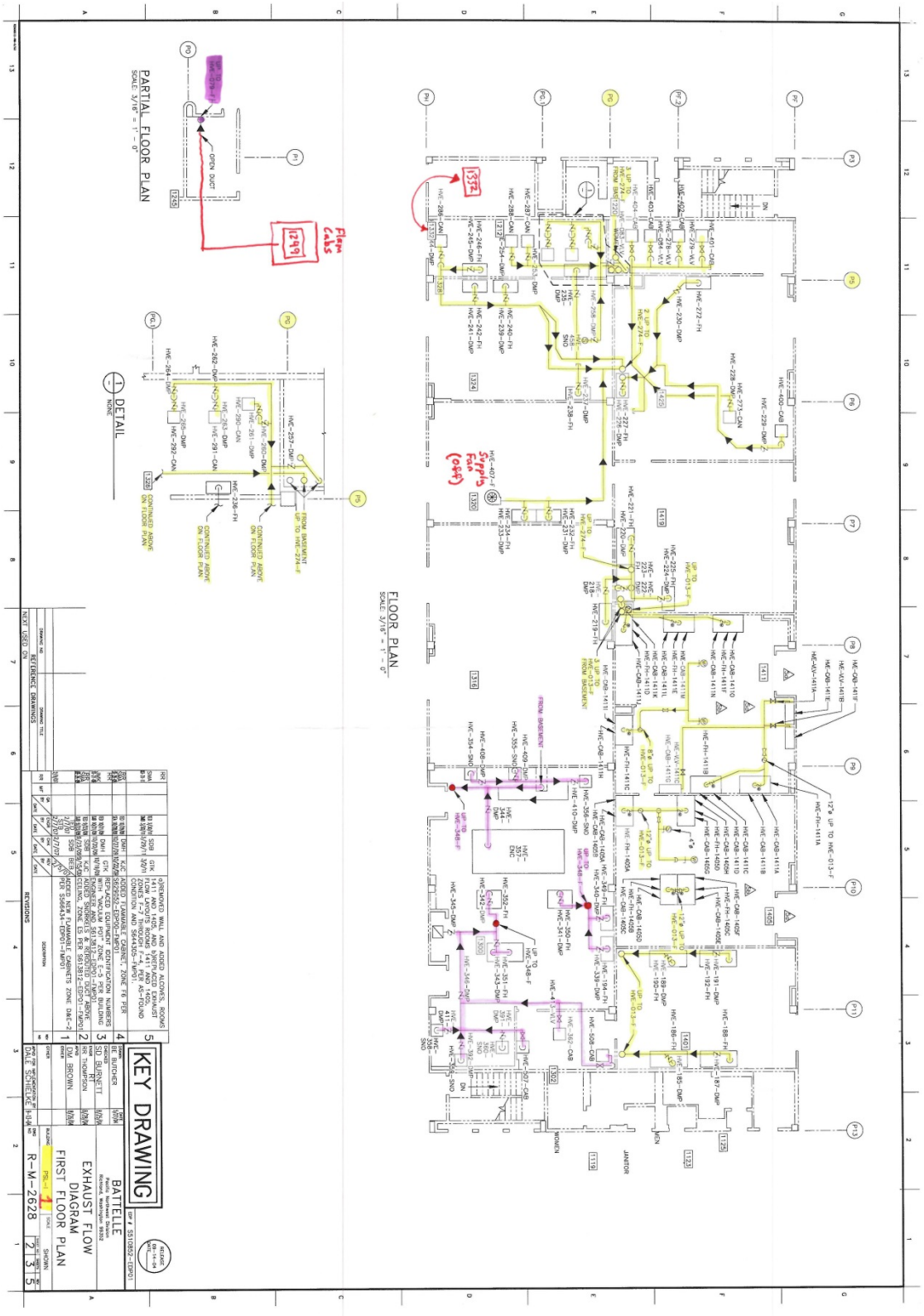

Figure 2.2. PSL-1 First Floor Exhaust Flow Diagram. Note: the West Fan, labeled here as HVE-274-F, has since been re-numbered as HVE-014-F.

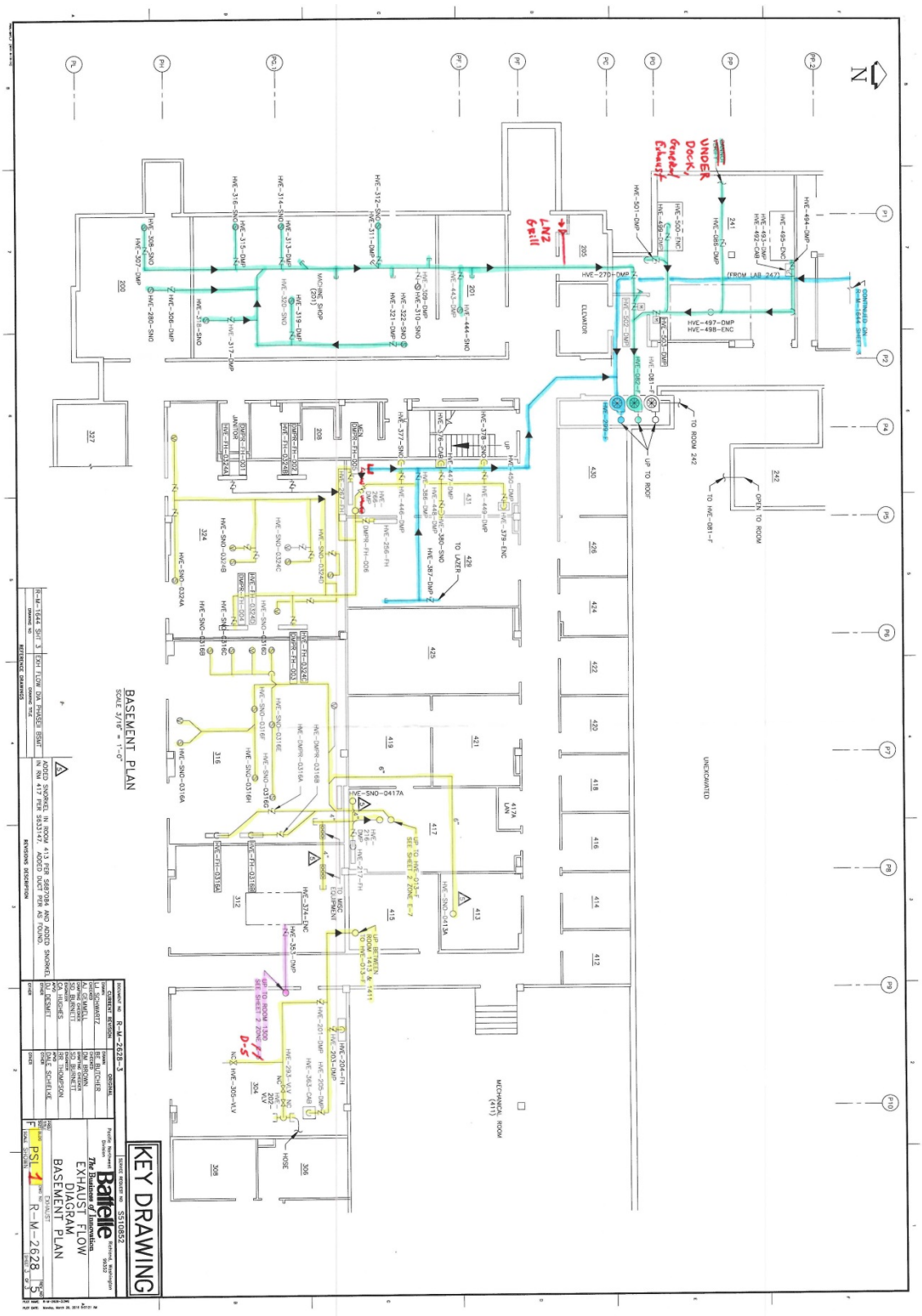

Figure 2.3. PSL-1 Basement Exhaust Flow Diagram. Note: the West Fan, labeled here as HVE-274-F, has since been re-numbered as HVE-014-F.

Figure 2.4. PSL-1 Exhaust Stacks in Pylon Located in Southwest Corner of the Courtyard. Pylon South and Pylon Center stacks extend approximately 8 ft. above the roof surface. Pylon North terminates below the grating. In the background, the three remaining stacks/fans are visible.

Figure 2.5. Fans on PSL-1 Rooftop; (a) 1300 Fan, East Fan and (b) West Fan

2.2 Testing Methods

The basic test process was to inject gas in a fume hood or snorkel and measure that gas in and around the exhaust stack on the rooftop. The gas injection equipment included a cylinder of pure sulfur hexafluoride (SF_6), a regulator, a mass flow controller, a mass flow meter, and tubing. The tubing was secured to a bench stand, which was positioned either within a fume hood with the sash mostly down or in the open end of a snorkel. SF_6 was released at a rate necessary to achieve a target stack exit concentration between 30 and 80 ppm. This target concentration was necessary to measure gas concentrations above the instrument detection limit at the rooftop sampling positions downwind of the stack. A photo of the tracer injection equipment setup in Room 247 (injection into snorkel) and the 1300 Lab (injection into fume hood) is included in Figure 2.6.

Figure 2.6. Tracer Injection Setup in (a) Lab 247 Snorkel and (b) Lab 1300 Fume Hood

For each gaseous injection location, the corresponding stack exit tracer concentration was sampled with either a “shepherd’s hook” or an open tube. The “shepherd’s hook” was designed to secure the sampling line inlet within the stack, several inches from the edge of the stack and just below the exit plane. For all stacks except the Pylon North stack, this “shepherd’s hook” was used for the stack measurement. In the case of the Pylon North stack, tubing was simply inserted within the duct and zip-tied to the grating. A photo of the “shepherd’s hook” design is shown in Figure 2.7. The bent portion catches the edge of the stack duct, while the long handle allows staff to secure the sample line on the 8-foot stacks without the use of a ladder. Figure 2.8 shows the “shepherd’s hook” in place on the West Fan.

Rooftop sampling points were positioned at approximately 5 feet above the roof deck to represent the breathing zone of a worker, standing upright. These sampling points were positioned with tripods that had ¼” tubing that was looped at the top of the tripod so the sample line inlet was pointed downward at the 5-foot mark to ensure that any precipitation would be unlikely to enter the tubing. These tripods were deployed on the rooftop for about a week, so overnight precipitation concerns were mitigated by this

tubing configuration. Figure 2.9 shows an example of the tripod on the rooftop. This particular sampling location was 115 feet north of the East Fan, which was deployed as part of the air intake test (described in Section 2.3).

Figure 2.7. Photo of "Shepherd's Hook" Used to Sample Fan Exhaust

Figure 2.8. Shepherd's Hook Sampling Assembly on the West Fan

Figure 2.9. Tripod with Sample Tube Located 115 ft. North of the East Fan is 10 ft. from Roof Edge

All sample lines were the same length (100 feet) to ensure identical sample lag times for each sample location. Gas sampling was performed with a small rocking piston pump to draw air through the sample lines and a photoacoustic gas analyzer that sampled from the sample line (see Figure 2.10). Three Brüel and Kjær gas analyzers (Model 1302, Denmark) were used to simultaneously measure rooftop concentrations from three locations. This equipment was staged in the PSL courtyard (see Figure 2.11). Note that any sample lines that were not in use were capped and all exhaust lines were routed away from the work area. All measurements made in these tests used the water correction feature in the gas analyzer. With this mode of operation, the SF_6 detection limit for the instrument is 5 ppb. The instrument collects near-instantaneous samples by drawing just enough air to fill its sample cell and provides analysis results in approximately 55 seconds.

Figure 2.10. Pumps and Gas Analyzers for Testing (from Flaherty and Antonio, 2016a)

Figure 2.11. PSL Courtyard with Shade Tent where Equipment, Sampling Lines were Located

2.3 Sample Configurations

These tests were performed for each of the six fans listed in Table 2.1. Table 2.2 presents a summary of the rooftop sampling locations used for each exhaust stack. These locations correspond to the sample points (circular markers) shown in Figure 1.1. Table 2.3 lists the rooftop and air intake sampling locations relative to the East Fan location for the air intake test. For each of the pylon stacks, a pair of sampling locations was positioned 30 feet downwind of the stack, and at two azimuth angles that were separated by 30°. For the remaining stacks, a pair of sampling locations was positioned at 20 feet, and another pair at 40 feet downwind of the stack at two azimuth angles, separated by 30°. For the pylon stacks, there was not enough room to position samplers at 40 feet (without running off of the rooftop), so just a single pair at 30 feet was used. Figure 2.12 shows the four sampling locations situated 20 and 40 feet away from the West Fan (HVE-014-F) at 240^{o} and 270^{o}, relative to the fan. The foreground of this figure also shows the 2D sonic anemometer that was deployed on the rooftop for these tests.

Table 2.3 presents a summary of the rooftop and air intake sampling positions during the air intake tests. As is depicted by the yellow markers in Figure 1.1, the sampling positions during this test were distributed in a manner that attempts to capture the structure of the plume between the emission point and the air intake positions. Sample lines were positioned at each of the PSL-1 and PSL-2 air intakes (with tubing within the pylon, and secured to the grating with a zip-tie), and tripod-mounted sample lines were also positioned several feet upwind of the air intake positions to compare the open-air concentration with the concentration within the air intake. An additional tripod sampler was positioned on the PSL-2 rooftop, north of the East Fan, as a mid-plume comparison point.

Table 2.2. Downwind Sampling Locations for each Stack Test. A reference measurement was made at the stack exit for each Test Pair.

Fan	Pylon North	Pylon Middle	Pylon South	West Fan	East Fan	1300 Fan
Test Pair 1	255°, 285° 30 ft.	255°, 285° 30 ft.	240°, 270° 30 ft.	240°, 270° 20 ft.	240°, 270° ~12 ft.	240°, 270° 20 ft.
Test Pair 2	N/A	N/A	N/A	240°, 270° 40 ft.	240°, 270° ~32 ft.	240°, 270° 40 ft.

Table 2.3. Downwind Sampling Locations for the Air Intake Test. A reference measurement was made at the East Fan exhaust.

Sampling Position	25'W, 18' S of PSL1 Air Intake	PSL 1 Air Intake	50'W, 10' N of Courtyard Corner	6'W, 10' S of PSL 2 Intake	PSL 2 Air Intake
Direction and Distance from East Fan	40° 40 ft.	40° 80 ft.	0° 115 ft.	15° 195 ft.	15° 205 ft.

