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Pacific Northwest National Laboratory
Operated by Battelle for the U.S. Department of Energy

Cold Vacuum Drying Facility Stack Air Sampling System Qualification Tests

J. A. Glissmeyer

January 2001

Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RL01830

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Richland, Washington 99352

Summary

This report documents tests that were conducted to verify that the air monitoring system for the Cold Vacuum Drying Facility ventilation exhaust stack meets the applicable regulatory criteria regarding the placement of the air sampling probe, sample transport, and stack flow measurement accuracy. These criteria ensure that the contaminants in the stack are well mixed with the airflow at the location of the probe so that the collected sample represents the whole. The sequence of tests addresses the

- acceptability of the flow angle relative to the probe
- uniformity of air velocity and gaseous and particle tracers in the cross section of the stack
- delivery of the sample from the sampler nozzle to the collection filter
- accuracy of the stack flow measurement system.

The tests conducted on the CVDF air monitoring system demonstrated that the location for the air-sampling probe meets all performance criteria for air sampling systems at nuclear facilities. The performance criterion for particle transport was also met. All tests were successful, and all acceptance criteria were met.

Acknowledgments

This work was supported by the U.S. Department of Energy under Contract DE-AC06-76RL01830, with project funding from the Spent Nuclear Fuels Program managed by Fluor Hanford, Inc. The author wishes to acknowledge the assistance of Dan Edwards from Pacific Northwest National Laboratory (PNNL), PNNL Craft Services, David J. Watson from Spent Nuclear Fuels, Bill Jeffers of the CVDF Startup Team, and the Ventilation and Balance Craft Unit of CH2M HILL Hanford Group for their assistance in conducting the tests.

Contents

Figures

Tables

1.0 Introduction

The Cold Vacuum Drying Facility (CVDF) is located close to the 105K-West Basin at the U.S. Department of Energy's (DOE) Hanford Site. The facility is designed to dry the contents of multi-canister overpacks (MCOs), which contain spent fuel and other materials retrieved from the two K Area basins. Free water inside the MCO cask is removed by a complex drying process involving suction pumping, repeated heating (up to 50ºC), purging the cask with inert gas, and drying under vacuum. The process offgas is filtered and added to the facility ventilation exhaust.

This report documents tests that were conducted to verify that the air monitoring system at the CVDF ventilation exhaust stack meets the applicable regulatory criteria regarding the placement of the air-sampling probe, the transport of the sample to the collection device, and the accuracy of the stack flow measurement system. The performance criteria, test methods, results, and conclusions are discussed. The detailed test procedures and data sheets are included in the appendices. These tests were conducted by Pacific Northwest National Laboratory;[1] the staff of Spent Nuclear Fuels[2] and Vent and Balance[3] assisted in performing the tests.

Process offgas emission monitoring for radionuclides in DOE facilities is required under federal and state law. A Notice of Construction (NOC) was submitted to the Washington State Department of Health describing the CVDF process, the offgas treatment system, and the offgas radionuclide monitoring system. The NOC also describes the standards to which the offgas treatment and monitoring must adhere. The tests documented in this report are required to demonstrate the efficacy of the air monitoring system and demonstrate compliance with the standards given in the NOC.

1.1 Background

On December 15, 1989, 40 CFR 61, Subpart H, "National Emission Standards for Emissions of Radionuclides Other than Radon from Department of Energy Facilities," came into effect. This regulation governs portions of the design and implementation of facility effluent air sampling. Further, 40 CFR 61, Subpart H requires the use of isokinetic sampling nozzles as described in American National Standards Institute (ANSI) N13.1-1969 (ANSI 1982). This standard has been replaced by ANSI/HPS N13.1-1999 (ANSI 1999), "Sampling and Monitoring Releases of Airborne Radioactive Substances from the Stacks and Ducts of Nuclear Facilities," though this version has yet to be formally incorporated into the U.S. Environmental Protection Agency (EPA) regulation (40 CFR 61, Subpart H). In the interim, EPA has accepted the key features of the updated standard as an accepted alternative to the older version (Nichols[4]).

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[1] Pacific Northwest National Laboratory is operated by Battelle for the U.S. Department of Energy.
[2] A division of Fluor Hanford, Inc.
[3] CH2M HILL Hanford Group (CHG).
[4] Letter from M. D. Nichols (EPA, Assistant Administrator for Air Radiation) to R. F. Pelletier (DOE). 1994, Washington, D.C.

1.2 Performance Criteria

The ANSI/HPS N13.1-1999 performance criteria for sampling nozzle placement and particle transport are described as follows:

1. Angular Flow – Sampling nozzles are usually aligned with the axis of the stack. If the air travels up the stack in cyclonic fashion, the air velocity vector approaching the nozzle could be misaligned with the sampling nozzles enough to impair the extraction of particles. Consequently, the flow angle is measured in the stack at the elevation of the sampling nozzle. The average air-velocity angle must not deviate from the axis of the stack and sampling nozzle by more than 20°.

2. Uniform Air Velocity – It is important that the gas momentum across the stack cross section where the sample is extracted be well mixed or uniform. Consequently, the velocity is measured at several points in the stack at the elevation of the sampling nozzle. The uniformity is expressed as the variability of the measurements about the mean. This is expressed using the relative coefficient of variance (COV), 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 center two-thirds of the area of the stack.

3. Uniform Concentration of Tracer Gases – A uniform contaminant concentration in the sampling plane enables the extraction of samples that represent the true concentration. This is first tested using a tracer gas. The fan is a good mixer, so injecting the tracer downstream of the fan provides worst-case results[1]. The acceptance criteria are that 1) the COV of the measured tracer gas concentration is ≤20% across the center two-thirds of the sampling plane and 2) at no point in the sampling plane does the concentration vary from the mean by >30%.

4. Uniform Concentration of Tracer Particles – Uniformity in contaminant concentration at the sampling elevation is further demonstrated using tracer particles large enough to exhibit inertial effects. Particles of 10-ìm aerodynamic diameter (AD) are used by default unless it is known that larger particles are present in the airstream. The acceptance criterion is that the COV of particle concentration is ≤20% across the center two-thirds of the sampling plane.

5. Sample Extraction and Transport System Performance – The criteria are that 1) nozzle transmission ratio for a 10-ìm AD particle is 0.8 to 1.3, 2) nozzle aspiration ratio for a 10-ìm AD particle is 0.8 to 1.5, and 3) the test particle penetration through transport system is ≥50% for 10-ìm AD particles.

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[1] Worst-case results are those that might be observed if the fan itself became contaminated and later released contaminants.

