PNNL-28593 Rev 0
WTP-RPT-248 Rev 0

Effluent Management Facility Stack Monitor Qualification

Assessment with Surrogate Stacks

May 2019

JE Flaherty
EJ Antonio

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

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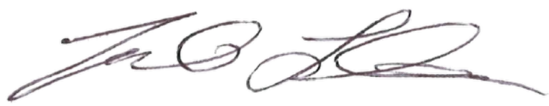
Pacific Northwest National Laboratory
Richland, Washington 99354

Completeness of Work

This report describes the result of work specified by Research Plan RP-WTPSP-161, Rev 0. The work followed the quality assurance requirements outlined in the Research Plan and/or Statement of Work. The descriptions provided in this report are an accurate account of both the conduct of the work and the data collected. Research Plan results are reported. The analysis results and this report have been reviewed and verified.



Julia Flaherty, Project Manager

Executive Summary

Sampling and monitoring at the Waste Treatment and Immobilization Plant (WTP) Effluent Management Facility (EMF) exhaust is required to meet the regulatory criteria that governs stacks that may exceed the 0.1-millirem per year threshold limit given in Title 40 of the Code of Federal Regulations, Part 61, National Emissions Standards for Hazardous Air Pollutants, Subpart H, National Emission Standard for Emissions of Radionuclides other than Radon from Department of Energy Facilities. As a result, the flow conditions and probe location must be within certain bounds as prescribed by the American National Standards Institute/Health Physics Society (ANSI/HPS) standard N13.1-1999.[1] Compliance with the standard may be demonstrated by tests on the stack itself, or with a surrogate stack (i.e., a scale model or other geometrically similar stack).

In lieu of performing ANSI/HPS N13.1-1999 stack sampling location qualification tests on the stack itself, or on a scale model of the stack, existing, geometrically similar stacks to the EMF were evaluated as allowed by the ANSI/HPS N13.1-1999 standard. Stack conditions that were considered were the normal operating conditions for the EMF stack. A normal flow rate was provided, and minimum and maximum flow rates were assumed to be 70% of the normal flow and 115% of the normal flow, respectively.

The EMF ventilation system is composed of two systems: (1) the Direct Feed Low Activity Waste (LAW) Effluent Management Facility Vessel Vent Process (DVP) and (2) the Active Confinement Ventilation (ACV) systems. The DVP system is the off-gas from vessel vents and the EMF evaporator, and will have higher radiological emissions compared with the ACV, which is the building ventilation system. The ACV contaminant is introduced in a typical way, upstream of the fans to the stack. The DVP flow, however, is introduced into the main stack after the first horizontal bend in the stack. This DVP injection location is not a typical location for the introduction of a contaminant stream. The potential mixing at the EMF probe location must therefore account for an introduction of contaminant at a mid-point within the stack as well as for the typical contaminant introduction location at the main stack fans.

The EMF stack sampling location meets many of the qualification criteria through the use of the LV-S1 scale model stack, which is geometrically similar to the EMF. The LV-S1 scale model stack velocity uniformity and flow angle data support the EMF stack qualification, while the gaseous tracer uniformity partially meets the needs to qualify the EMF stack sampling location. Particulate and gaseous tracer uniformity tests were primarily performed with injections of contaminant just downstream of the operating fan, which is pertinent to contaminants from the ACV system. One gaseous tracer test was performed with the injection at the centerline of the duct at a location comparable to the DVP location on the EMF duct. This test result of 1.9% coefficient of variance (COV) and 7.8% maximum deviation is within the ANSI/HPS N13.1-1999 criteria, which is 20% COV and 30% maximum deviation.

Because only one gaseous tracer test was performed with the LV-S1 stack from a gas injection location comparable to the DVP location, two other surrogate stacks were evaluated for qualification of the gaseous and particulate tracer uniformity for contaminants originating from the DVP fans. The LB-S1 and LV-S2 scale model stacks are similar to the EMF stack in that they have a “U-shaped” section with stack sampling in the downstream leg. Although there are

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

some stack features upstream of the DVP injection location that differ from the EMF, these stacks are functionally similar to the EMF based on features downstream of the DVP injection location. For all tracer uniformity test cases, the LB-S1 scale model tests were within the stack qualification criteria. Particulate uniformity test results were approximately 10% COV, while gaseous uniformity tests results were often below 5% COV and 10% maximum deviation. The LV-S2 scale model tests performed with Injection Port I2 (comparable to the DVP injection location) were within the stack qualification criteria. Particulate uniformity test results were generally between 6% and 19% COV, with higher values from Fan A (downstream fan) and at higher velocities. Gaseous tracer uniformity results were often less than 5% COV and 10% maximum deviation.

The EMF stack sampling location meets all of the qualification criteria through the combination of the LV-S1, LB-S1, and LV-S2 scale model stack test results.

Verification tests of velocity uniformity and flow angle are required on the EMF stack to ensure that the use of the surrogate stack is acceptable for representing the EMF. These tests must show that the velocity uniformity is less than 10% COV (to compare within 5% of the LV-S1 scale model result) and the flow angle is less than 20 degrees (to meet the ANSI/HPS N13.1-1999 qualification criterion).

Acknowledgments

Preparation of the analysis described in this report, as well as the production of the report itself, involved several Pacific Northwest National Laboratory (PNNL) staff. We would like to particularly acknowledge the support of our quality engineer, Kirsten Meier, and administrative support from Chrissy Charron and Veronica Perez. Project management support from Reid Peterson and Michael Minette is also highly valued. Xiao-Ying Yu, Jenn Yao, and Carmen Arimescu provided technical reviews of this document, while Matthew Barnett provided valuable insight concerning interpretation of the ANSI/HPS N13.1-1999 standard. Finally, Heather Culley provided editorial support for this report.

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Acronyms and Abbreviations

Ø	duct diameter
ACV	Active Confinement Ventilation system
ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
BNI	Bechtel National, Incorporated
CCN	Correspondence Control Number
CCP	Computational Computer Program
CFR	Code of Federal Regulations
COV	coefficient of variation = (standard deviation / mean) 100%
DV	hydraulic diameter × mean velocity
DVP	direct feed vessel vent process system
EMF	Hanford Effluent Management Facility
fpm	feet per minute
HLW	Hanford High Level Waste Facility
HPS	Health Physics Society
LAW	Hanford Low Activity Waste Facility
LB-S1	WTP analytical laboratory zone C3 (non-process) ventilation system exhaust stack
LV-S1	WTP low activity waste zone C3 (non-process) ventilation system exhaust stack
LV-S2	WTP low activity waste zone C5 (process area) ventilation system exhaust stack
NQA	nuclear quality assurance
PIC	potential impact category
PNNL	Pacific Northwest National Laboratory
QA	quality assurance
Re	Reynolds number
scfm	standard cubic feet per minute, an air volume flow unit at standard air density
SCN	subcontract change notice
WTP	Hanford Tank Waste Treatment and Immobilization Plant
WTPSP	Waste Treatment Plant Support Project

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1.0 Introduction

Sampling and monitoring at the Waste Treatment and Immobilization Plant (WTP) Effluent Management Facility (EMF) exhaust is required to meet the regulatory criteria that governs stacks that may exceed the 0.1-millirem per year threshold limit given in Title 40 of the Code of Federal Regulations, Part 61, National Emissions Standards for Hazardous Air Pollutants, Subpart H, National Emission Standard for Emissions of Radionuclides other than Radon from Department of Energy Facilities. As a result, the flow conditions and probe location must be within certain bounds as prescribed by the American National Standards Institute/Health Physics Society (ANSI/HPS) standard N13.1-1999. Compliance with the standard may be demonstrated by tests on the stack itself, or with a surrogate stack (i.e., a scale model or other geometrically similar stack).

Pacific Northwest National Laboratory (PNNL) has performed scale model stack tests for 11 of the 20 emission points that are planned for the WTP. Additionally, PNNL has full scale stack results from Idaho National Laboratory and PNNL facility stacks to use as references. One or more WTP scale model stack results were expected to be appropriate as a surrogate stack to the EMF. This report describes the EMF stack monitoring location as well as an assessment of existing surrogate stacks used to qualify the EMF stack sampling location.

1.1 Effluent Management Facility

An interim WTP configuration that supports near-term tank waste treatment in the Low Activity Waste (LAW) facility is being pursued to allow tank waste processing to begin before technical concerns with the Pretreatment Facility and the High Level Waste Facility (HLW) are completed. With this Direct Feed LAW configuration, the EMF will treat radioactive liquid effluents from the submerged bed scrubber condensate, caustic scrubber effluent, wet electrostatic precipitator drains, liquids from flushing or draining of transfer lines to and from the Tank Farms, and periodic liquid waste transfers generated by the WTP Laboratory facility (Walker 2016).

The EMF ventilation system is comprised of two systems: (1) the Direct Feed LAW Effluent Management Facility Vessel Vent Process (DVP) and (2) the Active Confinement Ventilation (ACV) systems. The DVP system is the off-gas from vessel vents and the EMF evaporator, and will have higher radiological emissions compared with the ACV, which is the building ventilation system. Figure 1.1 shows the basic configuration of the EMF duct and stack, including the location where the DVP flow is introduced into the primary ACV duct. The initial design simply specified that the DVP pipe meet the ACV duct. The design has subsequently been revised such that the DVP pipe continues 12 inches into the main EMF duct and has a 45-degree bend in the tip with the opening pointed downstream. Table 1.1 provides estimates of the unabated and abated emissions and dose from each of the two EMF ventilation systems. The total from the EMF stack is the sum of the emissions from these two systems. Based on the total potential to emit of approximately 0.3 mrem/year, the emission unit is considered a potential impact category (PIC) 2 facility, with continuous sampling for a record of stack emissions. The record sample location, approximately 25 feet upstream of the vertical bend of the duct into the stack, must be qualified per ANSI/HPS N13.1-1999.

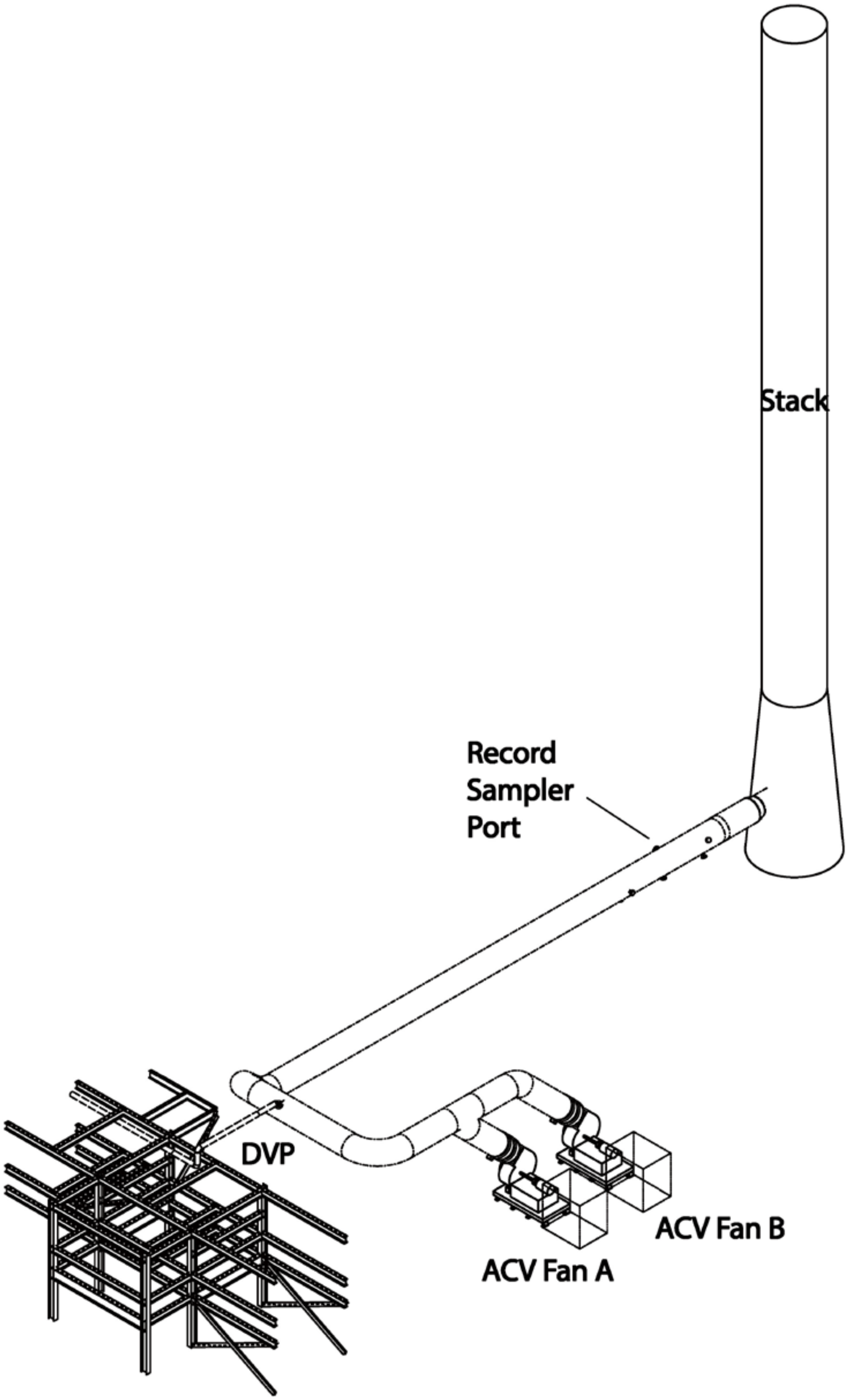


Figure 1.1. Isometric Drawing of the Effluent Management Facility Exhaust Duct and Stack