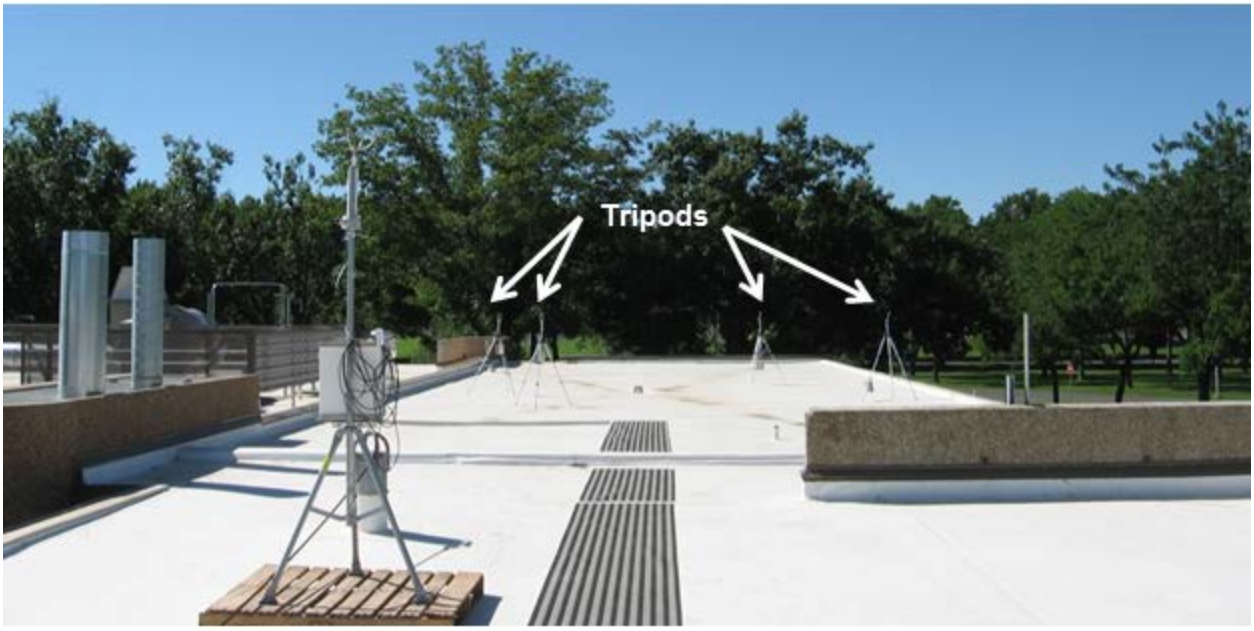

Figure 2.12. Sampling Array Situated 20 and 40 Feet West and West-Southwest of West Fan with 2D Sonic Anemometer in Foreground

2.4 Quality Assurance and Quality Control

The work presented in this report was performed according to quality assurance guidance listed in PNNL's How Do I…? (HDI) system. A test plan (Flaherty and Antonio 2016b) was written to document the scope of the work and the steps for executing the test. Data from these tests were recorded onto data sheets; test equipment used (with serial numbers) and calibration due dates were included. All data entry

blocks on each data form contained an entry or marking to indicate that it was intentionally left blank. Finally, each sheet was signed by one of the data takers indicating the form is complete.

After tests were completed, the handwritten data were transcribed into a spreadsheet and all electronic datasheets were reviewed for transcription errors. A signature on the data sheet was used to indicate the completion of this review. Additionally, calculations performed with the spreadsheet were independently verified with a hand-calculation (using a calculator).

Prior to and after performing the rooftop gas tests, a calibration check of the three B&K Model 1302 gas analyzers was performed. These checks were performed using gas mixtures from an A2LA-accredited supplier. This ensured that the instrument responds appropriately to SF_6 at two concentrations that were separated by over an order of magnitude in concentration difference. This also provides data to demonstrate that the instruments respond similarly to each other. The results of these tests are included in Appendix A.

3.0 Test Results

The primary reportable results from the PSL tracer study are the relative mean and maximum rooftop concentrations, compared against the mean stack discharge concentration. This section describes the meteorology during the tests, along with the concentration measurements from the tests. The completed data sheets for the tests are included in Appendix B.

3.1 Test Meteorology

The measurements described in subsequent sections were performed over the course of three days in late July. Since the rooftop measurement locations were open to the atmosphere, meteorological influence was the primary factor in the concentrations measured. Temperatures were high on each of the test days, with daily maximum temperatures in the upper 90s to lower 100s (degrees Fahrenheit). The winds were mostly light and variable. A 2D sonic anemometer (i.e., meteorological station), deployed on the western part of the PSL roof (Figure 1.1) was used to monitor the local wind speed and wind direction to guide the tripod sampler deployment locations during the tests. With the low winds and highly variable wind directions, recorded wind information on the data sheets (Appendix B) were often approximated as 1–2 mph with wide wind direction bands or an approximate center value for the wide band of observed wind directions.

From a dispersion perspective, hot days tend to represent relatively high levels of diffusion due to thermal mixing. The sun heats the ground, which results in heated air near the surface, which rises and mixes the air vertically. However, under light winds, plumes tend not to disperse as much as they would under higher winds, which results in greater mechanical mixing. Overall, the test conditions were moderate dispersion cases, and may represent typical plume concentrations.

3.2 Concentration Results

Gaseous tracer tests were performed under normal stack operating conditions. During the first day of testing, the centerline stack velocity for each stack was measured. The stack dimensions were then used to approximate the flow rate through the stack, as shown in Table 3.1.

Table 3.1. Stack Dimensions, Centerline Velocities, and Corresponding Flow Rates

	Pylon North	Pylon Middle	Pylon South	West Fan	East Fan	1300 Fan
Dimensions	4 in. Diam.	16 in. Diam.	12 in. Diam.	16 × 22 in.	16 × 22 in.	10 × 14 in.
Centerline Velocity (fpm)	4,130	3,360	2,790	4,975	5,150	4,830
Approx. Flow Rate (cfm)	360	4,695	2,190	12,160	12,590	4,695

During each tracer release, the stack exit concentrations, along with rooftop concentrations at a common fixed distance, but two azimuth angles, separated by 30°, were measured. The lateral separation between two measurement locations increases the probability that the plume will be detected by at least one of the

locations when the plume meanders downwind of the stack. Several approaches to examining these data have been taken here. First, the number of plume "hits" was tabulated to get a sense of the intermittency of detection. Then, the concentration time series were examined to evaluate the magnitude of the hits, the mean concentration, and the maximum concentration. Finally, the maximum concentration from the rooftop sampler, as a fraction of the stack exit concentration, was calculated and plotted on a plan view of the PSL rooftop to quantify the peak concentration and spatial relationships between the peaks.

3.2.1 Plume Detection

The concentrations measured at each of the sample locations varied from small negative values (an instrument artifact) to nearly 500 ppb. As a first examination of the data, the fraction of measurements that were above the instrument limit of detection (LOD) was tabulated. The instrument specification lists the LOD for SF_6 as 5 ppb when water correction is enabled. However, background measurements made during the course of the calibration checks for this test indicate that the standard deviation of the low-concentration measurement was approximately 3.5 ppb. A standard approach to define the LOD from measurements is to use 3 times the standard deviation of a low-concentration measurement record (Keith et al, 1983). The LOD, based on background measurements, is therefore approximately 10.4 ppb. For this evaluation, we take a conservative approach and assign 10 ppb as the LOD, rather than the 5 ppb defined in the instrument specifications. Since the global background concentration for SF_6 is approximately 10 ppt (NOAA, 2016), the LOD defines (from the instrument's perspective) the above-background concentration, so measurements that are greater than 10 ppb have been designated as plume hits.

Table 3.2 lists the fraction of measurements that were designated as plume "hits" from each stack test. This fraction is also represented by a colored bar with a width that corresponds to the fractional value in the table. Note that the Sample 1 and Sample 2 columns represent the two samples at a shared downwind distance (azimuth values not shown). For the pylon stacks, the 30 feet distance placed the samplers near the west edge of the roof, so the samplers were placed at just one downwind distance. For the remaining stacks, samplers were placed at both 20 and 40 feet. The air intake test (GM-7) had a different configuration altogether, so although the data are listed under the Sample 1 and Sample 2 columns, they were not simultaneous measurements at common distances. Instead, they were located at varying distances to capture the plume travel toward each of the PSL-1 and PSL-2 intakes. The locations are shown in Figure 1.1, and specific details about the concentrations and the locations will be presented in subsequent sections.

In general, 26 consecutive records of concentrations were measured during the test of a sample pair. The Pylon Middle measurements were aborted after 13 records because concentrations appeared to be consistently low, and low measurements had already been measured during a first attempt on this stack. (Instrument screen error caused data loss at one sampler location, but a full record was completed for the other location.) In many instances, one of the two measurements had fairly low numbers of plume hits, while the other had a fairly high plume hit count. This indicates the preferential plume direction was aligned with the sampler with higher hits. In the case of the West Fan, both samplers and both distances had relatively low plume hits, indicating that either the plume was narrower than the separation distance between the sampler pair, or the preferential direction of the plume was on one side or the other of the sampler pair. In either case, occasional plume meander across the sampler location was the likely source of the plume hits.

Table 3.2. Number of Plume Hits (>10 ppb) as a Fraction of the Total Number of Measurements

Test Run	Fan	Sample 1	Sample 2	Distance (ft)
GM-1	Pylon North	4/26	15/26	30
GM-2B	Pylon Middle	1/13	8/13	30
GM-3B	Pylon South	19/26	26/26	30
GM-4	West Fan	4/26	6/26	20
		4/26	7/26	40
GM-5	1300 Fan	19/26	24/26	20
		20/26	18/26	40
GM-6	East Fan	1/26	16/26	20
		1/26	20/26	40
GM-7	East Fan (Air Intake Study)	14/26	16/26	195 / 205
		7/26	10/26	40 / 80
		14/26	N/A	115 / N/A

3.2.2 Concentration Mean and Maxima

These tracer tests were performed in the open atmosphere, where varying wind speed, wind direction, cloud cover, rooftop structures, and other atmospheric and physical effects influence the concentrations measured at a fixed location. Concentration time series plots are presented in this section to illustrate the intermittency of the measured concentrations, the mean concentrations, and the magnitude of the concentration maxima. In each of these plots, any negative concentration values were replaced with zero values, and all remaining values remain unchanged. A dashed horizontal grey line has been drawn at the LOD value (10 ppb). To calculate the mean concentration during the course of the measurements, all the values less than 10 ppb where replaced with zeroes. When the mean concentration for the resulting measurement record was above 10 ppb, a dashed horizontal colored line at the mean concentration value is included.

The concentration time series plots from the measurements made downwind of the three pylon stacks is shown in Figure 3.1. As noted in Table 3.2, only 4 of the 26 measurements for the 285° sampling position (Sample 1 from the table) downwind of the Pylon North stack were above LOD, so the mean concentration is less than 10 ppb. The 255° sampling position (Sample 2 from the table), however, had 15 samples that were above LOD. In this case, the mean was 14.5 ppb, and the peak value was 96.5 ppb. Similarly, the measurements downwind of the Pylon Middle stack were below LOD for the 285° sampling position and above LOD for the 255° position. The mean concentration for this location was 37 ppb and the peak concentration was 314 ppb. The Pylon South stack had the highest record of above-LOD measurements in this group (and among all tests). Both of the samplers had above-LOD mean concentrations. The 270° sampling position had a mean concentration of 62 ppb and a peak concentration of 293 ppb. The 240° sampling position had a mean concentration of 198 ppb, and a peak concentration of 701 ppb. In this case, the peak concentration at both locations occurred at the same time.

The concentration time series plots from the measurements made downwind of the West, East, and 1300 Fan stacks is shown in Figure 3.2. The West Fan sampling points were primarily below the LOD, and the mean concentrations at the two 270° sampling positions were just slightly above 10 ppb. At 20 feet downwind, the mean was 17 ppb, while at 40 feet, the mean was 12 ppb. The peak concentrations were 226 ppb and 187 ppb at the 20 foot and 40 foot distances, respectively. On the other hand, the samplers downwind of the East Fan had fairly regular above-LOD measurements at the 270° locations. Both of the

240° locations had mean concentrations below 10 ppb, but the 270° location at 20 feet had a mean of 18 ppb and the 270° location at 40 feet had a mean of 11 ppb. The peak concentrations for these samplers were 41 ppb and 31 ppb, respectively. Finally, for the 1300 Fan, a high fraction of samples had above-LOD concentrations, and all four locations had mean values above 10 ppb. At both distances, the 240° location had slightly lower concentrations than the 270° location. At 20 feet and 240°, the mean was 34 ppb compared with 52.5 ppb at 270° and at 40 feett and 240°, the mean concentration was 27 ppb compared with 41ppb at the 270° location. Similarly, the peak values at the 240° location were slightly lower than at the 270° location. At 20 feet and 240°, the peak was 150 ppb, while the 270° location was 198 ppb. At 40 feet and 240°, the peak concentration was 131 ppb, while the 270° peak was 161 ppb.

