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ATMOSPHERIC TRACER DEPLETION TESTING FOR UNFILTERED AIR IN-LEAKAGE DETERMINATION AT THE WOLF CREEK NUCLEAR POWER PLANT

Revision 1

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Prepared for
Wolf Creek Nuclear Operating Corporation

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Environmental & Climate Sciences Dept.

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Final Report

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Revision Log

Section	Page #	Rev. #	Date	Reason(s) for Revision
Title page, Signature page	1	1	4/25/17	Added revision 1 to the title and changed the date to April 25, 2017
Executive Summary	v	1	4/25/17	Corrected value for inactive equipment room in-leakage in Table ES-1 in the Alpha test from 26 to 49 cfm.
Executive Summary	v	1	4/25/17	Fixed a typo in Table ES-1. The fractional depletion in ER 1512 is 0.1, not 0.01 as originally reported.
3.3.3	24	1	4/25/17	Corrected value for inactive equipment room in-leakage in Table 20 in the Alpha test from 26 to 49 cfm.
3.4	26	1	4/25/17	Corrected value for inactive equipment room in-leakage in Table 23 in the Alpha test from 26 to 49 cfm

Atmospheric Tracer Depletion Testing for Unfiltered Air In-Leakage Determination at the Wolf Creek Nuclear Power Plant

Executive Summary

Atmospheric Tracer Depletion tests were conducted at the Wolf Creek Nuclear Power Plant to quantify the unfiltered in-leakage (UI) into the Control Room (CR), Control Building (CB), and Equipment Rooms (ER) at the Wolf Creek Nuclear Power Plant. Wolf Creek has two independent charcoal filter Emergency Ventilation Systems (EVS) that can be used to purify air entering the control building and control room. The Bravo System contains a filtration system in Room 1501 in the Auxiliary Building for the Control Room and another filtration system (FGK02B) on Elevation 2016 for the Control Building. The Alpha system contains a filtration system in Room 1512 in the Auxiliary Building for the Control Room and another filtration system (FGK02A) on Elevation 2016 for the Control Building.

The Atmospheric Tracer Depletion (ATD) test is a technique to measure in-leakage using the concentration of perfluorocarbon compounds that have a constant atmospheric background. These levels are present in the Control Room and Control Building under normal operating conditions. When air is supplied by either of the EVS, most of the PFTS are removed by the charcoal filters. If the concentrations of the PFTs measured in protected areas are the same as the levels at the output of the EVS, the in-leakage of outside air into the protected area would be zero. If the concentration is higher in the protected area than at the output of the filter system, there is in-leakage and the in-leakage can be quantified by the difference.

Sampling was performed using state-of-the-art Brookhaven Atmospheric Tracer Samplers (BATS) air sampling equipment and analysis performed on Brookhaven National Laboratory (BNL) dedicated PFT analytical systems. In the Alpha test two tracers PMCH and mcPDCH were used to determine in-leakage into the control building. The analytical system was tuned to maximize sensitivity after initial analysis of the Alpha test. The increased sensitivity permitted accurate quantification of five isomers of the PFT PDCH (mtPDCH, pcPDCH, otPDCH, mcPDCH, and ptPDCH). These isomers were quantified in the low concentration samples in the Alpha test and in all samples in the Bravo test.

The best estimates of UI (R_{ui}) for the four zones are provided in Table ES-1. For the CB, this estimate averages the four tracers at the four elevations. For the CR, this estimate uses the four sampling units located in the Control Room.

Table ES-1 Best Estimate of Unfiltered In-Leakage Results

	Alpha Train		Bravo Train	
Location	F_{dep}	R_{ui} (cfm)	F_{dep}	R_{ui} (cfm)
CB	0.14	102 ± 24	0.121	88 ± 4
CR	0.0049	10 ± 2	0.0083	17 ± 10
ER 1501	0.26	49	0.06	28 ± 4
ER 1512	0.1	48 ± 7	0.08	3.3

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1.0 Overview

The Emergency Ventilation Systems used to protect the Control Room (CR), Control Building (CB), and Equipment Rooms (ER) At the Wolf Creek Nuclear power plant were were tested to quantify the unfiltered in-leakage (UI). Wolf Creek has two independent charcoal filter Emergency Ventilation Systems (EVS) that purify air entering the control building and control room, labeled Alpha and Bravo Both systems were tested.

The Atmospheric Tracer Depletion (ATD) is a technique that uses the atmospheric background of perfluorocarbon tracer (PFT) compounds and the removal of these compounds from the airstream filtered by the EVS systems to quantify UI. The PFTs will remain on the charcoal filter until heated above 200 °C. The background level of the compounds is measured upstream of the filter system. The removal of the PFTs is measured at the output of the filter system, and the concentration of the PFTs are measured in the air of the protected zones. When the EVS system has been in operation for a time sufficient to reach steady-state, air samples collected in the zone can be used to identify and quantify UI. If there were no UI, the concentration throughout the protected zone would be the same as that at the output of the filter. If the concentration is higher, there is in-leakage and the in-leakage can be quantified.. Thus, any difference in concentration between the output of the filter system and points in the protected zone is a measure of in-leakage of unfiltered air.

For maximum accuracy in the assessment of in-leakage it is best if the EVS has run long enough to reach steady-state. For example, if the air sample was collected soon after the start of the EVS system, the measured concentrations would be close to background and the predicted in-leakage would be high. The longer the charcoal systems work, the lower the PFT concentrations, until steady-state is reached. Due to the large volumes of the CB (365,000 ft^3) and the flow rates of the CB EVS system (750 ft^3/min), it would take several days for the charcoal filtration in the EVS to draw down the background levels of PFTs to their steady-state values. This is not practical for testing. To decrease the time to reach steady-state, additional charcoal filtration is needed. This is supplied using portable charcoal filter fan units that were acquired by Wolf Creek staff and were placed on the four levels of the Control Building (Elevation 2000 (Switchgear Room), El 2016 (Battery, CBEVS, and equipment rooms). El 2032 (Lower Cable Spreading Room), and El 2072 (Upper Cable Spreading Room) and in the active train Equipment Room in the Auxiliary Building. When the charcoal assist fans were operating, the double between the active and inactive equipment room were left open and fans were used to provide mixing between these two rooms. This is also the operating procedure for the doors on elevation 2016 and elevation 2000.

Brookhaven National Laboratory has a Quality Assurance Manual and operating procedures for Multi-tracer testing. These processes were reviewed by the Quality Assurance Office of Wolf Creek Nuclear Operating Corporation. Testing was performed in conformance the quality procedures.

2.0 Test Procedure

The Wolf Creek Power Plant Control Building consists of rooms on four elevations that receive conditioned air from the Emergency Ventilation System (EVS). Elevation 2000 contains two Switchgear Rooms. Elevation 2016 contains two rooms containing the EVS equipment and several rooms containing switchgear, and other associated equipment. Elevation 2032 contains one large room, the Lower Cable Spreading Room. Elevation 2073 also contains one large room, the Upper Cable Spreading Room. The EVS system in the Control building filters approximately 750 cfm of air. There are two independent EVS systems, Alpha and Bravo, for the Control Building.

The Control Room (CR), located at the 2047 Elevation has an EVS system rated at 2000 cfm. The CR EVS equipment is in the Auxiliary Building at the 2047 Elevation. There are two independent systems, Alpha and Bravo, for the Control Room. Equipment for the Alpha train is in Room 1512 and for the Bravo train in 1501. Ducting from the air handling equipment in these two rooms enters the CR and supplies filtered air that is recirculated through the EVS system.

Testing was conducted for both the Alpha and Bravo systems.

2.1 Charcoal Assist Fans

The calculations to measure in-leakage assume that steady-state has been reached. The initial conditions in the CR and CB are background concentrations of the PFTs. As the charcoal filters from the EVS are used, the ambient PFTs are removed and their levels decrease. At some point in time, the filtration is balanced with the in-leakage and a steady-state concentration is achieved within the test volume. The volume of the CB and the relatively small amount of filtered air (750 cfm) would require a long time to reach steady-state. To accelerate this process four charcoal filter fan units are placed in the CB. The fans on the 2000 and 2016-foot elevation were rated at 1000 cfm. The fans on the 2032 and 2073 elevation were rated at 350 cfm. A 500-cfm fan was used in the Equipment Room (ER) to assist the CR in reaching steady-state faster. The time to draw the system down to steady-state was calculated for both trains based on the additional charcoal assist fans, their flow rates, building volumes and the 2010 measured in-leakage rates. The results are provided in Table 1 assumed 1000 cfm fans on all levels of the CB.

Table 1. Calculated Charcoal-Assist Run Times and Time to Steady State (SS)

		Assumed	**Run Times, hr.**	
Location	**Train**	**UI, cfm**	**CB**	**ER**
CB	A	100	5.1	3.7
"	B	120	5.6	"
ER	Either	30	3.5	

Charcoal-Assist fans were utilized in each of the identified spaces though volumetric capacities varied from the estimate in some cases. The fans and run duration utilized resulted in achieving steady state for the test. Further detail regarding the accomplishment of steady state conditions is provided in section 3.1 of this report.

2.2 Sampling Equipment and Schedule

Based on previous tests, sampled air was expected to have fractional depletions running from 1.0 (outside air into the CBEVS – thus, no depletion), to: ~0.1 (CB SS levels): <0.001 (EVS filtered discharge air). Based on the 2010 results and pretest predictions, collecting adequate sample volumes to quantify each of the depleted levels and to automate that collection as much as possible were important goals. The identified sampling locations, the types of samplers and sample durations for the Alpha (tested first) and Bravo EVS trains are summarized in Table 2. Samples locations that were moved between tests are those locations that depend on which train of the emergency ventilation systems are operating. The table indicates the number of samples taken and their flow rate. The BATS were used for automated sampling at 35 locations during the 24-hour test period. The sample duration and flow rate (ranging from two to five hours and 50 to 450 ml/min) were selected based on the expected concentrations.

Table 2 provides the sample quantity, duration, rates, and locations. In the Table the following acronyms were used: Return Air (RA); Supply Air (SA, Switchgear (SWGR); CBEVS (control building emergency ventilation system); HEPA (high efficiency particulate air); recirculation (Recirc); Aux (Auxiliary Building); and Control Room Emergency Ventilations System (CREVS).

Table 2 Sampling Systems and Sample Quantity*, Duration*, Rates, and Locations

Location Number	Location	Number of samples*	Time (hours)*	Flow Rate (ml/min)	Comments
		2000' Elevation			
1	El 2000 Active RA Grill	12	2	100	Move between tests
2	El 2000 Active SA Grill	12	2	100	Move between tests
3	El 2000 SWGR 1-1	12	2	100	
4	EL 2000 SWGR 1-2	12	2	100	
5	EL 2000 SWGR 2-1	12	2	100	
6	EL 2000 SWGR 2-2	12	2	100	
		2016' Elevation			
7	EL 2016 Active RA grill	12	2	100	
8	EL 2016 - SWBD-1	12	2	100	
9	EL 2016-SWBD-2	12	2	100	
10	EL 2016-SWBD-3	12	2	100	
11	El 2016-SWBD-4	12	2	100	
12	EL-2016 CBEVS Inlet	12	2	100	Move between tests
13	EL 2016 CBEVS Outlet before HEPA	6	4	450	Move between tests
14	EL 2016 CBEVS Outlet after HEPA	6	4	450	Move between tests
15	EL 2016 CB Rercirc	8/2	2/4	450	Move between tests
		2032' Elevation			
16	EL 2032 Active RA Grill	12	2	100	Move between tests
17	El 2032 -1	12	2	100	
18	EL 2032-2	12	2	100	
19	EL 2032-3	12	2	100	
		Control Room			
20	CR RA Grill #1	8/2	2/4	450	
21	CR RA Grill #2	8/2	2/4	450	

22	CR Back of instrument panel near door	6	4	450	
23	CR Back of instrument panel down hallway	6	4	450	
		Auxiliary Building			
24	Aux – near CREVS	6	4	300	Move between tests
25	Aux - CREVS inlet before HEPA	6	4	300	Move between tests
26	Aux - CREVS inlet after HEPA	6	4	300	Move between tests
27	Aux - CREVS outlet before HEPA	1/4	4/5	450	Move between tests
28	Aux -CREVS outlet after HEPA	1/4	4/5	450	Move between tests
29	Aux - Eq room Active @ 300 cfm RA	8/2	2/4	450	Move between tests
30	Aux - Eq room inactive near RA Grill	12	2	450	Move between tests
31	Aux Eq Room Active Near CREVS	8/2	2/4	450	Move between tests
		Elevation 2073			
32	EL 2073 Active RA Grill	12	2	100	
33	El 2073 -1	12	2	100	
34	EL 2073-2	12	2	100	
35	EL 2073-3	12	2	100	

* For locations with multiple values for duration and number of samples, there was a change in the sampling duration during the test. For example, location 15 states that the number of samples is 8/2 and the duration is 2/3. This indicates that 8 samples were taken for 2 hours and 2 samples were taken for four hours. The total duration of all samples at a location is 24 hours.

2.2.1 Alpha Test

Sampling for the first train, the Alpha train, commenced at 0900 on Friday August 26th. . 1000 cfm charcoal fans were available on the 2000 and 2016 foot elevations. 350 cfm fans were used on the 2032 and 2073 foot elevations. To provide additional charcoal filtration, the emergency ventilation system was turned on at approximately 0245 on Friday August 26th. In additions, the fans on the 2032 and 2073 elevation were turned on at 0630 that morning and left on for 11.5 hours. This additional filtration brought the system closer to the steady-state values needed to measure in-leakage. The filtration times ae provided in Table 3.