Table 1.1. EMF Ventilation Emission and Dose Estimates from the ACV and DVP Systems

Ventilation System	Unabated Emission (Ci/year)	Abated Emission (Ci/year)	Unabated Dose (mrem/year)	Abated Dose (mrem/year)
ACV	1.21E+00	3.13E-02	4.41E-02	3.79E-05
DVP	7.24E+00	1.85E-01	2.64E-01	9.67E-05
Total	8.44E+00	2.16E-01	3.08E-01	1.35E-04

Source: Walker 2016

As shown in Figure 1.1, there are two fans, ACV A and ACV B, that supply the bulk of the air flow to the exhaust duct. One fan operates at a time, while the other serves as a backup. Although not shown on the figure, the DVP flow is also supplied by two exhausters such that one is in operation and the other serves as a backup. HEPA filters are located upstream of each set of the exhaust fans. The ACV flow is the bulk of the air flow through the stack at 26,870 cfm. The DVP flow is 160 cfm (Mitchell 2018). A summary of EMF stack parameters is presented in Table 1.2.

Table 1.2. EMF Stack Parameters

Stack Characteristic	Value
Duct diameter at sampling probe	46 in.
No. of duct diameters from upstream disturbance to sampling probe	23.5
No. of duct diameters from sampling probe to downstream disturbance	4.6
No. of duct diameters between horizontal bends	5.3
No. of duct diameters from Fan A junction to first horizontal bend	2.5
No. of operating fans	1
Total available fans	2
Normal operating flowrate	26,870 scfm
Normal operating air velocity at sampling probe	2,328 fpm
Normal air temperature at exit	87°F

Source: Mitchell 2018

This report describes the stack qualification approach for the WTP EMF, along with recommendations concerning verification testing.

2.0 Methods

The EMF stack emission sampling location must be qualified per ANSI/HPS N13.1-1999 to ensure that sample collection is representative of the overall stack emission. While the stack emission sampling location may be qualified by performing a full suite of tests on the stack, there is a risk in that approach because it would necessitate the facility infrastructure to be complete. If testing indicates that stack modifications are necessary, they can be challenging and costly at that stage. Alternatively, a surrogate stack may be used to qualify the stack emission sampling location as allowed by the ANSI/HPS N13.1-1999 standard. For the WTP, this has previously been achieved with a scale model of the stack, constructed before the actual stack was completed and commissioned. However, test results from a geometrically similar surrogate stack may be used for qualification purposes as well (e.g., Glissmeyer 2007). By conducting physical tests or analyses of previous results using a geometrically similar stack rather than the stack itself, risk is mitigated because analysis results are available prior to completing the facility, and facility modifications could be incorporated more readily. This section describes the stack qualification approach for the EMF.

2.1 Qualification Criteria

To qualify the EMF stack sample probe location against the requirements outlined in ANSI/HPS N13.1-1999, the design of the EMF stack was compared against the designs of previously-tested stacks. The qualification of a stack sampling location using a qualified, geometrically similar stack is permitted by the ANSI/HPS N13.1-1999 standard. The requirements to qualify the EMF stack based on the design from a previously qualified system (i.e., a surrogate) are paraphrased as follows:

- The surrogate and its sampling location must be geometrically similar (with proportional critical dimensions of components that influence contaminant mixing and/or velocity profile) to the EMF stack
- The product of the surrogate's hydraulic diameter and mean air velocity (DV) must be within a factor of six of the EMF stack
- The Reynolds number (Re[1]) for the prototype and surrogate stacks must be greater than 10,000.

Furthermore, the use of a surrogate is considered applicable if the following is demonstrated with subsequent tests, also known as verification tests, at the sampling probe location on the constructed stack:

- The velocity profile and flow angle in the constructed stack meet the criteria in the ANSI N13.1-1999 standard
- The velocity uniformity result for the constructed stack is within 5% coefficient of variance (COV) of the surrogate stack result.

The test criteria for qualifying stack sampling locations, paraphrased from ANSI/HPS N13.1-1999, are listed below.

[1] Re is the ratio of inertial to viscous forces within a fluid. When this dimensionless quantity is large (e.g., >10,000) flow is turbulent.

1. Uniform Air Velocity - The velocity shall be measured at several discrete points in the duct cross-section at the proposed location of the sampling nozzle. The variability of the measurements about the mean, expressed using the % COV, must be ≤ 20% in the center two-thirds of the duct cross-section where the sampling probe is to be located.
2. Angular Flow – Sampling nozzles are typically aligned with the axis of the stack, so the air velocity vector approaching the sampling nozzle shall be sufficiently aligned with the nozzle to assure correct particle flow into the probe. The flow angle shall be measured at several discrete points in the duct cross-section at the proposed location of the sampling probe, and the average angle should not exceed 20 degrees relative to the sampling nozzle axis.
3. Uniform Gaseous Tracer Concentration – Uniform contaminant concentrations across the cross-section of the duct at the sampling location ensures samples are representative of the stack emission. A gaseous tracer is injected in the duct at a location upstream of the sampling location, then is measured at the stack sampling location with discrete points in the duct cross-section. Concentration variance shall be ≤ 20% COV in the center two-thirds of the duct and the concentrations at all measurement points shall not deviate from the mean by > 30%.
4. Uniform Particulate Tracer Concentration – An additional test of contaminant uniformity shall use a particulate tracer with a 10 μm aerodynamic particle size (unless larger particles are known to be present in the exhaust stream) injected into the duct. The particulate measurements at discrete points in the duct cross-section must have ≤ 20% COV across the center two-thirds of the duct.

Gaseous and particulate tracer injections should be performed at locations that represent the most downstream location where facility contamination may be introduced. Typically, injections are located slightly downstream of the fans; since a contaminant is often introduced upstream of the duct fans, qualifying the tracer concentrations with injections downstream of the fans is conservative. The EMF ACV contaminant is introduced in a typical way, upstream of the fans to the stack. The DVP flow, however, is introduced into the main stack after the first horizontal bend in the stack. This DVP injection location is not a typical location for the introduction of a contaminant stream. The potential mixing at the EMF probe location must therefore account for the introduction of a contaminant at a mid-point within the stack as well as for the typical contaminant introduction location at the main stack fans.

Although not an explicit requirement within the standard, in practice, a gaseous tracer is injected in the duct centerline as well as along the duct walls to evaluate mixing when contaminants are introduced along a wall. Due to expected limitations of particulate injection and sampling near walls, only injections along the centerline are performed for the particulate uniformity tests.

No testing was performed as part of this EMF qualification analysis. Instead, previously-tested geometrically similar stacks were identified for the qualification of the EMF. The following parameters for the surrogate and EMF stack were compared to establish geometric similarity, DV, and Reynolds number compliance with the ANSI/HPS N13.1-1999 standard:

- Duct diameter (Ø)
- Number of duct bends or flow disturbance features
- Geometric nature of duct bends or flow disturbance features
- Sampling location
- Flow Rate

- Hydraulic Diameter × Mean Velocity
- Temperature
- Reynolds Number.

2.2 EMF Stack

The normal flow rate for the EMF is 26,870 cfm (Mitchell 2018). The minimum and maximum flows for the system were assumed to be 70% and 115% of the normal flow rate, respectively. Table 2.1 summarizes the flow rates, velocities, and range of DV values that are within a factor of six of the EMF stack for surrogate stack comparisons. Note that each stack flow rate (minimum/normal/maximum) has its own corresponding DV range. These will be used to evaluate the applicability of test results from surrogate stacks, per the requirement of the standard stated above. The Reynolds number criteria for the EMF stack itself is met in all expected normal temperature and flow conditions. At the minimum flow, the Reynolds number is 6.01E+05; at normal flow, it is 8.58E+05; and at maximum flow, it is 9.87E+05 (for normal temperature conditions).

Table 2.1. EMF Stack Flow Range Values

Stack Flow Parameter	Minimum (70% of Normal)	Normal	Maximum (115% of Normal)
Flow Rate (cfm)	18,809	26,870	30,901
Velocity (ft/min)	1,630	2,328	2,677
DV (ft^2/min)	6,247	8,925	10,264
1/6 DV	1,041	1,487	1,711
6 DV	37,484	53,549	61,582

The off-normal minimum flow for the EMF stack is 160 cfm, a condition that occurs when the ACV flow is zero (e.g., failure of the fan and backup fan), but the DVP continues to operate. This condition is expected to occur rarely, and its duration is expected to be relatively short (i.e., hours, rather than days). As a result, the emissions from this condition are most likely to be a very small fraction (<<10%) of the annual emission. Off-normal and accident conditions are not included in this stack monitoring location qualification.

As described in Section 1.1, the EMF exhaust is composed of two systems, the ACV and DVP. The ACV and DVP ventilation systems combine to produce the total flow through the EMF stack. Due to the geometry associated with the introduction of the DVP flow into the main EMF exhaust duct, some additional considerations are necessary to evaluate the contaminant mixing at the stack sampling locations. Details for these two exhaust systems are summarized below.

2.2.1 ACV Flow

The primary flow through the EMF exhaust stack comes from the ACV. The ventilation air is cascaded from facility areas of lower contamination potential to areas of higher contamination potential. Supply components for the ACV system generally follow the design of contamination area C2V ventilation supply systems used in other WTP facilities, which serve non-process operating areas. The exhaust component follows the design of C3V ventilation exhaust systems from other WTP facilities, which also serve non-process operating areas, but with slightly higher contamination potential compared with C2V. The ACV flow goes through one stage of HEPA filters before being exhausted out of the EMF stack. As listed in Section 1.1, the estimated unabated emissions from the ACV is 1.21E+00 Ci/year and abated emissions is 3.13E-02 Ci/year (Walker 2016).

2.2.2 DVP Flow

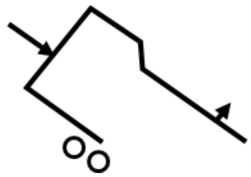
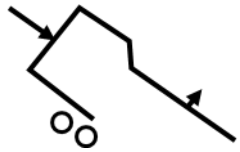
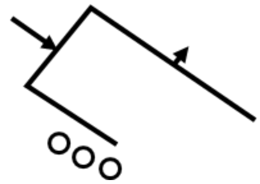
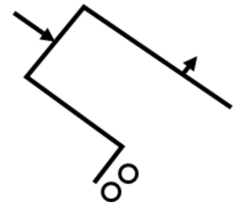
The DVP flow is a small fraction of the total flow exhausted from the EMF stack; however, the estimated emissions from the DVP are higher than those of the ACV because the DVP is the ventilation stream from the facility vessels used for evaporating liquid effluents. As listed in Section 1.1, the DVP unabated emissions are estimated to be 7.24E+00 Ci/year, while abated emissions are estimated to be 1.85E-01 Ci/year. Two stages of HEPA filters are used before the DVP exhaust fans (Walker 2016). The DVP meets the main ACV flow through an approximately 4-inch diameter pipe that meets the ACV duct after the first horizontal bend in the duct, approximately two-thirds of the distance between the two horizontal bends (Mitchell 2018).