The NOC for the stack, granted by the Washington State Department of Health, indicated that the accuracy of the stack flow measurement system would be verified following the method of 40 CFR 52, Appendix E. This method has the following criteria:

- The relative accuracy of the flow measurement system shall be <10% compared to the reference manual measurements.
- The zero drift over 24 hours shall be <3% of span.
- The calibration drift over 24 hours shall be <3% of span.
- The continual operability of the flow measurement system shall be 168 hours minimum.
- Where the flow measurement system relies on sensor angle relative to direction of flow, the relative accuracy of the flow measurement system shall be <4% compared to the readings at zero rotation when the sensor is rotated over a range of -10º to +10º in 5º increments.

1.3 Ventilation Exhaust Stack Description

The exhaust air originates from the process offgas and general ventilation in process bays, mechanical equipment room, transfer corridor, and process water tank room. The total exhaust air flow should normally be about 15,000 cfm. About 0 to 30% of the exhausted air could originate as process offgas depending on the number of process bays in operation at any given time. All exhaust air is filtered through high-efficiency particulate air (HEPA) filters prior to discharge. The ventilation, air monitoring systems, and possible radionuclide offgas constituents are described in the NOC (DOE 1999). The ventilation flow is powered by several fans located on the second floor of the CVDF.

The sampling probe placement and flow accuracy tests were done on the actual CVDF discharge stack as shown in Figure 1.1. The stack has an internal diameter of 30 inches and is about 48 feet tall. Figure 1.2 diagrams the stack, duct leading to the stack, the location of the air monitoring probe, and the location where test tracers were injected into the duct. The approximate number of stack diameters from the top of the stack breach to the sampling nozzle is 7.8. It is about 7.4 stack diameters from the qualification test ports to the top of the stack breach.

Figure 1.3 shows the location of the air monitoring probe, test ports, catwalk, and other features on the CVDF stack. Figure 1.4 shows the air monitoring skid with the connection for the sample transport line and the splitter dividing the sample flow between the record sampler and the alpha/beta continuous monitor.