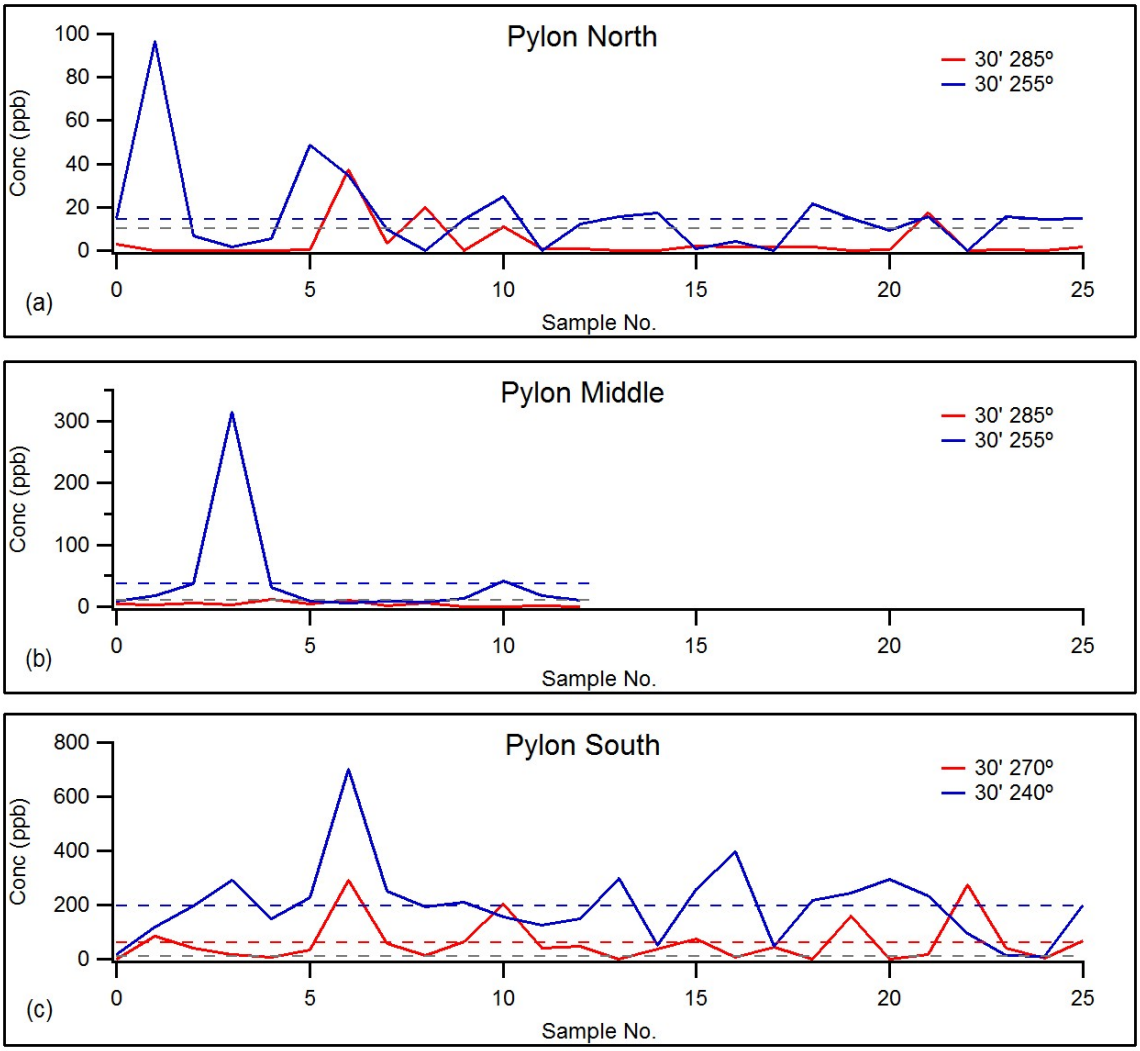

Figure 3.1. Time Series Plots of Concentrations Measured Downwind of Each of the Three Pylon Stacks. Mean stack concentrations were 51, 55, and 105 ppm at the Pylon North, Middle, and South Stacks, respectively.

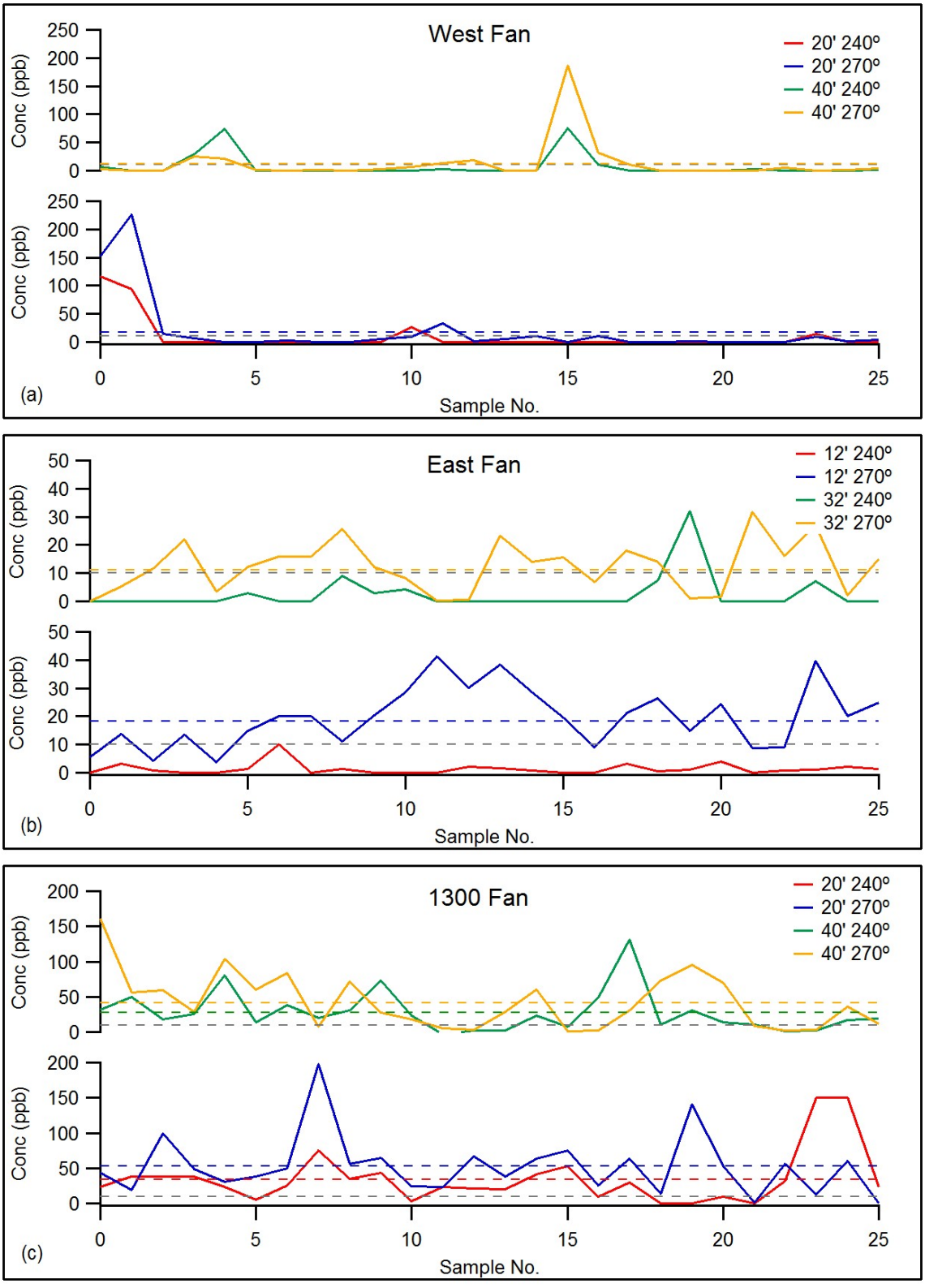

Figure 3.2. Time Series Plots of Concentrations Measured Downwind of the West, East, and 1300 Stacks. Mean stack concentrations were 37, 37, and 80 ppm at the West, East, and 1300 Fan Stacks, respectively.

The concentration time series for the rooftop measurements during the air intake test is shown in Figure 3.3. In this case, rather than deploying sampling pairs at common downwind distances, sampling locations were distributed to capture the plume path between the East Fan and the PSL-1 and PSL-2 air intake locations, as shown by the yellow markers in Figure 1.1. The pair of measurements made at the start of the test was the PSL-2 air intake location itself (labeled PS2 in Figure 3.3), and a rooftop location that was 6 feet west and 10 feet south of that air intake (labeled 6W_10S in Figure 3.3). Note that these concentration data show similar temporal behavior, with local peaks occurring at the same time for both locations (with the exception of Sample No 21, where the air intake saw a peak and the rooftop location saw a minimum).

The end of the test had three simultaneous measurements because the stack measurement, which was observed to be very stable for all previous tests, including the test with the PSL-2 air intake, was omitted during the test in favor of a spot-check at the end of the test to ensure the gas was flowing as expected. The three measurements at the end of this air intake test were located in the PSL-1 air intake (labeled PS1 in Figure 3.3), a rooftop location 25 feet west and 18 feet south of the PSL-1 air intake (labeled 25W_18S in Figure 3.3), and a rooftop location 50 feet west and 10 feet north of the northeast corner of the courtyard (labeled 50W_10N in Figure 3.3). This last measurement location was directly north of the East Fan stack, and on the north side of the courtyard, so although it is not expected that the concentration trend at this location would match the other locations, which are located more closely together, many of the primary peaks in the 50W_10N time series record match peaks in the PSL-1 air intake, and, to a lesser extent, the 25W_18S record. The highest concentration measured during all of these tests, 458 ppb, was measured at this relatively distant position. In this case, it appears that the plume was directed toward the north, so the centerline concentration may have been captured by the 50W_10N sampler, while the remaining sampler locations were measuring the edges of the plume.

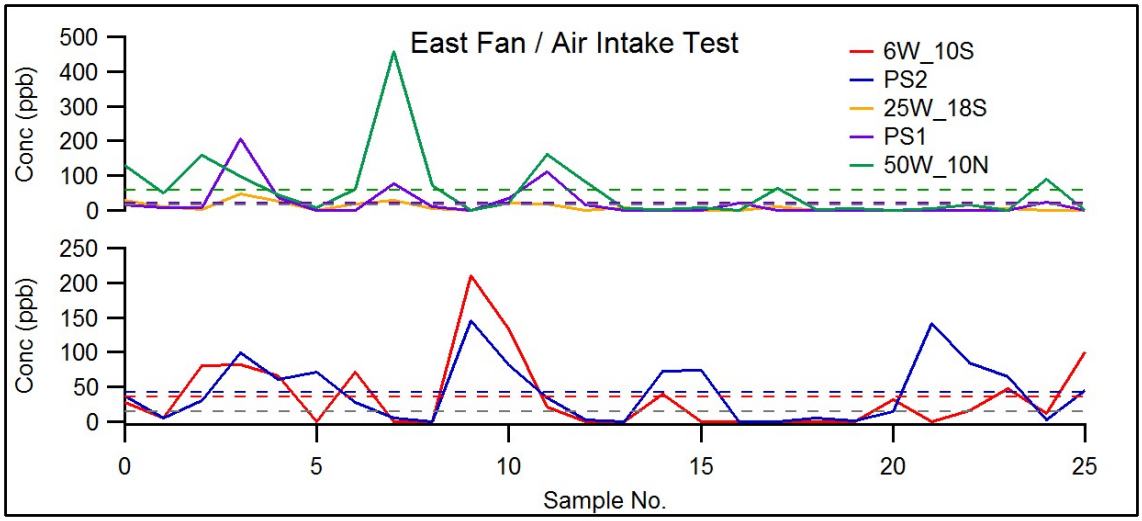

Figure 3.3. Time Series Plots of Concentrations Measured During Air Intake Sampling. Mean stack concentration was 37 ppm.

3.2.3 Relative Concentration Maxima

As noted in Section 3.2.2, the concentrations measured at a particular sampling location vary significantly over the course of a relatively short measurement period. The peak concentration was often a relatively isolated value, with mean concentrations often an order of magnitude lower than the peak. Therefore, the

most conservative measure of the rooftop concentration, the ratio of the peak rooftop concentration (presented in Section 3.2.2) to the average stack concentration, has been plotted in this section.

Figure 3.4, Figure 3.5, and Figure 3.6 show the concentration maximum at each sampler location downwind of the pylon stacks as a fraction of the mean stack concentration. In these and all plots in this section, for cases where the ratio is lower than the minimum value of the color scale, the minimum color (purple) is used. Similarly, when the concentration ratio is higher than the maximum value on the color scale, the maximum color (red) is used. The stack location is indicated by a red marker in each of these plots because the ratio of the stack concentration to the stack concentration is 1. In general, the peak concentrations for these tests were slightly higher for the sampler position that was further south. For the Pylon North stack, the southern sampler point was approximately 3 times higher than the northern sampler point. The difference was significantly larger for the Pylon Middle stack, which had a peak concentration 30 times higher at the southern point than the northern point. The Pylon South stack measurements were similar to the Pylon North stack in that the southern sampler point was 2 times higher than the northern sampler point; however, as described previously, the concentration ratios at both locations were higher than the corresponding locations downwind of the other pylon stacks.

The ratio of the peak concentrations downwind of the pylon stacks to the mean stack concentrations were as low as 0.0002 and as high as 0.007. This means that the highest concentrations, approximately 30 feet downwind of these stacks, was 3 to 4 orders of magnitude lower than the concentration coming out of the stack.

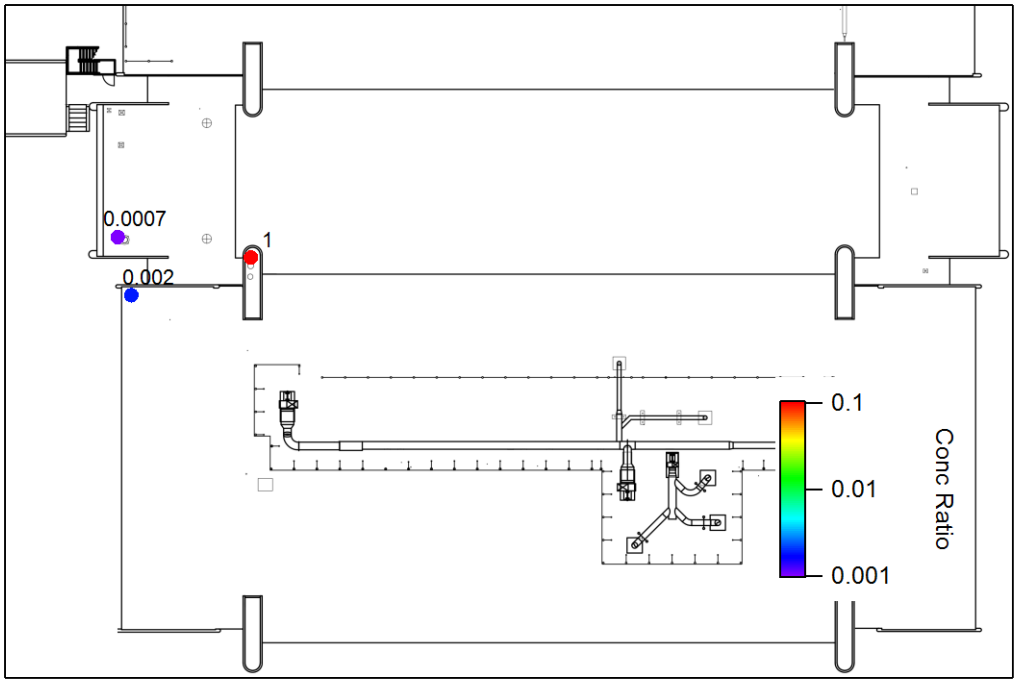

Figure 3.4. Colored Dot Plots Representing Maximum Concentration Ratios from Pylon North Sampling. Sample positions are illustrative, and not to scale.