2.3 Geometrically Similar Stacks

There are two requirements to qualify the EMF stack against a surrogate that are quantitative (i.e., DV must be within a factor of six and the Reynolds numbers must be greater than 10,000). There is also a requirement that is more qualitative—the EMF and surrogate stacks as well as sampling location must be geometrically similar. The ANSI/HPS N13.1-1999 standard states that the geometrically similar stack shall have proportional critical dimensions, and that the critical dimensions are those associated with components that can influence the degree of contaminant mixing and/or the velocity profile. Consequently, the requirement for geometric similarity requires a reasonable expectation that the surrogate stack will have flow and contaminant mixing features that are similar to the EMF stack. To evaluate this more subjective requirement of geometric similarity, three scale model stacks have been included to assess the EMF stack sampling qualification. Table 2.2 presents a comparison between the EMF and three scale model stacks that are the primary sources of data to qualify the EMF stack. Based on the evaluation of the major features of each of these stacks, existing scale model test results from these stacks are expected to satisfy the requirement for the EMF evaluation.

Table 2.2 includes a simple stack schematic for the EMF and surrogate stacks. (More detailed stack drawings are available in Figure 2.1, Figure 2.2, and Figure 2.3.) The schematics indicate the location and number of fans (open circles), number of stack bends, injection location that is most comparable to the introduction of the DVP flow (arrow pointed toward the duct), and stack sampling location (arrow pointed away from the duct). Each stack shares the following basic features—a “U-shaped” section with stack sampling on the downstream leg. The LV-S1 stack is very similar to the EMF, and will be used to evaluate velocity uniformity and flow angle results, as well as gaseous and particulate tracer uniformity for contaminants originating from the ACV fans. However, the LV-S1 scale model stack does not include adequate test results to address contaminants originating from the DVP fan. As a result, the LB-S1 and LV-S2 scale models stacks were also considered. Although the LB-S1 and LV-S2 duct configurations are not as similar to the EMF, they are functionally similar to the EMF based on features downstream of the DVP injection location. Features that are upstream of the DVP injection location are expected to have relatively minor influence on the tracer mixing results from the DVP, so these stacks are used to evaluate the gaseous and particulate tracer results originating from the DVP fans. Further details concerning each surrogate stack are presented in sub-sections below.

Table 2.2. EMF and Surrogate Stack Features

	EMF	LV-S1	LB-S1	LV-S2
Simple Stack Schematic[1]				
Ø at Sampling Location	46 in.	48 in. (full scale) 12 in. (scale model)	60 in. (full scale) 12 in. (scale model)	60 in. (full scale) 12 in. (scale model)
Injection Section Duct	5.3 Ø	1.45·Ø	6.73·Ø	9.62 Ø
Distance to last disturb.	23.5 Ø	12.4·Ø	10.3·Ø	18.4·Ø
Applicable Stack Qualification Tests				
Velocity Uniformity	N/A	Yes	N/A	N/A
Flow Angle	N/A	Yes	N/A	N/A
Gaseous Tracer Uniformity	N/A	ACV - Yes DVP - Limited	DVP - Yes	DVP - Yes
Particulate Tracer Uniformity	N/A	ACV – Yes DVP - No	DVP - Yes	DVP – Yes

1. Line drawings representing the duct arrangement, with open circles to represent the fans, a long arrow pointed toward the duct to represent the DVP (or comparable) injection location, and a short arrow pointed away from the duct to represent the stack sampling location.

2.3.1 LV-S1

Of the previously-tested scale model stacks from the WTP, LV-S1 is the most geometrically similar stack to the EMF. Figure 2.1 shows a schematic of the LV-S1 scale model stack. It had two fans, then a horizontal bend, followed by both a horizontal and subsequent pair of vertical bends before a long horizontal run of duct to the sample location. These general features are similar to the EMF stack geometry (Figure 1.1). The distance from LV-S1 Fan B to the first 90^o elbow is 1.57 Ø, while the distance from the first 90^o elbow to the second 90^o elbow is 1.45·Ø. The sampling probe location (Test Port 2) is 12.4·Ø from the downstream end of the second elbow. The vertical bends for LV-S1 are 30 degrees, compared to 45 degrees for the EMF.

Numerous velocity uniformity, flow angle, gaseous tracer, and particulate tracer tests were performed with the scale model of the LV-S1 stack (Glissmeyer et al. 2011). A summary of the Reynolds numbers and DV values from each of the test types is presented in Table 2.3. The Reynolds numbers are all on the order of 100,000, which is an order of magnitude larger than the criterion of Reynolds numbers greater than 10,000. All DV values are greater than both 1,041 ft^2/min and 1,487 ft^2/min (as well as less than 37,484 ft^2/min and 53,549 ft^2/min), which means that all test results are acceptable for representing the minimum and normal operating flow rates. The minimum DV required to represent the maximum EMF flow is 1,711 ft^2/min; however, the lowest DV values from the LV-S1 tests are lower than this value, meaning that only the higher flow rate test results are appropriate in representing the maximum EMF flow.

The LV-S1 scale model qualification test results were within the criteria described by ANSI/HPS N13.1-1999. Additional information about the test results in relationship to the EMF stack is presented in Section 3.0.

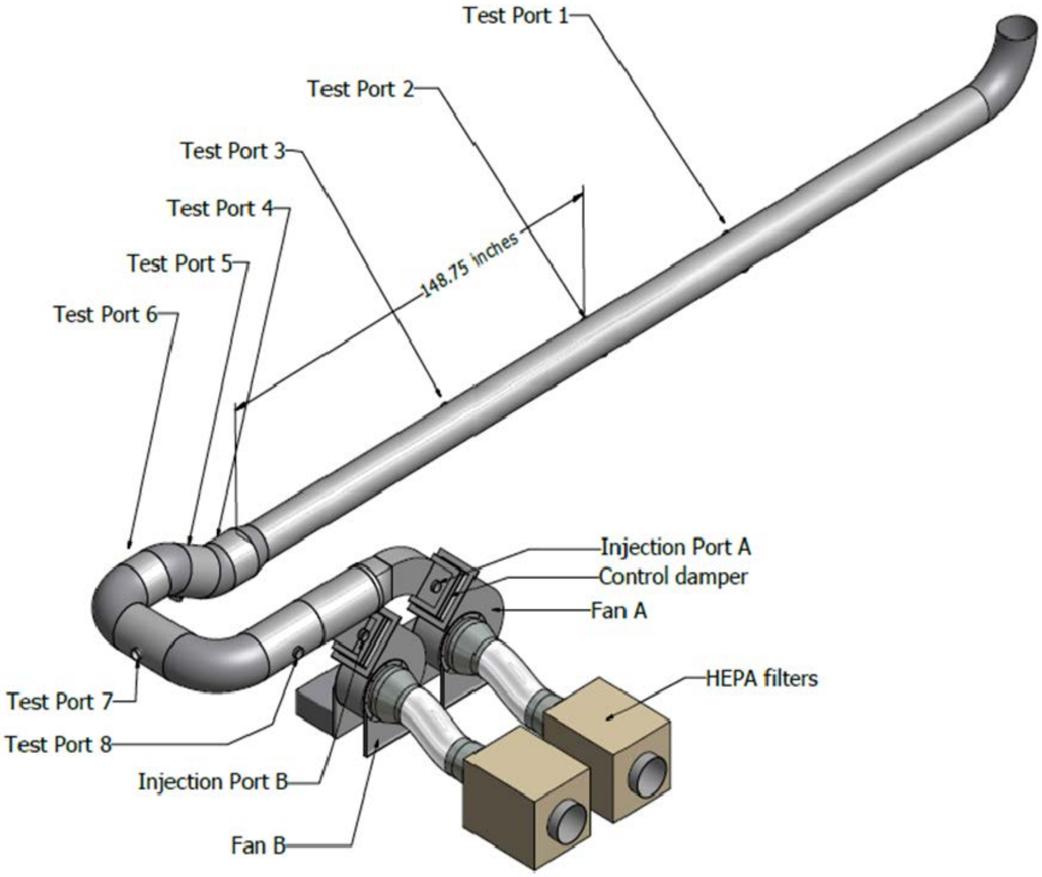


Figure 2.1. LV-S1 Scale Model Stack Schematic

Table 2.3. Summary of LV-S1 Scale Model Stack Test Reynolds Numbers and DV Values

Test Type	Re	DV (ft^2/min)
Velocity Uniformity	1.49E+05 – 2.96E+05	1.55E+03 – 2.94E+03
Flow Angle	1.61E+05 – 3.18E+05	1.67E+03 – 3.22E+03
Gaseous Tracer	1.75E+05 – 3.28E+05	1.72E+03 – 3.09E+03
Particulate Tracer	1.73E+05 – 3.18E+05	1.65E+03 – 3.00E+03

2.3.2 LB-S1

The LB-S1 scale model stack is an additional duct geometry that is reasonably similar to the EMF. Figure 2.2 shows a schematic of the LB-S1 scale model stack, which had three fans, a horizontal bend, and an additional horizontal bend before a horizontal run of duct to the sample location. This stack has an additional fan compared with the EMF exhaust duct, and is missing the vertical bends (after the second horizontal bend) that are present in the EMF duct. The distance from LB-S1 Fan A to the first 90º elbow is 0.77 Ø, while the distance from the first 90º elbow to the second 90º elbow is 6.73·Ø. The sampling probe location is 10.3·Ø from the downstream end of the second elbow. Although the LB-S1 stack has an additional fan and lacks the vertical bends, comparable levels of mixing may be expected from the LB-S1 and EMF stacks.

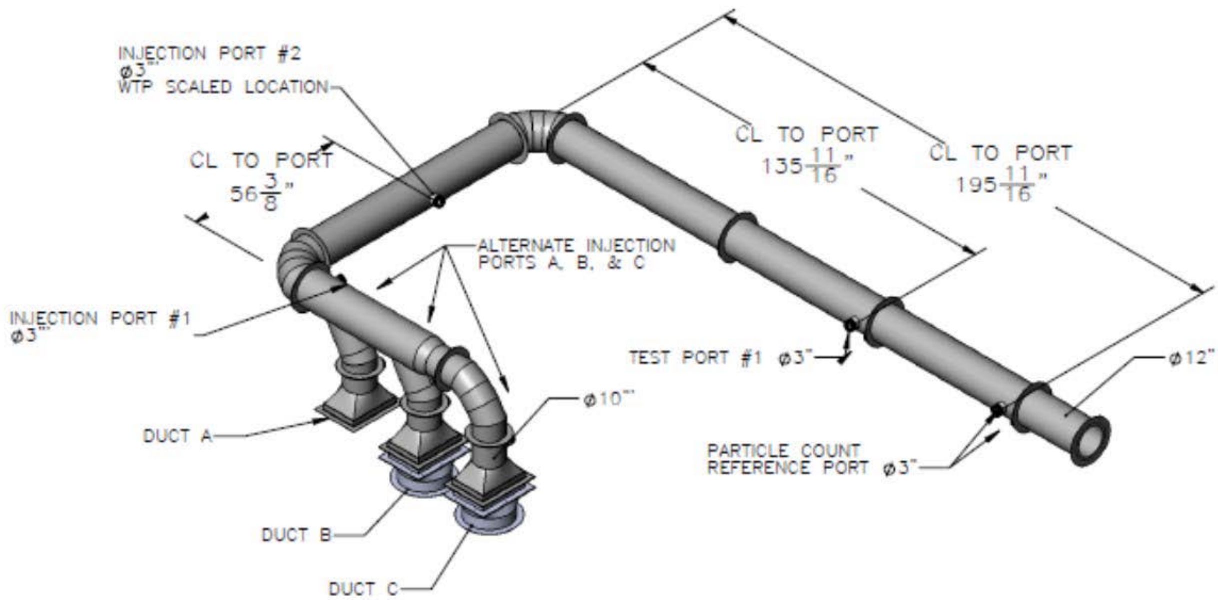


Figure 2.2. LB-S1 Scale Model Stack Schematic. Ducts A, B, and C represent the interface to Fans A, B, and C, respectively.