Figure 1.1. CVDF Ventilation Exhaust Stack

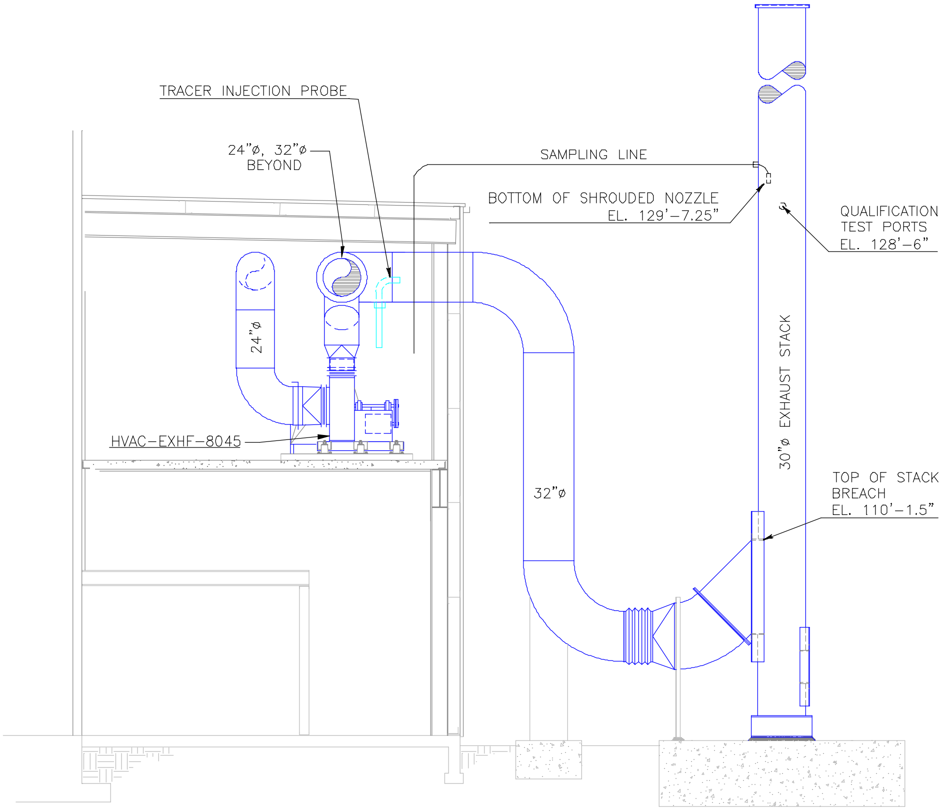

Figure 1.2. Diagram of CVDF Stack and Duct

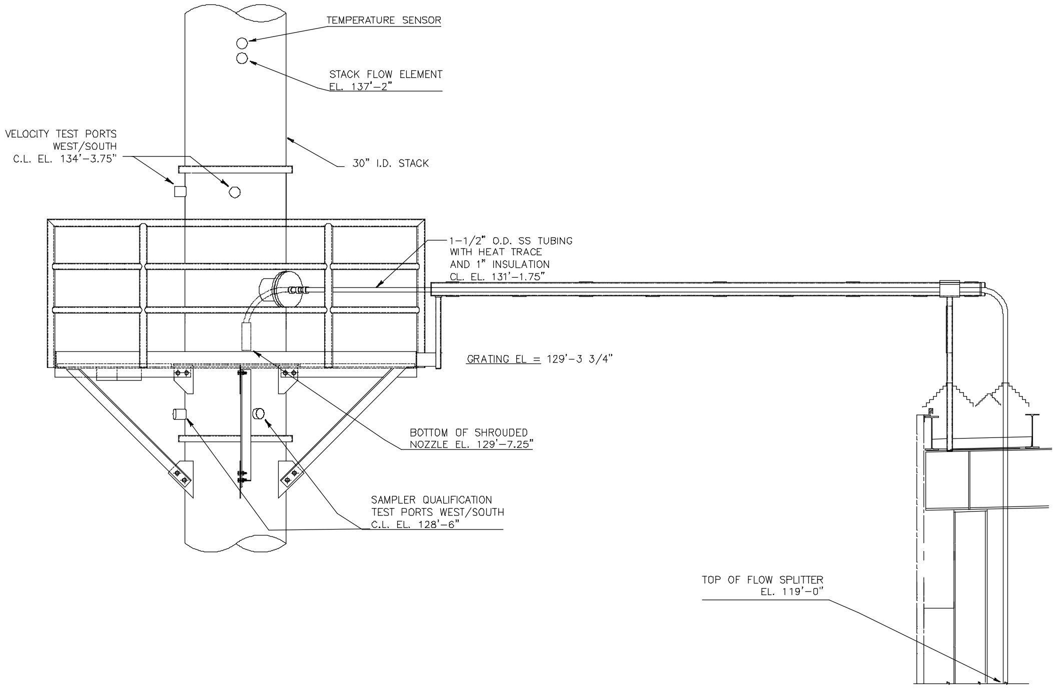

Figure 1.3. Location of Sampling Probe and Test Ports on CVDF Stack

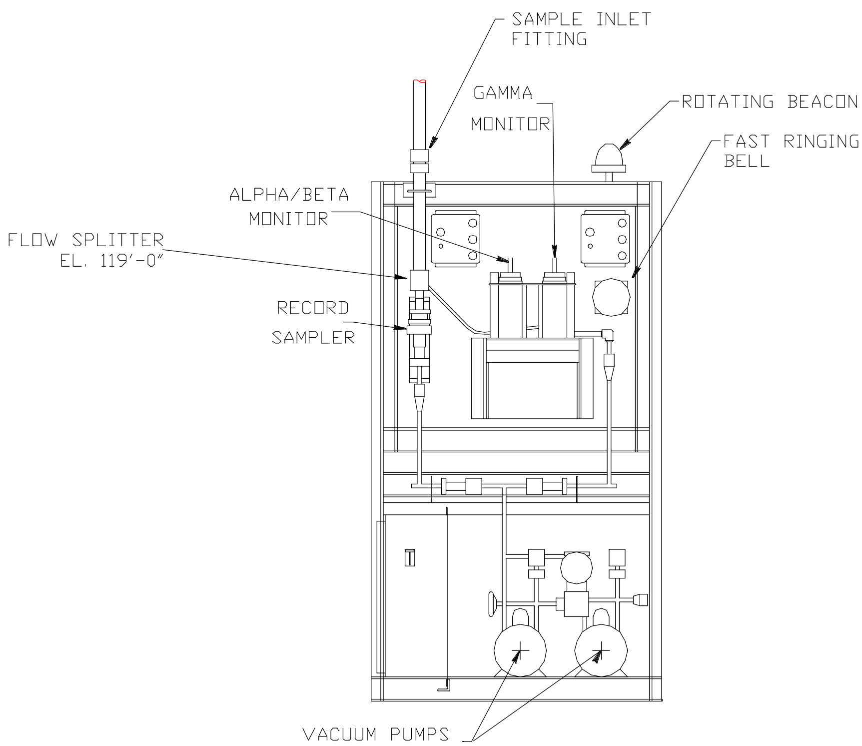

Figure 1.4. Diagram of Air Monitoring Skid

2.0 Qualification Tests

The qualification test methods and results are described in this chapter. Tests were conducted to determine compliance with performance criteria covering angular flow, air-velocity uniformity, gaseous-tracer uniformity, particle-tracer uniformity, particle penetration, and flow element accuracy. Measurements for the first four of these tests were made at the test ports shown in Figures 1.2 and 1.3 and at the normal stack flowrate of about 15,000 acfm. A temporary scaffold was constructed to facilitate access to the test ports as shown in Figure 2.1.

2.1 Angular Flow

The air-velocity vector approaching the sample nozzle should be aligned with the axis of the nozzle within an acceptable angle so sample extraction performance is not degraded. The method used to demonstrate this condition is presented in the following section.

2.1.1 Method

The test method used was based on 40 CFR 60, Appendix A, Method 1, Section 2.4, "Verification of the Absence of Cyclonic Flow." This test was conducted at the normal flowrate in the stack. Measurements were made using a type-S pitot tube, a slant tube or electronic manometer, and a protractor level attached to the pitot tube as shown in Figure 2.2. The flow angle was measured at the elevation of the sampling nozzle. The grid of measurement points was laid out in accordance with the EPA procedure

Figure 2.1. Temporary Scaffold

Figure 2.2. Equipment to Measure Flow Angle

for ten points on each of two linear traverses, arranged perpendicular to each other. The center point was added for additional information over what otherwise be a long distance between points 5 and 6. Thus, there were 11 points along the South-North direction and also along the West-East direction. The pitot tube was rotated until a null differential pressure reading was obtained, and the angle of rotation was then recorded. Appendix A provides the detailed procedure.

2.1.2 Results

The resulting average flow angle was 4º, meeting the <20° flow-angle acceptance criterion. The maximum measured value was 7º near the North side of the stack. Appendix A includes the data sheet, and a plot of the results.

2.2 Uniformity of Air Velocity

The uniformity of air velocity in the stack cross section where the air sample is being extracted ensures that the air momentum in the stack is well mixed. The method used to demonstrate air velocity uniformity and the results obtained are detailed in the following sections.

2.2.1 Method

To determine uniformity, air velocity was measured at the same points as those used for the angular flow test. The method used was based on 40 CFR 60, Appendix A, Method 1. The equipment included a standard Prandtl-type pitot tube and a calibrated electronic manometer as shown in Figures 2.3 and 2.4. The procedure is detailed in Appendix B.

Figure 2.3. Standard Pitot Tube

Figure 2.4. Electronic Manometer

2.2.2 Results

The measured COV of 3% across the center two-thirds of the area of the stack meets criterion that the air velocity COV be ≤20%. Figure 2.5 shows a bar graph of the mean velocity measured at each point. This shows that the velocity uniformity was nearly ideal at the test elevation.

2.3 Uniformity of Tracer Gases

A uniform contaminant concentration at the sampling plane enables the extraction of samples that represent the true concentration. This was first tested using a tracer gas as described in Section 2.3.1.

2.3.1 Method

The concentration uniformity is first demonstrated with a tracer gas injected into the exhaust duct (see Figure 1.2) just inside the CVDF and downstream of the last fan. The concentration of the tracer gas is then measured near the sampling probe using the same grid of points as used in the other tests. From the measurements, the COV and maximum deviation from the mean are calculated as measures of uniformity.

In successive tests, the sulfur hexafluoride[1] tracer was injected along the centerline of the duct and 5 inches (approximately 17% of a hydraulic diameter) from the top, bottom, and both sides of the duct wall. The test with the top injection position was repeated.

The gas samples are withdrawn from the stack through a simple probe shown in Figure 2.6. A Bruel and Kjaer (Naerum, Denmark) Model 1302 gas analyzer, calibrated for the tracer gas, is used for the measurements and is shown in Figure 2.7. The tests were done at the normal stack flowrate. The procedure is detailed in Appendix C.

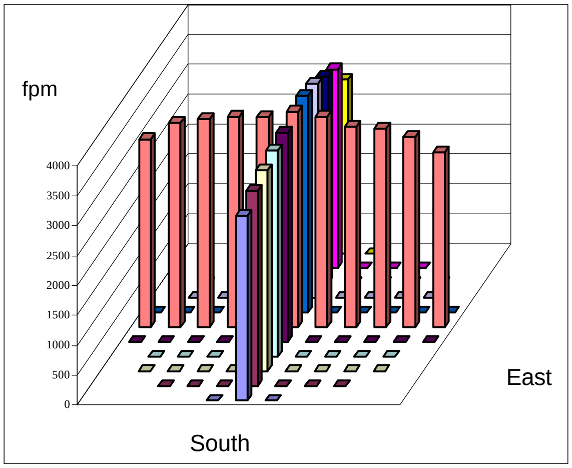

Figure 2.5. Mean Velocity at Measurement Points (COV 3%)

[1] A tracer used for many purposes including building ventilation studies, tracing piping, and wind flow field measurements.