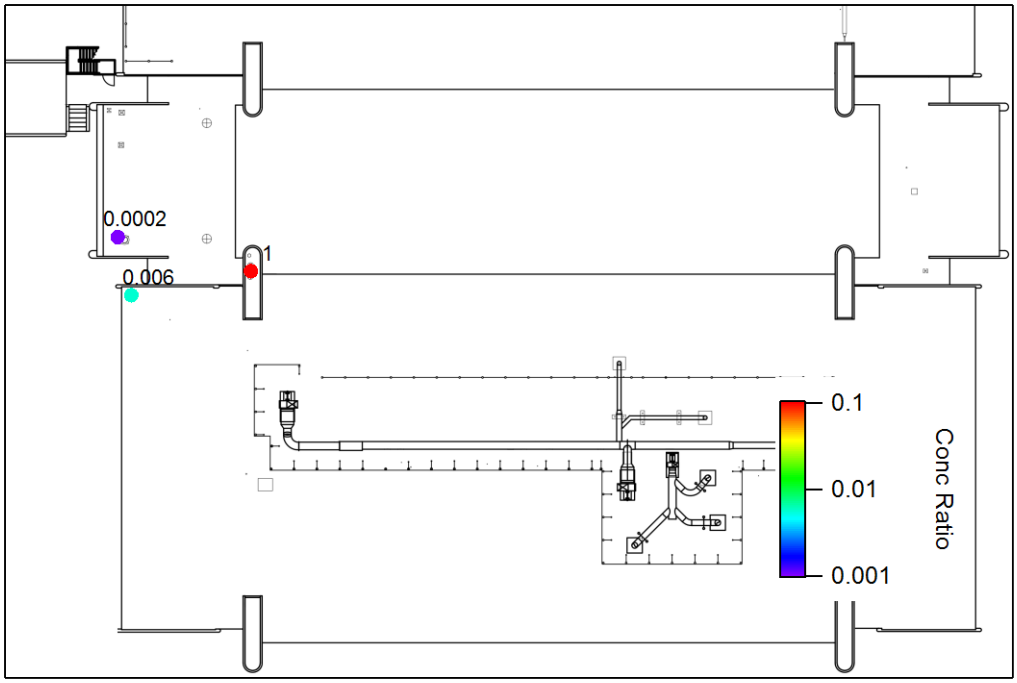

Figure 3.5. Colored Dot Plots Representing Maximum Concentration Ratios from Pylon Middle Sampling. Sample positions are illustrative, and not to scale.

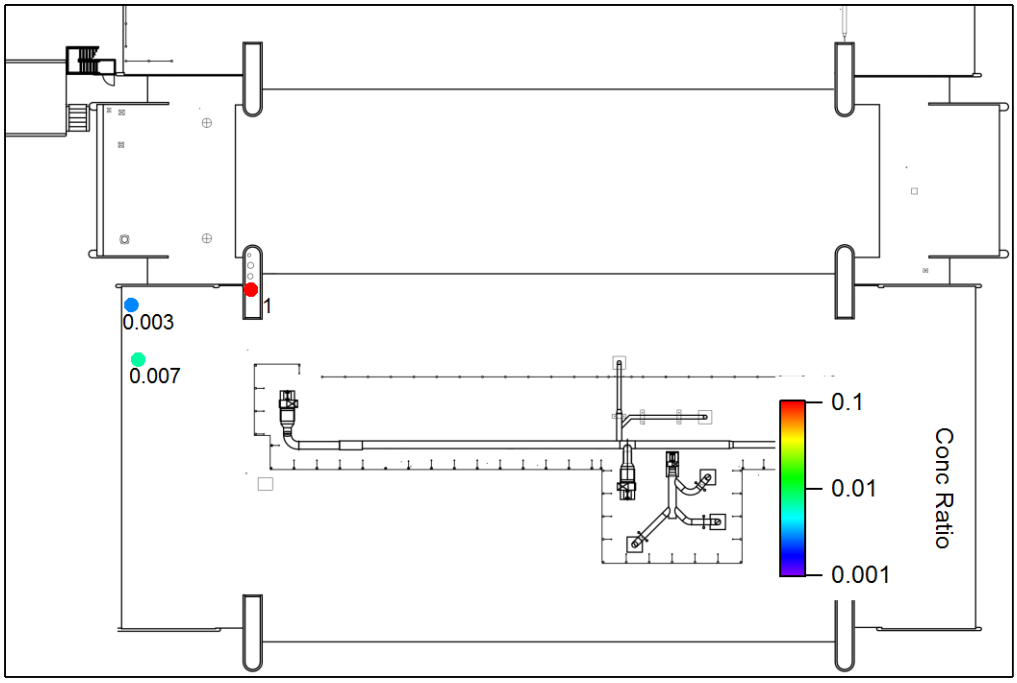

Figure 3.6. Colored Dot Plots Representing Maximum Concentration Ratios from Pylon South Sampling. Sample positions are illustrative, and not to scale.

Figure 3.7, Figure 3.8, and Figure 3.9 show the ratio of the concentration maxima to the mean stack concentration at each sampler location downwind of the West, East, and 1300 Fan stacks, respectively. As noted previously, pairs of samplers were located at 20 feet and 40 feet downwind of these stacks. The concentration maxima downwind of the West Fan were similar at three of the locations, and the lowest maximum concentration (at 40 feet) was 4 times lower than the corresponding azimuth sample at 20 feet. The East Fan sample location concentration maxima ratios were all at or below 0.01, with the lowest value nearly 4 orders of magnitude lower than the stack mean. Finally, all of the sampler concentration maxima ratios downwind of the 1300 Fan stack were 0.002.

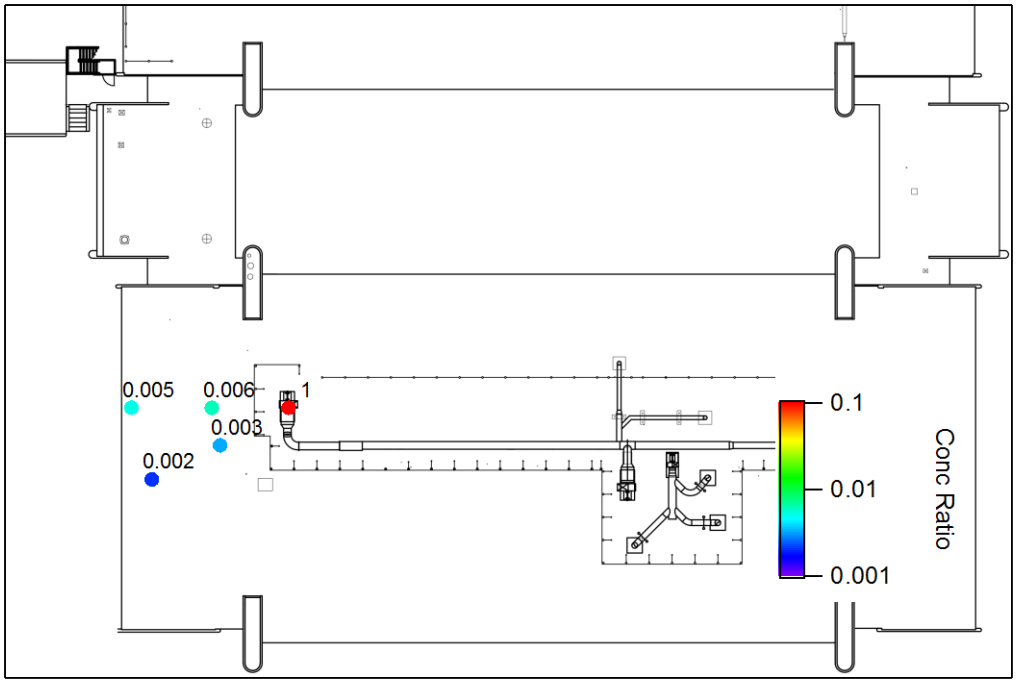

Figure 3.7. Colored Dot Plots Representing Maximum Concentration Ratios from West Fan Sampling. Sample positions are illustrative, and not to scale.

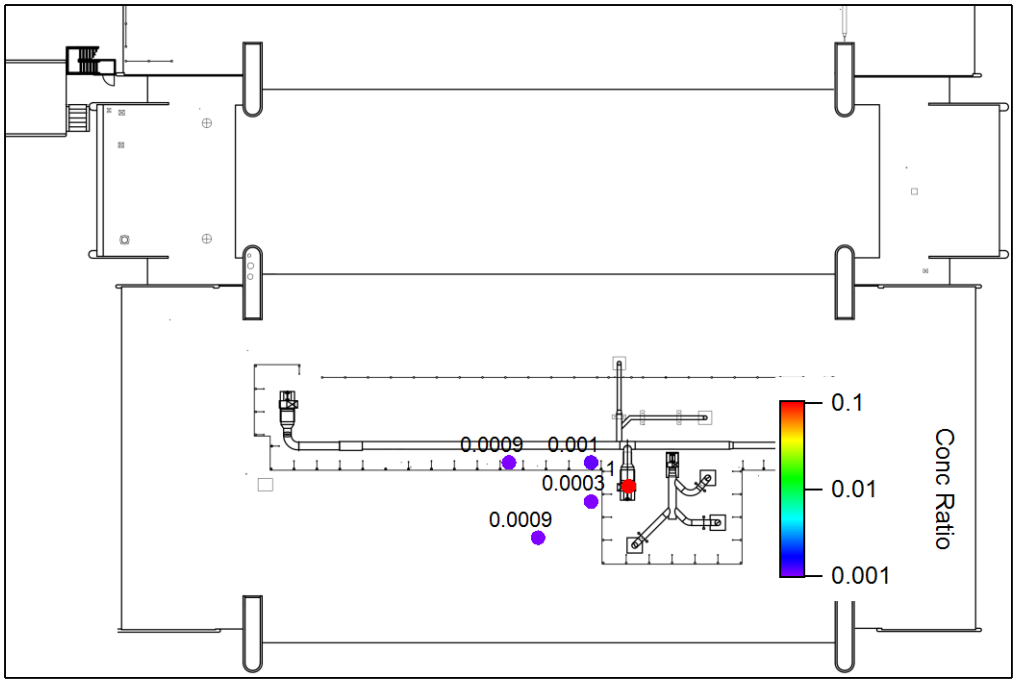

Figure 3.8. Colored Dot Plots Representing Maximum Concentration Ratios from East Fan Sampling. Sample positions are illustrative, and not to scale.

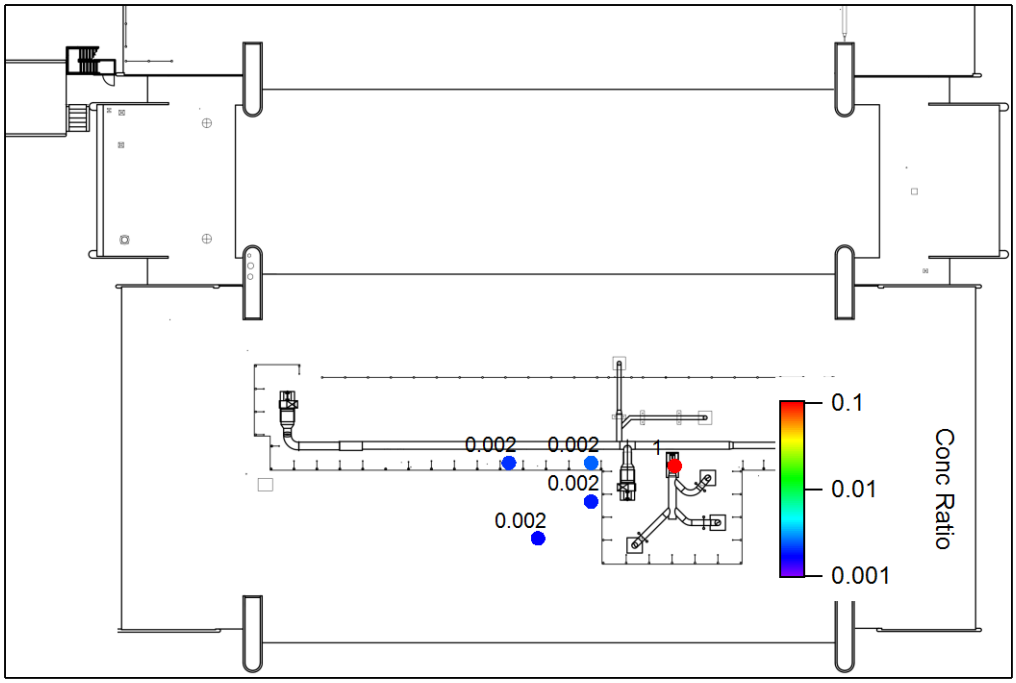

Figure 3.9. Colored Dot Plots Representing Maximum Concentration Ratios from 1300 Fan Sampling. Sample positions are illustrative, and not to scale.

The concentration maxima from the samplers deployed for the air intake test are presented in Figure 3.10. As was described previously, the highest peak concentration was directly north of the fan, and was only 2 orders of magnitude lower than the stack concentration. The sampler that was closest to the fan had a peak concentration that was 3 orders of magnitude lower than the stack concentration, and was the lowest peak concentration observed during the test. The air intake locations for PSL-1 and PSL-2 had maximum concentration ratios that were 0.006 and 0.004, respectively.

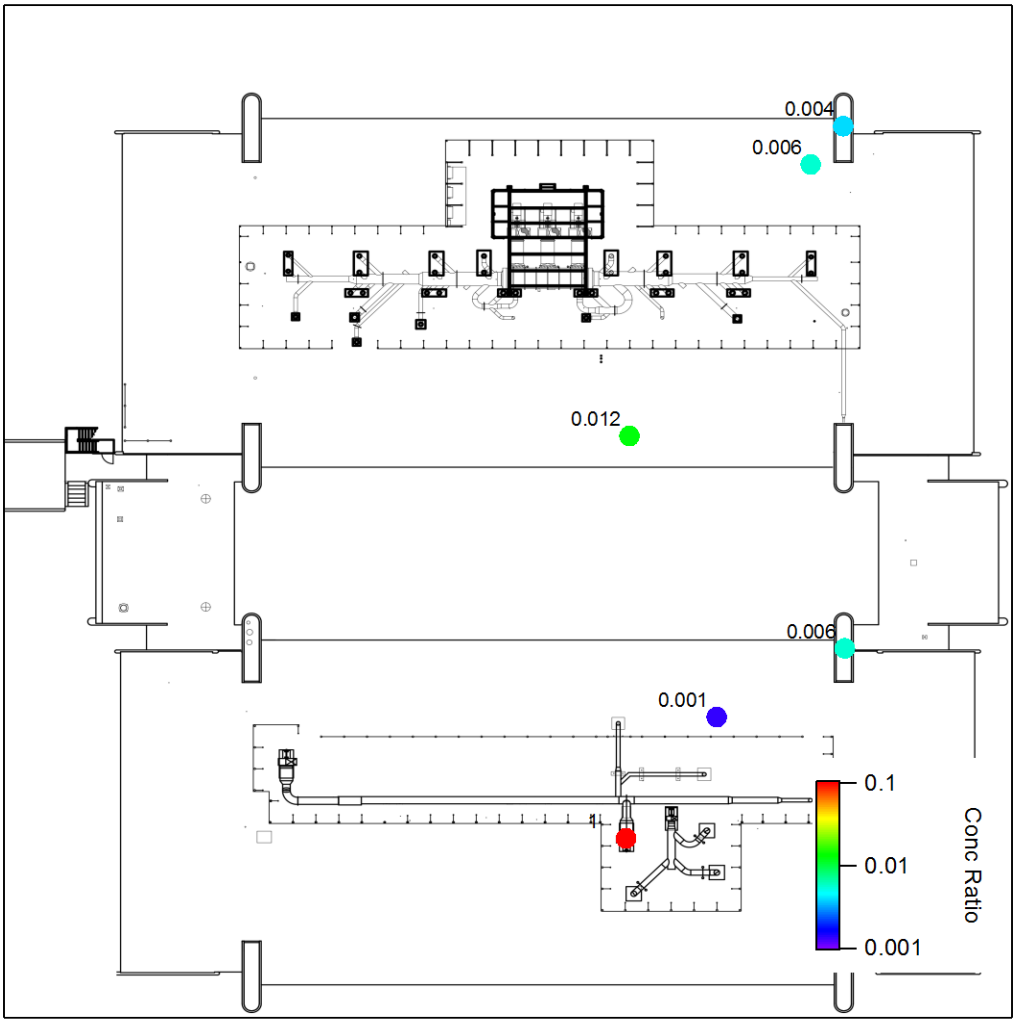

Figure 3.10. Colored Dot Plots Representing Maximum Concentration Ratios from the East Fan during Air Intake Sampling. Sample positions are illustrative, and not to scale.