Numerous velocity uniformity, flow angle, gaseous tracer, and particulate tracer tests were performed with the scale model of the LB-S1 stack; these were reported in Glissmeyer and Geeting (2013). A summary of the Reynolds numbers and DV values from the tracer uniformity test types is presented in Table 2.4. Only these two test types are included because the LV-S1 stack serves to address the bulk flow through the stack, but the paucity of data for the DVP injection from the LV-S1 scale model stack requires additional data from the LB-S1 scale model stack. The LB-S1 scale model stack included many tracer injection tests performed from the Injection Port 2 location, which is comparable to the DVP injection location. The Reynolds numbers from the tracer tests are all on the order of 300,000, which is an order of magnitude larger than the criterion of a Reynolds number greater than 10,000. All DV values are greater than 1,711 ft^2/min and less than 37,484 ft^2/min, which means that all test results are acceptable for representing the full range of normal EMF operating conditions (from the assumed minimum to maximum EMF flow rates).

The LB-S1 scale model results were within the criteria prescribed by ANSI/HPS N13.1-1999. Additional information about the test results in relationship to the EMF stack are presented in Section 3.0.

Table 2.4. Summary of LB-S1 Scale Model Stack Tracer Test Reynolds Numbers and DV Values

Test Type	Re	DV (ft^2/min)
Gaseous Tracer	2.93E+05 – 4.95E+05	2.89E+03 – 4.51E+03
Particulate Tracer	3.35E+05 – 4.66E+05	3.06E+03 – 4.43E+03

2.3.3 LV-S2

The LV-S2 scale model stack is another duct geometry that is reasonably similar to the EMF. Figure 2.3 shows a schematic of the LV-S2 scale model stack, which had two fans that flow into a rectangular duct, a horizontal bend, a duct size reduction, a transition from rectangular to round duct, two horizontal bends, and a horizontal run of duct to the sample location. Although this stack has two fans, as the EMF does, it contains a rectangular duct, a reducer, and a rectangle-to-round transition that are different from the EMF. The distance between the two round elbows is 9.62 Ø, and the sampling probe location is 18.4·Ø from the downstream end of the second elbow. The addition of duct bends upstream of the location where the DVP injection is expected is unlikely to significantly impact the mixing for comparisons with the DVP injection, but will likely produce enhanced mixing for the bulk duct flow. The omission of the vertical bends may result in reduced mixing. As a result, the LV-S2 stack results may be conservative in representing the EMF stack mixing.

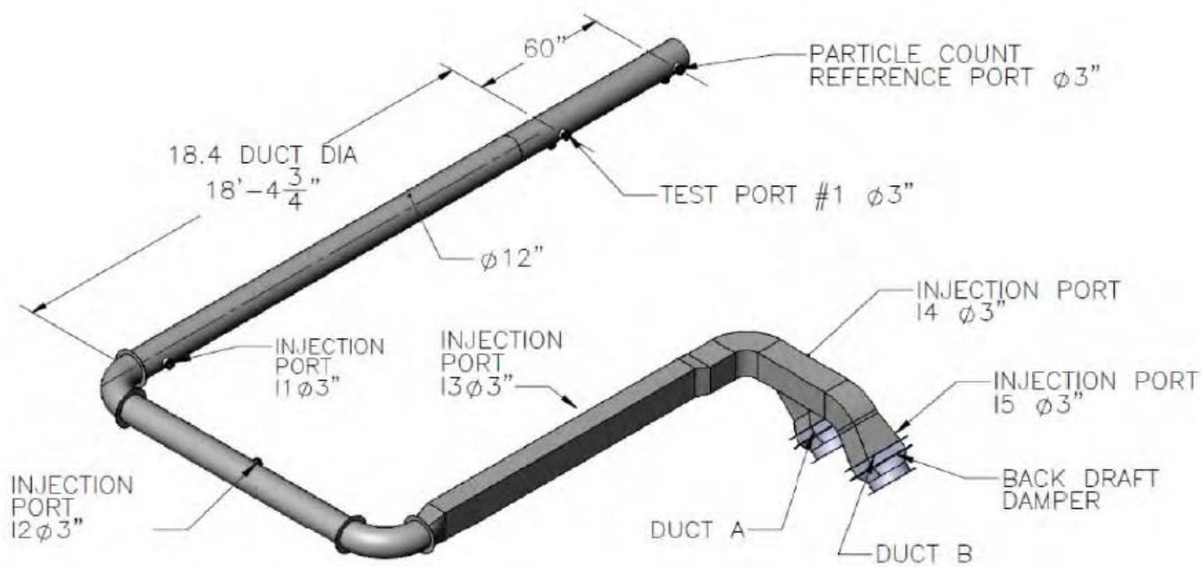


Figure 2.3. LV-S2 Scale Model Stack Schematic. Ducts A and B represent the interface to Fans A and B, respectively.

Numerous velocity uniformity, flow angle, gaseous tracer, and particulate tracer tests were performed with the scale model of the LV-S2 stack (Glissmeyer et al. 2014). A summary of the Reynolds numbers and DV values from the tracer uniformity test types is presented in Table 2.5. Only these two test types are included because the LV-S1 stack serves to address the bulk flow through the stack, but the paucity of data for the DVP injection from the LV-S1 scale model stack requires additional data from the LV-S2 scale model stack. The LV-S2 scale model stack included many tracer injection tests performed from the Injection Port I2 location, which is comparable to the DVP injection location. The Reynolds numbers are on the order of 300,000, which is an order of magnitude larger than the criterion of a Reynolds number greater than 10,000. All DV values are greater than both 1,041 ft^2/min and 1,487 ft^2/min (and less than 37,484 and 53,549 ft^2/min), which means that all test results are acceptable for representing the minimum and normal operating flow rates. The minimum DV required to represent the maximum EMF flow is 1,711 ft^2/min; however, the lowest DV values from the LV-S2 particulate tracer tests are lower than this value, meaning that only the higher flow rate test results are appropriate in representing the maximum EMF flow.

The LV-S2 scale model results were within the criteria prescribed by ANSI/HPS N13.1-1999. Additional information about the test results in relationship to the EMF stack are presented in Section 3.0.

Table 2.5. Summary of LV-S2 Scale Model Stack Tracer Test Reynolds Numbers and DV Values

Test Type	Re	DV (ft^2/min)
Gaseous Tracer	1.74E+05 – 4.86E+05	1.74E+03 – 4.77E+03
Particulate Tracer	1.44E+05 – 4.63E+05	1.51E+03 – 4.58E+03

2.4 Additional Stacks for Comparison

The HV-S1 and HV-C2 stacks were also reviewed to evaluate mixing from stacks that include a limited number of mixing elements. Although these stacks are not geometrically similar to the EMF, their results were considered as supplemental data in assessing and bounding the potential mixing of the DVP injection into the main EMF duct. In addition, the HV-C2 stack serves to provide data for comparing dual-fan and single-fan operations, which is pertinent to the LB-S1 scale model stack.

Figure 2.4 shows the schematic of the HV-S1 stack. It had two fans, one in operation and one in standby. Injection Port C, located just downstream of the fans, was used for all tracer tests. Sampling was performed at both Test Port 2 and Test Port 1, although the majority of tests used Test Port 2. Test Port 2 was 24.6 Ø downstream of the horizontal bend, and 20 Ø downstream of the small 11 degree vertical bends that change the elevation of the duct.

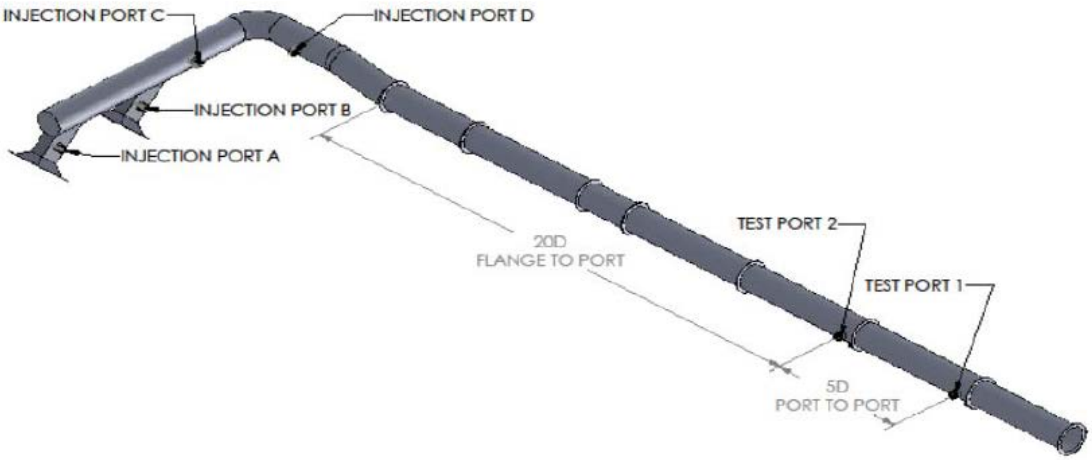


Figure 2.4. HV-S1 Scale Model Stack Schematic. Injections Ports A and B were located downstream of Fans A and B, respectively.

Figure 2.5 is a schematic of the HV-C2 scale model stack, which is one of the simplest stacks that has been tested. It includes two fans that were operated both individually and together. Tracer injection was performed in one of the two duct sections that connect the fans to the main duct. This stack also had a control damper and a backdraft damper after each fan, although tests were also performed without any dampers for comparison. Tests were performed at Test Ports 1, 2, and 3, which were 4.5, 9.5, and 14.5 Ø downstream of the location where the Fan A duct segment meets the main duct.

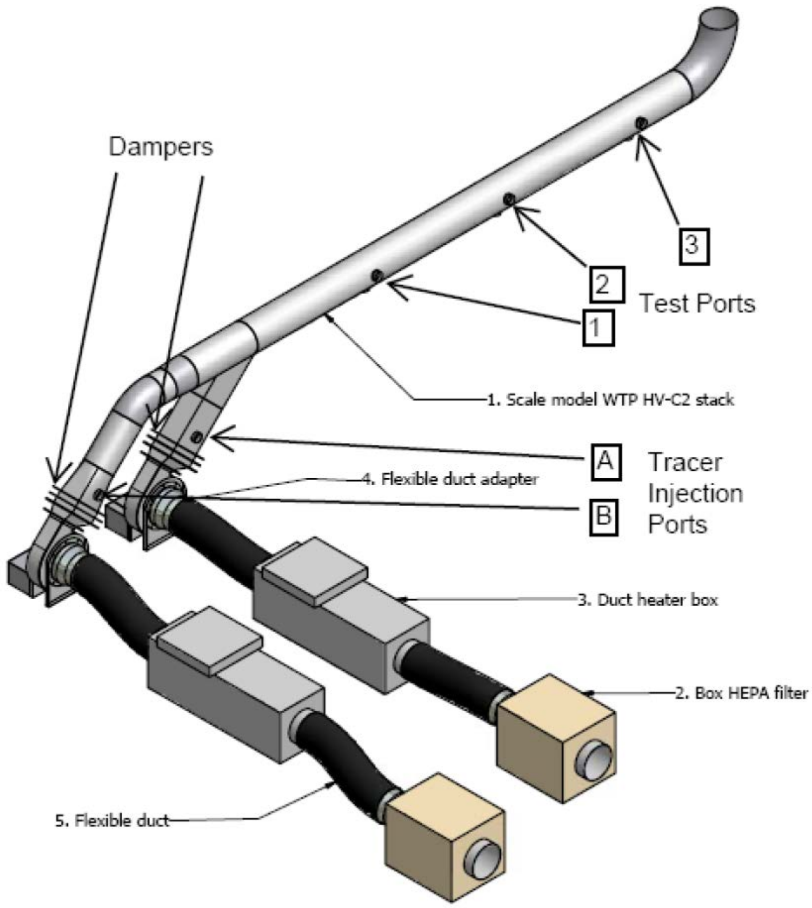


Figure 2.5. HV-C2 Scale Model Stack Schematic. Tracer Injections Ports A and B were located downstream of Fans A and B, respectively.

2.5 Quality Assurance

The PNNL QA program is based on the requirements defined in the U.S. Department of Energy Order 414.1C, Quality Assurance, as well as 10 CFR 830, Energy/Nuclear Safety Management and Subpart A – Quality Assurance Requirements. The Waste Treatment Plant Support Program (WTPSP) implements an American Society of Mechanical Engineers (ASME) nuclear quality assurance (NQA)-1-2000 QA program, using a graded approach presented in ASME NQA-1-2000, Part IV, Subpart 4.2, Graded Approach Application of Quality Assurance Requirements for Research and Development. The WTPSP QA Plan (QA-WTPSP-0001) describes the technology life cycle stages, which include the progression of technology development, commercialization, and retirement in process phases of basic and applied research and development, engineering and production, and operation until process completion. The work described in this report has been completed under the QA Technology level of development work, as the data will be used to apply for air discharge permits.