The transition between the Alpha and Bravo train requires the normal ventilation to be started. The full transition requires time for the switch and a three-hour break between sampling for the Alpha and Bravo trains was planned. After getting the system in alignment, the pressure differential between the control room and the outside was less than the level required in the test specifications, 0.25 inches of water. Verification that the plant was in the appropriate lineup was made, but the pressure differential was still not high enough. This issue was documented in the station's corrective action program and the test on the Bravo train was terminated approximately 4 hours after it started.

A repair was made and the test of the Bravo train was re-scheduled for September 9th and 10th.

2.2.2 Bravo Train

For the Bravo train the BATS were set to start at 0900 on Friday, September 9th. Sampling continued until 0900 on September 10th. The sampling plan outlined in Table 2 was followed. The operation of the Charcoal assist fans is provided in Table 3. To provide additional charcoal filtration, the emergency ventilation system was turned on at approximately 0900 on Thursday September 8th.

Table 3. Charcoal Assist Operation Times

Alpha Train

Elevation	Date	Time On	Time Off	Duration
2000	26 - Aug	09:25	15:00	5:35
2016	26 - Aug	09:35	15:05	5:30
2032	26 - Aug	06:30	19:00	11:30
2073	26 - Aug	06:35	19:05	11:30
CBEVS	26 - Aug	09:00	13:00	4:00

Bravo Train

Elevation	Date	Time On	Time Off	Duration
2000	9 -Sept	15:50	21:22	5:32
2016	9 -Sept	15:45	21:19	5:34
2032	9 -Sept	15:40	21:29	5:49
2073	9 -Sept	15:33	21:25	5:52
CBEVS	9 -Sept	15:15	19:00	3:45

2.3 Perfluorocarbon Tracers

The PFT method usually consists of the tracers themselves, injection techniques, samplers, and analyzers. In the Atmospheric Tracer Depletion test performed at Wolf Creek no additional tracers are introduced. Instead, the background levels of the PFTs are reduced when passing through a charcoal filter. The difference between levels of tracer depleted from ambient air and the levels measured in the CR allows a measure of in-leakage of unfiltered air. PFTs have the following advantages over conventional tracers:

- PFTs exist in normal ambient air and are removed by the EVS charcoal filtration system which allows calculation of tracer depletion, allowing measurement of UI without the need for any additional tracers
- PFT technology is the most sensitive of all non-radioactive tracer technologies and concentrations in the range of parts per quadrillion (1 in 10^{15}) are routinely measured. With large sample sizes the detection limit can be as low as 1 part in 10^{18}.
- The PFTs technology is a multi-tracer technology permitting up to eleven PFTs (Table 4) to be simultaneously deployed, sampled, and analyzed with the same instrumentation. This results in multiple lines of reasoning to confirm the predicted in-leakage in a tracer depletion test. All eleven PFTs can be analyzed in fifteen minutes on a specially designed laboratory-based gas chromatograph.

PFTs have a stable background. Charcoal filtration in the EVS removes PFTs from air with varying efficiency depending on the volatility of the PFTS. The more volatile, lower molecular weight compounds are removed less efficiently than the lower volatility higher molecular weight compounds.

Table 4 Chemical Acronym, Name, and Formula for PFT Tracers

Chemical Acronym	Chemical Name	Chemical Formula
PDCB[1]	Perfluorodimethylcyclobutane	C_6F_{12}
PMCP[1]	Perfluoromethylcyclopentane	C_6F_{12}
PMCH	Perfluoromethylcyclohexane	C_7F_{14}
oc-PDCH[2]	ortho-cis-perfluorodimethylcyclohexane	C_8F_{16}
mt-PDCH[2]	Meta-trans-perfluorodimethylcyclohexane	C_8F_{16}
pc-PDCH[2]	Para-cis--perfluorodimethylcyclohexane	C_8F_{16}
otPDCH[2]	Othro-trans- perfluorodimethylcyclohexane	C_8F_{16}
mc-PDCH[2]	Meta-cis-dimethylcyclohexane	C_8F_{16}
pt-PDCH[2]	Perfluorotrans 1,4 dimethylcyclohexane	C_8F_{16}
PTCH	Perfluorotrimethylcyclohexane	C_9F_{18}
iPPCH	Perfluoro-iso-propocyclohexane	C_9F_{18}

[1] Chemically distinct isomers
[2] Chemically distinct isomers

In a typical tracer depletion test the four PDCH isomers (mt, pc, mc, and pt-PDCH) are used in the analysis. Charcoal filters capture only about 90% of the PDCB and PMCP and thus, they are not acceptable for determining depletion below this level and cannot be used in tracer depletion tests. PMCH and ocPDCH typically show greater than 95% removal and can be used if necessary when in-leakage leads to concentrations much greater than 5% of their background values. The four PDCH's selected for use typically have >99.5% removal by the charcoal filter and this makes them suited for cases when in-leakage is low and the depleted concentration is near 1% of the background value.

In the Alpha test, analytical issues with the gas chromatogram (GC) provided unreliable readings for mt, pc, and mt-PDCH. For this reason, PMCH and mc-PDCH were used to determine in-leakage in the Control Building. The higher amount of bypass of PMCH through the charcoal filter makes this tracer unusable in the Control Room and Auxiliary Buildings where the depleted concentrations is less than 5%. Prior to performing the gas chromatogram analysis for samples in these buildings, the operations of the GC were optimized to remove interferences of the PDCH isomers that were occurring. This included changing the reducing catalyst and changing some of the operating termperatures. For the Control Room and Auxiliary Building the four PDCH isomers (mt, pc, mc, and pt) were used.

The Bravo test data were analyzed after the optimization of the GC and the four PDCH isomers were used for analysis of in-leakage in the Control Building and the Auxiliary Building. In the Control Room interferences with mt and pc-PDCH values on some of the samples required that ot-PDCH also be used as a measure of in-leakage. ot-PDCH is typically not used as the other four tracers should provide adequate confirmation of in-leakage. This was not the case for the Control Building and thus ot-PDCH was included.

3.0 Results

All samples were analyzed and the computations to translate the measurements of the gas chromatograph to concentration were performed. This report provides results based on interpretation of PMCH and mcPDCH for the Control Building (CB) in the Alpha test and four isomers of PDCH for the Control Room (CR) in the Alpha test. In the Bravo tests, four isomers of PDCH were used in the CB and five isomers in the CR. A discussion of the selection of tracers used is presented when discussing the data. This section provides an evaluation of whether steady-state was reached and the concentrations measured in the CB, CR, Equipment Rooms (ER), at the exhaust of the charcoal filter system, and at background. These concentrations are used to estimate in-leakage and the results are presented. Comparisons between different tracers were checked for consistency and found to generally be within a few percent. Exceptions to this are discussed later in the report with the data presentation.

3.1 Approach to Steady-State Concentrations

Since automatic samples were collected using the BATS over 1- to 5-hr durations for the 24 hr Atmospheric Tracer Depletion tests, it was possible to observe the results approaching steady state. The calculations of in-leakage (Section 3.3) assume that steady-state conditions have been attained. If the data collection is completed before steady-state has been reached, in-leakage will be conservatively over predicted

Figures 1 and 2 show the approach to steady-state for the BATS located at the 2000 Elevation labeled Switchgear 1-1 (Location 3 in Table 2). BATS 3 was used at this location in the Alpha test and BATS 4 was used in the Bravo test. Both figures plot the fractional depletion of each tracer over time. The fractional depletion is the concentration of the tracer divided by the background concentration of that tracer. This normalization allows a direct comparison between different tracers. Assuming that the charcoal filter effectively removes all the tracer, the different tracers should provide identical results. The excellent match between tracers is evident in Figures 1 and 2. In Figure 1, the concentrations decrease rapidly during the first six hours when the extra charcoal assist fans were operating. After that time, the concentrations decrease slowly appearing to be close to steady-state after approximately twenty hours. Similar graphs could be provided for the data from other BATS units in the analysis. Appendix 1 lists all the data collected in this report and can be used to confirm that steady-state is reached.

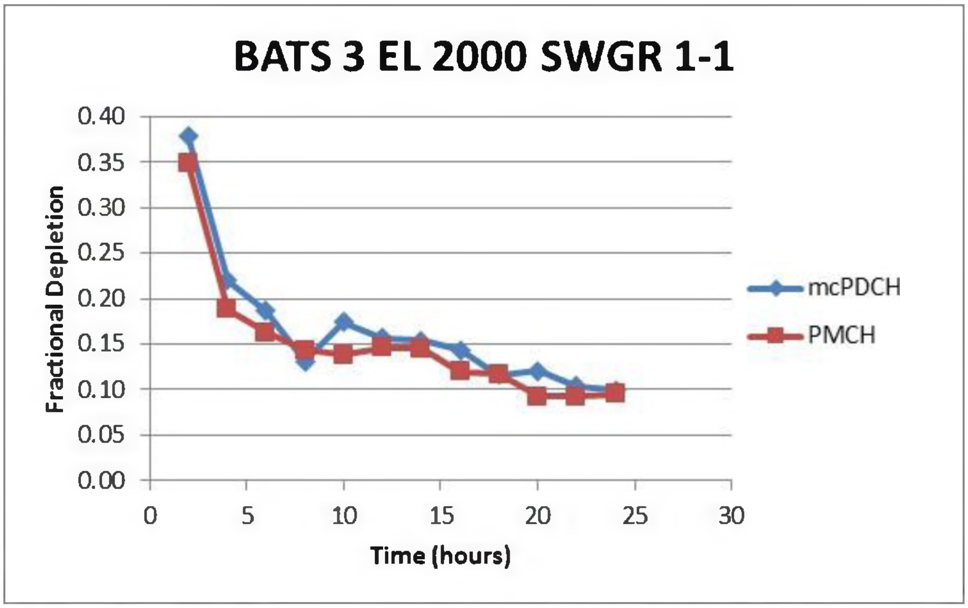

Figure 1 PMCH and mcPDCH concentrations at Location 3 2000-foot elevation SWGR 1-1

Figure 2 shows the concentration of the four PDCH isomers over time at this same location. In the Bravo test BATS 4 was used to collect the data. Note that the concentrations in the Bravo test at the first data point were significantly lower (Alpha test initial point ~0.36, Bravo test ~0.28). This is due to the earlier start time of the EVS in the Bravo test. At this lower starting value, the concentrations overshot the equilibrium level when the additional charcoal fans were turned on. They later rebounded up to the steady-state values and approached steady-state at the end of the test. Also, note, that the steady-state concentrations in the switchgear room are higher in the Bravo test (~0.14 versus the Alpha test ~0.1) indicating higher in-leakage in this room during the Bravo test.

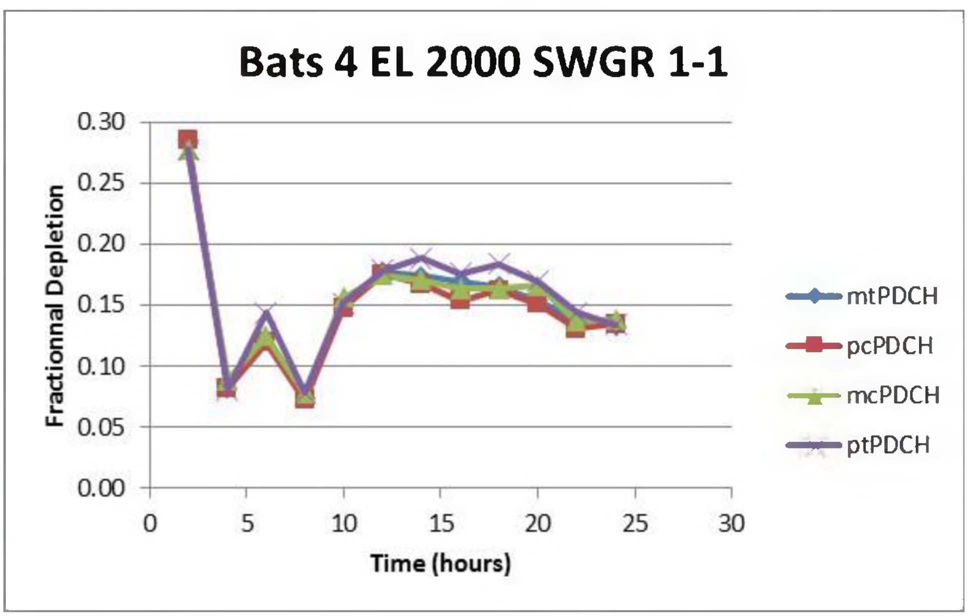

Figure 2 PDCH isomers tracer concentrations at Location 3 2000-foot elevation SWGR 1-1.

3.2 Concentrations

3.2.1 Background Concentrations

In this report, the concentrations are reported in units of Area/L. The Area is the area under the curve of the peak on the GC output. This value could be translated to fL/L which would represent the femtoliters (10^{-15} L) of PFT per liter of air using the known standards that are analyzed with the samples. This step is omitted in this report because everything is normalized to the background concentration reported in units of Area/L. Thus, the key analysis parameter, F_{dep}, is the sample concentration in Area/L divided by the background concentration in Area/L. At the low concentrations in this test, the relationship between Area/L and fL/L is linear and no further calculations are required. In a few cases, the measured Areas were high enough to enter the non-linear response range. In these cases, the concentration in fL/L was calculated to determine F_{dep}.