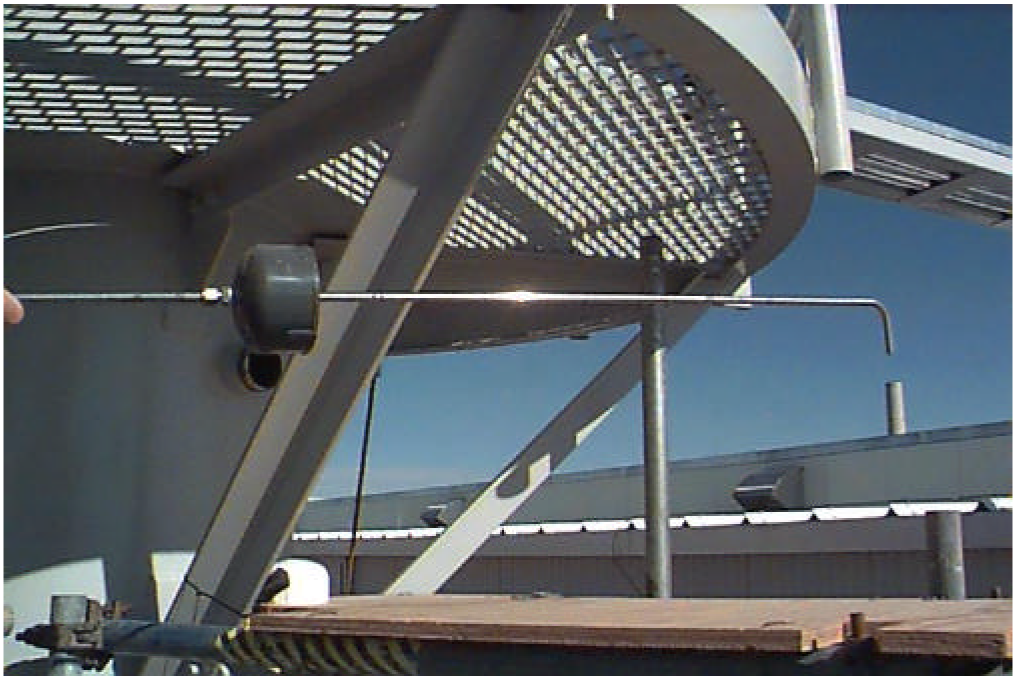

Figure 2.6. Tracer Gas Measurement Probe

Figure 2.7. Tracer Gas Analyzer

2.3.2 Results

Six test runs were performed, one at each injection point, and one repeat at the top injection point. Table 2.1 summarizes the results of the individual test runs. The detailed data sheets are included in Appendix C. The acceptance criteria are that 1) the COV of the tracer gas concentration be ≤20% across the center two-thirds of the sampling plane and 2) at none of the measurement points does the average concentration differ from the mean concentration by >30%. The COV results ranged from 0% to 4% for the center two-thirds of the stack, and the largest deviation of any single-point concentration from the mean concentration in any one run ranged from 1 to 6%. The acceptance criteria were met in all cases. Figure 2.8 shows how uniform the concentration measurements were, even in the worst case.

Table 2.1. Tracer Gas Mixing Results

Injection Point	Percent COV	Maximum % Deviation from Mean
5” from top of duct	4, 0	6, 1
5” from bottom of duct	1	1
5” from south side of duct	0	1
Center of duct	1	1
5” from north side of duct	1	1

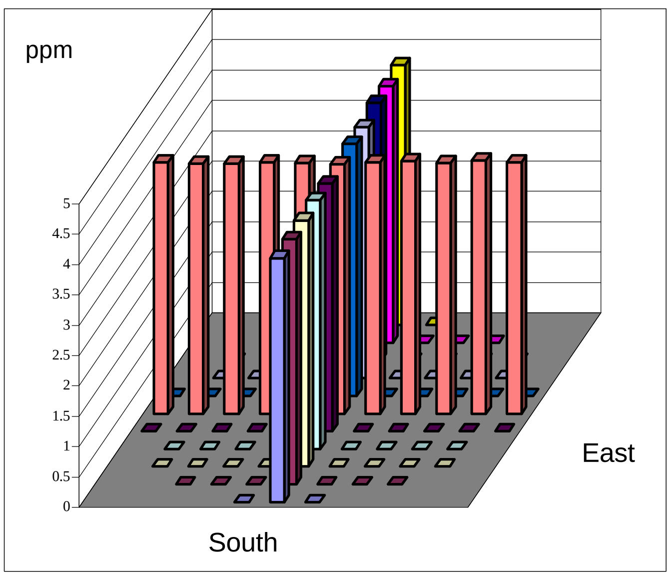

Figure 2.8. Worst Case Measurements of Gas Tracer Concentration (top injection, COV 4%)

2.4 Uniformity of Tracer Particles

The second demonstration of uniform contaminant concentration is made using tracer particles.

2.4.1 Method

The test method for uniformity of tracer particles is similar to the test for uniformity of tracer gases, with the tracer gas replaced by tracer particles. However, only the centerline injection position is required. The concentration of the tracer particles, in the size range of interest, was measured at the same test points used in the other tests. The particles were made by spraying vacuum-pump oil through a nozzle mounted inside a chamber. Particles were then injected into the duct in a stream of compressed air.

A simple probe was used to extract the sample from the stack and transport it to the optical particle counter (OPC, Met-One Model A2408, Grants Pass, Oregon) arranged as shown in Figure 2.9. The OPC sorts the number of particles into six size channels. Each concentration reading was the count of particles collected in one minute in the 9 to 11 ìm channel. Three readings were taken at each point and averaged. The COV of the average concentration readings at each point is calculated and the result compared to the acceptance criterion for uniformity. The particle mixing is acceptable if the COV of the tracer particles of 10-ìm AD is less than 20% across the center two-thirds of the sampling plane. The detailed procedure is included in Appendix D.

2.4.2 Results

The uniformity of particle concentration was measured twice at the normal stack flowrate, and the results are summarized in Table 2.2. The data sheets are included in Appendix D. The row labeled "raw

Figure 2.9. Optical Particle Counter and Probe Arrangement

Table 2.2. Particle Tracer Uniformity Results for the Center Two-Thirds of the Stack

	% Coefficient of Variation	
	Run 1	Run 2
Raw data	11	5
Normalized	9	5

data" shows results without any normalization with time. The results after normalization are also shown. The normalization method adjusted all of the concentration readings by the same amount so that the centerpoint readings taken from the two traverse directions were equalized. The effect of normalization would be more pronounced in cases where there was a shift in concentration with time. The improvement in uniformity in Run 2 was probably caused by completing the run in a shorter time than in Run 1. The particle generator output also becomes more uniform over time. The performance criterion was met in both runs. Figure 2.10 is a bar chart showing the normalized concentration data for Run 1.