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

WTPSP addresses internal verification and validation activities by conducting an Independent Technical Review of the final data report in accordance with WTPSP's procedure, QA-WTPSP-601, Document Preparation and Change. This review verifies that the reported results are traceable, that inferences and conclusions are soundly based, and that the reported work satisfies the research plan objectives. Appendix A lists the reviewed research plan and calculation packages used to quality-assure the information included in this report.

3.0 Results

The primary flow through the EMF duct is from the ACV system, which has a typical contaminant introduction geometry (upstream of fans and HEPA filters). The LV-S1 scale model stack is geometrically similar to the EMF stack; therefore, it was used as a surrogate to the EMF. However, the introduction of the DVP system flow into the main EMF duct, downstream of the first stack bend, suggests the use of the LV-S1 scale model stack alone would be insufficient because only one test was performed with the LV-S1 scale model with a tracer injected at a location comparable to the DVP injection location. Consequently, the scale model test results pertaining to ACV flow sampling based on the geometrically similar LV-S1 stack will be presented first. Then, scale model test results from two functionally similar stacks, LB-S1 and LV-S2, will be presented to address DVP flow sampling.

3.1 ACV Flow Sampling

The stack sampling location relative to the ACV flow, which is the primary contributor to the flow through the EMF exhaust, may be evaluated using the LV-S1 scale model tests. Table 3.1 presents a summary of the stack qualification criteria test results grouped by operating fan (A or B) and Test Port location (1, 2, or 3). In the case of the LV-S1 stack, the planned sampling location was Test Port 2, but tests were also performed 5 Ø upstream and downstream of the Test Port 2 location to evaluate these locations in case of changes to the sampling location. In all cases, the test results were well below the stack qualification criteria listed in ANSI/HPS N13.1-1999.

Statistical analyses of LV-S1 scale model stack results evaluated whether differences in test parameters were statistically significant (Glissmeyer et al. 2011). Velocity tests revealed that the test port and fan flow had statistically significant effects on the velocity uniformity results. Similarly, the test port and fan flow had a statistically significant effect on the flow angle. Gas and particle tests were also analyzed statistically (Glissmeyer et al. 2011). The primary outcome from the assessment of these test results was that there were some variables that were determined to have statistically significant effects on the velocity, flow angle, or tracer mixing results. However, the results were all within the qualification limits, so the statistically significant effects of test variables were not of practical significance.

Table 3.1. Summary of LV-S1 Scale Model Test Results Grouped by Fan and Test Port Location. Tracer tests are limited to those with Fan A or Fan B injections.

Fan	Test Port (dist. from bend)	Velocity (% COV)	Flow Angle (°)	Particulate Tracer (% COV)	Gaseous Tracer (% COV)	Gaseous Tracer (% Max Deviation)
A	1 (7.4·Ø)	5.4 – 5.9	6.4 – 7.9	3.5 – 6.5	2.2 – 2.4	4.5 – 5.4
	2 (12.4·Ø)	3.5 – 4.5	4.8-8.7	5.5 – 6.1	1.4	2.9
	3 (17.4·Ø)	6.0	9.4	7.5	1.8	4.0
B	1 (7.4·Ø)	4.3 – 6.5	5.2 – 8.4	3.0 – 7.5	1.6 – 2.4	3.2 – 6.0
	2 (12.4·Ø)	4.8 – 6.2	9.0 – 10.9	2.6 – 3.9	1.7 – 5.1	2.6 – 12.4
	3 (17.4·Ø)	4.7 – 6.7	7.3 – 10.5	2.0 – 6.8	1.4 – 1.8	2.5 – 3.4

Adapted from Glissmeyer et al. 2011

The three test ports used for the LV-S1 scale model tests were all upstream of the EMF sampling location, which is 23.5·Ø from the downstream end of the vertical bend. These LV-S1 scale model test results are expected to be conservative estimates of the mixing at the EMF stack sampling locations. The results from individual tests are tabulated in Appendix B.

3.2 DVP Flow Sampling

The DVP injection location is approximately two-thirds of the distance between the two horizontal bends in the EMF duct. One gas tracer test was performed using the LV-S1 scale model stack with an injection at Test Port 7, with the injection probe outlet positioned in the center of the duct. This location was between the two horizontal duct bends, and is similar to the DVP injection location. The result of this gas tracer test was 1.9% COV and 7.8% maximum deviation from the mean. This shows that the stack sampling position is very well-mixed, even when the injection is only one horizontal bend upstream of the sampling location; however, this test was performed only once, at maximum flow conditions for the LV-S1 stack. Although this result indicates that the DVP injection location is likely to be acceptably well-mixed for a gaseous contaminant, if the injection probe were positioned along the centerline of the main duct, additional data to support the DVP injection location under varied test conditions (flow rates, contaminant phase) are needed. The remainder of Section 3.2 addresses these additional data needs. Additional tracer data from scale model stacks that are functionally similar with regard to the geometry downstream of the DVP location have been evaluated to explicitly address the potential mixing from the DVP injection location.

LB-S1 scale model stack particulate and gaseous tracer results are summarized in Table 3.2. Five particulate tracer tests were performed with the Fan A and Fan B operating combination under the LB-S1 stack minimum, normal, and maximum flow rates. There was no appreciable relationship between the mixing result and flow rate, and the results, ranging from 7.3% to 11.4% COV, may be interpreted as indicative of the variability in testing. Particulate tests with fan combinations AC and BC were only performed once each. All test results were below the 20% COV qualification criterion. The injections were all performed in the center of the duct at Injection Port 2, which is approximately 1/2 of the distance between the two horizontal bends in the duct.

Eighteen gaseous tracer tests were performed with the Fan A and Fan B operating condition, with injection positions near the duct wall as well as in the duct centerline. Six tests were performed with each of Fans A and C, and Fans B and C. Gaseous tracer mixing was higher (i.e., lower % COV values) for center injection positions in comparison with near-wall injections (see figures in Glissmeyer and Geeting 2013). In all cases, results were below 8% COV, which is considerably lower than the 20% criterion. Additionally, the maximum deviation results were below 15%, which is considerably lower than the 30% criterion. LB-S1 scale model stack tests were performed for flows that represent minimum, normal, and maximum full scale stack flow rates. The results of individual particulate tracer and gaseous tracer tests are tabulated in Appendix B.

Table 3.2. LB-S1 Tracer Test Results from Injection Port 2

Operating Fans	Particulate Tracer (% COV)	Gaseous Tracer (% COV)	Gaseous Tracer (% Max Deviation)
AB	7.3 – 11.4	2.2 – 7.3	4.3 – 14.9
AC	10.2	1.0 – 2.9	2.0 – 6.5
BC	14.1	3.4 – 6.4	7.0 – 13.4

Adapted from Glissmeyer and Geeting 2013

LV-S2 scale model stack particulate and gaseous tracer results are summarized in Table 3.3. Injections were performed at Injection Ports I2 and I3, but Table 3.3 is limited to results from Injection Port I2, which is located between the last two bends in the scale model stack, approximately 1/2 the distance between these two bends. Nine particulate tracer tests were performed with Fan A or Fan B with stack minimum or stack maximum flow rates. Figure 3.1 shows the distribution of the particulate tracer test results, according to whether the flow rate was meant to represent the LV-S2 minimum flow or maximum flow. In general, the maximum flow conditions had higher % COV values, although all were below the threshold value of 20% COV. Two of the Fan A tests at maximum flow had mixing results that were between 18% and 20% COV.

Eighteen gaseous tracer tests were performed at Injection Port I2, with injection positions near the duct wall as well as in the duct centerline. Figure 3.2 shows the distribution of the gaseous tracer test results according to the fan operating condition as well as for the various injection positions within the duct. Gaseous tracer mixing was similar among the various injection positions. Fan B maximum flows appeared to generally have lower levels of mixing (i.e., higher COV values) compared with the Fan A results, with the exception of the center injection position. All results were well below the 20% COV criterion as well as the 30% maximum deviation criterion.

Table 3.3. LV-S2 Tracer Test Results from Injection Port I2

Operating Fan	Particulate Tracer (% COV)	Gaseous Tracer (% COV)	Gaseous Tracer (% Max Deviation)
A	6.4 – 19.2	1.3 – 6.9	4.1 – 14.6
B	7.8 – 14.4	1.9 – 8.3	4.4 – 19.7

Adapted from Glissmeyer et al. 2014

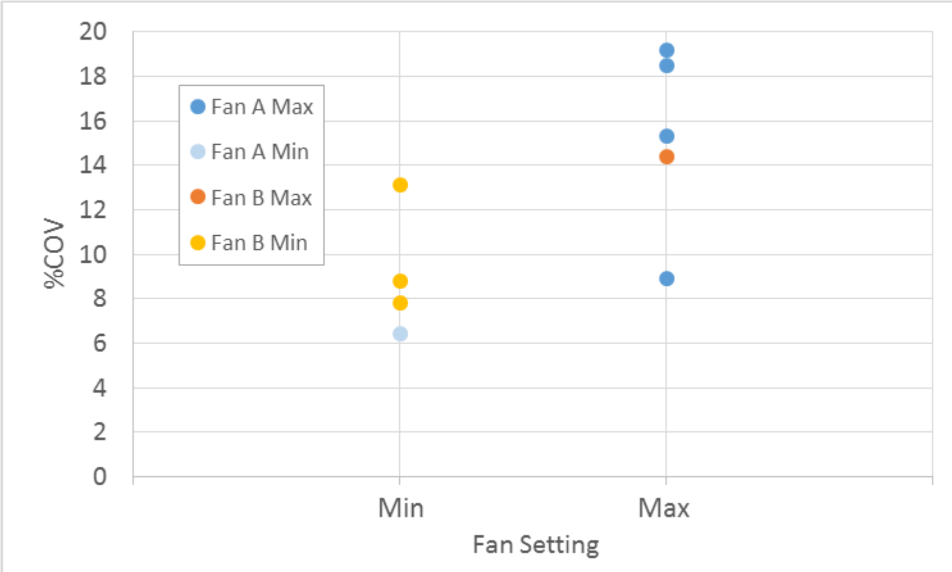


Figure 3.1. LV-S2 Particulate Tracer Test Mixing Results as a Function of LV-S2 Fan Condition. Note that testing errors on the order of 4% is typical for particulate tests.

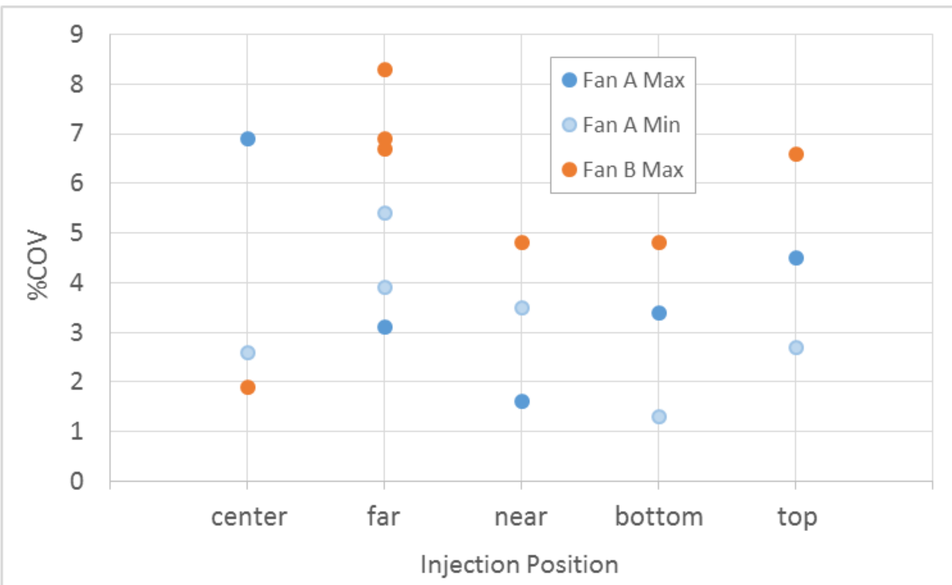


Figure 3.2. LV-S2 Gaseous Tracer Test Mixing Results as a Function of Injection Position and LV-S2 Fan Condition. Note that testing errors on the order of 3% is typical for gas tests.