To accurately determine depletion of ambient PFTs it is critical to have an accurate determination of those levels before any filtration occurs. These ambient background concentrations were obtained from the BATS sampler that was placed on the inlet of the CBEVS which takes outside air and passes it through the charcoal filter. These concentrations are the values found everywhere before the charcoal systems are turned on. Figure 3 shows the background concentrations for the Alpha test. The twelve background concentrations are summarized in Table 5 in terms of the average concentration in GC response in area for each per liter of air, standard deviation, and percentage variation in standard deviation.

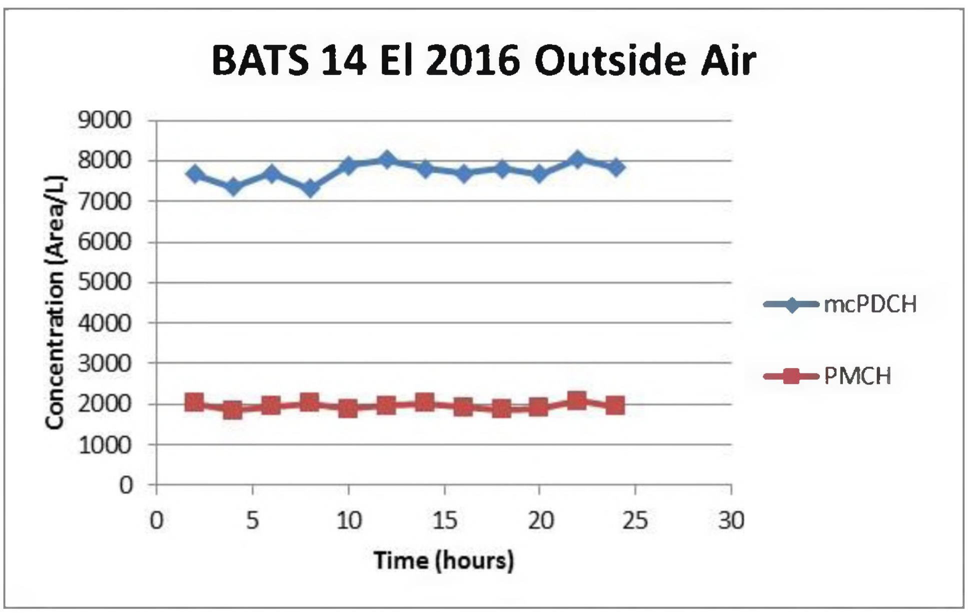

Figure 3 Outside air (background) concentrations for PMCH and mcPDCH.

Table 5 Background Concentrations (Area/L) in the Alpha Test.

	PMCH	mcPDCH
Average (Area/L)	2209.3	7735.1
Standard Deviation	150.7	227.6
% Standard deviation	6.8	2.9

In the Bravo test five different PDCH isomers were used in the analysis of in-leakage. Their background values based on eight samples is provided in Table 6. These samples were analyzed after optimization and the GC response increased the measured response (Area/L) for mcPDCH by about 50%.

Table 6 Background concentrations (Area/L) measured during the Bravo tests.

	pcPDCH	mtPDCH	otPDCH	mcPDCH	ptPDCH
Average (Area/L)	11904	8439	1147	11982	6973
Standard Deviation	824	475	69	1229	1067
% Standard Deviation	6.9	5.6	6.0	10.3	15.3

During the analysis phase of the test the Electron Capture Device on the GC failed. It was replaced and this also increased the detector response. The number of area counts increased on known standards. To address this, additional background air samples collected on Long Island were used to determine the background level. Comparing the known standards with the Long Island background data showed that it was a good surrogate for the Wolf Creek background. This is expected because the background of PFTs well mixed in the Northern Hemisphere. After the replacement of the Electron Capture Device, a 12-liter Long Island air sample was analyzed with each set of samples to confirm that the response was not changing. Known standards were analyzed with each set of data for all data in this test.

3.2.2 Control Building Concentrations

Sampling in the CB was performed using four to seven BATS at each of the four elevations in the CB envelope (Table 2). The background concentrations (Tables 5 and 6) of the different tracers differ by more than an order of magnitude. To judge the consistency between the four tracers it is more convenient to examine the fractional depletion (F_{dep}), defined as the measured value divided by the background value. F_{dep} is used in the equations for in-leakage as will be discussed in Section 3.3. Recall that the backgrounds provided in Table 5 and 6 are in Area/L and a count of 10,000 in units of Area/L is approximately 10 fL/L (or 1 part in 10^{15}) depending on the tracer.

The different GC operating conditions required care when normalizing the data. The F_{dep} results of the Alpha test data analyzed prior to the failure of the Electron Capture Device were normalized using the background data analyzed just prior to the analysis of this group of data. The F_{dep} results after the failure of the Electron Capture Device were normalized to background data from the plant and from Long Island that were compared to known standards. This approach insured that the normalization procedure used data analyzed under the same operating conditions.

Figure 4 shows a typical time evolution of the two tracers in the Lower Cable Spreading Room (LCSR) on the 2032-foot elevation for the Alpha test. The graph plots the normalized concentration, F_{dep}, versus time after the start of the Alpha test. The concentrations appear to be near steady-state in this example after about 15 hours. In the analysis, the last 3 samples (6 hours of data) are used to calculate average F_{dep}.

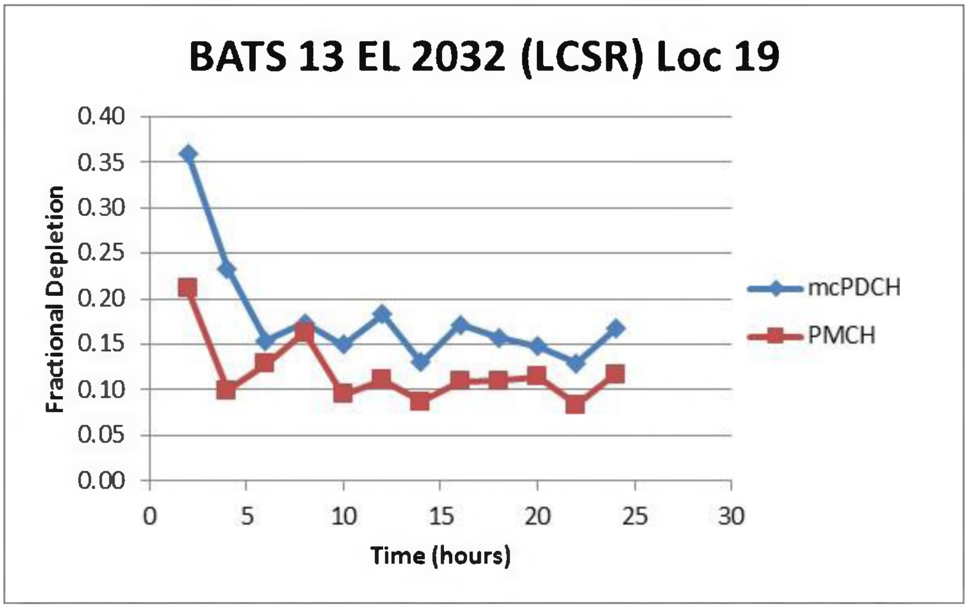

Figure 4 Time-dependent mcPDCH concentration at Elevation 2032.

Table 7 presents the average F_{dep} during the last six hours of the Alpha test along with the average for the two tracers used in the Alpha test, the standard deviation between the tracer F_{dep}, and the percentage difference defined as 100 multiplied by the standard deviation and divided by the average.

Table 7 CB Fractional depletion in the Alpha Test

	PMCH	mcPDCH	Avg	Std Dev	% Diff
El 2000	0.13	0.18	0.16	0.038	24.4
El 2016	0.13	0.21	0.17	0.056	32.8
El 2032	0.09	0.14	0.12	0.030	26.1
El 2073	0.10	0.14	0.12	0.023	19.3
Average	0.11	0.17	0.14		

Examining Table 7 the fractional depletion as measured by PMCH is always 30 to 50% lower than mcPDCH. This reflects the difficulties in the GC analysis as these numbers should be much more similar. There were often interfering peaks near the mcPDCH value that may have been contributed to the mcPDCH peak. The levels that we are attempting to quantify to are less than 1 part in 10^{17}. Thu,s only minor contamination of non-PFTs (e.g. carbon tetrachloride and other hydrocarbons) can cause problems. Both values were used to calculate in-leakage to provide a range in the estimate. Appendix A provides the summary for the average fractional depletion during the last six hours of the test for all BATS in the Control Building.

The analysis for the Bravo test was performed after optimization of GC performance. This data set is much better than the Alpha data set in term agreement between the four different tracers as the standard deviation is 10% or less on all four elevations. Like the Alpha test, the two Cable Spreading Rooms show lower F_{dep} than found at Elevation 2000 or 2016.

Table 8 CB Fractional depletion in the Bravo Test

	mtPDCH	pcPDCH	mcPDCH	ptPDCH	Avg	Std Dev	% Diff
El 2000	0.127	0.143	0.147	0.142	0.140	0.008	6.1
El 2016	0.134	0.153	0.130	0.159	0.144	0.014	10.0
El 2032	0.098	0.105	0.101	0.102	0.101	0.003	2.9
El 2073	0.096	0.104	0.091	0.102	0.098	0.006	5.9
Average	0.114	0.126	0.117	0.126	0.121	0.006	5.3

3.2.3 Control Room (CR) Concentration Results

Sampling in the CR was performed in 4 locations:

1) BATS #40 sequential air sampling at the NW corner return air grill in the CR proper (not far from the entrance into the CR),

2) BATS #48 behind the console in the middle of the north wall in the line of sight of the door.

3) BATS #47 behind the console in the middle of the west wall

4) BATS #54 at the return air grill in the room behind the console.

BATS 40 and 54 collected eight, two hour samples and two, four hour samples at the end of the test. BATS 47 and 48 collected six, four hour samples. The last sample was used to determine the steady-state value in the Control Room. The optimization of the GC was performed prior to analyzing these samples and the four isomers of PDCH were used in the analysis. Table 9 shows the F_{dep} value on the last sample in the test. The average fractional depletion in the 2010 tests of each tracer is also presented the values from 2010. In Table 9, in the Alpha test, BATS 40 had all readings near zero and therefore the values are conservatively not reported. otPDCH values were not calculated for the Alpha test and are not reported. The BATS 47 data from the Bravo test were complicated by several interferences in the gas chromatograph results and are not reliable, for example, the concentrations are often greater on this BATS in the Control Room than the BATS in the Control Building. This cannot be correct and therefore, they were not used in the averages in Table 9. Similarly, the mtPDCH and ptPDCH values from BATS 54 are not reliable and were not used in the averaging. Values highlighted in yellow are outliers and not used in the averaging process. They were deemed outliers if the F_{dep} value was more than a factor of 2 greater than the F_{dep} value entering the charcoal filter. The air entering the charcoal filter is a combination of the two return air ducts in the Control Room and a return air duct in the Auxiliary Building room that houses the charcoal filter. Concentrations in the Auxiliary Building are higher than in the Control Room. Therefore, the value in the Control Room should be slightly lower than the value entering the charcoal filter.

Table 9 Main Control Room F_{dep} values at the end of the test.

Alpha Test	BATS ID	pcPDCH F_{dep}	mtPDCH F_{dep}	otPDCH F_{dep}	mcPDCH F_{dep}	ptPDCH F_{dep}
	40	N/A	N/A	N/A	N/A	N/A
	47	0.023	0.051	N/A	0.026	0.020
	48	0.014	0.012	N/A	0.018	0.011
	54	0.024	0.045	N/A	0.026	0.015
	Average	0.020	0.036		0.023	0.015

2010 Alpha	Average	0.0048[1]	N/A[1]	N/A	0.0062	0.0052
Bravo Test	40	0.019	0.036	0.001	0.017	0.002
	47	0.068	0.283	0.015	0.044	0.002
	48	0.002	0.016	0.002	0.002	0.006
	54	0.033	0.143	0.009	0.017	0.148
	Average[2]	0.018	0.026	0.004	0.012	0.004
2010 Bravo	Average	0.0013[1]	N/A[1]		0.0027	0.0013

[1] In the 2010 tests, pc and mtPDCH were reported together.

[2] Values highlighted in yellow omitted from the average.

Comparing the results in Table 9 from 2010 and 2016 the fractional depletion is much higher in 2016. A major cause of this is breakthrough of tracers past the charcoal filters. After absorption on to the charcoal, release of the PFTs requires heating to temperatures in excess of 200 °C. Thus, the breakthrough cannot be attributed to release from the charcoal. On a new filter, the F_{dep} value for each PDCH isomer should be less than 0.001. This was the case in 2004 and 2010. In 2016 the F_{dep} values were much higher exiting the charcoal filter. Table 10 provides the F_{dep} value for BATS 91 which was located at the exhaust of the charcoal filter beyond the HEPA filter. This is the supply air after filtration for the Control Room. In general, the Alpha train charcoal filter was showing between 1 and 4% breakthrough. The Bravo train charcoal filter was better showing 0.1 to 1.5% breakthrough. The breakthrough was higher than the F_{dep} values in 2010.

Table 10 Air concentrations after leaving the charcoal filter in the Auxiliary Building (BATS 91).