4.0 Summary

A series of SF_6 tracer tests were performed on the PSL-1 rooftop during late July 2016. The primary objective of these tests was to experimentally determine the gaseous tracer concentration at rooftop locations relative to the tracer concentration at the exhaust point. This information will be used to contribute to an evaluation of potential worker exposures from routine work access.

Tests were performed by releasing SF_6 at a prescribed, constant rate into one of six fume hoods or laboratory snorkels. Concentrations were measured at pairs of sampling locations positioned at a common downwind location relative to the corresponding stack (but at two azimuth angles, separated by 30°) on the PSL-1 rooftop. The number of plume "hits," concentration time series, and colored dot plots showing the ratio of the maximum sampler concentration to the mean stack concentration were presented in Section 3.0.

The concentrations at the sampling locations were highly variable, with many measurements that were below the instrument detection limit (10 ppb). Several samplers had only one measurement that was above the detection limit, while one sampler had all measurements above the detection limit. The stack concentrations were between 37 and 105 ppm, so the concentrations measured at the sampling points were very low compared with the stack emission. Table 4.1 presents a summary of the ratio of the mean sampler concentration to the mean stack concentration for each of the six stacks under investigation. The highest mean concentration, which was 30 feet downwind of the Pylon South stack, was nearly 3 orders of magnitude lower than the stack concentration, at a ratio of 1.9E-3 to the stack concentration. The lowest mean concentrations were about five orders of magnitude lower than the stack concentration. In some cases (e.g., GM-4, GM-5), the pair of samples had similar relative concentrations, but in other cases (e.g., GM-1, GM-3B), the two locations could differ by an order of magnitude.

Table 4.1. Summary of Mean Rooftop Sampler Concentrations Relative to the Mean Stack Concentration

Test Run	Fan	Sample 1	Sample 2	Distance (ft.)
GM-1	Pylon North	2.8E-05	1.1E-04	30
GM-2B	Pylon Middle	1.7E-05	6.8E-04	30
GM-3B	Pylon South	5.9E-04	1.9E-03	30
GM-4	West Fan	2.6E-04	4.7E-04	20
		2.0E-04	3.2E-04	40
GM-5	1300 Fan	4.3E-04	6.6E-04	20
		3.5E-04	5.2E-04	40
GM-6	East Fan	1.0E-05	4.9E-04	20
		3.3E-05	3.0E-04	40

Table 4.2 presents a summary of the ratio of the maximum sampler concentration to the mean stack concentration for each of the six stacks under investigation. As was shown in the time series plots in Section 3.2.2, there is a large difference between the mean concentration and the maximum concentration measured at a sampler location. The highest peak concentration ratio, which was 30 feet downwind of the Pylon South stack, was about 2.5 orders of magnitude lower than the stack concentration, or 0.66% of the stack concentration. The lowest peak concentration ratio was nearly 4 orders of magnitude lower than the

stack concentration. In general, the maximum concentrations were about an order of magnitude larger than the mean concentrations.

Table 4.2. Summary of Maximum Rooftop Sampler Concentrations Relative to the Mean Stack Concentration

Test Run	Fan	Sample 1	Sample 2	Distance (ft.)
GM-1	Pylon North	7.3E-04	1.9E-03	30
GM-2B	Pylon Middle	2.2E-04	5.7E-03	30
GM-3B	Pylon South	2.8E-04	6.6E-03	30
GM-4	West Fan	3.2E-03	6.2E-03	20
		2.1E-03	5.1E-03	40
GM-5	1300 Fan	1.9E-03	2.5E-03	20
		1.7E-03	2.0E-03	40
GM-6	East Fan	2.7E-04	1.1E-03	20
		8.6E-04	8.6E-04	40

Table 4.3 presents a summary of both the ratio of the mean and maximum sampler concentrations to the mean stack concentration during the air intake test. In this case, samplers were not deployed in pairs, but at locations that were anticipated to illustrate the plume path between the source (East Fan) and the PSL-1 and PSL-2 air intake locations. For this test (and all tests), the highest maximum sampler concentration was 1.2% of the stack mean concentration at a distance of 115 feet from the fan. The mean sampler concentration at this location, however, was comparable to the other sampler locations in other tests, and was 0.16% of the stack mean concentration.

Table 4.3. Summary of Mean and Maximum Sampler Concentrations Relative to the Mean Stack Concentration during the Air Intake Test

Fan	Relative Mean Conc.	Relative Max. Conc.	Distance (ft.)
East Fan (Air Intake Study)	2.0E-04	1.3E-03	40
	5.8E-04	5.6E-03	80[a]
	1.6E-03	1.2E-02	115
	9.8E-04	5.7E-03	195
	1.1E-03	4.0E-03	205[b]

a. The PSL-1 air intake, b. The PSL-2 air intake

Measurements were made in the open atmosphere, which means that they were subject to a variety of changing dispersion conditions. Overall, some items to note from this study are:

- Measurements were made during hot summer days with light and variable winds.
  - High temperatures promote thermal mixing, but the light winds moved plumes slowly, so overall, the dispersion conditions could be characterized as moderate.
- Concentrations at fixed locations varied significantly over the 25-minute sampling period.
  - At most sampling locations, there were many measurement records that were below the instrument detection limit.

  - Concentration maxima were 2 to 4 orders of magnitude lower than the stack concentration.
  - Mean concentrations were 3 to 5 orders of magnitude lower than the stack concentration.
  - Mean concentrations were 3 to 15 times lower than the maximum concentration.
- Concentrations at the air intakes were 3 orders of magnitude or more lower than the stack emission concentration.

These test results are expected to represent fairly typical relative gas concentrations for the PSL rooftop. This study will inform other study components to develop a more complete picture of a worker's potential exposure from PSL-1 rooftop activities.

5.0 References

Flaherty JE and EJ Antonio. 2016a. Life Sciences Laboratory 2 Fan Exhaust Mixing Study. PNNL-25502. Pacific Northwest National Laboratory, Richland WA 99352

Flaherty JE and EJ Antonio. 2016b. Physical Sciences Laboratory Rooftop Stack Mixing Study Test Plan. 98668-TP-002. Pacific Northwest National Laboratory, Richland WA 99352.

Keith LH, W Crummett, J Deegan, Jr., RA Libby, JK Taylor, and G Wentler. 1983. Principles for Environmental Analysis. *Anal. Chem.*, (55), 2210-2218.

National Oceanic and Atmospheric Administration (NOAA), Earth Systems Research Laboratory. 2016. Global Mean SF6 concentration. Retrieved from http://www.esrl.noaa.gov/gmd/hats/combined/SF6.html.

Appendix A

Calibration Check Data Sheets

Appendix A

Calibration Check Data Sheets

SULFUR HEXAFLUORIDE GAS INSTRUMENT CALIBRATION

Site	Q AVEPAD	Instrument	B&K Model 1302
Date/Time	7/20/16 0905	Serial No.	1804888
Testers	EA	Property No.	WD54623

Setup:	6.3 ft	B&K sample inlet tube length
	1003 mbar	station pressure
	74 deg F	ambient temp — analyzer corrects to 20 deg C
	37 percent	RH ambient humidity

Pre-Test background, ppb
Not compensating for water vapor, monitoring task 2
NA
Compensating for water vapor, monitoring task 1
5.76, 3.89, 2.46, 6.66, -1.4, 6.17, -1.3, 3.76, 6.35, 1.16

	0.105	ppm		5.0	ppm
Cylinder	CLM09744		Cylinder	CLM003104	
start P =	1950	psi	start P =	2000	psi
end P =	1950	psi	end P =	2000	psi

Calibration readings: (ppm)
Compensating for water vapor

0.1060	4.80
0.0970	4.82
0.0997	4.82
0.0961	4.78
0.0978	4.80
0.0955	4.81
0.0984	4.80
0.0996	4.79
0.0977	4.80
0.0982	4.78
0.10 = avg	**4.80** = avg
0.939 = avg/standard	**0.960** = avg/standard

Standards Used:	Expiration date:
0.105 ppm SF_6, cylinder CLM09744	2/4/2019
5.0 ppm SF_6, cylinder CLM003104	1/28/2019
Weather Station Used:	
Control Co. Dew Point Pen, SN 122277883, Barcode: 39432	2/11/2017

Entries made by:	Ernest Antonio	Technical Data Review performed by:	Carmen Arimescu
Signature/date	7/20/2016	Signature/date	8/16/2016
	Signature on file with original		Signature on file with Original

SULFUR HEXAFLUORIDE GAS INSTRUMENT CALIBRATION

Site	Q AVEPAD	Instrument	B&K Model 1302
Date/Time	7/20/16 0950	Serial No.	1765299
Testers	EA	Property No.	WD17210

Setup:
- 6.3 ft B&K sample inlet tube length
- 1003 mbar station pressure
- 71 deg Fambient temp analyzer corrects to 20 deg C
- 36.5 percent RH ambient humidity

Pre-Test background, ppb
Not compensating for water vapor, monitoring task 2
NA
Compensating for water vapor, monitoring task 1
9.44, 10.6, 10.6, 7.69, 9.78, 6.31, 7.51, 3.91, 8.27, 5.52

0.105 ppm

Cylinder CLM09744
start P = 1950 psi
end P = 1910 psi

5.0 ppm

Cylinder CLM003104
start P = 2000 psi
end P = 2000 psi

Calibration readings: (ppm) **Compensating for water vapor**	**Calibration readings: (ppm)** **Compensating for water vapor**
0.105	4.89
0.104	4.91
0.104	4.90
0.102	4.90
0.103	4.90
0.106	4.90
0.100	4.89
0.105	4.89
0.100	4.90
0.103	4.90
0.103 = avg	**4.90** = avg
0.982 = avg/standard	**0.980** = avg/standard

Standards Used:	Expiration date:
0.105 ppm SF_6, cylinder CLM09744	2/4/2019
5.0 ppm SF_6, cylinder CLM003104	1/28/2019
Weather Station Used:	
Control Co. Dew Point Pen, SN 122277883, Barcode: 39432	2/11/2017

Entries made by:	Ernest Antonio	Technical Data Review performed by:	Carmen Arimescu
Signature/date	7/20/2016	Signature/date	8/16/2016
	Signature on file with original		Signature on file with Original

SULFUR HEXAFLUORIDE GAS INSTRUMENT CALIBRATION

Site	Q AVEPAD	Instrument	B&K Model 1302
Date/Time	7/20/16 1020h	Serial No.	1788615
Testers	EA	Property No.	WD54624

Setup:	6.3 ft	B&K sample inlet tube length
	1003 mbar station pressure	
	76 deg F ambient temp	analyzer corrects to 20 deg C
	35.3 percent RH ambient humidity	

Pre-Test background, ppb
Not compensating for water vapor, monitoring task 2
NA
Compensating for water vapor, monitoring task 1
13.2, 6.17, 7.62, 8.38, 4.03, 4.24, 2.99, 5.41, 4.05, 3.86

	0.105	ppm		5.0	ppm
Cylinder	CLM09744		Cylinder	CLM003104	
start P =	1900	psi	start P =	2000	psi
end P =	1900	psi	end P =	2000	psi

Calibration readings: (ppm)
Compensating for water vapor

0.105
0.104
0.107
0.107
0.108
0.108
0.106
0.103
0.104
0.107

0.106 = avg
1.009 = avg/standard

Calibration readings: (ppm)
Compensating for water vapor

5.04
5.06
5.05
5.05
5.06
5.06
5.06
5.06
5.05
5.05

5.05 = avg
1.011 = avg/standard

Standards Used:	Expiration date:
0.105 ppm SF_6, cylinder CLM09744	2/4/2019
5.0 ppm SF_6, cylinder CLM003104	1/28/2019
Weather Station Used:	
Control Co. Dew Point Pen, SN 122277883, Barcode: 39432	2/11/2017

Entries made by:	Ernest Antonio	Technical Data Review performed by:	Carmen Arimescu
Signature/date	7/20/2016	Signature/date	8/16/2016
	Signature on file with original		Signature on file with Original

SULFUR HEXAFLUORIDE GAS INSTRUMENT CALIBRATION

Site	Q AVEPAD	Instrument	B&K Model 1302
Date/Time	8/8/16 1500	Serial No.	1804888
Testers	EA	Property No.	WD54623

Setup:	6.3 ft	B&K sample inlet tube length
	996 mbar	station pressure
	73.8 deg F	ambient temp analyzer corrects to 20 deg C
	36 percent	RH ambient humidity

Pre-Test background, ppb
Not compensating for water vapor, monitoring task 2
NA
Compensating for water vapor, monitoring task 1
3.15, 4.44, 2.48, -504, -3.3, 518

	0.105	ppm		5.0	ppm
Cylinder	CLM09744		Cylinder	CLM003104	
start P =	1900	psi	start P =	1980	psi
end P =	1900	psi	end P =	1970	psi

Calibration readings: (ppm)	**Calibration readings: (ppm)**
Compensating for water vapor	**Compensating for water vapor**
0.0976	4.80
0.1020	4.81
0.0996	4.80
0.0985	4.81
0.1010	4.81
0.1010	4.82
0.0981	4.82
0.0963	4.81
0.0999	4.80
0.1020	4.81
0.10 = avg	**4.81** = avg
0.949 = avg/standard	**0.962** = avg/standard