A comparison of Figures 2.5, 2.8, and 2.10 shows that the tracer gas is more uniform than the tracer particles and velocity. The higher COV for particles indicates that the particles mix slower, probably because of their inertial and drag properties. The gas mixes very well with the air, so the concentration is quite uniform, even though the velocity is less uniform. This underscores the need for the separate tests, because the results of one test do not predict those of the others.

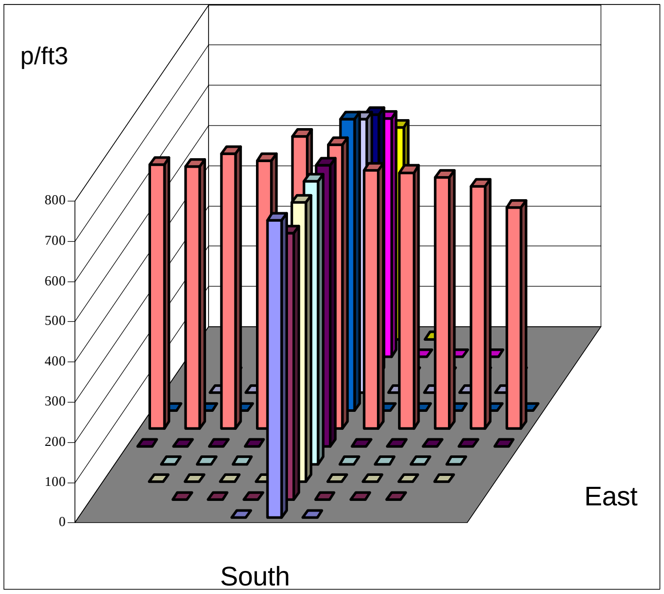

Figure 2.10. Plot of Tracer Particle Measurements from Run 1 (COV 9%)

2.5 Sample Extraction and Transport System Performance

The acceptance criteria are: 1) nozzle transmission ratio for a 10 ìm AD particle is 0.8 to 1.3, 2) nozzle aspiration ratio for a 10 ìm AD particle is 0.8 to 1.5, and 3) the test particle penetration through transport system is ≥50% for 10 ìm AD particles. The nozzle characteristics are inherent in the design and were verified in wind-tunnel tests (McFarland et al. 1989; Glissmeyer and Ligotke 1995) and in the manufacturer's submittals. The overall particle transport is required to be verified experimentally or with the DEPOSITION 4.0 code (Riehl et al. 1996). The nozzle design factors are addressed in DEPOSITION 4.0; however, the results are combined into the overall transmission result for the nozzle and not stated separately.

Particle penetration through the sampling lines was assessed using the DEPOSITION 4.0 code. Prior to use, the code was verified against a test case. The sample transport elements modeled in the code include sampling nozzles, straight tubes at any angle to the horizontal plane, bends, and expansions and contractions in tube size. The code does not model splitters.

Figure 2.11 is a diagram of the segments of the sampler tubing. The characteristics of the sampling system elements, from the free stream to the splitter, are listed in Table 2.3.

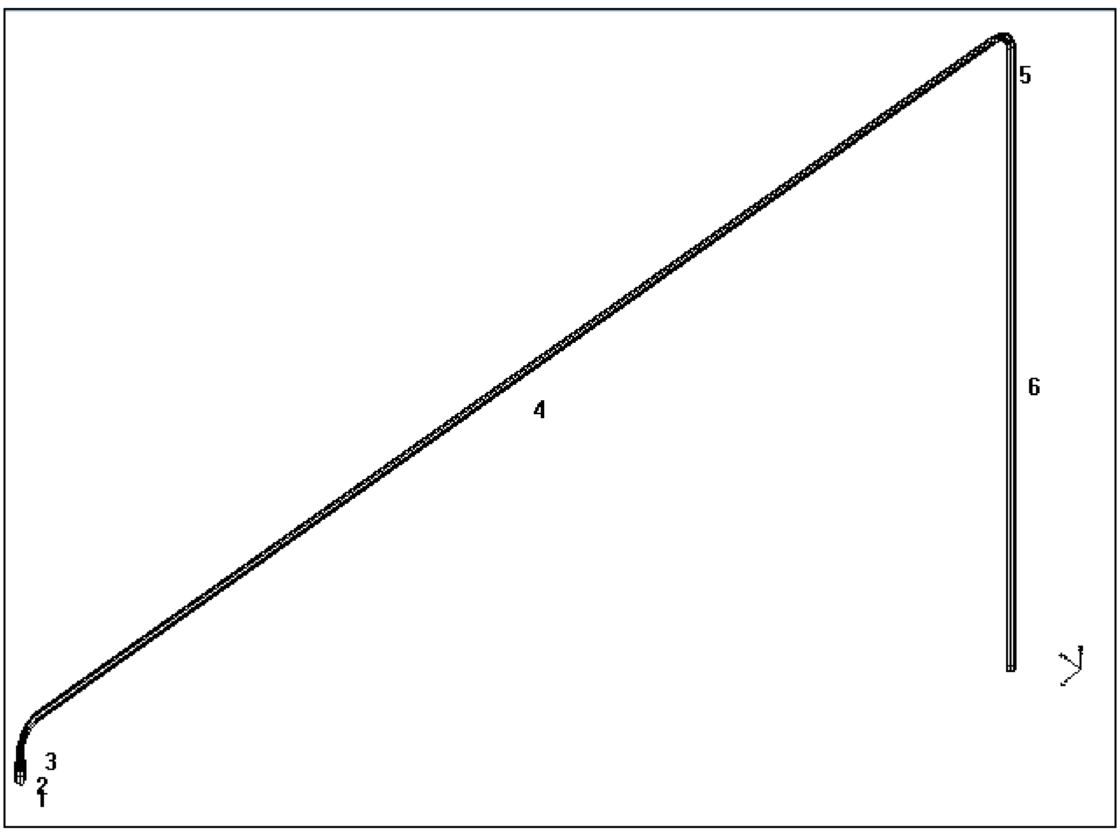

Figure 2.11. Diagram Labeling the Elements 1-6 (see Table 2.3) of the Sampling System Tubing

Table 2.3. Model Inputs and System Characteristics

Sampled Air Temperature 39ºC
Sampled Air Pressure 740.0 mm Hg based on lowest observed during gas mixing tests
Particle Density 1 g/ml
Flow rate 56.6 L/min
Free Stream Velocity 17 m/s
Particle Size 10 ìm AD
Sampling Tube inside diameter 34.8 mm
Element 1: Shrouded probe Inner inlet diameter 18.3 mm Shroud diameter 53.8 mm Shroud velocity reduction ratio 3.31 Probe angle with Free Stream 0º
Element 2: Tube Tube length 0.075 m Inclination from the horizontal plane 90º from the figure) Upward flow
Element 3: Bend 90º clockwise
Element 4: Tube Tube Length 5.404 m Inclination from the horizontal plane 0º
Element 5: Bend 90º clockwise
Element 6: Tube Tube length 3.52 m Inclination from the horizontal plane 90º Downward flow

There is an unknown number of two-tube unions used in the sampling system. The tubing inside diameter is 34.8 millimeters and that of a Swagelok™ union is 34.0 millimeters. Thus, the airflow experiences a slight contraction and expansion over a lineal distance of only 8 millimeters. This small contraction/expansion is outside the valid range for the model, and the model evaluates to 100% penetration for this step change. These fittings were not given further consideration in the analysis.