BATS 91	Test	pcPDCH F_{dep}	mtPDCH F_{dep}	otPDCH F_{dep}	mcPDCH F_{dep}	ptPDCH F_{dep}
	Alpha	0.019	0.038	N/A	0.021	0.010
	Bravo	0.004	0.015	0.001	0.003	0.004

To account for breakthrough of the charcoal filter, the values in Table 10 are subtracted from those in Table 9 to give a best estimate of the increase in concentration due to in-leakage. In cases where the adjusted F_{dep} value is less than zero, it is set to 0.002. Table 11 presents the adjusted F_{dep} values in the Control Room. The values in Table 11 are used to calculate in-leakage.

Table 11 Main Control Room F_{dep} values at the end of the test adjusted for breakthrough

Alpha Test	BATS ID	pcPDCH F_{dep}	mtPDCH F_{dep}	otPDCH F_{dep}	mcPDCH F_{dep}	ptPDCH F_{dep}
	40	N/A	N/A	N/A	N/A	N/A
	47	0.004	0.012	N/A	0.003	0.011
	48	0.002[1]	0.002[1]	N/A	0.002[1]	0.001
	54	0.006	0.007	N/A	0.003	0.005
	Average	0.0041	0.0071		0.0027	0.0057
2010 Alpha	Average	0.0048[1]	N/A[1]	N/A	0.0062	0.0052
Bravo Test	40	0.015	0.021	0.0004	0.014	0.002[1]
	48	0.002[1]	0.001	0.001	0.002[1]	0.002
	54	0.029		0.008	0.014	
	Average	0.015	0.011	0.003	0.010	0.002
2010 Bravo	Average	0.0013[1]	N/A[1]		0.0027	0.0013

[1] Values with an adjusted F_{dep} of less than 0 were set to 0.002.

3.2.4 Equipment Room Concentrations

During each test, four BATS were placed on the CREVS unit. BATS 93 at the inlet of the system prior to the first HEPA filter, BATS 94 downstream of the first HEPA filter, BATS 84 just after the charcoal filter and BATS 91 immediately after the second HEPA filter. The expected results from these BATS would be that the depletion prior to the charcoal would be greater than the depletion in the samples after the charcoal. This was observed for each unit except BATS 84 on both trains. Due to concerns over particulate from the sample immediately downstream of the charcoal bed, an additional filter was placed in the tubing leading to BATS 84. It is likely that small amounts of air from the Auxiliary room entered the air flow at the connection of this additional filter and skewed the results of these samples to higher concentrations at this location than the other three. The air sample from BATS 91 represents the air that has passed through filtration and is recirculated in the Control Room. Table 12 presents the best estimate for the steady-state concentration at each of these locations in the Alpha and Bravo test. The Alpha test shows higher concentrations throughout. This is partially due to the higher breakthrough as discussed previously. Similar to the Control Room data, the F_{dep} values are adjusted for breakthrough by subtracting the F_{dep} values at BATS 91. Table 13 provides the adjusted F_{dep} value. Even with the correction, the Alpha test shows higher F_{dep} values suggesting more in-leakage into the Auxiliary room or Control Room.

Table 12 BATS F_{dep} values on the Auxiliary Room CREVS system

BATS	Location	mtPDCH	pcPDCH	mcPDCH	ptPDCH
	Alpha Test				
93	Aux in before HEPA	0.056	0.097	0.072	0.071
94	Aux in after HEPA	0.037	0.062	0.065	0.082
84	AUX After Charcoal Filter	0.092	0.073	0.133	0.065
91	AUX CREVS out After HEPA	0.019	0.038	0.021	0.010
	Bravo Test				
93	Aux in before HEPA	0.019	0.075	0.023	0.025
94	Aux in after HEPA	0.017	0.015	0.020	0.017
84	AUX After Charcoal Filter	0.013	0.034	0.016	0.016
91	AUX CREVS out After HEPA	0.003	0.015	0.003	0.004

Table 13 BATS F_{dep} values for each tracer adjusted for breakthrough on the Auxiliary Room CREVS.

BATS	Location	mtPDCH	pcPDCH	mcPDCH	ptPDCH
	Alpha Test				
93	Aux in before HEPA	0.038	0.058	0.051	0.062
94	Aux in after HEPA	0.018	0.023	0.044	0.072
84	AUX After Charcoal Filter	0.074	0.034	0.113	0.055
91	AUX CREVS out After HEPA	0	0	0	0
	Bravo Test				
93	Aux in before HEPA	0.016	0.060	0.020	0.021
94	Aux in after HEPA	0.014	0.000	0.017	0.013
84	AUX After Charcoal Filter	0.010	0.019	0.013	0.012
91	AUX CREVS out After HEPA	0	0	0	0

To measure in-leakage into the Auxiliary Rooms that house the CREVS equipment, two BATS were placed in the active Equipment Room, one underneath the supply air duct for the room (BATS 39) and the other near the operating CREVS (BATS 28) and one BATS (BATS 42) was placed in the in-active Equipment Room. BATS 81, which had tubing directly into the recirculation air pipe, failed in both tests. In this test the portable charcoal filter was placed in the active Equipment Room (Room 1512 Alpha Train CREVS and Room 1501 Bravo train CREVS). To promote mixing the door connecting the two rooms was left open and a fan was used to push air into the Bravo room during the period when the charcoal filter was running. After stopping the charcoal filter, the door between the rooms was closed. The average F_{dep} adjusted for leakage past the charcoal filter over the last six hours of each test is presented in Table 13. The results show that there is poor mixing between the two rooms as the concentrations in the in-active Equipment Room are a factor of two higher than in the Active Equipment Room in the Alpha test. In the previous test in 2010, when there was no fan in the Inactive equipment room this disparity was much greater. Note, that two of the BATS in the Auxiliary room were analyzed prior to optimization of the GC and the Fdep values for PMCH and mcPDCH are reported. All other data includes the four PDCH isomers. In the Bravo test the concentrations were similar. In both cases the concentrations as measured by F_{dep} are lower at the location immediately below the supply air duct. This makes sense as this air is mixed with the filtered air coming out of the duct. The average of the two BATS in the Active Equipment room will be used in calculating in-leakage.

Table 14 Equipment Room Concentrations Adjusted Fractional Depletion Values.

Unit	Active CREVS	Location	PMCH	mtPDCH	pcPDCH	mcPDCH	ptPDCH
				Alpha			
28	Aux Near Crevs	Eq Room 1512 (Alpha)	0.16			0.12	
39	Below Supply Air Duct	Eq Room Alpha RA Near CREVS		0.056	0.030	0.079	0.062
42	AUX Inactive Equipment Room	In-active Eq Room 1501 (Bravo)	0.26			0.25	
				Bravo			
28	Aux Near Crevs	Eq Room 1501 (Bravo)		0.097	0.065	0.127	0.116
39	Below Supply Air Duct	Eq Room Bravo RA		0.027	0.015	0.037	0.026
42	AUX Inactive Equipment Room	In-active Eq Room 1512 (Alpha)		0.077	0.075	0.097	0.086

3.3 In-Leakage Calculations

The charcoal systems in the CR and CBEVSs are capable of nearly 100% removal of the PFT isomers of PDCH found in the air. In these tests, we found breakthrough of several percent for the tracers. For this reason, the F_{dep} values were adjusted to account for breakthrough past the charcoal filter. Thus, after the EVSs have been running for the appropriate time, if there is no UI, the concentration of the PFTs in the envelopes will approach zero after adjustment for breakthrough. If there is a finite amount of UI, then the concentration will come to equilibrium at some low level greater than zero.

There are four zones to consider for unfiltered in-leakage: the control building (CB), the control room (CR), the active equipment room (ERa) and the in-active equipment room (ERi). At Steady-State without any extra charcoal assist, the rate of UI is given by for the control room:

$$R_{UI\text{-}CR} = R_{fSA} \cdot (C_{cr} - C_{ch})/C_{bg}/(1 - C_{cr}/C_{bg}) \quad (1)$$

Where:

$R_{UI\text{-}CR}$ is the unfiltered in-leakage into the control building (cfm) or control room;

R_{fSA} is the measured supply of filtered air (cfm);

C_{cr} is the measured concentration in the control room;

C_{ch} is the measured concentration in the exhaust from the charcoal filter;

C_{bg} is the background concentration.

The term $(C_{cr} - C_{ch})/C_{bg}$ is the F_{dep} value found in Table 11. The term C_{cr}/C_{bg} is the F_{dep} values in Table 10. Naming F_{depadj} as the adjusted depletion values in Table 11 and F_{depcr} as the non-adjusted control room depletion values in Table 10 allows Eqn (1) to be defined as:

$$R_{UI\text{-}CR} = R_{fSA} \bullet F_{depadj}/(1 - F_{depcr}) \qquad (2)$$

It is important to recognize that the depleted concentration used to calculate F_{dep} is the measured concentration minus the concentration of the PFT that has passed through the charcoal filters (Section 3.2.5). This is often important for the CR because the concentrations are very low as compared to background.

At steady state (SS), the rate of UI into the Control Building is given by:

$$R_{UI\text{-}CB} = R_{fSA\text{-}CB} \bullet F_{dep}/(1 - F_{dep}) + \varepsilon R_{CR} \bullet (C_{CB} - C_{CR})/(C_{bg} - C_{CB}) \qquad (3)$$

where the first term on the right accounts for the tracer depletion by the Control Building filtered supply-air (SA) rate and the second term accounts for the fraction, ε, of the exfiltrating Control Room pressurization air, R_{cr}, that enters the Control Building. That fraction, ε, could range from 0 to 1; thus, the calculated rate of UI will be a range rather than a discrete value. Based on the data, the concentration in the control building is much greater than in the control room and the correction for leakage through the charcoal bed is not accounted for in the analysis. Thus, Eqn (3) reduces to:

$$R_{UI\text{-}CB} = (R_{fSA\text{-}CB} + \varepsilon R_{CR}) \bullet F_{dep}/(1 - F_{dep}) \qquad (4)$$

The exfiltration from the Control Room acts as an additional source of filtered air to the Control Building

A material balance around the active Equipment Room, which includes the CR Filtration System, was performed with the assumption that a portion (ε_1) of the total out-leakage (~350 cfm) from the CR enters the ER_a in addition to the 350-cfm supplied directly from the CR air handling System plus any UI directly into that zone. The assumption is that the higher pressure in the CR will allow some fraction of its total out-leakage to enter the Equipment Rooms – perhaps more into ER_i than into ER_a. The resulting SS solution for UI into the ER_a was given by:

$$R_{UI\text{-}ERa} = \frac{[R_{ERa} + \varepsilon_1 \bullet (R_{UI\text{-}CR} + 350)]\, F_{depERa} - [{}^{8}/_{9} \bullet R_{ERa} + \varepsilon_1 \bullet (R_{UI\text{-}CR} + 350)] \bullet F_{depCR}}{1 - F_{depERa}} \qquad (5)$$

where R_{ERa} is the 350-cfm rate from the Control Room Air handling system directly into ER_a (equivalent to the 300 cfm return from this zone back to the filtration system plus the 50 cfm of pressurization air in this zone), the 350 cfm is the CR pressurization rate, the F_{dep} are for the respective depleted concentration ratios, and ε_1 is defined above (ε_1 might range from 0.1 to certainly no more than 0.6 of the total CR out-leakage entering the ER_a). The ${}^{8}/_{9}$ of R_{ERa} was because the 18,000 cfm of the CR AC system only contains 16,000 cfm of CR recycle air.

A material balance around the inactive equipment room was done assuming that a fraction (ε_2) of the CR out-leakage and a fraction (ε_3) of that from ER_a enter the ER_i along with its UI. The SS solution is:

$$R_{UI\text{-}ERi} = \frac{[\varepsilon_3\{50 + R_{UI\text{-}ERa} + \varepsilon_1(R_{UI\text{-}CR} + 350)\} + \varepsilon_2(\ )]F_{depERi} - \varepsilon_3\{\ \}F_{depERa} - \varepsilon_2(\ )F_{depCR}}{1 - F_{depERi}} \quad (6)$$

where the terms have been previously defined and the terms in the { } and ( ) are as first defined in the equation (i.e. { } = 50 +$R_{ui\text{-}Era}$ + $\varepsilon_1(R_{UI\text{-}CR} + 350)$ and ( ) = $R_{UI\text{-}CR} + 350$).

The filtered supply air rates are given in the Table 15.

Table 15 Nominal and measured flow rates of EVS systems.

EVS	Flow Path	Nominal cfm
CB	Outside Filtered Air	750
"	Re-circulated	1,450
CR	Filtration	2,000
"	Re-circulated	1,300

Using Eqns., 2, 4, 5 and 6 the following UI rates and uncertainties were computed from the PFT concentrations in Section 3.2. For the calculations, the assumed transfer factors ε_1, ε_2, and ε_3 were set to 0.3, a mid-point value in the range.

3.3.1 Control Building Unfiltered In-Leakage

Using Eqn 3 and the concentrations in Tables 7 (Alpha test) and 8 (Bravo test) and setting the fraction of pressurization air leaking from the Control Room into the Control Building at 0.3 the following unfiltered in-leakage (UI) rates and uncertainties were computed for the Control Building. Raising the fraction from 0.3 to 0.6 would increase the estimate for unfiltered in-leakage by 10 to 15%.