Standards Used:	Expiration date:
0.105 ppm SF_6, cylinder CLM09744	2/4/2019
5.0 ppm SF_6, cylinder CLM003104	1/28/2019
Weather Station Used:	
Control Co. Dew Point Pen, SN 122277883, Barcode: 39432	2/11/2017

Entries made by:	Ernest Antonio	Technical Data Review performed by:	Carmen Arimescu
Signature/date	Signature on file with Original 8/8/2016	Signature/date 8/16/2016	Signature on file with Original

SULFUR HEXAFLUORIDE GAS INSTRUMENT CALIBRATION

Site	Q AVEPAD	Instrument	B&K Model 1302
Date/Time	8/8/16 1530	Serial No.	1765299
Testers	EA	Property No.	WD17210

Setup:	6.3 ft	B&K sample inlet tube length
	996 mbar	station pressure
	72.4 deg F	ambient temp analyzer corrects to 20 deg C
	40 percent	RH ambient humidity

Pre-Test background, ppb
Not compensating for water vapor, monitoring task 2
NA
Compensating for water vapor, monitoring task 1
7.33, 4.78, 6.72, 7.65, 5.07, 4.13

	0.105	ppm		5.0	ppm
Cylinder	CLM09744		Cylinder	CLM003104	
start P =	1900	psi	start P =	1970	psi
end P =	1890	psi	end P =	1950	psi

Calibration readings: (ppm)	**Calibration readings: (ppm)**
Compensating for water vapor	**Compensating for water vapor**
0.100	4.89
0.105	4.91
0.103	4.91
0.103	4.91
0.102	4.91
0.104	4.91
0.102	4.91
0.100	4.91
0.106	4.89
0.102	4.90
0.103 = avg	**4.91** = avg
0.978 = avg/standard	**0.981** = avg/standard

Standards Used:	Expiration date:
0.105 ppm SF_6, cylinder CLM09744	2/4/2019
5.0 ppm SF_6, cylinder CLM003104	1/28/2019
Weather Station Used:	
Control Co. Dew Point Pen, SN 122277883, Barcode: 39432	2/11/2017

Entries made by:	Ernest Antonio	Technical Data Review performed by:	Carmen Arimescu
Signature/date	Signature on file with Original 8/8/2016	Signature/date 8/16/2016	Signature on file with Original

SULFUR HEXAFLUORIDE GAS INSTRUMENT CALIBRATION

Site	Q AVEPAD	Instrument	B&K Model 1302
Date/Time	8/8/16 1600	Serial No.	1788615
Testers	EA	Property No.	WD54624

Setup:	6.3 ft	B&K sample inlet tube length
	966 mbar station pressure	
	72 deg F ambient temp	analyzer corrects to 20 deg C
	39.4 percent RH ambient humidity	

Pre-Test background, ppb
Not compensating for water vapor, monitoring task 2
NA
Compensating for water vapor, monitoring task 1
12.1, 6.33, 3.46, 1.30, 2.13, 0.363, 0.888

	0.105	ppm		5.0	ppm
Cylinder	CLM09744		Cylinder	CLM003104	
start P =	1890	psi	start P =	1940	psi
end P =	1890	psi	end P =	1940	psi

Calibration readings: (ppm)
Compensating for water vapor

0.104
0.103
0.106
0.107
0.105
0.105
0.108
0.104
0.104
0.103

0.105 = avg
0.999 = avg/standard

Calibration readings: (ppm)
Compensating for water vapor

5.02
5.06
5.04
5.05
5.06
5.07
5.06
5.05
5.04
5.05

5.05 = avg
1.010 = avg/standard

Standards Used:	Expiration date:
0.105 ppm SF_6, cylinder CLM09744	2/4/2019
5.0 ppm SF_6, cylinder CLM003104	1/28/2019
Weather Station Used:	
Control Co. Dew Point Pen, SN 122277883, Barcode: 39432	2/11/2017

Entries made by:	Ernest Antonio	Technical Data Review performed by:	Carmen Arimescu
Signature/date	Signature on file with Original 8/8/2016	Signature/date 8/16/2016	Signature on file with Original

Appendix B

Gas Mixing Data Sheets

Appendix B

Gas Mixing Data Sheets

GAS MIXING DATA FORM

Site	**PNNLPSL-1**	Run No.	**GM-1**
Date	**7/26/16**	Fan	**Pylon North (081)**
Start/End Time	1343 / 1501 h	Injection Location	**242**
Testers	JEF, EA	Wind Speed	2 **mph**
Concentration units	ppm	Wind Direction	100° +/- 20°

Sample No.	Sample Locations		
	081-F	**30' - 285°**	**30' - 285°**
1	51.2	3.06E-03	1.48E-02
2	50.9	-1.40E-03	9.65E-02
3	51.4	-9.90E-03	6.66E-03
4	51.2	-2.40E-03	1.73E-03
5	51.1	-1.30E-03	5.66E-03
6	50.1	2.45E-04	4.89E-02
7	51.0	3.72E-03	3.48E-02
8	51.4	3.28E-03	9.71E-03
9	49.3	2.01E-02	-2.40E-03
10	51.0	-3.69E-04	1.45E-02
11	51.3	1.10E-02	2.51E-02
12	52.0	7.22E-04	-1.50E-03
13	50.7	6.91E-04	1.21E-02

Sample No.	Sample Locations		
	081-F	**30' - 285°**	**30' - 285°**
14	51.8	-3.74E-04	1.56E-02
15	51.6	-3.70E-03	1.73E-02
16	51.4	2.24E-03	6.68E-04
17	51.2	1.85E-03	4.22E-03
18	51.2	1.85E-03	-3.50E-03
19	51.3	1.85E-03	2.18E-02
20	51.6	-3.30E-03	1.50E-02
21	51.4	4.80E-04	9.42E-03
22	51.8	1.73E-02	1.58E-02
23	52.0	-5.60E-03	-1.40E-03
24	52.0	3.10E-04	1.56E-02
25	51.2	-2.60E-03	1.45E-02
26	51.7	1.74E-03	1.48E-02
Averages ---------->	51.26	1.52E-03	1.56E-02
Standard Deviation ---->	0.58	6.29E-03	2.02E-02
Maximum---------->	52.00	2.01E-02	9.65E-02

	Start	Finish	
Stack center velocity	4132	4132	fpm
Stack Static Pressure	NA	NA	in wc
Ambient temp	95.0	99.5	F
Ambient pressure	998.1	997.3	in Hg
Ambient humidity	25%	23%	RH
Mass Flow Rate	1	1	LPM

Instuments Used:		**Cal Due**
B&K 1302 Gas Analyzer	SN 1804888	Cat2 M&TE
B&K 1302 Gas Analyzer	SN 1765299	Cat2 M&TE
B&K 1302 Gas Analyzer	SN 1788615	Cat2 M&TE
Control Co. Dew Point Pen, SN 122277883		2/11/2017
Omega Mass Flow Controller, SN 27708		FIO
MetOne 2D Sonic, SN M7746		FIO

Notes:	1 283, 259, 237, 212, 0.187	post-test
ppb	2 5.08, 3.28, -2.3, 0.190, -0.342	background
	3 -2.3, 1.97, -3.4, 1.43, -4.2E-3	

Start recording data 1433h.

Stack center velocity taken from information provided by Adam Gemmell.

Sample 1 Distance:	30	Direction:	285°	B&K SN:	1788615
Sample 2 Distance:	30	Direction:	255°	B&K SN:	1765299

Entries made by:	Ernest Antonio	Technical Data Review performed by:	Carmen Arimescu
Signature/date	Signature on file with Original 7/26/2016	Signature/date	8/16/2016 Signature on file with Original

GAS MIXING DATA FORM

Site	**PNNLPSL-1**	Run No.	**GM-2**
Date	**7/26/16**	Fan	**Pylon Middle HVE-082-F**
Start/End Time	1515 / 1615	Injection Location	**201 Machine Shop Snorkel**
Testers	JEF, EA	Wind Speed	2 **mph**
Concentration units	ppm	Wind Direction	100° +/- 20°

Sample No.	Sample Locations		
	082-F	**30' - 285°**	**30' - 255°**
1	3.19	-1.10E-03	2.68E-04
2	3.18	-1.08E-04	4.24E-04
3	3.14	2.80E-03	4.52E-03
4	3.12	-3.00E-03	-1.20E-03
5	3.14	-1.60E-03	-1.90E-03
6	3.14	2.07E-03	5.27E-03
7	3.13	-6.90E-03	8.87E-05
8	3.14	-2.30E-03	3.03E-03
9	3.14	-2.70E-03	4.65E-04
10	3.14		2.47E-03
* 11	15.3		6.85E-03
12	15.3		N/A
* 13	15.6		4.18E-03

Sample No.	Sample Locations		
	082-F	**30' - 285°**	**30' - 255°**
14	15.5		7.88E-03
15	15.5		1.11E-02
16	15.5		-2.40E-03
17	15.6		-2.00E-03
18	15.4		4.31E-03
19	15.4		3.57E-03
20	15.5		3.02E-03
21	15.4		5.96E-03
22	15.2		3.27E-03
23	15.4		2.13E-03
24	15.3		6.70E-03
25	15.4		1.89E-03
26	15.4		2.45E-03
Averages ---------->	10.7	-1.43E-03	2.69E-03
Standard Deviation ---->	6.09	2.89E-03	3.22E-03
Maximum---------->	15.6	2.80E-03	1.11E-02

	Start	Finish	
Stack center velocity	3363	3363	fpm
Stack Static Pressure	NA	NA	in wc
Ambient temp	96	96.9	F
Ambient pressure	997.2	996.2	in Hg
Ambient humidity	25%	22%	RH
Mass Flow Rate	1	5.12	LPM

Instuments Used:		**Cal Due**
B&K 1302 Gas Analyzer	SN 1804888	Cat2 M&TE
B&K 1302 Gas Analyzer	SN 1765299	Cat2 M&TE
B&K 1302 Gas Analyzer	SN 1788615	Cat2 M&TE
Control Co. Dew Point Pen, SN 122277883		2/11/2017
Omega Mass Flow Controller, SN 27708		FIO
MetOne 2D Sonic, SN M7746		FIO

Notes: Halfway through the test the gas analyzer for 30' - 285° went blank.
Overheating?

At 15:12 start gas @ 1.0 L/min in Machine Shop.

*At 15:32 adjust to 5 L/min. At 15:35 adjusted to 5.12 L/min (max flow rate of Omega Flow Controller)

15:40 WD54624 screen went blank.

Stack center velocity taken from information provided by Adam Gemmell.

Sample 1 Distance:	30	Direction:	285	B&K SN:	1788615
Sample 2 Distance:	30	Direction:	255	B&K SN:	1765299

Entries made by:	Ernest Antonio	Technical Data Review performed by:	Carmen Arimescu
Signature/date	Signature on file with Original 7/26/2016	Signature/date	8/16/2016 Signature on file with Original

GAS MIXING DATA FORM

Site	**PNNLPSL-1**	Run No.	**GM-2B**
Date	**7/26/16**	Fan	**Pylon Middle HVE-082-F**
Start/End Time	1630 / 1650	Injection Location	**201 Machine Shop Snorkel**
Testers	JEF, EA	Wind Speed	1.5 **mph**
Concentration units	ppm	Wind Direction	90° +/- 20°

Sample No.	Sample Locations		
	082-F	**30' - 285°**	**30' - 255°**
1	55.4	4.85E-03	9.47E-03
2	54.9	3.08E-03	1.84E-02
3	55.2	5.38E-03	3.70E-02
4	54.5	2.85E-03	3.14E-02
5	54.8	1.21E-02	3.18E-02
6	54.9	4.92E-03	9.59E-03
7	55.1	9.74E-03	5.84E-03
8	55	1.20E-03	8.43E-03
9	55.6	6.14E-03	7.00E-03
10	55.3	-5.03E-04	1.32E-02
11	54.4	-3.80E-03	4.15E-02
12	55.3	1.20E-03	1.74E-02
13	53.3	-3.10E-03	1.09E-02

Sample No.	Sample Locations		
14			
15			
16			
17			
18			
19			
20			
21			
22			
23			
24			
25			
26			
Averages ---------->	54.9	3.39E-03	1.86E-02
Standard Deviation ---->	0.59	4.57E-03	1.24E-02
Maximum---------->	55.6	1.21E-02	4.15E-02

	Start	Finish	
Stack center velocity	3363	3363.0	fpm
Stack Static Pressure	NA	NA	in wc
Ambient temp	96.9	96.9	F
Ambient pressure	996.2	996.2	in Hg
Ambient humidity	22%	22%	RH
Mass Flow Rate	6	6	LPM

Instuments Used:		**Cal Due**
B&K 1302 Gas Analyzer	SN 1804888	Cat2 M&TE
B&K 1302 Gas Analyzer	SN 1765299	Cat2 M&TE
B&K 1302 Gas Analyzer	SN 1788615	Cat2 M&TE
Control Co. Dew Point Pen, SN 122277883		2/11/2017
Alicat Mass Flow Controller, SN 53382		FIO
MetOne 2D Sonic, SN M7746		FIO

Notes: Following B&K (SN 1788615) display failing during last test (GM-2), unit was turned off then turned back on. Diplay seems to have been reset and is working now. Also swapped out Omega Flow Controller (SN 27708) with Alicat Mass Flow Controller (SN 53382) which had a set point of 6 L/min. Display shows erroneous reading.

Stack center velocity taken from information provided by Adam Gemmell.

None of the Sample 1 and Sample 2 measurements are significantly above background, so measurements were stopped after 13 records.