The DEPOSITION 4.0 calculated results for the six elements are listed in Table 2.4. The element controlling the penetration is the long horizontal run from the stack to the sampling skid. The estimated overall particle penetration from the free stream to the splitter was 56%, which should then be multiplied by the penetration through the splitter.

Table 2.4. DEPOSITION 4.0 Calculation Results

<table>
<tr><td colspan="6">DEPOSITION 4.0. Tue Oct 24 15:43:29 2000</td></tr>
<tr><td colspan="2">Exit
Stokes #</td><td colspan="2">Exit
Reynolds #</td><td colspan="2">Total
Penetration</td></tr>
<tr><td colspan="2">0.0086</td><td colspan="2">2170</td><td colspan="2">56.0%</td></tr>
<tr><td colspan="6"></td></tr>
<tr><td>Element #</td><td>Element</td><td>Penetration</td><td>Stokes #</td><td>Reynolds #</td><td>Notes</td></tr>
<tr><td>1.</td><td>Probe</td><td>107.6%</td><td>0.0086</td><td>2170</td><td>Probe diameter: 18.3 mm, Shroud diameter: 53.8 mm, Velocity reduction ratio 3.31</td></tr>
<tr><td>2.</td><td>Tube</td><td>100.0%</td><td>0.0086</td><td>2170</td><td>Length: 0.075 m, At 90.000 degrees from horizontal.</td></tr>
<tr><td>3.</td><td>Bend</td><td>96.3%</td><td>0.0086</td><td>2170</td><td>Bend angle: 90.000 degrees.</td></tr>
<tr><td>4.</td><td>Tube</td><td>56.1%</td><td>0.0086</td><td>2170</td><td>Length: 5.404 m, At 0.000 degrees from horizontal.</td></tr>
<tr><td>5.</td><td>Bend</td><td>96.3%</td><td>0.0086</td><td>2170</td><td>Bend angle: 90.000 degrees.</td></tr>
<tr><td>6.</td><td>Tube</td><td>100.0%</td><td>0.0086</td><td>2170</td><td>Length: 3.52 m, At 90.000 degrees from horizontal.</td></tr>
<tr><td colspan="6">Ambient temperature (deg.C): 39.0</td></tr>
<tr><td colspan="6">Ambient pressure (mm Hg): 740.0</td></tr>
<tr><td colspan="6">Flow rate (L/min): 56.6</td></tr>
<tr><td colspan="6">Free stream velocity (m/s): 17.0</td></tr>
<tr><td colspan="6">Particle diameter (μm): 10.0</td></tr>
<tr><td colspan="6">Note: Calculations were made with the best possible extrapolations of the model(s).</td></tr>
</table>

Glissmeyer et al. (1997) measured the particle penetration through the Nuclear Research Corporation splitter. The maximum deposition measured was 2.7% for 10 ìm AD particles, for which the penetration is 100 - 2.7 = 97.3%. Multiplying the DEPOSITION estimate by the splitter penetration yields an overall penetration of 54.5%. This exceeds, by a small amount, the 50% criterion in ANSI/HPS N13.1-1999.

2.6 Stack Flow Measurement System Relative Accuracy

The accuracy of the CVDF stack flow measurement system was assessed using the methods given in regulation, 40 CFR 52, Appendix E. This method was chosen because it was cited in the NOC. The stack air flow measurement system is part of what the supplier calls the Generic Effluent Monitoring System (GEMS). Fourteen pairs of flow readings, at the maximum stack flow, were obtained in a 168-hour period. Each pair consisted of flow measurements obtained by the reference method, 40 CFR 60 Method 2, and the GEMS. Vent and Balance Staff performed the manual flow traverses and recorded the GEMS stack flow readings. The manual flow traverses were conducted following Procedure SNF-W441-PAT-050-2, Rev. 0, which follows the EPA method given in 40 CFR 60, Method 2.

The fourteen pairs of readings were obtained over a 168-hour period starting on September 29 and ending on October 6, 2000. The stack flow was fairly constant over this period. Vent and Balance staff recorded velocity pressures at each test point and converted the readings to approximate velocity using a look-up table (ACGIH 1984), which performs the calculation of

$$\text{Velocity, fpm} = 4005 \times \text{Sqrt (Velocity pressure, inches of water)}$$

and assumes that the measurement conditions are dry air at 70ºF and 29.92 inches mercury pressure. The measurement was performed with a Dwyer Instruments s-type pitot tube and an electronic manometer. The pitot tube correction factor was not used in the recorded calculation of flow on the data sheets. The pitot tube correction factor given in Dwyer Instruments compliance certificates is 0.84. The GEMS performs a similar calculation, but with a conversion factor unique to the Dietrich Standard Annubar™ installed in the stack; however, the actual stack temperature is factored into the calculation prior to display. Vent and Balance staff also used a stack diameter slightly larger than that measured and used by the GEMS. Consequently, prior to comparing the readings from the two measurement methods, the reference measurements were corrected for stack diameter, temperature, and the pitot tube correction factor. The correction for pitot tube factor was significant and the temperature correction was small (<0.9%).

The recorded data and calculation of relative accuracy are shown in Table 2.5. First, the differences between the two measurements and the square of the differences is calculated. The sum and mean of the differences and the sum of squares of differences are calculated. The 95% confidence interval is calculated and added to the absolute value of the mean of differences. The percent ratio of this value to the mean reference flow is the percent relative accuracy. The resulting value was 6.3%, meeting the <10% criterion given in the regulation. Most of the percent relative accuracy is due to systematic error. The systematic error could be caused by incorrect scaling factors in the GEMS and improper calibration of the pressure sensor. Further explanation is not possible until the details of the scaling factors and calibration data are available. If the systematic error were removed, the relative accuracy would improve to around 1%.

The regulation also contains criteria for zero drift, calibration drift, and orientation sensitivity. It was felt that because of the configuration of the GEMS, that these criteria did not apply. Nevertheless, because the flow sensing element (Annubar™) could be rotated after a jam nut was loosened, the orientation sensitivity test was conducted.