As described in Section 2.4, test results from stacks that are not geometrically similar to the EMF were also reviewed to provide a contrast with conditions under which mixing might be expected to be less effective, based on stack geometry. The two stacks selected to provide such contrast are the HV-S1 and HV-C2 scale model stacks, which were both tested at PNNL.

HV-S1 tracer tests were performed with Fans A or B with Injection Port C. There was only one 90 degree bend after this injection; the injection location itself was just downstream of the fans, which may be a location where significant initial mixing occurs. The sampling location at Test Port 2 is slightly farther downstream than the EMF stack sampling location. HV-S1 scale model stack particulate and gaseous tracer results are summarized in Table 3.4. Particulate mixing between the two fans was similar, with slightly lower COV values from Fan B. Most test results were on the order of 10% COV. Gaseous tracer results from the HV-S1 scale model stack indicate a high level of mixing. Typical results were 2% COV with a maximum deviation of 4%.

Table 3.4. HV-S1 Tracer Test Results at Test Port 2 from Injection Port C

Operating Fan	Particulate Tracer (% COV)	Gaseous Tracer (% COV)	Gaseous Tracer (% Max Deviation)
A	8.4 – 11.7	1.1 – 2.0	2.6– 4.4
B	4.4 – 11.1	1.5 – 4.7	3.3 – 7.9

Adapted from Glissmeyer et al. 2013

The HV-C2 scale model stack was tested under two different configurations—with and without dampers. When dampers were installed downstream of the fans, both a control damper and backdraft damper were used with varying damper positions (angles). Tests were also performed with either one or two fans in operation. HV-C2 scale model stack particulate and gaseous tracer results from Test Port 1 are summarized in Table 3.5. At Test Port 1, the single-fan operations appear to produce sufficiently well-mixed particulate results when dampers were not installed as well as when dampers were installed. When both fans were operating, however, the particulate tracer tests were above 20% COV when no damper was installed. With the dampers installed, two tests under identical damper conditions were 13.5% and 31.0% COV, so the comparison with the stack sampling criterion is inconclusive. Gaseous tracer results had lower COV results than the particulate results, and the gaseous tracer was sufficiently well-mixed when dampers were not installed as well as when dampers were installed for single-fan operations. With both fans operating, however, gaseous tracer results were up to 37.6% COV when no dampers were installed, and up to 22.9% COV with dampers installed. Similarly, with both fans operating, maximum deviation values were as high as 84.6% without dampers and 57.4% with dampers, which exceeded the qualification criterion.

HV-C2 scale model stack particulate and gaseous tracer results from Test Port 2 are summarized in Table 3.6. Fewer tests were performed at Test Port 2 compared with Test Port 1. Particulate tests without dampers were not performed when only Fan A or Fan B was operating, and only one test was performed with both fans operating. Particulate tracer results were approximately 18% COV when both fans were operating without dampers, while the highest value was nearly 14% COV when both fans were operating with dampers. Single-fan operation tests were approximately 3% COV. Gaseous tracer tests were also more limited at Test Port 2. Although Fan A was operated both with and without dampers (although only one test was performed for each configuration), with Fan B or with both fans operating, only tests with dampers were performed. Results with dampers in place were within the qualification criteria. With both fans in operation, the highest values were approximately 10% COV and 28% maximum deviation. Test Port 2 results tend to have lower COV results than Test Port 1 results due to the additional 5 Ø of mixing distance between the ports.

Table 3.5. HV-C2 Tracer Test Results at Test Port 1. The table lists Injection Port A results when both fans were operating. Two damper operations contain various control and back flow damper positions.

Operating Fan	Damper	Particulate Tracer (% COV)	Gaseous Tracer (% COV)	Gaseous Tracer (% Max Deviation)
A	None	9.8	2.6 – 9.1	4.3 – 15.6
	Two	3.5 – 14.4	1.4 – 7.6	3.5 – 11.1
B	None	4.3	2.9	6.0
	Two	2.0	2.5	6.9
A & B	None	31.6 – 35.5	9.3 – 37.6	22.1 – 84.6
	Two	13.5 – 31.0	5.5 – 22.9	12.7 – 57.4

Adapted from Glissmeyer and Droppo 2007

Table 3.6. HV-C2 Tracer Test Results at Test Port 2. The table lists Injection Port A results when both fans were operating. Two damper operations contain various control and back flow damper positions.

Operating Fan	Damper	Particulate Tracer (% COV)	Gaseous Tracer (% COV)	Gaseous Tracer (% Max Deviation)
A	None	N/A	14.6	34.8
	Two	2.5	1.3	2.6
B	None	N/A	N/A	N/A
	Two	3.0	1.1	1.9
A & B	None	18.2	N/A	N/A
	Two	7.4 – 13.8	2.0 – 10.0	4.5 – 28.3

Adapted from Glissmeyer and Droppo 2007

Additional comparisons between the results from Test Ports 1 and 2 are presented in Figure 3.3 and Figure 3.4 for the gaseous tracer tests performed with the HV-C2 scale model stack. Figure 3.3 shows the results of gaseous tracer tests when both fans were running, and with dampers in place. The different injection positions within the injection port shows some variability, although the clearest trend appears to be that Port 2 results are lower than Port 1 results. Near Right and Far Right injection positions had the largest differences between the Port 1 and Port 2 results, with Port 1 results at Far Right failing to meet the qualification criterion with a uniformity value of approximately 24% COV. Figure 3.4 shows the results of gaseous tracer tests when only one fan, A or B, was operating. Although only the center injection position was common to both Port 1 and Port 2, Port 2 results were again smaller, although perhaps only slightly, than the Port 1 result. All tests were well within the qualification criterion in this case. Figure 3.3 and Figure 3.4 illustrate that, in the case of the HV-C2 stack, the single-fan operation tends to result in greater levels of mixing. Although there is a significant difference between the HV-C2 stack geometry and the LB-S1 stack geometry, it may indicate that the results of operating two fans in the LB-S1 stack may be conservative, or at least comparable to results if only one fan was in operation.

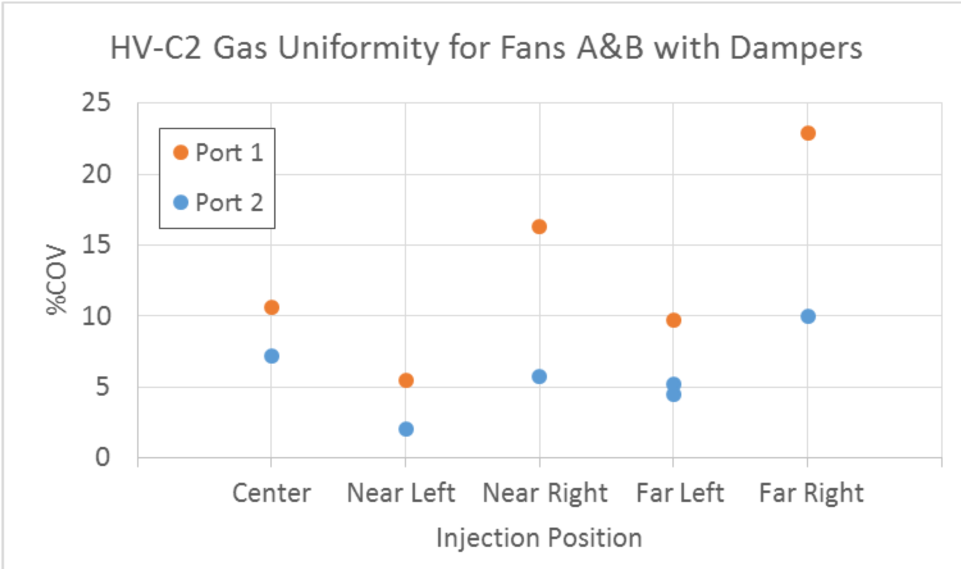


Figure 3.3. HV-C2 Gaseous Tracer Test Mixing Results with Fans A & B as a Function of Injection Position and Test Port. Note that testing errors on the order of 3% is typical for gas tests.

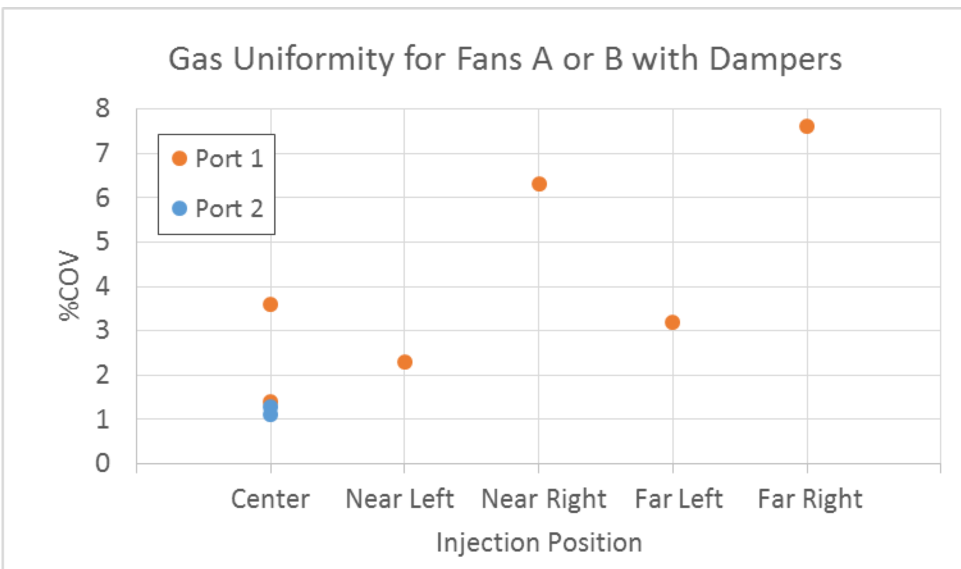


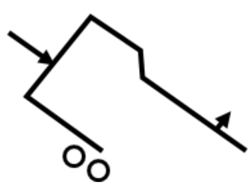
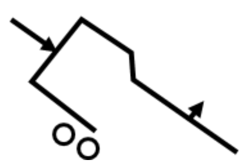
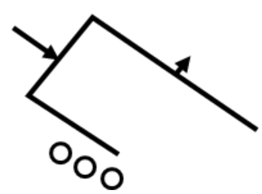
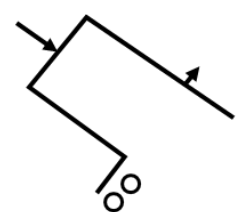
Figure 3.4. HV-C2 Gaseous Tracer Test Mixing Results with Fans A or B as a Function of Injection Position and Test Port. Note that testing errors on the order of 3% is typical for gas tests.

4.0 Summary and Conclusions

Based on its potential for radiological dose impact, the Hanford Waste Treatment Plant Effluent Management Facility Stack is considered a PIC 2 facility. As a result, continuous sampling is employed to provide a record of stack emissions. The planned location for the record sampler probe is 23.5 Ø downstream of the nearest upstream flow disturbance feature, which is a vertical bend in the duct. In lieu of performing ANSI/HPS N13.1-1999 stack sampling location qualification tests on the stack itself, or on a scale model of the stack, existing geometrically similar stacks were evaluated as allowed by the ANSI/HPS N13.1-1999 standard.

Table 4.1 presents a summary of the EMF and three surrogate stacks that were evaluated according to the criteria described in the ANSI/HPS N13.1-1999 standard. The simple stack schematic provides an overview of the location and number of fans (open circles), number of stack bends, injection location that is most comparable to the introduction of the DVP flow (arrow pointed toward the stack), and stack sampling location (arrow pointed away from the stack). Each stack shares the following basic features—a “U-shaped” section with stack sampling on the downstream leg. The LV-S1 stack is very similar to the EMF, and was used to evaluate velocity uniformity and flow angle results, as well as gaseous and particulate tracer uniformity for contaminants originating from the ACV fans, as indicated in the LV-S1 column of Table 4.1. The LV-S1 scale model stack does not include adequate test results to address contaminants originating from the DVP fan. As a result, the LB-S1 and LV-S2 scale model stacks were also considered. Although the LB-S1 and LV-S2 duct configurations are not as similar to the EMF, they are functionally similar to the EMF based on features downstream of the DVP injection location. Features that are upstream of the DVP injection location are expected to have a relatively minor influence on the tracer mixing results from the DVP; therefore, these stacks are used to evaluate the gaseous and particulate tracer results originating from the DVP fans, as indicated in the LB-S1 and LV-S2 columns of Table 4.1.