The fractional depletion should be adjusted by the leakage past the charcoal filter (Table 10). This adjustment will make the fractional depletion lower and lead to a lower prediction of in-leakage. For conservatism, it is assumed that there is no leakage past the charcoal filters for the Control Building. Using the measured values after the HEPA filter would reduce the estimate of in-leakage by 5 – 10%. The fractional depletions were calculated for the last six hours (last three samples) from the BATS data for each tracer. In the Alpha train test the tracers PMCH and mcPDCH were used. The agreement between tracers is typically within about 10%. For the Alpha test the mcPDCH tracer was about 30% higher than the PMCH tracer. Table 16 presents the results for the Alpha test including the average F_{dep} and calculated in-leakage Rui (cfm) along with the standard deviation in the estimate. Recall that each room has four to seven BATS that are used in the average for F_{dep}. These values are used to obtain the standard deviation in F_{dep}.

The in-leakage into the Control Building for the Alpha train was higher than in 2004 when it was calculated to be less than 50 cfm for both trains. However, it was less than the value of 165 cfm determined in 2010 for the Alpha train. There is a clear distinction between the four floors with the two upper zones (the two Cable Spreading Rooms) showing much lower in-leakage than the two lower floors.

For the Bravo train test four isomers of PDCH were used in the analysis. The predicted in-leakage is presented in Table 17 for each isomer on each elevation. Similar to the Bravo test the two Cable Spreading Rooms showed about 25% less in-leakage than the rooms on Elevation 2016 and 2000. The in-leakage in the Bravo test was lower than in the Alpha test and slightly lower than the 2010 test for the Bravo train (measured in-leakage of 109 cfm). As in the 2010 test, the Control Building in-leakage was lower in the Bravo train as compared to the Alpha train.

Table 16 Estimated Unfiltered In-leakage Rui (cfm) in the Control Building for the Alpha test.

Elevation	Tracer 1 PMCH	Average F_{dep}	Calculated Rui (cfm)
EL 2000	Switchgear Rooms	0.13 ± 0.028	95.9 ± 17.8
EL 2016	CBEVS and Battery Rooms	0.13 ± 0.009	97.4 ± 5.6
EL 2032	Lower Cable Spreading Room	0.09 ± 0.008	70.0± 6.1
EL 2073	Upper Cable Spreading Room	0.1 ± 0.023	77.0± 15.5
	Average of all floors	0.11± 0.2	85.1± 13.7

Elevation	Tracer 2 mcPDCH	Average F_{dep}	Calculated Rui (cfm)
EL 2000	Switchgear Rooms	0.18± 0.04	126.2± 24.3
EL 2016	CBEVS and Battery Rooms	0.21± 0.02	141.8± 8.3
EL 2032	Lower Cable Spreading Room	0.14± 0.02	102.9± 10.4
EL 2073	Upper Cable Spreading Room	0.14± 0.03	102.9± 15.8
	Average of all floors	0.16± 0.04	103.0± 20.8
	Average of all tracers	0.14 ± 0.04	118.5± 16.8

Table 17 Estimated Unfiltered In-leakage Rui (cfm) in the Control Building for the Bravo test

Tracer 1 mtPDCH last 6 hours

Elevation		Measured Fdep	Calculated Rui (cfm)
EL 2000	Switchgear Rooms	0.127 ± 0.026	95.0 ± 16.8
EL 2016	CBEVS and Battery Rooms	0.134 ± 0.028	99.1 ± 17.2
EL 2032	Lower Cable Spreading Room	0.098 ± 0.009	75.3 ± 7.0
EL 2073	Upper Cable Spreading Room	0.096 ± 0.011	74.4 ± 8.4
Average		0.114 ± 0.020	86.0 ± 12.9

Tracer 2 pcPDCH

Elevation		Measured Fdep	Calculated Rui (cfm)
EL 2000	Switchgear Rooms	0.143 ± 0.013	104.6 ± 8.3
EL 2016	CBEVS and Battery Rooms	0.153 ± 0.010	110.7± 6.3
EL 2032	Lower Cable Spreading Room	0.105 ± 0.017	80.1± 11.2
EL 2073	Upper Cable Spreading Room	0.104 ± 0.010	79.7 ± 6.42
Average		0.126 ± 0.025	93.8 ± 16.2

Bravo Test
Tracer 3 mcPDCH

Elevation		Measured Fdep	Calculated Rui (cfm)
EL 2000	Switchgear Rooms	0.147 ± 0.033	107.1 ± 18.5
EL 2016	CBEVS and Battery Rooms	0.130 ± 0.016	96.5 ± 10.1
EL 2032	Lower Cable Spreading Room	0.101 ± 0.018	77.3 ± 12.3
EL 2073	Upper Cable Spreading Room	0.091 ± 0.011	70.8 ± 8.4
Average		0.117 ± 0.026	87.9 ± 16.8

Tracer 4 ptPDCH

Measured Fdep		Measured Fdep	Calculated Rui (cfm)
EL 2000	Switchgear Rooms	0.142 ± 0.012	103.9 ± 8.9
EL 2016	CBEVS and Battery Rooms	0.159 ± 0.031	114.6 ± 18.3
EL 2032	Lower Cable Spreading Room	0.102 ± 0.021	78.4 ± 14.1
EL 2073	Upper Cable Spreading Room	0.102 ± 0.023	78.4 ± 15.9
Average		0.126 ± 0.029	93.8 ± 18.4
	Average of all 4	0.121± 0.023	87.9 ± 4.0

3.3.2 Control Room Unfiltered In-Leakage

Using Eqn. 2 and the Control Room F_{dep} values Table 11, the Control Room Unfiltered In-leakage (UI) rates were calculated and are presented in Table 18. Due to the variability between tracers only the mean values were used in the calculations. The in-leakage was higher in 2016 than in 2010. Fractional depletion values were near 1% in the Bravo test for 3 tracers. In contrast, they were always less than 0.5% in 2010. In the Bravo tests, there were interferences around the pcPDCH to mtPDCH range in the chromatogram that may have led to higher predicted F_{dep} values. Other possibilities include the high rate of breakthrough of the tracers through the charcoal filter make data interpretation more uncertain due to subtraction of similar values (measured F_{dep} minus F_{dep} leaking past the charcoal) or difficulties maintaining a positive pressure differential. The test requires a positive pressure differential of 0.25 inches of water or greater between the Control Room and the outside of the Building. In starting the test there were some difficulties obtaining this pressure differential. In the Alpha test the pressure differential was over 0.3 inches of water, whereas in the Bravo test it was 0.25 inches of water. This difference may be the cause of the higher in-leakage in the Bravo test. There were no difficulties in obtaining a pressure differential greater than 0.25 in the 2010 tests.

Table 18 Estimated Unfiltered In-leakage (cfm) in the CR

Unit	UI (cfm) based on pcPDCH	UI (cfm) based on mtPDCH	UI (cfm) based on otPDCH	UI (cfm) based on mcPDCH	UI (cfm) based on ptPDCH	Average UI (cfm)
Alpha Avg	8.4	12.9	N/A	7.8	11.4	10.1 ± 2.1
Bravo Avg	31.2	22.6	6.3	20.2	4.0	16.9 ± 10.3

For the Bravo train, UI is higher than for the Alpha train. The wide variation between the predicted UI from different tracers is reflected in the error estimate that is approximately 60% of the mean value.

3.3.3 Equipment Room Unfiltered In-Leakage

Equation 5 was used to estimate the active Equipment Room UI. The average UI and fractional depletion for all four tracers and all samplers were also used (Table 14). The parameter ε_1 is a measure of the fraction of the control room out-leakage that enters the active equipment room (Section 3.3). R_{ERa} (cfm) is the flow of filtered air from the EVS directly into the room. The values are substantially higher than in 2010. In 2010 the estimates ranged from 4 to 6 cfm for the Alpha Train to 5 to 8 cfm for the Bravo Train. In 2016 the estimates for the Alpha Train range from 40 to 55 cfm and from 20 to 30 cfm for the Bravo train. The cause for this is the Fdep values ranging from 0.06 to 0.1 in 2016 were much higher than in 2010 (0.01 to 0.02). A higher value for F_{dep} implies greater in-leakage.

Table 19 Estimated unfiltered in-leakage in the active equipment room as a function of ε_1.

Train	ε_1	R_{ERa} (cfm)	R_{ui-CR} (cfm)	F_{dep} ERa	F_{dep} CR	R_{ui-ERa} (cfm)
Alpha	0.1	350	10.1	0.1	0.0049	40.1
(ER1512)	0.3					47.6
	0.5					55
Best Estimate						48 ± 7
Bravo	0.1	350	15.7	0.064	0.0078	23.2
(ER1501)	0.3					27.6
	0.5					31.9
Best Estimate						28 ± 4

Equation 3 (Section 3.3) was used to estimate the in-leakage into the inactive equipment room. This room is not pressurized with 300 cfm of filtered air, so the UI is expected to be much higher than for the active Equipment Room. That was not the case in 2016. The Inactive Equipment Room in-leakage was less than for the Active Equipment Room. This is partially because the Fdep value in the Inactive Equipment Room was similar to the value in the Active Equipment Room, indicating that these were well mixed. This suggests that the fans that operated for the first 4 hours of the test equilibrated the two rooms and there were only minor changes after the door was closed. In 2010, the door between the two rooms was closed for the entire test. For simplicity, the UI of the active equipment room was selected to be the value when $\varepsilon_1 = 0.3$. The parameter ε_2 represents the fraction of the out leakage from the active equipment room to the inactive equipment room and ε_3 represents the fraction of the out leakage from the control room to the inactive equipment room. During the Alpha train test, Equipment Room 1501 is the inactive room. During the Bravo test, Equipment Room 1512 is the inactive room.

Table 20 Estimated unfiltered in-leakage in the inactive equipment room.

Train	ε_2	ε_3	R_{ui-CR} (cfm)	$F_{dep-ERA}$	F_{dep-CR}	R_{ui-Era} (cfm)	$F_{dep-ERi}$	R_{ui-ERi} (cfm)	Inactive ER
Alpha	0.3	0.3	10.1	0.1	0.0049	47.6	0.255	49	1501
Bravo	0.3	0.3	16.9	0.064	0.0083	27.6	0.084	3.3	1512

The UI into the inactive equipment room is much greater than for the active equipment room and much higher than in the control room. This is due to the absence of pressurization with filtered air. Although not shown, reducing the fraction of out leakage received by the inactive equipment room (parameters ε_2, ε_3) reduces the predicted UI. In-leakage into Equipment Room1501 when it was the inactive room is much greater than into Equipment Room 1512 in the inactive state. This is due to the much higher concentrations found in Equipment Room 1512, which may be due to not attaining steady-state.

As originally assumed, the CRE is not a single zone – there are statistically different UI rates into the CR, ER1501, and ER1512.

3.3.4 Summary of unfiltered in-leakage results

The best estimate of UI for the four rooms is provided in Table 21. In general, there was excellent agreement (<10%) between the estimates provided by the four individual tracers in each region for the Bravo test and the CR in the Alpha tests. In the CB in the Alpha test, two tracers were used and the difference between the two tracers was about 25 to 30%.

Table 21 Summary of Unfiltered In-Leakage Results

	Alpha Train		Bravo Train	
Location	F_{dep}	R_{ui} (cfm)	F_{dep}	R_{ui} (cfm)
CB	0.14	102 ± 24	0.121	88 ± 4
CR	0.0049	10.1 ± 2.1	0.0083	17 ± 10
ER 1501	0.26	32 ± 4	0.06	28 ± 4
ER 1512	0.10	48 ± 7	0.08	3.3 ± 1

3.3.5 Use of Results

Both the net fractional depletion and the UI rates reported in Table 21 are useful in determining operator exposure. The net fractional depletion is equivalent to a net fractional concentration, which is the parameter needed for exposure assessment. Table 22 shows the relative exposure normalized to the control room in the Alpha Test.

Table 22 Relative Exposure Levels

	Alpha Train Test	Bravo Train Test
CR	1.0	1.7
CB	28.6	24.7
ER1501 (Bravo)	53.1	12.2
ER1512 (Alpha)	2.0	16.3

During Alpha Train use, someone in ER1501 will have 53 times the exposure rate of an operator in the CR and, in ER1512, 2 times. During Bravo Train use, the CR will have 1.7 times higher exposure rate than during Alpha train use.

3.4 Comparison to 2004 and 2010 Test Results

Table 23 lists the best estimate for unfiltered in-leakage (Rui) for the Control Building (CB), Control Room (CR), Active Equipment Room (Era), and Inactive Equipment Room (ERi) for both the Alpha and Bravo trains. The 2016 Bravo test showed the highest control room in-leakage of any of the tests. Although not shown here, the standard deviation in the estimated in-leakage for the Bravo Control Room in 2016 was high (11 cfm) as compared to a few cfm in all other tests. This reflects the differences in the five tracers used in the analysis. Two tracers showed low values for in-leakage (< 7 cfm) while 3 tracers showed high values for in-leakage (18 – 30 cfm). Another difference in the 2016 results is the higher in-leakage in the active equipment room and lower in-leakage in the Inactive equipment room. This is partially due to improved mixing between these two rooms due to the use of fans in both rooms for the first four hours of the test and having an open door between the rooms during this mixing period. The estimated unfiltered in-leakage into the Control Building was lower than in 2010, but higher than in 2004. In all cases, the in-leakage was acceptable and within allowable NRC guidelines.

Table 23 Best estimate values for unfiltered in-leakage for Wolf Creek Control Room Habitability Tests.