Sample 1 Distance:	30'	Direction:	285°	B&K SN:	1788615
Sample 2 Distance:	30'	Direction:	255°	B&K SN:	1765299

Entries made by:	Ernest Antonio	Technical Data Review performed by:	Carmen Arimescu
Signature/date	Signature on file with Original 7/26/2016	Signature/date	8/16/2016 Signature on file with Original

GAS MIXING DATA FORM

Site	**PNNLPSL-1**	Run No.	**GM-3**
Date	**7/27/16**	Fan	**Pylon South (299)**
Start/End Time	0902 / 0910	Injection Location	**247 Snorkel**
Testers	JEF, EA	Wind Speed	1 **mph**
Concentration units	ppm	Wind Direction	varying…

Sample No.	Sample Locations		
	299	40' - 0°	20' - 0°
1	109	1.05E-03	9.15E-02
2	107	-8.20E-03	-5.00E-03
3	109	-1.20E-02	-2.00E-03
4	108	-1.00E-02	-5.80E-03
5	107	-5.60E-03	-4.70E-03
6	108	-1.10E-02	-2.80E-03
7			
8			
9			
10			
11			
12			
13			

Sample No.	Sample Locations		
14			
15			
16			
17			
18			
19			
20			
21			
22			
23			
24			
25			
26			
Averages ---------->	108.00	-0.01	0.01
Standard Deviation ---->	0.89	0.00	0.04
Maximum---------->	109.00	0.00	0.09

	Start	Finish	
Stack center velocity	2787		fpm
Stack Static Pressure	NA		in wc
Ambient temp	87.5		F
Ambient pressure	1002		in Hg
Ambient humidity	34%		RH
Mass Flow Rate	5		LPM

Instuments Used:		**Cal Due**
B&K 1302 Gas Analyzer	SN 1804888	Cat2 M&TE
B&K 1302 Gas Analyzer	SN 1765299	Cat2 M&TE
B&K 1302 Gas Analyzer	SN 1788615	Cat2 M&TE
Control Co. Dew Point Pen, SN 122277883		2/11/2017
Omega Flow Controller, SN 27708		FIO
MetOne 2D Sonic, SN M7746		FIO
TSI Mass Flow Meter	SN 41403 1426 002	FIO

Notes: Winds changed direction. Aborted this test to reposition tripods.

Added TSI Mass Flow Meter (SN 41403 1426 002) to measure gas tracer release. ~14.4 SLPM as Air

Delivery P = 17 psi Tank P = 200 psi (first red tick mark) Gas off at ~0913h.

Stack center velocity taken from information provided by Adam Gemmell.

Sample 1 Distance:	40'	Direction:	0°	B&K SN:	1788615
Sample 2 Distance:	20'	Direction:	0°	B&K SN:	1765299

Entries made by:	Ernest Antonio	Technical Data Review performed by:	Carmen Arimescu
Signature/date	Signature on file with Original 7/27/2016	Signature/date	8/16/2016 Signature on file with Original

GAS MIXING DATA FORM

Site	**PNNLPSL-1**	Run No.	**GM-3B**
Date	**7/27/16**	Fan	**Pylon South (299)**
Start/End Time	0945 / 1013	Injection Location	**247 Snorkel**
Testers	JEF, EA	Wind Speed	1 **mph**
Concentration units	ppm, ppb	Wind Direction	85°

Sample No.	Sample Locations (ppb)		
	299	30' - 270°	30' - 240°
1	107	-3.10	17.6
2	106	84.3	118
3	109	42.3	198
4	106	16.6	291
5	106	6.68	148
6	106	33.5	227
7	104	293	701
8	105	57.7	252
9	106	13.9	193
10	106	63.3	209
11	106	203	155
12	104	41.2	127
13	106	46.5	148

Sample No.	Sample Locations (ppb)		
	299	30' - 270°	30' - 240°
14	105	-548	298
15	105	37.5	52.1
16	103	73	257
17	104	5.34	396
18	100	44.3	46.1
19	108	-5.6	217
20	107	158	244
21	103	-1.6	296
22	107	18.0	235
23	107	273	93.9
24	105	39.4	13.6
25	108	3.58	10.8
26	105	67.0	201
Averages ---------->	105.5	40.9	197.9
Standard Deviation ---->	1.9	144.3	142.4
Maximum---------->	109.0	293.0	701.0

	Start	Finish	
Stack center velocity	2787	2787	fpm
Stack Static Pressure	NA	NA	in wc
Ambient temp	87.8	87.2	F
Ambient pressure	1002	1001	in Hg
Ambient humidity	32%	30%	RH
Mass Flow Rate	5	5	LPM

Instuments Used:		**Cal Due**
B&K 1302 Gas Analyzer	SN 1804888	Cat2 M&TE
B&K 1302 Gas Analyzer	SN 1765299	Cat2 M&TE
B&K 1302 Gas Analyzer	SN 1788615	Cat2 M&TE
Control Co. Dew Point Pen, SN 122277883		2/11/2017
Omega Flow Controller, SN 27708		FIO
MetOne 2D Sonic, SN M7746		FIO
TSI Mass Flow Meter	SN 41403 1426 002	FIO

Notes: Readings from 30' - 270o and 30' - 240o are all ppb, however the 299 readings in are ppm.

Gas on @ ~ 9:46 5 SLPM set point. 13.4 SLPM air on TSI.

Stack center velocity taken from information provided by Adam Gemmell.

Sample 1 Distance:	30'	Direction:	270°	B&K SN:	1788615
Sample 2 Distance:	30'	Direction:	240°	B&K SN:	1765299

Entries made by:	Ernest Antonio	Technical Data Review performed by:	Carmen Arimescu
Signature/date	Signature on file with Original 7/27/2016	Signature/date	8/16/2016 Signature on file with Original

GAS MIXING DATA FORM

Site	**PNNLPSL-1**	Run No.	**GM-4A**
Date	**7/27/16**	Fan	**HVE-274-F (West)**
Start/End Time	12:00 / 12:28	Injection Location	**Lab 1425, Hood #1**
Testers	JEF, EA	Wind Speed	<1 **mph**
Concentration units	ppm / ppb	Wind Direction	160 - 200 deg

Sample No.	Sample Locations ppb		ppb
	247-F	20' - 240°	20' - 270°
1	33.8	116	152
2	35.1	94.4	226
3	37.1	0.418	15.1
4	35.8	-8.3	6.19
5	38.4	-6.7	-6.1
6	38.9	-9.1	-4.2
7	36.2	-8.0	2.95
8	37.7	-5.4	-3.1
9	37.6	-4.7	-3.0
10	37.2	-9.4	5.2
11	38.9	26.2	9.57
12	36.3	-5.9	32.8
13	34.0	-7.9	1.13

Sample No.	Sample Locations ppb		ppb
	247-F	20' - 240°	20' - 270°
14	34.1	-1.8	5.64
15	36.1	-8.2	10.4
16	38.1	-2.9	-2.6
17	35.0	-8.2	10.2
18	37.1	-8.3	-0.448
19	35.5	-3.1	-3.7
20	37.6	-5.0	1.92
21	37.8	0.281	-1.2
22	36.7	-8.9	-0.745
23	36.9	-4.8	-3.7
24	37.3	14.5	9.48
25	36.5	-2.5	1.1
26	36.9	-2.2	3.46
Averages ---------->	36.6	5.0	17.9
Standard Deviation ---->	1.4	30.6	52.1
Maximum---------->	38.9	116.0	226.0

	Start	Finish	
Stack center velocity	4826	meas. 7/26	fpm
Stack Static Pressure	N/A	N/A	in wc
Ambient temp	92.8	90.1	F
Ambient pressure	1001.0	1001.0	in Hg
Ambient humidity	27%	30%	RH
Mass Flow Rate	20	20	LPM

Instuments Used:		**Cal Due**
B&K 1302 Gas Analyzer	SN 1804888	Cat2 M&TE
B&K 1302 Gas Analyzer	SN 1765299	Cat2 M&TE
B&K 1302 Gas Analyzer	SN 1788615	Cat2 M&TE
Control Co. Dew Point Pen, SN 122277883		2/11/2017
Omega Flow Controller, SN 27708		FIO
MetOne 2D Sonic, SN M7746		FIO
TSI Mass Flow Meter	SN 41403 1426 002	FIO

Notes: Winds light & variable.

Chasing the wind direction was getting impractical. Picked west and 30o S of West for sampling locations.

Blue Tape Tube…

Sample 1 Distance:	20	Direction:	240°	B&K SN:	1788615
Sample 2 Distance:	20	Direction:	270°	B&K SN:	1765299

Entries made by:	Julia Flaherty	7/27/2016	Technical Data Review performed by: Carmen Arimescu
Signature/date	*On File with Original*		Signature/date 8/16/2016
			Signature on file with Original

GAS MIXING DATA FORM

Site	**PNNLPSL-1**	Run No.	**GM-4B**
Date	**7/27/16**	Fan	**HVE-274-F (West)**
Start/End Time	12:28	Injection Location	**Lab 1425, Hood #1**
Testers	JEF, EA	Wind Speed	~2 **mph**
Concentration units	ppm / ppb	Wind Direction	60 - 90 deg

Sample No.	Sample Locations (ppb)		
	247-F	40' - 240°	40' - 270°
1	35.5	6.20	2.01
2	34.9	-6.1	-1.9
3	37.8	-7.5	-2.8
4	38.4	29.6	24.9
5	35.3	73.5	20.8
6	36.6	-2.9	1.83
7	35.3	-11	-1.6
8	36.7	-1.9	1.35
9	37.1	-6.0	0.101
10	38.5	-3.2	2.90
11	37.5	0.463	6.91
12	35.4	2.15	13.6
13	37.3	0.204	17.9

Sample No.	Sample Locations (ppb)		
	247-F	40' - 240°	40' - 270°
14	39.1	-6.6	-7.6
15	36.8	-6.8	0.326
16	36.5	75.8	187
17	36.2	10.6	32.0
18	36.3	-0.665	10.3
19	36.3	-6.6	-0.957
20	35.0	-2.6	-0.500
21	35.5	-6.1	-5.0
22	38.1	2.65	0.253
23	38.6	-1.4	5.84
24	35.2	-2.9	-0.047
25	37.5	-2.9	1.31
26	35.9	1.98	4.48
Averages ---------->	36.67	4.92	12.05
Standard Deviation ---->	1.24	21.94	36.93
Maximum---------->	39.1	75.8	187.0

	Start	Finish	
Stack center velocity	4826	meas. 7/26	fpm
Stack Static Pressure	N/A	N/A	in wc
Ambient temp	90.1	94.6	F
Ambient pressure	1001.0	1000.0	in Hg
Ambient humidity	30%	27%	RH
Mass Flow Rate	20	20	LPM

Instuments Used:		**Cal Due**
B&K 1302 Gas Analyzer	SN 1804888	Cat2 M&TE
B&K 1302 Gas Analyzer	SN 1765299	Cat2 M&TE
B&K 1302 Gas Analyzer	SN 1788615	Cat2 M&TE
Control Co. Dew Point Pen, SN 122277883		2/11/2017
Omega Flow Controller, SN 27708		FIO
MetOne 2D Sonic, SN M7746		FIO
TSI Mass Flow Meter	SN 41403 1426 002	FIO

Notes: purple tape tube…

Note that, for this, and all tests using the Alicat mass flow meter, the mass flow rate that is recorded is the set point.

The screen display is not functioning correctly, so the mass flow meter will be used to evaluate this flow rate.

Sample 1 Distance:	40'	Direction:	240°	B&K SN:	1788615
Sample 2 Distance:	40'	Direction:	270°	B&K SN:	1765299

Entries made by:	Julia Flaherty
Signature/date	
Technical Data Review performed by:	Carmen Arimescu
Signature/date	8/16/2016
	Signature on file with Original

GAS MIXING DATA FORM

Site	**PNNLPSL-1**	Run No.	**GM-5A**
Date	**7/27/16**	Fan	**HVE-384-F**
Start/End Time	1313 / 1343	Injection Location	**Lab 1300, HVE-349-FH**
Testers	JEF, EA	Wind Speed	~1 **mph**
Concentration units	ppm, ppb	Wind Direction	60 - 100 deg

Sample No.	Sample Locations ppb		ppb
	348-F	20' - 240°	20' - 270°
1	85.9	23.6	43.5
2	78.4	37.9	19.0
3	86.2	37.6	99.7
4	84.9	38.2	49.0
5	81.0	23.8	31.2
6	70.0	5.01	37.8
7	75.5	25.7	50.1
8	74.8	74.9	198
9	79.6	34.8	56.4
10	85.4	42.9	64.2
11	79.3	3.08	24.2
12	79.4	23.3	23.8
13	83.0	20.7	66.4

Sample No.	Sample Locations ppb		ppb
	348-F	20' - 240°	20' - 270°
14	75.3	20	37.6
15	75.2	41.3	63.5
16	82.1	52.7	75.4
17	76.6	9.38	25.5
18	78.8	29.2	63.1
19	77.1	-2.7	13.4
20	82.8	-2.7	141
21	84.5	9.01	53.1
22	82.4	-0.9	1.49
23	82.1	32.1	59.5
24	68.1	150	13.2
25	76.3	150	60.5
26	81.6	22.8	-1.1
Averages ---------->	79.47	34.68	52.67
Standard Deviation ---->	4.68	38.45	42.64
Maximum---------->	86.2	150.0	198.0

	Start	Finish	
Stack center velocity	~4700	on 7/26/16	fpm
Stack Static Pressure	NA	NA	in wc
Ambient temp	93.0	93.0	F
Ambient pressure	1000.0	1000.0	in Hg
Ambient humidity	26%	28%	RH
Mass Flow Rate	20	20	LPM

Instuments Used:		**Cal Due**
B&K 1302 Gas Analyzer	SN 1804888	Cat2 M&TE
B&K 1302 Gas Analyzer	SN 1765299	Cat2 M&TE
B&K 1302 Gas Analyzer	SN 1788615	Cat2 M&TE
Control Co. Dew Point Pen, SN 122277883		2/11/2017
Omega Flow Controller, SN 27708		FIO
MetOne 2D Sonic, SN M7746		FIO
TSI Mass Flow Meter	SN 41403 1426 002	FIO

Notes: Increasing cloud cover over the course of this test.

13:35 S/N 1788615 went squirrely. Screen blank, then full of junk, then restarted meas.