In the orientation sensitivity test, the flow element is rotated at -10, -5, 0, 5, and 10 degrees relative to the axis of the stack. The GEMS readout is recorded at each rotation. This is repeated three times at three different stack flowrates, i.e., 100%, 67%, and 33% of maximum operating stack flowrate. Before each series of rotations, a manual reference flow measurement was obtained by Vent and Balance staff using the same method as the 168-hour test. This time the pitot tube factor was accounted for in the recorded reference data. The temperature and stack diameter corrections were made to the reference readings. The nine sets of measurements are shown in Table 2.6.

Table 2.5. Stack Flow Measurement Accuracy

Pitot factor =	0.84

	Stack dia in.	X-Area ft2	Area
Used by V&B	30.125	4.950	A1
Measured and used in GEMS	30	4.909	A2
		0.992	A2:A1

Test	**Reference Readings**							**GEMS**	**Calculations**	
Order	Date	Recorded acfm	Corrected for pitot factor	Temp F	Baro in. Hg	Static in. WC	Area, temp and pitot factor corrected acfm	GEMS reading acfm	Differences, di	di^2
1	29-Sep-2000	20339	17085	80	29.119	0.40	17090	16100	989.7	979443
2	2-Oct-2000	20597	17301	73	29.59	0.26	17194	15900	1293.9	1674211
3	2-Oct-2000	20137	16915	74	29.58	0.28	16826	16000	825.7	681743
4	2-Oct-2000	20161	16935	75	29.57	0.29	16861	16000	861.5	742176
5	2-Oct-2000	20062	16852	75	29.55	0.28	16779	16000	778.7	606371
6	3-Oct-2000	20142	16919	72	29.67	0.25	16798	15900	898.3	806959
7	3-Oct-2000	20716	17401	73	29.67	0.26	17293	16000	1293.3	1672500
8	5-Oct-2000	20097	16881	72	29.83	0.31	16761	16000	760.8	578785
9	5-Oct-2000	20156	16931	73	29.84	0.34	16826	16000	825.8	681906
10	5-Oct-2000	20057	16848	74	29.81	0.34	16759	15900	858.8	737593
11	5-Oct-2000	20132	16911	75	29.79	0.33	16837	15900	937.2	878423
12	6-Oct-2000	20671	17364	72	29.752	0.28	17239	16000	1239.5	1536339
13	6-Oct-2000	20354	17097	74	29.754	0.28	17007	16000	1007.0	1014036
14	6-Oct-2000	20330	17077	75	29.72	N.A.	17003	16000	1002.8	1005684
						Mean corrected reference	**16948**			
								Sum of di =	13573.0	
								d = Mean di =	969.5	
								Sum di^2 =	13596169.0	
								95% Confidence interval	105.9	
								Sum absolute mean difference plus confidence interval	1075.4	
								Percentage relative accuracy	**6.3%**	

Table 2.6. Rotational Sensitivity Data

Test	Reference Readings acfm				Area &	GEMS reading acfm				
Order	Reference	Temp F	Baro in. Hg	Static in WC	Temp Corrct	10 CCW	5 CCW	0	5 CW	10 CW
6	5510	80	29.469	0.01	5512	5490	5520	5540	5500	5390
3	5572	77	29.460	0.02	5558	5380	5430	5560	5450	5380
9	5617	81	29.128	0.03	5624	5400	5510	5510	5560	5490
5	11817	78	29.469	0.17	11798	10900	11200	11300	11200	10600
2	11941	73	29.462	0.22	11867	11200	11300	11400	11400	11200
8	12208	79	29.152	0.21	12200	11300	11400	11600	11500	11400
7	17493	79	29.451	0.48	17482	16100	16500	16600	16500	16100
4	17805	78	29.464	0.43	17777	16400	16600	16800	16600	16600
1	17813	75	29.466	0.41	17735	16300	16700	16700	16700	16400

The initial interpretation of the 40 CFR 52 Appendix E method was that the ratio of the readings of the GEMS to the reference method measurements were to be computed and plotted as a function of rotation angle as shown in Figure 2.12. Figure 2.12 shows that all of the data for a flowrate greater than about 5,700 acfm fall outside the ±4% acceptable range. This was expected because there already was a 6% systematic error between the GEMS and the reference method.

It was not clear why the rotational sensitivity criterion should be tighter than that given for the 168-hr test. Clarification of the method was sought and received from EPA (see Appendix E) such that the ratio calculated should be that of the GEMS at the rotational angles relative to the GEMS reading at zero rotation. These ratios are listed in Table 2.7 and plotted in Figure 2.13. This approach allows a look at the rotational sensitivity without the interference of the systematic error already identified. Figure 2.13 shows that when that bias is removed (effectively pulling all data points so they coincide with one at zero degrees rotation) only one data point falls outside the acceptable range, and that is at a 10º rotation. In any case, as long as the rotation angle is fixed at 0º, the overall relative accuracy requirement is satisfied. It is recommended that the zero rotation angle of the GEMS flow element be verified as part of the regular system inspection procedure.

Table 2.7. Ratio GEMS to Reference Reading

	Ratio GEMS To Reading to Zero Rotation				
Reference	-10	-5	0	5	10
5512	0.99	1.00	1.00	0.99	0.97
5558	0.97	0.98	1.00	0.98	0.97
5624	0.98	1.00	1.00	1.01	1.00
11798	0.96	0.99	1.00	0.99	0.94
11867	0.98	0.99	1.00	1.00	0.98
12200	0.97	0.98	1.00	0.99	0.98
17482	0.97	0.99	1.00	0.99	0.97
17777	0.98	0.99	1.00	0.99	0.99
17735	0.98	1.00	1.00	1.00	0.98