Table 4.1. EMF Stack and Surrogate Applicable Stack Qualification Data Availability

	EMF	LV-S1	LB-S1	LV-S2
Simple Stack Schematic[1]				
Velocity uniformity	N/A	Yes	N/A	N/A
Flow angle	N/A	Yes	N/A	N/A
Gaseous uniformity	N/A	ACV - Yes DVP - Limited	DVP - Yes	DVP - Yes
Particulate uniformity	N/A	ACV – Yes DVP - No	DVP - Yes	DVP – Yes

1. Line drawings representing the duct arrangement, with open circles to represent the fans, a long arrow pointed toward the duct to represent the DVP (or comparable) injection location, and a short arrow pointed away from the duct to represent the stack sampling location.

4.1 LV-S1 Scale Model

The LV-S1 scale model stack serves as a geometrically similar stack that was used to qualify the EMF stack sampling location. It shares many of the general features of the EMF stack, such as a single-fan operation with a backup fan. The geometry of this stack includes fans connected to a relatively short section of duct, followed by a horizontal bend, then another relatively short section of duct, followed by another horizontal bend and a pair of vertical bends before a long section of duct that contains the sampling port. Some of the specific dimensions and vertical bend angles differ between the LV-S1 and EMF stacks; however, the general features that impact velocity, flow, and mixing are very similar.

The LV-S1 scale model test Reynolds numbers were sufficiently high and DV values generally represent the expected flow rates for the EMF. Some of the lowest flow conditions have DV values that are too low to represent the EMF maximum flow conditions. Appendix B includes tables with individual test results and identifies the applicability of each test to the EMF flow conditions (based on DV value). In all cases, the LV-S1 scale model test results were within the stack qualification criteria. However, the gaseous and particulate tracer results were primarily performed with either Injection Port A or B, which is reasonable for conservatively representing the ACV flow contaminant, because these injection locations were just downstream of the operating fan. These injection locations, however, are not representative of the DVP flow contaminant, which is between the two horizontal stack bends. Injection Ports A and B are upstream of the first horizontal bend, which means that there is more potential for mixing from the A and B injection locations. One gaseous tracer test was performed with an injection from Test Port 7, which is comparable to the location where the DVP flow is introduced. The test result was 1.9% COV and 7.8% maximum deviation, which is considerably smaller than the criteria of 20% COV and 30% maximum deviation. This result was from a test with Fan A operating; Fan B test results may have slightly lower levels of mixing, since, in this case, Fan B is downstream of Fan A. Although this gaseous mixing result is favorable for the EMF stack mixing from the DVP, additional data from the LB-S1 and LV-S2 stacks were assessed to provide additional support for the mixing from the DVP injection location.

4.2 LB-S1 and LV-S2 Scale Models

The LB-S1 stack is an additional duct geometry that is reasonably similar to the EMF stack. It is considered functionally similar to the EMF in regard to the contaminant mixing from the DVP location. The LB-S1 stack operates two fans at a time, which differs from the single-fan operations of the EMF stack. The geometry of the stack is similar in that the fans connect to a relatively short section of duct, followed by a horizontal bend, then another relatively short section of duct, and then a long section of duct that contains the sampling port. However, there is no elevation change in the LB-S1 stack, so there are no vertical bends in the duct. The LB-S1 stack used a contaminant injection location that is similar to the DVP injection location; features that impact mixing are expected to be similar between the LB-S1 and EMF stacks.

The LB-S1 scale model test Reynolds numbers were sufficiently high and DV values represent the expected flow rates for the EMF. Appendix B includes tables with individual test results and identifies the applicability of each test to the EMF flow conditions (based on DV value). In all cases, the LB-S1 scale model tests were within the stack qualification criteria. Particulate uniformity test results were approximately 10% COV, while gaseous uniformity tests results were often below 5% COV and 10% maximum deviation. The LB-S1 sampling location was 10.5 Ø downstream of the nearest upstream flow disturbance, compared with the EMF sampling location, which was 23.5 Ø downstream of the nearest upstream flow disturbance. Therefore, although there are differences in stack geometries that may reduce mixing in the LB-S1 stack compared with the EMF stack, the LB-S1 stack sampling location was significantly farther upstream than the EMF stack sampling location, which means that LB-S1 results are potentially conservative compared with the EMF mixing results.

Another configuration difference to consider is the dual-fan operations of the LB-S1 stack tests compared with the single-fan operations of the EMF. Although the HV-C2 stack is a very simple stack design with little relationship to the EMF or LB-S1 stack designs, it provides data comparing single-fan operations with dual-fan operations. For the HV-C2 scale model tests, single-fan operations tended to result in greater levels of mixing compared with dual-fan operations. Therefore, it may indicate that LB-S1 results are conservative or at least comparable to mixing that would occur if only one fan were operating.

The LV-S2 stack is another reasonably similar stack considered to be functionally similar to the EMF stack in regard to the contaminant mixing from the DVP location. The LV-S2 stack is similar to the EMF in that it has two fans, with one fan operating at a time and the other serving as a backup fan. However, the two fans flow into a rectangular duct, which remains rectangular through a horizontal bend and a duct size reduction. After the transition from a rectangular to a round duct, the LV-S2 stack is similar to the LB-S1 stack in that there are two horizontal bends with similar relative duct lengths compared with the EMF. As was the case with the LB-S1 stack, the LV-S2 stack does not include vertical bends.

The LV-S2 scale model test Reynolds numbers were sufficiently high and DV values generally represent the expected flow rates for the EMF. Some of the lowest flow conditions have DV values that are too low to represent the EMF maximum flow conditions. The LV-S2 scale model tests performed with Injection Port I2 were within the stack qualification criteria. Particulate uniformity test results were generally between 6% and 19% COV, with higher values from Fan A (downstream fan) and at higher velocities. Gaseous tracer uniformity results were often less than 5% COV and 10% maximum deviation.

4.3 EMF Qualification Summary

The EMF stack sampling location meets many of the qualification criteria (i.e., velocity uniformity, flow angle, particulate tracer uniformity, and gaseous tracer uniformity) through the LV-S1 scale model stack test results. Particulate and gaseous tracer uniformity tests were primarily performed with injections of contaminant just downstream of the operating fan, which is pertinent to contaminants from the ACV system. Because only one gaseous tracer test was performed with the LV-S1 stack from a gas injection location comparable to the DVP location, the LB-S1 and LV-S2 stacks were evaluated for qualification of the gaseous and particulate tracer uniformity for contaminants originating from the DVP fans. The EMF stack sampling location meets all of the qualification criteria through the combination of the LV-S1, LB-S1, and LV-S2 scale model stack test results.

Off-normal and accident conditions are not included in this stack monitoring location qualification. The off-normal minimum flow is expected to occur rarely; its duration is expected to be relatively short, and therefore the emissions during this condition is expected to be a very small fraction of the total annual emission.

Note that the original design of the DVP injection was an approximately 4-inch diameter pipe that ended at the wall of the main stack duct. Based on the LV-S1 test result, the mixing of the gaseous tracer is expected to be sufficient if the DVP injection was configured with the pipe outlet within the center two-thirds of the main stack duct area. The pipe may remain straight toward the centerline of the duct or bent with a 90-degree or larger bend such as 135 degrees (45 degrees with respect to the duct centerline). If bent, the pipe outlet may be pointed either downstream or upstream; previous testing has indicated comparable mixing results for low flow injections in either configuration.

4.4 Verification Testing

As described in ANSI/HPS N13.1-1999, the use of a surrogate stack is considered acceptable if subsequent tests, known as verification tests, at the constructed stack sampling location show that the velocity profile and flow angle meet the criteria of the standard and the velocity profile is within 5% of the surrogate stack result. Table 4.2 lists these criteria for the EMF, based on the LV-S1 scale model stack use as a surrogate for these two test types. The DV values for the LV-S1 scale model tests were applicable for the EMF minimum and normal flow conditions; however, six of the tests with the lowest stack velocities are not applicable to the EMF maximum flow condition. Accordingly, the velocity uniformity stack verification criteria are separated into two categories in Table 4.2. First, under EMF minimum or normal flow conditions, the average of all the LV-S1 scale model velocity uniformity tests was considered. Then, EMF maximum flow conditions use the average that results when the six lowest LV-S1 scale model velocity tests are excluded. In general, a velocity uniformity test result at the EMF stack of less than 10% COV will be acceptable, along with a flow angle test result of less than 20 degrees.

Table 4.2. EMF Stack Verification Testing Result Criteria

Verification Test Type	EMF Minimum or Normal Flows Result Criterion	EMF Maximum Flow Result Criterion
Velocity Uniformity	0 – 10% COV	0.5 – 10.5% COV
Flow Angle	0 – 20°	0 – 20°

5.0 References

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Appendix A – EMF Stack Qualification QA Documents

Document Number	Document Title
RP-WTPSP-161	Effluent Management Facility Stack Sampling Location Qualification Using a Comparative Analysis of Previously-Tested Geometrically Similar Stacks
CCP-WTPSP-1347	Evaluating LV-S1 Scale Model Test DV and Reynolds Numbers for Acceptance for Geometric Similarity to the EMF
CCP-WTPSP-1357	Evaluating LB-S1 and LV-S2 Scale Model Test DV and Reynolds Numbers for Acceptance for Geometric Similarity to the EMF
CCP-WTPSP-1363	EMF Stack Monitoring, DV and Reynolds Number Calculations

Appendix B – Surrogate Stack Test Result Tables

The following tables present the individual test results for the most relevant surrogate stacks, LV-S1 and LB-S1. Table B.1 presents the velocity uniformity results from the LV-S1 scale model tests. Most tests met the criteria for representing all three EMF flow conditions; however, six of the lowest velocity tests have DV values too low to represent the assumed maximum EMF flow condition. Table B.2 presents the flow angle results from the LV-S1 scale model tests. Five flow angle tests have DV values too low to represent the assumed maximum EMF flow condition, while other tests meet the criteria for representing all three EMF flow conditions.

Table B.1. LV-S1 Scale Model Stack Velocity Uniformity Results. EMF Flow columns indicate whether the DV value is representative of the EMF minimum, normal, or maximum flow rates.

Fan	Test Port	Flow Condition	Run No.	% COV	Velocity (fpm)	Re	DV	EMF Flow		
								Min	Norm	Max
A	1	115%	VT-19	5.9	2995	2.96E+05	2.94E+03	Y	Y	Y
			VT-20	5.5	2961	2.90E+05	2.90E+03	Y	Y	Y
			VT-21	5.4	2940	2.85E+05	2.88E+03	Y	Y	Y
	2	115%	VT-22	4.5	2997	2.89E+05	2.94E+03	Y	Y	Y
		70%	VT-18	3.5	1768	1.67E+05	1.73E+03	Y	Y	Y
			VT-24	3.7	1692	1.69E+05	1.66E+03	Y	Y	N
	3	115%	VT-23	6.0	2893	2.92E+05	2.84E+03	Y	Y	Y
B	1	115%	VT-12	6.5	2784	2.65E+05	2.73E+03	Y	Y	Y
		70%	VT-13	4.3	1581	1.49E+05	1.55E+03	Y	Y	N
	2	115%	VT-5	6.2	2556	2.52E+05	2.50E+03	Y	Y	Y
			VT-6	6.1	2528	2.45E+05	2.48E+03	Y	Y	Y
			VT-7	5.1	2523	2.41E+05	2.47E+03	Y	Y	Y
			VT-8	5.7	2720	2.55E+05	2.67E+03	Y	Y	Y
			VT-9	5.2	2744	2.54E+05	2.69E+03	Y	Y	Y
			VT-10	5.7	2731	2.52E+05	2.68E+03	Y	Y	Y
		70%	VT-14	4.8	1595	1.49E+05	1.56E+03	Y	Y	N
	3	115%	VT-11	6.3	2840	2.74E+05	2.78E+03	Y	Y	Y
		70%	VT-15	6.4	1676	1.62E+05	1.64E+03	Y	Y	N
			VT-16	4.7	1674	1.61E+05	1.64E+03	Y	Y	N
			VT-17	6.7	1658	1.57E+05	1.62E+03	Y	Y	N

Table B.2. LV-S1 Scale Model Stack Flow Angle Results. EMF Flow columns indicate whether the DV value is representative of the EMF minimum, normal, or maximum flow rates.