Rebooted again at 13:37

Sample 1 Distance:	20 ft	Direction:	240°	B&K SN:	1788615
Sample 2 Distance:	20 ft	Direction:	270°	B&K SN:	1765299

Entries made by:	Ernest Antonio	Technical Data Review performed by:	Carmen Arimescu
Signature/date	Signature on file with Original 7/27/2016	Signature/date	8/16/2016 Signature on file with Original

GAS MIXING DATA FORM

Site	**PNNLPSL-1**	Run No.	**GM-5B**
Date	**7/27/16**	Fan	**HVE-384-F (1300)**
Start/End Time	1343 / 1407	Injection Location	**Lab 1300, HVE-349-FH**
Testers	JEF, EA	Wind Speed	<1 **mph**
Concentration units	ppm / ppb	Wind Direction	120°

	ppb	ppb
Sample No.	Sample Locations	
	348-F	40' - 240°	40' - 270°
1	84.4	32.2	161
2	76.1	50.2	56.3
3	82.7	17.5	59.5
4	77.2	25.7	28.5
5	80.0	80.3	104
6	87.6	14.1	59.8
7	80.8	38.5	83.6
8	79.9	20.2	7.44
9	73.7	31.2	71.7
10	84.8	73.1	27
11	69.6	23.8	17.5
12	73.1	-3.1	5.44
13	83.7	2.20	3.67

	ppb	ppb
Sample No.	Sample Locations	
	348-F	40' - 240°	40' - 270°
14	79.4	1.78	28.2
15	82.7	23.8	60.5
16	76.3	7.49	1.46
17	81.2	48.3	2.29
18	77.0	131	30.7
19	78.3	10.1	73.1
20	78.6	31.0	95.3
21	77.8	13.3	69.8
22	73.5	10.5	8.65
23	78.4	1.1	2.37
24	79.4	2.37	2.83
25	81.8	17.0	35.6
26	76.0	18.9	11.3
Averages ---------->	79.00	27.79	42.60
Standard Deviation ---->	4.10	29.67	40.05
Maximum---------->	87.6	131.0	161.0

	Start	Finish	
Stack center velocity	~4700	on 7/26/16	fpm
Stack Static Pressure	NA	NA	in wc
Ambient temp	93.2	91.7	F
Ambient pressure	1000.0	999.8	in Hg
Ambient humidity	28%	29%	RH
Mass Flow Rate	20	20	LPM

Instuments Used:		**Cal Due**
B&K 1302 Gas Analyzer	SN 1804888	Cat2 M&TE
B&K 1302 Gas Analyzer	SN 1765299	Cat2 M&TE
B&K 1302 Gas Analyzer	SN 1788615	Cat2 M&TE
Control Co. Dew Point Pen, SN 122277883		2/11/2017
Omega Flow Controller, SN 27708		FIO
MetOne 2D Sonic, SN M7746		FIO
TSI Mass Flow Meter	SN 41403 1426 002	FIO

Notes:

B&K S/N 1788615had problems with display pixels throughout this test.

Sample 1 Distance:	40'	Direction:	240°	B&K SN:	1788615
Sample 2 Distance:	40'	Direction:	270°	B&K SN:	1765299

Entries made by:	Ernest Antonio	Technical Data Review performed by:	Carmen Arimescu
Signature/date	Signature on file with Original 7/27/2016	Signature/date	8/16/2016 Signature on file with Original

GAS MIXING DATA FORM

Site	**PNNLPSL-1**	Run No.	**GM-6A**
Date	**7/27/16**	Fan	**HVE-013-F**
Start/End Time	1438 / 1505	Injection Location	**Lab 1401, Hood #4**
Testers	JEF, EA	Wind Speed	1.5 **mph**
Concentration units	ppm / ppb	Wind Direction	60 deg

Sample No.	Sample Locations (ppb)		
	013-F	40' - 240° (ppb)	40' - 270° (ppb)
1	37.2	-3.3	-1.4
2	37.0	-1.4	5.28
3	37.1	-1.3	11.6
4	37.5	-2.1	21.9
5	36.9	-0.331	3.46
6	38.3	3.04	12.3
7	36.7	-0.830	15.9
8	38.1	-0.035	16
9	37.7	9.03	25.7
10	36.7	2.82	12.1
11	38.2	4.28	8.15
12	37.1	-8.3	0.232
13	38.2	-3.1	0.436

Sample No.	Sample Locations (ppb)		
	013-F	40' - 240° (ppb)	40' - 270° (ppb)
14	36.8	-2.2	23.4
15	38.1	-1.0	14.0
16	37.3	-1.9	15.5
17	35.7	-5.4	6.94
18	37.1	-2.7	18.1
19	36.6	7.33	14.1
20	35.7	32.0	0.984
21	37.3	-5.3	1.60
22	36.8	-8.1	31.8
23	38.2	-2.3	16.2
24	37.0	7.1	27.0
25	36.3	-7.0	1.99
26	36.1	-2.3	15.2
Averages ---------->	37.14	0.26	12.25
Standard Deviation ---->	0.75	7.85	9.14
Maximum---------->	38.3	32.0	31.8

	Start	Finish	
Stack edge velocity	~4800	on 7/26/16	fpm
Stack Static Pressure	NA	NA	in wc
Ambient temp	92.8	93.2	F
Ambient pressure	999.8	999.2	in Hg
Ambient humidity	27%	27%	RH
Mass Flow Rate	20	20	LPM

Instuments Used:		**Cal Due**
B&K 1302 Gas Analyzer	SN 1804888	Cat2 M&TE
B&K 1302 Gas Analyzer	SN 1765299	Cat2 M&TE
B&K 1302 Gas Analyzer	SN 1788615	Cat2 M&TE
Control Co. Dew Point Pen, SN 122277883		2/11/2017
Omega Flow Controller, SN 27708		FIO
MetOne 2D Sonic, SN M7746		FIO
TSI Mass Flow Meter	SN 41403 1426 002	FIO

Notes: **SN 888: 311, 143, 129, 105**

BKG SN 615: 1.95, -2.2, -3.7, 0.351

SN 299: 1.88, 6.84, 0.741, 1.05

Sampling tripods were not moved fromt eh 1300 fan setup.

Since the East fan & 1300 fan are only ~8ft apart (E -W), the "40' " sampler is probably more like 32.

Sample 1 Distance:	~32'	Direction:	~240°	B&K SN:	1788615
Sample 2 Distance:	~32'	Direction:	~270°	B&K SN:	1765299

Entries made by:	Ernest Antonio	Technical Data Review performed by:	Carmen Arimescu
Signature/date	Signature on file with Original 7/27/2016	Signature/date	8/16/2016 Signature on file with Original

GAS MIXING DATA FORM

Site	**PNNLPSL-1**	Run No.	**GM-6B**
Date	**7/27/16**	Fan	**HVE-013-F (East)**
Start/End Time	1505 / 1535	Injection Location	**Lab 1401, Hood #4**
Testers	JEF, EA	Wind Speed	~1 **mph**
Concentration units	ppm / ppb	Wind Direction	~ 60 - 90 **deg**

	ppb	ppb
Sample No.	Sample Locations	
	013-F	20' - 240°	20' - 270°
1	34.8	-0.295	5.58
2	37.2	3.2	13.7
3	37.2	0.781	4.16
4	37.3	-1.5	13.6
5	37.5	-2.1	3.77
6	36.8	1.43	14.7
7	37.1	10.1	20.1
8	37.2	-3.2	20.2
9	38.4	1.33	11.2
10	37.4	-1.2	20.5
11	37.6	-3.4	28.7
12	37.8	-0.107	41.3
13	37.2	2.22	30.2

	ppb	ppb
Sample No.	Sample Locations	
	013-F	20' - 240°	20' - 270°
14	37.2	1.51	38.4
15	37.1	0.75	28.6
16	36.4	0.03	19.7
17	37.2	-0.8	9.06
18	37.3	3.2	21.2
19	37.7	0.485	26.5
20	37.7	1.06	14.9
21	37.3	3.93	24.4
22	35.9	-1.9	8.78
23	37.4	0.72	9.12
24	36.7	0.96	39.7
25	37.2	2.18	20.1
26	34.9	1.29	24.8
Averages ---------->	37.06	0.80	19.73
Standard Deviation ---->	0.80	2.66	10.62
Maximum---------->	38.4	10.1	41.3

	Start	Finish	
Stack edge velocity	~4800	on 7/26/16	fpm
Stack Static Pressure	NA	NA	in wc
Ambient temp	93.2	94.0	F
Ambient pressure	999.2	998.9	in Hg
Ambient humidity	27%	27%	RH
Mass Flow Rate	20	20	LPM

Instuments Used:		**Cal Due**
B&K 1302 Gas Analyzer	SN 1804888	Cat2 M&TE
B&K 1302 Gas Analyzer	SN 1765299	Cat2 M&TE
B&K 1302 Gas Analyzer	SN 1788615	Cat2 M&TE
Control Co. Dew Point Pen, SN 122277883		2/11/2017
Omega Flow Controller, SN 27708		FIO
MetOne 2D Sonic, SN M7746		FIO
TSI Mass Flow Meter	SN 41403 1426 002	FIO

Notes: Stack center velocity overloaded intrument , so edge measurement was made by Adam Gemmel.

Sampling tripods were not moved from the 1300 fan setup. Since the East fand & the 1300 fan are only ~8 ft apart (E - W) the 20' sampler is probably more like 12 '.

Display on B&K S/N 1788615 blanked out w/ 6 measurements to go, last 6 measurements were pulled from memory bank of instrument.

Sample 1 Distance:	~12'	Direction:	~240°	B&K SN:	1788615
Sample 2 Distance:	~12'	Direction:	~270°	B&K SN:	1765299

Entries made by:	Ernest Antonio	Technical Data Review performed by:	Carmen Arimescu
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GAS MIXING DATA FORM

Site	**PNNLPSL-1**	Run No.	**GM-7A**
Date	**7/30/16**	Fan	**HVE-013-F**
Start/End Time	0903 / 0938	Injection Location	**Lab 1401, Hood #4**
Testers	JEF, EA	Wind Speed	<1 **mph**
Concentration units	ppm, ppb	Wind Direction	190 **deg**

	ppm	ppb	ppb
Sample No.	Sample Locations		
	013-F	6W 10S	PS2 in
1	36.1	27.6	37.1
2	36.4	5.84	5.69
3	38.6	81.1	30.3
4	36.4	81.6	98.7
5	37.9	66.0	60.9
6	37.2	-0.872	71.8
7	36.9	71.8	27.4
8	37.4	-9.3	4.92
9	37.1	-8.6	-0.222
10	36.9	210	146
11	37.1	134	82.3
12	37.1	20.6	33.8
13	37.1	-6.2	2.07

	ppm	ppb	ppb
Sample No.	Sample Locations		
	013-F	6W 10S	PS2 in
14	37.3	-10	-0.075
15	37.2	40.3	72.3
16	37.5	0.63	73.6
17	36.8	-9.3	-2.1
18	36.5	-4.7	-1.2
19	37.8	-6.4	4.84
20	39	-7	0.95
21	37.9	32.2	14.7
22	37.4	-10	142
23	35.8	15.7	84.9
24	37.2	47.7	64.9
25	36.9	11.4	2.03
26	36.2	101	45.1
Averages ---------->	37.1	33.7	42.4
Standard Deviation ---->	0.7	53.9	44.1
Maximum---------->	39.0	210	146

	Start	Finish	
Stack edge velocity	~4800	on 7/26/16	fpm
Stack Static Pressure	NA	NA	in wc
Ambient temp	85	87	F
Ambient pressure	993	993	in Hg
Ambient humidity	33%	34%	RH
Mass Flow Rate	20	20	LPM

Instuments Used:		**Cal Due**
B&K 1302 Gas Analyzer	SN 1804888	Cat2 M&TE
B&K 1302 Gas Analyzer	SN 1765299	Cat2 M&TE
B&K 1302 Gas Analyzer	SN 1788615	Cat2 M&TE
Control Co. Dew Point Pen, SN 122277883		2/11/2017
Omega Flow Controller, SN 27708		FIO
MetOne 2D Sonic, SN M7746		FIO
TSI Mass Flow Meter	SN 41403 1426 002	FIO

Notes: This test will measure air intake concentrations at both PS1 and PS2 air intake locations.

Sample 1 Distance:	6' W & 10' S of PS2 Pylon	B&K SN:	1788615
Sample 2:	PS2 Pylon	B&K SN:	1765299

Entries made by:	Ernest Antonio	Technical Data Review performed by:	Carmen Arimescu
Signature/date	Signature on file with Original 7/30/2016	Signature/date	8/16/2016 Signature on file with Original

GAS MIXING DATA FORM

Site	**PNNLPSL-1**	Run No.	**GM-7B**
Date	**7/30/16**	Fan	**HVE-013-F**
Start/End Time	0943 / 1030	Injection Location	**Lab 1401, Hood #4**
Testers	JEF, EA	Wind Speed	<1 **mph**
Concentration units	ppb	Wind Direction	180 **deg**

Sample No.	Sample Locations		
	25W-18S	PS1-in	50W-10N
1	30.3	16.2	129
2	9.45	7.23	50.1
3	2.51	7.02	158
4	48.6	206	96.7
5	26	37.7	43.7
6	-4.6	-2.8	8.81
7	18.2	-6.6	59.7
8	29.3	77.1	458
9	4.24	10.3	70.9
10	-4.1	-7.6	1.07
11	21.3	33.4	20.6
12	18.2	112	162
13	0.844	14.8	82.2

Sample No.	Sample Locations		
	25W-18S	PS1-in	50W-10N
14	7.28	-1.7	5.79
15	-4.7	-11	1.54
16	-5.9	-6.1	7.37
17	-7.5	21.3	0.857
18	9.97	-5	62.5
19	-6.5	-2.6	1.96
20	4.46	-5.5	4.18
21	-4.9	-4.8	-0.619
22	-5	-3.7	4.09
23	-3.8	-5.7	16.3
24	4.43	-1.7	-0.828
25	-10	24.8	90.2
26	-0.302	-7.3	-4
Averages ---------->	6.8	19.1	58.9
Standard Deviation ---->	14.7	47.4	95.8
Maximum---------->	48.6	206	458

	Start	Finish	
Stack edge velocity	~4800	on 7/26/16	fpm
Stack Static Pressure	NA	NA	in wc
Ambient temp	85	87	F
Ambient pressure	993	993	in Hg
Ambient humidity	33%	34%	RH
Mass Flow Rate	20	20	LPM

Instuments Used:		**Cal Due**
B&K 1302 Gas Analyzer	SN 1804888	Cat2 M&TE
B&K 1302 Gas Analyzer	SN 1765299	Cat2 M&TE
B&K 1302 Gas Analyzer	SN 1788615	Cat2 M&TE
Control Co. Dew Point Pen, SN 122277883		2/11/2017
Omega Flow Controller, SN 27708		FIO
MetOne 2D Sonic, SN M7746		FIO
TSI Mass Flow Meter	SN 41403 1426 002	FIO

Notes: Continued gas release, but just check the East fan concentration at the end of the test. Hopefully is consistent, as shown in GM-7A. Check! Conc ~ 36 ppm post-test. (see below)

Background S/N: 1804888 0.124, 0.027, 0.016, 0.0133, 0.0143

S/N 1788615 -2.9 E-3, -4.6 E-3, -4.7 E-3, -1.1 E-3, -5.4 E-3

S/N 1765299 0.00209, -536 E-6, -773 E-6, -1.4 E-3, -5.4 E-3

HVE-013-F conc at end of measurements (ppm): 26.4, 35.9, 36.6, 38.0, 37.2

Sample 1 Distance: 25' W, 18' S of PS1 in pylon B&K SN: 1804888

Sample 3 Distance: 50' W, 10' N of courtyard NE corner B&K SN: 1765299

Entries made by:	Ernest Antonio	Technical Data Review performed by:	Carmen Arimescu
Signature/date	Signature on file with Original 7/30/2016	Signature/date	8/16/2016 Signature on file with Original

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