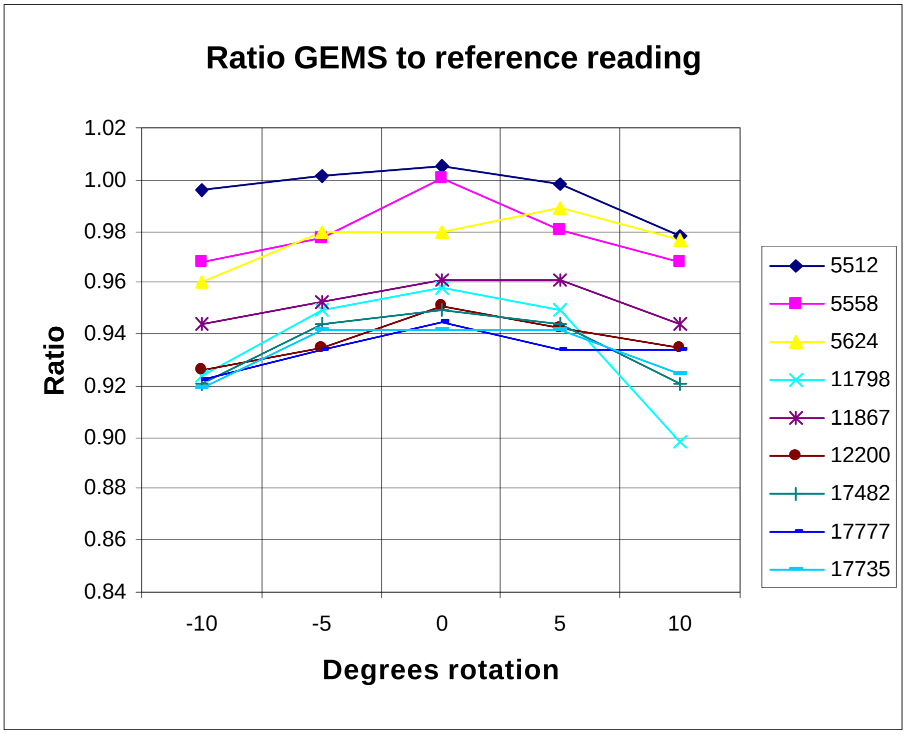

Figure 2.12. Plotted Ratios of GEMS to Reference Stack Flow Readings

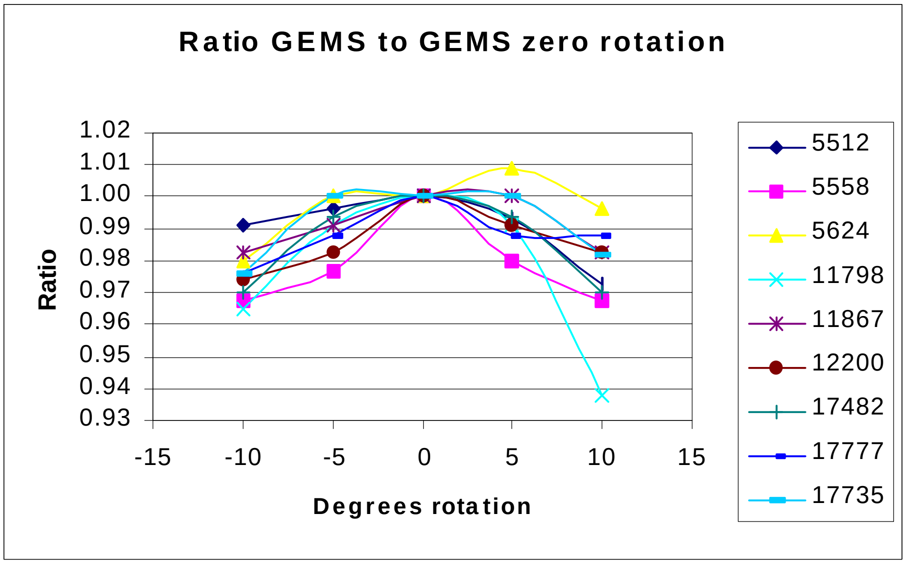

Figure 2.13. Plotted Ratios of GEMS Readings to GEMS Zero Rotation Reading

3.0 Conclusions

The tests conducted on the CVDF air monitoring system demonstrated that the location for the air-sampling probe meets all performance criteria for air sampling systems at nuclear facilities. The performance criterion for particle transport was also met. Table 3.1 summarizes the conclusions for these tests.

With regard to the last row in the table, the compliance of the sampling nozzle with certain detailed acceptance criteria were not separately tested in connection with this installation. These two acceptance criteria for nozzles are that the transmission be in the 0.8 to 1.3 range and that the aspiration ratio be in the 0.8 to 1.5 range for 10-ìm -AD particles. The nozzle characteristics are inherent in the design and

Table 3.1. Conclusions on Air Sampling System Tests

Test	Runs/Configuration	Results	Criteria	Meets
Flow Angle	1 at test ports at sampler nozzle elevation	4 degrees	<20 degrees	Yes
Velocity Uniformity	1 at test ports	3% COV	COV ≤20%	Yes
Gas tracer uniformity with injection in duct downstream of all fans	2 with injection 5” from top of duct	4% and 0% COV, 6% and 1% deviation from mean	COV ≤20% in center 2/3 of stack ≤30% maximum deviation from mean	Yes
	1 with injection 5” from bottom of duct	1% COV, 1% deviation from mean		Yes
	1 with injection 5” from south side of duct	0% COV, 1% deviation from mean		Yes
	1 with injection in center of duct	1% COV, 1% deviation from mean		Yes
	1 with injection 5” from north side of duct	1% COV, 1% deviation from mean		Yes
Particle tracer uniformity with injection in duct downstream of all fans	2 with center injection	11% and 5% COV	COV ≤20% in center 2/3 of stack	Yes
Particle penetration from free stream to filter	DEPOSITION 4.0 run and previous experimental results	54.5% for 10 ìm AD particles	≥50% for 10 ìm AD particles	Yes

were verified previously in wind tunnel tests (McFarland et al. 1989; Glissmeyer and Ligotke 1995) and in the manufacturer's submittals. These factors are addressed in the modeling done with DEPOSITION 4.0; however, the results are combined into the overall transmission result for the nozzle and not stated separately. This study concludes that these criteria are met.

The tests conducted on the stack flow measurement system demonstrate that the flow measurements are sufficiently accurate. The test results are summarized in Table 3.2. The continual operability and relative accuracy criteria were fully met. It is felt that the sensor does not use rotational angle as part of the measurement and that the additional criterion for rotational sensitivity do not apply. The sensor element should be locked into zero rotation.

Table 3.2. Conclusions on Stack Flow Accuracy

Parameter	Runs/Configuration	Test Results	Criteria	Meets
Rotational Sensitivity	9 runs -- Three reference readings for each of three flow settings, 1 GEMS reading per 5 rotational settings per run	Max. deviation 6% relative to zero rotation. 35 of 36 points <4% deviation	±4% of reference value	1 of 36 points out of range, but applicability of requirement questionable. Rotation to be maintained at 0º.
Continual operability	Two consecutive 168-hour periods of continual operation	Operated continuously	168-hours minimum	Yes
Relative accuracy	14 paired readings of system and reference measurements over 168-hr period	6.3%	<10% of mean reference value	Yes

4.0 References

40 CFR 52, Appendix E. U.S. Environmental Protection Agency. "Performance Specifications and Specification Test Procedures for Monitoring Systems for Effluent Stream Gas Volumetric Flowrate." *Code of Federal Regulations*.

40 CFR 60, Appendix A, Method 2, as amended. U.S. Environmental Protection Agency. "Method 2 - Determination of Stack Gas Velocity and Volumetric Flow Rate." *Code of Federal Regulations*.

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

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DEPOSITION 4.0 available for download at url:
http://wwwmengr.tamu.edu/Software/Deposition/deposition.html

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