	Rui-CB		Rui-CR		Rui-ERa		Rui-ERi	
Year	Alpha (cfm)	Bravo (cfm)	Alpha (cfm)	Bravo (cfm)	Alpha (cfm)	Bravo (cfm)	Alpha (cfm)	Bravo
2016	102	88	10.1	16.9	48	28	49	3.3
2010	165	109	11.9	5.0	5.1	8.8	68	25
2004	63	14	6.9	10.5	23	2.1	32	5.6

4.0 Summary and Conclusions

Testing of unfiltered in-leakage into the Control Room, Control Building, and the Equipment Rooms that contain the CREVS was measured using up to five PFTs with automated samplers that allowed the PFT concentrations to be followed over time. The data did show that near steady-state conditions were reached in all areas after fifteen to eighteen hours into each test. On the Alpha test the difference between the two tracers used in the analysis (PMCH and mcPDCH) was about 25 to 30%. Technical difficulties in the gas analyses created substantial interference in the output of the chromatogram that prevented the other tracers from being used in the analysis. These interferences would have prohibited meaningful analysis of the lower concentrations found in the Control Room, Equipment Rooms and the CREVS systems. To solve these technical issues the reducing catalyst on the GC system was replaced and the system optimized for performance with the new catalyst. This change allowed for quantification of four PFTs to be used for the Control Room samples in the Alpha test and all samples in the Bravo test. The agreement of the four PFTs was generally within 10%. This agreement between different tracers increases confidence in the results.

Appendix A: Data

The equations that predict unfiltered in-leakage (Eqns 1 – 5 in the body of the report) are strictly valid only if steady-state conditions have been reached. The BATS units collected data over the entire 24-hour test period for each train and can be used to evaluate if steady-state has been reached. This appendix contains all the fractional depletion (F_{dep}) data used in the analysis. F_{dep} is defined as the measured concentration divided by the background concentration and is the value used in all in-leakage calculations. In addition to determining if steady-state has been reached, the agreement between different tracers can be examined. An EXCEL workbook (Wolf Creek Depletion Calculations 2-17.xls) containing the calculations presented in the report.

Alpha Test

Control Building Elevation 2000 (Switchgear Rooms)

BATS 3 EL 2000 SWGR 1-1

Sample ID	Fractional Depletion PMCH	Fractional Depletion mcPDCH	Stop Time (hours)
811	0.35	0.55	2
10129	0.19	0.33	4
10350	0.16	0.26	6
10071	0.14	0.23	8
10730	0.14	0.25	10
9147	0.15	0.25	12
5265	0.14	0.24	14
3275	0.12	0.19	16
3762	0.12	0.18	18
6114	0.09	0.14	20
11621	0.09	0.15	22
10221	0.10	0.17	24

BATS 32 EL 2000 SWGR 1-2

4184	0.23	0.38	2
1371	0.16	0.22	4
11817	0.12	0.19	6
970	0.09	0.13	8
2716	0.12	0.17	10
7505	0.10	0.16	12
3063	0.10	0.15	14
8273	0.10	0.14	16
8231	0.09	0.12	18

6878	0.10	0.12	20
4996	0.09	0.10	22
1723	0.12	0.10	24

BATS 20 EL 2000 SWGR

11819	0.40	0.76	2
11244	0.26	0.51	4
11201	0.18	0.39	6
11648	0.18	0.34	8
11326	0.18	0.36	10
10656	0.15	0.36	12
8450	0.17	0.32	14
11043	0.13	0.26	16
11094	0.12	0.25	18
10431	0.14	0.25	20
10758	0.14	0.24	22
10565	0.11	0.21	24

BATS 17 EL 2000 SWGR 2-2

9681	0.00	0.00	2
10470	0.85	0.57	4
8492	0.17	0.40	6
11359	0.18	0.39	8
2878	0.22	0.39	10
9444	0.17	0.34	12
6633	0.14	0.26	14
2098	0.15	0.24	16
10918	0.11	0.19	18
162	0.12	0.22	20
7448	0.11	0.20	22
3615	0.14	0.19	24

BATS 30 EL 2000 SWGR 2-1 RA Grill

0	0.00	0.00	2

0	0.00	0.00	4
0	0.00	0.00	6
4283	0.42	0.49	8
11878	0.25	0.41	10
12307	0.24	0.40	12
12044	0.17	0.29	14
10329	0.02	0.27	16
10992	0.17	0.15	18
8749	0.20	0.32	20
11407	0.17	0.15	22
3314	0.13	0.13	24

BATS 15 EL 2000 SWGR 2-1 RA Grill

1411	0.36	0.69	2
4646	0.43	0.50	4
9963	0.19	0.44	6
778	0.18	0.36	8
10584	0.28	0.44	10
10768	0.23	0.37	12
10729	0.19	0.21	14
10446	0.17	0.27	16
10495	0.14	0.26	18
10901	0.17	0.22	20
10785	0.17	0.22	22
10038	0.13	0.16	24

BATS 4 EL 2000 SWGR RA Grill

6790	0.43	0.69	2
2332	0.22	0.44	4
6515	0.20	0.30	6
9215	0.18	0.28	8
6159	0.17	0.29	10
11673	0.15	0.33	12
6111	0.17	0.25	14
4503	0.15	0.24	16
10121	0.15	0.17	18
3334	0.12	0.19	20
12396	0.12	0.16	22
11831	0.15	0.21	24

Control Building Elevation 2016

Sample ID	Fractional Depletion PMCH	mcPDCH	Stop Time (hours)
BATS 12 EL 2016 SWBD 3			
7737	0.32	0.38	4
8770	0.22	0.32	6
11423	0.25	0.29	8
1559	0.20	0.28	10
3195	0.16	0.24	12
11554	0.20	0.23	14
9643	0.11	0.19	16
7950	0.13	0.17	18
9500	0.14	0.21	20
7513	0.12	0.17	22
9453	0.10	0.19	24
BATS 35 EL 2016 SA Grill			
2303			2
6926	0.29	0.53	4
10670	0.18	0.39	6
10830	0.18	0.34	8
10739	0.00	0.00	10
11372	0.21	0.34	12
2523	0.17	0.29	14
2773	0.15	0.28	16
10004	0.16	0.00	18
10693	0.16	0.28	20
11203	0.12	0.22	22
7731	0.13	0.21	24
BATS 34 EL 2016 SWBD 1			
2303	0.40	0.76	2
8841	0.23	0.45	4
453	0.19	0.37	6
3329	0.17	0.26	8
4058	0.20	0.32	10
2589	0.18	0.29	12
7526	0.16	0.30	14
7369	0.13	0.25	16
2471	0.13	0.25	18
7424	0.14	0.22	20
4449	0.13	0.19	22
4359	0.13	0.20	24

BATS 27 EL 2016 SWBD 3

11985	0.33	0.77	2
10400	0.23	0.65	4
10124	0.22	0.41	6
10823	0.16	0.40	8
10503	0.22	0.33	10
10461	0.20	0.36	12
3024	0.02	0.01	14
10521	0.16	0.25	16
10502	0.13	0.24	18
10995	0.16	0.23	20
10491	0.11	0.21	22
16042	0.15	0.20	24

BATS 45 EL 2016 After Charcoal

1603	0.36	0.40	4
9605	0.23	0.25	8
7450	0.15	0.16	12
8926	0.13	0.15	16
10654	0.13	0.15	20
1421	0.12	0.14	24

BATS 44 EL 2016 Recirc

	mtPDCH	pcPDCH	mcPDCH	ptPDCH	Time (hours)
6259	0.40	0.37	0.55	0.31	3
848	0.31	0.23	0.38	0.23	6
7702	0.24	0.19	0.30	0.18	9
2697	0.20	0.15	0.25	0.15	12
9732	0.24	0.17	0.27	0.16	15
3906	0.24	0.18	0.28	0.16	18
7284	0.21	0.17	0.26	0.14	21
5467	0.18	0.14	0.23	0.12	24

Control Building Elevation 2032 (Lower Cable Spreading Room)

BATS 6 EL2032 (LCSR) Loc 17

Sample ID	Fractional Depletion PMCH	Fractional Depletion mcPDCH	Stop Time (hours)
5538	0.25	0.37	2
10592	0.18	0.49	4
9298	0.10	0.35	6
559	0.08	0.16	8
11550	0.01	0.00	10
8803	0.14	0.14	12
6893	0.10	0.19	14
10724	0.11	0.13	16
6155	0.09	0.15	18
10019	0.11	0.15	20
5296	0.08	0.10	22
6904	0.11	0.09	24

BATS 9 EL 2032 (LCSR) Loc 18

Sample ID	Fractional Depletion PMCH	Fractional Depletion mcPDCH	Stop Time (hours)
2735	0.21	0.39	2
1400	0.12	0.31	4
7439	0.08	0.15	6
1370	0.11	0.14	8
7389	0.09	0.13	10
5875	0.10	0.15	12
1824	0.10	0.14	14
430	0.12	0.16	16
143	0.09	0.14	18
6286	0.11	0.11	20
2834	0.06	0.13	22
4830	0.08	0.15	24

BATS 13 EL 2032 (LCSR) Loc 19

Sample ID	Fractional Depletion PMCH	Fractional Depletion mcPDCH	Stop Time (hours)
12177	0.21	0.36	2
11922	0.10	0.23	4

10856	0.13	0.15	6
12199	0.16	0.17	8
6618	0.10	0.15	10
12372	0.11	0.18	12
11568	0.09	0.13	14
12364	0.11	0.17	16
12406	0.11	0.16	18
10051	0.11	0.15	20
11874	0.08	0.13	22
10955	0.12	0.17	24

BATS 6 EL2032 (LCSR) Loc 17

Sample ID	Fractional Depletion PMCH	Fractional Depletion mcPDCH	Stop Time (hours)
2682	0.24	0.37	2
4322	0.15	0.23	4
3192	0.11	0.15	6
8176	0.08	0.08	8
8643	0.10	0.10	10
8847	0.12	0.18	12
3708	0.10	0.10	14
4966	0.09	0.08	16
2288	0.07	0.09	18
9770	0.10	0.16	20
1864	0.00	0.17	22
1856	0.17	0.13	24

Control Building Elevation 2073 (Upper Cable Spreading Room)

Sample ID	Fractional Depletion PMCH	mcPDCH	Stop Time (hours)
BATS 2 UCSR Location 32			
10885	0.29	0.43	2
11074	0.17	0.29	4
11180	0.11	0.19	6
251	0.09	0.06	8
2240	0.15	0.14	10
10224	0.10	0.07	12
10547	0.16	0.11	14
10075	0.06	0.12	16
11434	0.13	0.10	18
4907	0.05	0.09	20
11830	0.10	0.15	22
1434	0.06	0.12	24

Sample ID	Fractional Depletion PMCH	mcPDCH	Stop Time (hours)
BATS 11 EL 2073 (UCSR) Loc 33			
8088	0.26	0.47	2
9876	0.15	0.36	4
11289	0.11	0.21	6
2763	0.08	0.16	8
8180	0.00	0.00	10
2196	0.13	0.24	12
10836	0.15	0.21	14
12425	0.09	0.17	16
4152	0.10	0.16	18
11117	0.12	0.18	20
10620	0.09	0.15	22
1373	0.10	0.22	24

Sample ID	Fractional Depletion PMCH	mcPDCH	Stop Time (hours)
BATS 36 EL 2073 (UCSR) Loc 34			
6925	0.26	0.41	2

6529	0.25	0.25	4
3512	0.13	0.19	6
3059	0.12	0.16	8
2845	0.11	0.16	10
3029	0.12	0.21	12
3141	0.12	0.19	14
3489	0.13	0.19	16
2712	0.10	0.15	18
2905	0.11	0.16	20
2904	0.11	0.13	22
4346	0.17	0.12	24

Sample ID	Fractional Depletion PMCH	Fractional Depletion mcPDCH	Stop Time (hours)
	BATS 18 EL 2073 (UCSR) Loc 35		
10227	0.00	0.00	2
10633	0.26	0.58	4
10940	0.23	0.34	6
11140	0.23	0.17	8
11481	0.10	0.23	10
10239	0.13	0.20	12
10086	0.13	0.23	14
11073	0.18	0.18	16
4596	0.18	0.20	18
4000	0.10	0.16	20
11933	0.10	0.15	22
11751	0.12	0.17	24

Control Room

BATS 54 MCR RA 2

Sample ID	mtPDCH	pcPDCH	mcPDCH	ptPDCH	Stop Time Hours
12449	0.046	0.085	0.048	0.034	2
12092	0.034	0.066	0.039	0.018	4
11032	0.031	0.054	0.034	0.017	6
1118	0.029	0.061	0.030	0.017	8
6558	0.027	0.045	0.030	0.016	10
12210	0.030	0.046	0.032	0.017	12
10460	0.027	0.046	0.028	0.016	14
10977	0.026	0.048	0.028	0.016	16
11722	0.024	0.047	0.025	0.013	20
11164	0.024	0.045	0.026	0.015	24

BATS 47 MCR 2nd Hall

Sample ID	mtPDCH	pcPDCH	mcPDCH	ptPDCH	Stop Time Hours
9418	0.039	0.075	0.041	0.050	4
10468	0.027	0.044	0.029	0.029	8
11997	0.024	0.043	0.027	0.019	12
10117	0.021	0.041	0.023	0.021	16
11066	0.023	0.051	0.026	0.020	20
2375	0.023	0.048	0.025	0.026	24