Fan	Test Port	Flow Condition	Run No.	Flow Angle (°)	Velocity (fpm)	Re	DV	EMF Flow Min	EMF Flow Norm	EMF Flow Max
A	1	115%	FA-11	7.9	3140	3.03E+05	3.08E+03	Y	Y	Y
			FA-12	7.8	3200	3.14E+05	3.14E+03	Y	Y	Y
			FA-13	6.4	3000	2.92E+05	2.94E+03	Y	Y	Y
	2	115%	FA-14	4.8	3090	2.98E+05	3.03E+03	Y	Y	Y
		70%	FA-16	7.7	1700	1.61E+05	1.67E+03	Y	Y	N
			FA-17	8.7	1870	1.76E+05	1.83E+03	Y	Y	Y
	3	115%	FA-15	9.4	3030	2.87E+05	2.97E+03	Y	Y	Y
B	1	115%	FA-9	8.4	2980	2.91E+05	2.92E+03	Y	Y	Y
		70%	FA-10	5.2	1700	1.65E+05	1.67E+03	Y	Y	N
	2	115%	FA-2	10.8	2440	2.37E+05	2.39E+03	Y	Y	Y
			FA-3	10.9	3290	3.18E+05	3.22E+03	Y	Y	Y
			FA-4	9.0	2980	2.91E+05	2.92E+03	Y	Y	Y
		70%	FA-1	8.5	1816	1.78E+05	1.78E+03	Y	Y	Y
	3	115%	FA-8	10.5	2970	2.82E+05	2.91E+03	Y	Y	Y
		70%	FA-5	7.3	1740	1.69E+05	1.71E+03	Y	Y	N
			FA-6	8.1	1740	1.68E+05	1.71E+03	Y	Y	N
			FA-7	9.0	1720	1.65E+05	1.69E+03	Y	Y	N

Table B.3 presents the particulate tracer uniformity results from the LV-S1 scale model tests. Most tests met the criteria for representing all three EMF flow conditions; however, two of the lowest velocity tests have DV values too low to represent the assumed maximum EMF flow condition. Table B.4 presents the gaseous tracer uniformity results from the LV-S1 scale model tests. All tests met the criteria for representing all three EMF flow conditions.

Table B.5 presents the particulate tracer uniformity results from the LB-S1 scale model tests. All tests met the criteria for representing all three EMF flow conditions. Table B.6 presents the gaseous tracer uniformity results from the LB-S1 scale model tests. All tests met the criteria for representing all three EMF flow conditions.

Table B.3. LV-S1 Scale Model Stack Particulate Tracer Uniformity Results. EMF Flow columns indicate whether the DV value is representative of the EMF minimum, normal, or maximum flow rates.

Fan	Test Port	Flow Condition	Run No.	% COV	Velocity (fpm)	Re	DV	EMF Flow Min	EMF Flow Norm	EMF Flow Max
A	1	115%	PT-13	3.5	2385	2.41E+05	2.34E+03	Y	Y	Y
			PT-14	5.3	2600	2.63E+05	2.55E+03	Y	Y	Y
			PT-15	6.5	2630	2.66E+05	2.58E+03	Y	Y	Y
	2		PT-17	6.1	2605	2.63E+05	2.55E+03	Y	Y	Y
			PT-18	5.5	2940	2.98E+05	2.88E+03	Y	Y	Y
	3		PT-16	7.5	2550	2.58E+05	2.50E+03	Y	Y	Y
B	1	115%	PT-1	7.5	2915	3.02E+05	2.86E+03	Y	Y	Y
		70%	PT-12	3.0	1710	1.73E+05	1.68E+03	Y	Y	N
	2	115%	PT-3	2.6	3060	3.18E+05	3.00E+03	Y	Y	Y
			PT-11	3.9	3010	3.04E+05	2.95E+03	Y	Y	Y
		70%	PT-9	3.3	1680	1.73E+05	1.65E+03	Y	Y	N
	3	115%	PT-5	2.7	2965	3.04E+05	2.91E+03	Y	Y	Y
		70%	PT-6	4.0	1860	1.94E+05	1.82E+03	Y	Y	Y
			PT-7	5.2	1800	1.84E+05	1.76E+03	Y	Y	Y
			PT-8	6.8	1860	1.90E+05	1.82E+03	Y	Y	Y
			PT-20	2.0	1915	1.94E+05	1.88E+03	Y	Y	Y

Table B.4. LV-S1 Scale Model Stack Gaseous Tracer Uniformity Results. EMF Flow columns indicate whether the DV value is representative of the EMF minimum, normal, or maximum flow rates.

Fan	Test Port	Flow Condition	Injection Port & Location	Run No.	% COV	% Max. Dev.	Velocity (fpm)	Re	DV	EMF Flow Min	EMF Flow Norm	EMF Flow Max
A	1	115%	A Center	GT-9	2.2	4.5	2970	3.07E+05	2.91E+03	Y	Y	Y
				GT-10	2.3	5.4	2960	3.01E+05	2.90E+03	Y	Y	Y
				GT-11	2.4	4.7	2955	2.99E+05	2.90E+03	Y	Y	Y
	2			GT-12	1.4	2.9	2955	3.00E+05	2.90E+03	Y	Y	Y
	3			GT-13	1.8	4.0	2875	2.92E+05	2.82E+03	Y	Y	Y
B	1	115%	B Center	GT-1	2.4	6.0	3150	3.16E+05	3.09E+03	Y	Y	Y
		70%	B Center	GT-20	1.6	3.2	1860	1.95E+05	1.82E+03	Y	Y	Y
	2	115%	B Center	GT-2	2.1	5.6	3105	3.06E+05	3.04E+03	Y	Y	Y
			B Bottom-Near	GT-14	4.3	7.3	2935	2.94E+05	2.88E+03	Y	Y	Y
			B Top-Near	GT-15	2.4	4.8	2935	2.93E+05	2.88E+03	Y	Y	Y
			B Top-Far	GT-16	3.3	6.6	3010	3.04E+05	2.95E+03	Y	Y	Y
			B Bottom-Far	GT-17	5.1	9.1	3020	3.08E+05	2.96E+03	Y	Y	Y
				GT-18	3.3	6.3	2930	3.13E+05	2.87E+03	Y	Y	Y
				GT-19	4.3	12.4	3015	3.13E+05	2.95E+03	Y	Y	Y
			8 Center	GT-21	3.3	5.6	3015	3.14E+05	2.95E+03	Y	Y	Y
			7 Center	GT-22	1.9	7.8	3010	3.13E+05	2.95E+03	Y	Y	Y
			6 Center	GT-23	3.1	6.5	2965	3.10E+05	2.91E+03	Y	Y	Y
			5 Center	GT-24	6.1	10.9	2925	3.03E+05	2.87E+03	Y	Y	Y
			4 Center	GT-25	9.0	21.0	2950	3.06E+05	2.89E+03	Y	Y	Y
		70%	B Center	GT-7	1.7	2.6	1790	1.79E+05	1.75E+03	Y	Y	Y
				GT-8	2.2	3.6	1755	1.75E+05	1.72E+03	Y	Y	Y
B	3	115%	B Center	GT-3	1.4	2.5	3085	3.01E+05	3.02E+03	Y	Y	Y
		70%	B Center	GT-4	1.8	3.4	1825	1.79E+05	1.79E+03	Y	Y	Y
				GT-6	1.8	2.9	1800	1.81E+05	1.76E+03	Y	Y	Y
				GT-5	1.6	3.3	1800	1.77E+05	1.76E+03	Y	Y	Y

Table B.5. LB-S1 Scale Model Stack Particulate Tracer Uniformity Results at Test Port 1 from Injection Port 2. EMF Flow columns indicate whether the DV value is representative of the EMF minimum, normal, or maximum flow rates.

Fans	Flow Condition	Run No.	% COV	Velocity (sfpm)	Re	DV	EMF Flow		
							Min	Norm	Max
AB	Max	PT-3	11.1	4399	4.66E+05	4.36E+03	Y	Y	Y
		PT-4	9.2	4477	4.62E+05	4.43E+03	Y	Y	Y
		PT-5	10.1	4469	4.54E+05	4.42E+03	Y	Y	Y
	Norm	PT-6	7.3	3633	3.93E+05	3.60E+03	Y	Y	Y
	Min	PT-7	11.4	3089	3.35E+05	3.06E+03	Y	Y	Y
AC	Max	PT-2	10.2	4392	4.51E+05	4.35E+03	Y	Y	Y
BC	Max	PT-1	14.1	4364	4.46E+05	4.32E+03	Y	Y	Y

Table B.6. LB-S1 Scale Model Stack Gaseous Tracer Uniformity Results at Test Port 1. EMF Flow columns indicate whether the DV value is representative of the EMF minimum, normal, or maximum flow rates.

Fans	Flow Condition	Injection Port & Location	Run No.	% COV	% Max Dev.	Velocity (sfpm)	Re	DV	EMF Flow		
									Min	Norm	Max
AB	Max	2 Center	GT-13	2.2	4.3	4458	4.65E+05	4.41E+03	Y	Y	Y
		2 Far	GT-14	3.7	7.4	4459	4.63E+05	4.41E+03	Y	Y	Y
		2 Near	GT-15	3.8	6.3	4455	4.62E+05	4.41E+03	Y	Y	Y
		2 Bottom	GT-16	5.0	8.4	4470	4.65E+05	4.43E+03	Y	Y	Y
		2 Top	GT-17	5.0	11.1	4274	4.50E+05	4.23E+03	Y	Y	Y
	Normal	2 Center	GT-19	3.0	5.5	3760	3.95E+05	3.72E+03	Y	Y	Y
		2 Far	GT-20	3.8	7.7	3732	3.92E+05	3.69E+03	Y	Y	Y
		2 Near	GT-21	5.2	10.9	3758	3.92E+05	3.72E+03	Y	Y	Y
		2 Bottom	GT-22	5.3	9.3	3756	3.90E+05	3.72E+03	Y	Y	Y
		2 Top	GT-18	4.8	11.5	3773	3.95E+05	3.73E+03	Y	Y	Y
	Min	2 Center	GT-24	2.5	5.5	2992	3.13E+05	2.96E+03	Y	Y	Y
			GT-25	3.6	6.1	2998	3.10E+05	2.97E+03	Y	Y	Y
		2 Far	GT-26	4.6	8.8	2979	3.02E+05	2.95E+03	Y	Y	Y
		2 Near	GT-27	3.5	11.9	2927	2.95E+05	2.90E+03	Y	Y	Y
		2 Bottom	GT-23	7.3	14.9	2953	3.15E+05	2.92E+03	Y	Y	Y
			GT-29	5.9	14.2	2953	2.97E+05	2.92E+03	Y	Y	Y
			GT-30	4.6	11.6	2942	2.97E+05	2.91E+03	Y	Y	Y
			GT-31	4.1	11.6	2966	3.09E+05	2.94E+03	Y	Y	Y
		2 Top	GT-28	3.6	10.9	2915	2.93E+05	2.89E+03	Y	Y	Y
AC	Max	2 Center	GT-7	1.0	2.0	4504	4.68E+05	4.46E+03	Y	Y	Y
		2 Far	GT-8	1.7	4.0	4422	4.56E+05	4.38E+03	Y	Y	Y
		2 Near	GT-9	1.8	4.4	4498	4.61E+05	4.45E+03	Y	Y	Y
		2 Bottom	GT-10	2.9	6.5	4488	4.60E+05	4.44E+03	Y	Y	Y
		2 Top	GT-11	1.4	2.9	4494	4.62E+05	4.45E+03	Y	Y	Y
	Min	2 Center	GT-12	1.6	3.5	3105	3.21E+05	3.07E+03	Y	Y	Y
BC	Max	2 Center	GT-1	3.4	7.0	4560	4.92E+05	4.51E+03	Y	Y	Y
		2 Far	GT-2	5.2	12.4	4531	4.80E+05	4.49E+03	Y	Y	Y
		2 Near	GT-3	3.6	10.0	4533	4.95E+05	4.49E+03	Y	Y	Y
		2 Bottom	GT-5	6.4	13.4	4442	4.84E+05	4.40E+03	Y	Y	Y
		2 Top	GT-4	5.4	9.9	4534	4.94E+05	4.49E+03	Y	Y	Y
BC	Min	2 Center	GT-6	3.5	9.9	3016	3.05E+05	2.99E+03	Y	Y	Y

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