BATS 48 MCR 1st Hall

Sample ID	mtPDCH	pcPDCH	mcPDCH	ptPDCH	Stop Time Hours
11862	0.058	0.061	0.070	0.032	4
533	0.045	0.029	0.010	0.030	8
3603	0.034	0.025	0.011	0.025	12
3169	0.035	0.026	0.038	0.028	16
2088	0.036	0.025	0.038	0.025	20
7380	0.014	0.012	0.018	0.011	24

Auxiliary Building

Inactive Equipment Room

BATS
42 Inactive Equipment Room

Sample ID	Fractional Depletion PMCH	mcPDCH	Stop Time (hours)
12297	0.36	0.35	2
11519	0.28	0.25	4
8603	0.26	0.21	6
10314	0.28	0.24	8
10296	0.28	0.25	10
10331	0.29	0.26	12
6997	0.29	0.27	14
1464	0.27	0.23	16
5526	0.24	0.25	20
7207	0.27	0.27	24

Active Equipment Room

BATS
28 Aux Near CREVS

Sample ID	Fractional Depletion PMCH	mcPDCH	Stop Time (hours)
10106	0.30	0.55	2
10472	0.23	0.37	4
9949	0.19	0.25	6
10638	0.16	0.14	8
10683	0.17	0.17	10
2397	0.15	0.13	12
11209	0.17	0.12	14
4901	0.15	0.16	16
10426	0.16	0.17	18
3181	0.15	0.15	20
7483	0.17	0.13	22
8280	0.16	0.13	24

BATS
39 Below Supply Air Duct

Sample ID	Fractional Depletion mtPDCH	pcPDCH	mcPDCH	ptPDCH	Stop Time Hours
11785	0.000	0.001	0.001	0.425	2
10207	0.295	0.256	0.405	0.288	4
12151	0.160	0.146	0.197	0.152	6
8470	0.113	0.094	0.144	0.103	8
6078	0.099	0.080	0.118	0.088	10
11402	0.098	0.079	0.123	0.093	12
4455	0.091	0.083	0.112	0.087	14
10617	0.092	0.089	0.115	0.086	16
11124	0.094	0.076	0.120	0.079	20
908	0.075	0.068	0.099	0.071	24

CREVS Data

BATS
93 CREVS Inlet before HEPA

Sample ID	Fractional Depletion mtPDCH	pcPDCH	mcPDCH	ptPDCH	Stop Time Hours
10034	0.057	0.159	0.071	0.068	4
4572	0.045	0.110	0.056	0.038	9
9734	0.046	0.103	0.056	0.063	14
10385	0.043	0.103	0.054	0.061	19
11474	0.041	0.097	0.048	0.029	24

BATS
94 CREVS Inlet after HEPA

Sample ID	Fractional Depletion mtPDCH	pcPDCH	mcPDCH	ptPDCH	Stop Time Hours
12333	0.053	0.138	0.065	0.055	4
4743	0.046	0.099	0.058	0.069	9
4934	0.045	0.098	0.057	0.065	14
10136	0.004	0.016	0.010	0.007	19
11876	0.041	0.087	0.049	0.043	24

BATS
84 After Charcoal Filter

Sample ID	Fractional Depletion PMCH	mcPDCH	Stop Time (hours)
200	0.14	0.35	4
8627	0.11	0.20	9
10612	0.10	0.16	14
11573	0.09	0.15	19
479	0.09	0.15	24

BATS
91 Crevs Outlet After HEPA

Sample ID	Fractional Depletion mtPDCH	pcPDCH	mcPDCH	ptPDCH	Stop Time Hours
7087	0.025	0.086	0.033	0.027	4
511	0.022	0.048	0.026	0.027	9
31	0.020	0.044	0.024	0.024	14
9299	0.020	0.041	0.024	0.009	19
8833	0.019	0.038	0.021	0.010	24

Bravo Test

Control Building 2000-foot Elevation (Switchgear Rooms)

Bats 20 EL 2000 SWGR 1-2 Loc 4.

Sample ID	Fractional Depletion mtPDCH	pcPDCH	mcPDCH	ptPDCH	Stop Time Hours
1478	0.169	0.254	0.191	0.358	2
8955	0.095	0.171	0.111	0.144	4
9991	0.080	0.153	0.092	0.139	6
10645	0.070	0.164	0.082	0.120	8
6001	0.026	0.079	0.043	0.069	10
10175	0.112	0.207	0.128	0.197	12
10182	0.098	0.159	0.111	0.197	14
10040	0.103	0.177	0.124	0.164	16
11446	0.099	0.136	0.112	0.171	18
12248	0.097	0.178	0.118	0.161	20
7730	0.100	0.174	0.108	0.153	22
1949	0.077	0.113	0.082	0.123	24

BATS 17 EL 2000 Active RA grill

Sample ID	Fractional Depletion mtPDCH	pcPDCH	mcPDCH	ptPDCH	Stop Time Hours
1332	0.317	0.479	0.232	0.165	2
638	0.215	0.325	0.165	0.093	4
8143	0.157	0.250	0.114	0.120	6
8814	0.153	0.243	0.112	0.107	8
4398	0.204	0.334	0.149	0.086	10
1536	0.308	0.593	0.213	0.128	12
4970	0.270	0.530	0.197	0.133	14
6365	0.308	0.622	0.221	0.146	16
608	0.350	0.749	0.232	0.148	18
8619	0.366	0.817	0.253	0.145	20
10872	0.385	0.878	0.262	0.158	22
12216	0.253	0.537	0.203	0.144	24

BATS 32 EL 2000 beneath Active RA

Sample ID	Fractional Depletion mtPDCH	pcPDCH	mcPDCH	ptPDCH	Stop Time Hours
9805	0.277	0.362	0.250	0.234	2

1419	0.189	0.285	0.165	0.143	4
7678	0.158	0.265	0.128	0.152	6
6321	0.175	0.288	0.154	0.137	8
2230	0.247	0.401	0.215	0.205	10
7523	0.276	0.521	0.236	0.204	12
799	0.301	0.631	0.252	0.212	14
3467	0.303	0.718	0.244	0.175	16
1681	0.287	0.741	0.188	0.157	18
3065	0.764	2.190	0.581	0.273	20
5721	0.352	0.932	0.274	0.175	22
6457	0.231	0.520	0.185	0.192	24

BATS 3 EL 2000 Inactive RA

Sample ID	Fractional Depletion mtPDCH	pcPDCH	mcPDCH	ptPDCH	Stop Time Hours
11155	0.270	0.270	0.304	0.281	2
7201	0.153	0.150	0.185	0.139	4
3316	0.119	0.117	0.144	0.110	6
12392	0.116	0.114	0.142	0.127	8
10632	0.152	0.156	0.195	0.141	10
3867	0.175	0.174	0.200	0.164	12
4254	0.173	0.162	0.232	0.153	14
8003	0.164	0.164	0.187	0.156	16
2839	0.163	0.158	0.198	0.148	18
11687	0.163	0.160	0.198	0.169	20
10202	0.151	0.154	0.178	0.135	22
11608	0.138	0.141	0.167	0.138	24

BATS 25 EL 2000 SWGR 2-2

Sample ID	Fractional Depletion mtPDCH	pcPDCH	mcPDCH	ptPDCH	Stop Time Hours
6647	0.231	0.228	0.314	0.201	2
5244	0.138	0.138	0.169	0.129	4
1608	0.112	0.105	0.156	0.108	6
2164	0.133	0.133	0.188	0.124	8
1636	0.081	0.082	0.112	0.104	10
1771	0.195	0.183	0.217	0.203	12
9179	0.154	0.152	0.176	0.140	14
4214	0.145	0.144	0.168	0.173	16
10805	0.118	0.026	0.326	0.128	18

6536		0.137	0.131	0.161	0.122	20
9854		0.124	0.128	0.154	0.108	22
12214		0.117	0.117	0.154	0.141	24

BATS 4 EL 2000 SWGR 1-1

Sample ID	Fractional Depletion mtPDCH	pcPDCH	mcPDCH	ptPDCH	Stop Time Hours
8073	0.282	0.284	0.277	0.277	2
9187	0.082	0.082	0.089	0.081	4
9039	0.122	0.119	0.125	0.144	6
9518	0.075	0.072	0.078	0.079	8
8264	0.150	0.148	0.156	0.151	10
651	0.177	0.175	0.175	0.179	12
691	0.174	0.167	0.171	0.189	14
8362	0.169	0.154	0.164	0.176	16
7150	0.166	0.162	0.163	0.184	18
916	0.154	0.151	0.166	0.169	20
5472	0.137	0.131	0.137	0.144	22
2940	0.133	0.135	0.138	0.134	24

Control Building 2016 Elevation

Bats 45 EL2016 After Charcoal Filter

Sample ID	Fractional Depletion mtPDCH	pcPDCH	mcPDCH	ptPDCH	Stop Time Hours
563	0	0	0	0	4
938	0.180	0.196	0.181	0.112	8
3758	0.152	0.165	0.148	0.166	12
2022	0.161	0.175	0.156	0.208	16
5783	0.176	0.193	0.184	0.229	20
7798	0.148	0.162	0.143	0.141	24

Bats 49 EL2016 after charcoal and HEPA filter

Sample ID	Fractional Depletion mtPDCH	pcPDCH	mcPDCH	ptPDCH	Stop Time Hours
11843	0.000	0.000	0.000	0	4
11598	0.053	0.104	0.054	0	8
11595	0.068	0.107	0.075	0.06539	12
10309	0.079	0.097	0.079	0.00171	16
8575	0.065	0.080	0.064	0.05554	20
10214	0.054	0.071	0.056	0.04214	24

Bats 12 2016 SA Grill

Sample ID	Fractional Depletion mtPDCH	pcPDCH	mcPDCH	ptPDCH	Stop Time Hours
1537	0.27	0.28	0.24	0.22	2
3805	0.17	0.20	0.14	0.14	4
2865	0.13	0.16	0.12	0.17	6
438	0.12	0.14	0.11	0.16	8
8931	0.00	0.00	0.00	0.00	10
1895	0.19	0.35	0.18	0.25	12
5218	0.17	0.17	0.16	0.22	14
5068	0.17	0.16	0.15	0.24	16
2937	0.19	0.20	0.17	0.27	18
12324	0.16	0.18	0.15	0.22	20
10027	0.15	0.17	0.13	0.19	22
11418	0.13	0.14	0.12	0.18	24

Bats 16 El 2016 SWBD 1

Sample	Fractional Depletion	Stop Time

ID	mtPDCH	pcPDCH	mcPDCH	ptPDCH	Hours
8813	0.26	0.32	0.23	0.24	2
11011	0.14	0.15	0.12	0.00	4
931	0.13	0.14	0.11	0.12	6
7062	0.09	0.27	0.12	0.10	8
3738	0.14	0.20	0.14	0.02	10
1274	0.16	0.19	0.15	0.22	12
1496	0.16	0.19	0.15	0.05	14
8295	0.10	0.16	0.12	0.15	16
2059	0.10	0.17	0.12	0.17	18
1960	0.10	0.16	0.11	0.18	20
4453	0.09	0.17	0.11	0.14	22
6436	0.09	0.13	0.10	0.15	24

BATs 27 EL 2016 SWBD 2

Sample ID	Fractional Depletion mtPDCH	pcPDCH	mcPDCH	ptPDCH	Stop Time Hours
6855	0.25	0.24	0.23	0.23	2
11097	0.16	0.15	0.15	0.16	4
10920	0.13	0.12	0.12	0.12	6
11057	0.11	0.11	0.10	0.13	8
12395	0.09	0.07	0.08	0.08	10
12454	0.18	0.17	0.17	0.21	12
10819	0.06	0.06	0.06	0.07	14
11924	0.16	0.16	0.15	0.16	16
10564	0.16	0.15	0.16	0.18	18
10931	0.16	0.16	0.15	0.18	20
6712	0.15	0.14	0.14	0.16	22
991	0.14	0.14	0.14	0.14	24

BATS 44 EL 2016 CBEVS Recirc

Sample ID	Fractional Depletion mtPDCH	pcPDCH	mcPDCH	ptPDCH	Stop Time Hours
2825					2
2579	0.29	0.29	0.28	0.28	4
9676	0.40	0.40	0.39	0.45	6
976	0.45	0.44	0.44	0.52	8
11021	0.00	0.00	0.00	0.00	10

BATS 35 EL 2016 SWBD 4

Sample ID	Fractional Depletion mtPDCH	pcPDCH	mcPDCH	ptPDCH	Stop Time Hours
11669	0.24	0.23	0.23	0.23	2
590	0.14	0.13	0.13	0.13	4
1481	0.11	0.11	0.10	0.10	6
4769	0.12	0.12	0.12	0.11	8
10119	0.42	0.16	0.91	0.17	10
10736	0.19	0.18	0.19	0.18	12
10996	0.17	0.16	0.15	0.15	14
10462	0.16	0.16	0.15	0.14	16
10741	0.15	0.16	0.15	0.16	18
10621	0.18	0.18	0.16	0.14	20
12495	0.14	0.13	0.13	0.12	22
2128	0.12	0.12	0.12	0.11	24

Control Building 2036-foot Elevation (Lower Cable Spreading Room)

Bats 5 LCSR Front

Sample ID	Fractional Depletion mtPDCH	pcPDCH	mcPDCH	ptPDCH	Stop Time Hours
4200	0.141	0.155	0.124	0.126	2
6638	0.101	0.117	0.083	0.083	4
28	0.079	0.099	0.065	0.070	6
4735	0.081	0.097	0.068	0.080	8
9840	0.107	0.131	0.101	0.100	10
1678	0.123	0.141	0.106	0.158	12
6089	0.133	0.144	0.122	0.166	14
7428	0.152	0.154	0.131	0.157	16
1285	0.135	0.135	0.122	0.145	18
166	0.115	0.116	0.107	0.144	20
493	0.293	0.316	0.265	0.357	22
12158	0.106	0.122	0.092	0.121	24

Bats 9 LCSR RA Grill

Sample ID	Fractional Depletion mtPDCH	pcPDCH	mcPDCH	ptPDCH	Stop Time Hours
2494	0.109	0.194	0.111	0.122	2
4795	0.061	0.138	0.066	0.005	4
632	0.065	0.103	0.058	0.062	6
2742	0.063	0.111	0.051	0.054	8
7770	0.099	0.149	0.093	0.000	10
7502	0.113	0.170	0.107	0.112	12
9403	0.101	0.156	0.097	0.089	14
12348	0.107	0.149	0.105	0.087	16
8916	0.111	0.191	0.104	0.090	18
2950	0.100	0.166	0.093	0.005	20
7751	0.112	0.119	0.109	0.120	22
11850	0.081	0.119	0.079	0.074	24

BATS 13 LCSR Middle

Sample ID	Fractional Depletion mtPDCH	pcPDCH	mcPDCH	ptPDCH	Stop Time Hours
167	0.125	0.122	0.119	0.126	2
10604	0.181	0.079	0.364	0.087	4
10287	0.042	0.016	0.064	0.069	6
12390	0.068	0.059	0.063	0.070	8
5625	0.097	0.083	0.089	0.090	10
10194	0.111	0.102	0.102	0.111	12
2212	0.113	0.111	0.107	0.127	14
2633	0.294	0.651	0.125	0.155	16
4438	0.107	0.106	0.101	0.105	18
2486	0.099	0.098	0.092	0.099	20
8033	0.067	0.061	0.057	0.060	22
12237	0.327	0.826	0.105	0.127	24

BATS 6 LCSR back

Sample ID	Fractional Depletion mtPDCH	pcPDCH	mcPDCH	ptPDCH	Stop Time Hours
10782	0.125	0.120	0.158	0.122	2
11401	0.122	0.138	0.158	0.090	4
10064	0.055	0.056	0.085	0.066	6
10213	0.055	0.057	0.098	0.068	8
10860	0.087	0.087	0.113	0.089	10
7426	0.091	0.093	0.137	0.095	12
10324	0.114	0.105	0.197	0.097	14
11131	0.187	0.322	0.169	0.126	16
8678	0.106	0.108	0.143	0.103	18
12111	0.108	0.105	0.155	0.101	20
8898	0.080	0.081	0.110	0.088	22
10868	0.085	0.088	0.112	0.084	24

Control Building Elevation 2073 (Upper Cable Spreading Room)

Bats 18 UCSR Near Door

Sample ID	Fractional Depletion mtPDCH	pcPDCH	mcPDCH	ptPDCH	Stop Time Hours
11509	0.000	0.000	0.000	0.000	2
10796	0.110	0.118	0.101	0.166	4
10295	0.054	0.065	0.056	0.095	6
10661	0.069	0.082	0.058	0.068	8
10915	0.101	0.101	0.086	0.113	10
11646	0.126	0.144	0.107	0.117	12
6508	0.126	0.128	0.108	0.096	14
3892	0.120	0.126	0.101	0.121	16
10434	0.122	0.159	0.108	0.113	18
755	0.116	0.111	0.123	0.104	20
10270	0.247	0.110	0.470	0.132	22
4206	0.097	0.101	0.085	0.113	24

Bats 36 UCSR RA Grill

Sample ID	Fractional Depletion mtPDCH	pcPDCH	mcPDCH	ptPDCH	Stop Time Hours
2155	0.137	0.179	0.122	0.000	4
2186	0.130	0.244	0.095	0.151	6
3183	0.074	0.100	0.058	0.062	8
6102	0.063	0.113	0.063	0.004	10
3794	0.095	0.115	0.082	0.096	12
2622	0.153	0.260	0.125	0.042	14
7443	0.109	0.144	0.099	0.083	16
6359	0.106	0.134	0.099	0.104	18
9835	0.100	0.135	0.095	0.010	20
2560	0.096	0.135	0.088	0.091	22
8850	0.092	0.107	0.085	0.075	24

BATS 13 LCSR Middle

Sample ID	Fractional Depletion mtPDCH	pcPDCH	mcPDCH	ptPDCH	Stop Time Hours
0	0	0	0	0	
0	0.000	0.000	0.000	0.000	
8145	0.130	0.129	0.113	0.125	2
7202	0.089	0.078	0.088	0.096	4

10230	0.065	0.026	0.113	0.119	6
8784	0.070	0.062	0.059	0.075	8
6343	0.090	0.077	0.084	0.086	10
3848	0.108	0.105	0.103	0.111	12
3951	0.106	0.099	0.097	0.097	14
919	0.108	0.095	0.101	0.091	16
1526	0.105	0.097	0.089	0.101	18
4056	0.091	0.083	0.084	0.093	20
7690	0.083	0.077	0.082	0.083	22
1273	0.10842	0.10989	0.08792	0.0746	24

Sample	Fractional Depletion				Stop Time
ID	mtPDCH	pcPDCH	mcPDCH	ptPDCH	Hours
11915	0.127	0.142	0.132	0.145	2
11260	0.109	0.631	0.256	0.153	4
10128	0.066	0.058	0.072	0.113	6
10543	0.368	1.062	0.272	0.179	8
10416	0.074	0.066	0.084	0.104	10
10886	0.100	0.095	0.112	0.165	12
10445	0.076	0.077	0.109	0.121	14
11358	0.099	0.098	0.112	0.125	16
10022	0.469	1.321	0.351	0.203	18
11357	0.117	0.181	0.114	0.111	20
6870	0.081	0.071	0.086	0.188	22
8428	0.07176	0.0691	0.08097	0.09376	24

Control Room

Bats 40 MCR RA Grill 1

Sample ID	Fractional mtPDCH	Depletion pcPDCH	otPDCH	mcPDCH	ptPDCH	Stop Time Hours
7752	0.030	0.046	0.006	0.027	0.001	2
6040	0.025	0.055	0.009	0.026	0.023	4
9226	0.020	0.041	0.003	0.021	0.019	6
1376	0.023	0.039	0.002	0.019	0.007	8
9075	0.021	0.041	0.005	0.019	0.001	10
9209	0.022	0.037	0.001	0.018	0.018	12
8268	0.019	0.034	0.003	0.019	0.008	14
10763	0.020	0.042	0.001	0.017	0.001	16
7045	0.019	0.033	0.002	0.016	0.018	20
9736	0.019	0.036	0.001	0.017	0.002	24

BATS
48 Control Room Hall 2

Sample ID	Fractional mtPDCH	Depletion pcPDCH	otPDCH	mcPDCH	ptPDCH	Stop Time Hours
9653	0.002	0.019	0.001	0.002	0.003	4
11280	0.003	0.014	0.001	0.007	0.005	8
8523	0.002	0.015	0.001	0.002	0.001	12
9878	0.002	0.015	0.000	0.002	0.003	16
10357	0.002	0.017	0.002	0.002	0.004	20
11029	0.002	0.016	0.000	0.002	0.006	24

BATS
47 Control room hall 1 (bad data)

Sample ID	Fractional mtPDCH	Depletion pcPDCH	otPDCH	mcPDCH	ptPDCH	Stop Time Hours
8913	0.029	0.120	0.006	0.014	0.006	4
4069	0.043	0.182	0.014	0.034	0.103	8
10733	0.064	0.273	0.016	0.044	0.009	12
11445	0.080	0.320	0.019	0.051	0.003	16
10487	0.079	0.335	0.021	0.060	0.042	20
2992	0.068	0.283	0.015	0.044	0.002	24

RA Grill 2

Bats 54

Sample ID	Fractional mtPDCH	Depletion pcPDCH	otPDCH	mcPDCH	ptPDCH	Stop Time Hours
11054	0.043	0.110	0.006	0.017	0.133	2
10412	0.034	0.065	0.007	0.015	0.087	4
10335	0.000	0.075	0.004	0.010	0.076	6
10960	0.000	0.068	0.004	0.010	0.059	8
11137	0.000	0.086	0.006	0.009	0.063	10
10597	0.000	0.091	0.004	0.011	0.094	12
10511	0.000	0.154	0.007	0.013	0.109	14
10200	0.031	0.136	0.008	0.014	0.137	16
10293	0.039	0.135	0.008	0.017	0.149	20
12016	0.033	0.143	0.009	0.017	0.148	24

Auxiliary Building

Inactive Equipment Room

BATS 42	Inactive Equipment Room					
Sample ID	Fractional mtPDCH	Depletion pcPDCH	otPDCH	mcPDCH	ptPDCH	Stop Time Hours
10256	0.135	0.131	0.142	0.154	0.130	2
4032	0.051	0.048	0.059	0.063	0.047	4
5013	0.076	0.073	0.085	0.091	0.075	6
10122	0.095	0.094	0.104	0.112	0.096	8
3974	0.106	0.105	0.107	0.123	0.104	10
10865	0.113	0.112	0.109	0.130	0.112	12
8589	0.115	0.111	0.119	0.131	0.112	14
11517	0.069	0.068	0.073	0.078	0.070	16
9699	0.083	0.081	0.092	0.098	0.081	20
8432	0.044	0.042	0.061	0.055	0.044	24

Active Equipment Room

BATS 39	Below RA Grill					
Sample ID	Fractional mtPDCH	Depletion pcPDCH	otPDCH	mcPDCH	ptPDCH	Stop Time Hours
6062	0.087	0.088	0.173	0.100	0.084	2
11299	0.044	0.044	0.079	0.054	0.043	4
11309	0.027	0.024	0.068	0.044	0.024	6
11725	0.023	0.023	0.049	0.034	0.024	8
10557	0.022	0.023	0.060	0.033	0.025	10
11486	0.024	0.022	0.051	0.034	0.021	12
11631	0.026	0.025	0.048	0.036	0.028	14
11262	0.027	0.026	0.061	0.039	0.024	16
11713	0.030	0.028	0.046	0.039	0.032	20
11494	0.029	0.028	0.045	0.040	0.032	24

BATS 28 — Below Active Room Near CREVS

Sample ID	Fractional mtPDCH	Depletion pcPDCH	otPDCH	mcPDCH	ptPDCH	Stop Time Hours
	0	0	0	0	0	2
11581	0.078	0.077	0.148	0.110	0.097	4
12193	0.443	0.427	0.474	0.488	0.443	6
1278	0.438	0.436	0.497	0.499	0.478	8
9982	0.428	0.416	0.453	0.474	0.419	10
2833	0.627	0.704	0.704	0.671	0.572	12
3499	0.510	0.498	0.503	0.556	0.508	14
1611	0.250	0.243	0.252	0.287	0.254	16
1115	0.153	0.154	0.154	0.189	0.147	18
9816	0.104	0.104	0.152	0.139	0.123	20
6603	0.097	0.096	0.147	0.139	0.135	22
2968	0.102	0.084	0.806	0.128	0.091	24

CREVS System

BATS 84 — Aux after Charcoal

Sample ID	Fractional mtPDCH	Depletion pcPDCH	otPDCH	mcPDCH	ptPDCH	Stop Time Hours
1404	0.017	0.051	0.001	0.020	0.018	4
3761	0.010	0.032	0.001	0.010	0.000	9
2254	0.011	0.030	0.001	0.013	0.013	14
1180	0.012	0.032	0.001	0.014	0.000	19
5497	0.015	0.036	0.001	0.018	0.016	24

BATS 91 — CREVS outlet after HEPA

Sample ID	Fractional mtPDCH	Depletion pcPDCH	otPDCH	mcPDCH	ptPDCH	Stop Time Hours
10126	0.003	0.023	0.000	0.004	0.000	4
7175	0.003	0.015	0.000	0.003	0.004	9
11361	0.003	0.015	0.000	0.003	0.004	14
9729	0.004	0.015	0.000	0.003	0.000	19
1120	0.000	0.085	0.004	0.010	0.004	24

BATS 93	CREVS inlet before HEPA					
Sample ID	Fractional mtPDCH	Depletion pcPDCH	otPDCH	mcPDCH	ptPDCH	Stop Time Hours
10788	0.024	0.023	0.000	0.025	0.024	4
3482	0.013	0.016	0.000	0.015	0.014	8
7098	0.019	0.018	0.000	0.019	0.028	12
1612	0.010	0.012	0.000	0.012	0.020	16
4117	0.019	0.018	0.000	0.020	0.025	20
378	0.027	0.037	0.000	0.026	0.026	24

BATS 94	CREVS inlet after HEPA					
Sample ID	Fractional mtPDCH	Depletion pcPDCH	otPDCH	mcPDCH	ptPDCH	Stop Time Hours
11630	0.027	0.025	0.020	0.025	0.023	4
11547	0.017	0.015	0.011	0.015	0.014	8
10447	0.020	0.020	0.014	0.019	0.017	12
11036	0.022	0.021	0.018	0.022	0.019	16
11527	0.022	0.019	0.016	0.021	0.018	20
11743	0.015	0.013	0.017	0.018	0.015	24