Lawrence Berkeley National Laboratory
EETD – Applications Team

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Side-by-side Fume Hood Testing: ASHRAE 110 Containment Report

Comparison of a Conventional and a Berkeley Fume Hood

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Table of Contents

Side-by-Side ASHRAE 110-1995 Fume Hood Testing
Conducted at Lawrence Berkeley National Laboratory, Bldg. 63-103

1 Executive Summary

Lawrence Berkeley National Laboratory (LBNL) has developed and patented a high-performance fume hood, The Berkeley hood. The Berkeley hood's main design feature uses a gentle flow of air, introduced at the sash perimeter, to direct fumes inside the hood away from the face of the hood, and therefore away from the user. This push-pull approach not only provides for improved containment and greater operator safety, but also allows for much lower exhaust volume – 50% lower in the tests reported herein – dramatically reducing the amount of conditioned air that must be continually supplied and exhausted to a laboratory.

The side-by-side fume hood testing compares two otherwise identical hoods – one conventional and one Berkeley hood – by measuring the escape of a tracer gas from each per the American Society of Heating Refrigeration and Air-conditioning Engineers (ASHRAE) 110-1995 Method (more below). Test results indicate that the Berkeley hood provides substantially better containment of potentially harmful fumes, and therefore greater operator safety, than a conventional fume hood. It outperformed the conventional hood in all tests.

2 Overview

2.1 Testing Fume Hood Containment Performance

The purpose of an enclosing or containment laboratory hood is to contain toxic materials generated within the hood in order to keep exposure to laboratory hood users below the relevant health hazard exposure guidelines (e.g. OSHA PEL's or ACGIH TLV's). It has long been recognized that many factors affect the hood's ability to contain including face velocity, hood design, room airflow patterns and user activities. Prior to the 1980's, face velocity and visual smoke observations were used as the major indicators of hood performance. Recent studies have indicated that face velocity alone may not be predictive of adequate hood performance.[1]

2.1.1 ASHRAE 110-1995 Method

The American National Standards Institute and ASHRAE Standard, ANSI/ASHRAE 110-1995, *Method of Testing Performance of Laboratory Fume Hoods*, is the foremost protocol used when testing laboratory-type fume hood performance. The ASHRAE-110 "Method" is an elaborate, three-part test that involves face velocity testing, flow visualization, and a tracer gas test. However, the ASHRAE 110 standard specifies the test, not the performance standard.

[1] From correspondence by ANSI/AIHA Z9.5 Standards committee, June 2003.

2.1.2 ANSI/AIHA Performance Standard

Using the ASHRAE 110 tracer gas containment test, the American National Standards Institute (ANSI) and American Industrial Hygiene Association (AIHA) have established containment performance standards in ANSI/AIHA Z9.5-2003 for as manufactured (AM) as installed (AI), and as used (AU) fume hoods established by ASHRAE. In this case, "performance" refers to the level of confinement of possible hazards and protection of the employees for the work which is performed inside a laboratory-type hood.

An interpretation was solicited from the ANSI/AIHE Z9.5 committee to provide an interpretation of a section in the ANSI/AIHA *Standard for Laboratory Ventilation*, ANSI/AIHA Z9.5-2003, regarding an equivalent performance indicator for "traditional" face velocity. This interpretation would be used to evaluate laboratory-type hoods having design features that do not use traditional face velocity as their method of confinement.

2.1.3 ANSI/AIHA Performance Thresholds

The response from ANSI/AIHA to the solicitation, noted above, to an equivalent performance indicator for "traditional" face velocity with performance thresholds was provided:

> "Therefore ANSI Z9.5 requires that some form of containment test using a challenge agent such as a tracer gas that can quantitatively measure hood "leakage" be used to determine if a hood's containment is acceptable. The hood "user" or "owner" needs to define what containment is acceptable. At the current time ANSI Z9.5 recommends that ASHRAE 110-1995 be used as this containment test. For a 4 lpm challenge the recommended maximum acceptable "leakage" is 0.05 ppm at the breathing zone for hoods tested under controlled conditions and/or 0.1 ppm for hoods as installed in the laboratory."[2]

2.2 Side-by-side hood evaluations

2.2.1 Comparative Approach

In an effort to demonstrate equivalent or superior performance of a Berkeley fume hood compared to a conventional fume hood (see next section), the California Energy Commission (CEC) sponsored a series of so-called "side-by-side" comparative performance evaluations. An example of each hood type was installed and tested in the same room. The basic hoods were produced by the same manufacturer (Jamestown Metal Products) and are of the same nominal size. Testing method employed was the ASHRAE 110-1995 protocol. Containment performance threshold levels were obtained from the ANSI Z9.5-2003 Laboratory Ventilation Standard. This report provides the results for the side-by-side tests. A companion report provides results for an innovative human-as-mannequin (HAM) side-by-side test series.

2.2.2 An Innovative Laboratory-type hood

Researchers at Lawrence Berkeley National Laboratory (LBNL) are developing an innovative containment technology that reduces required airflow through laboratory fume hoods. This technology provides containment at 50 to 70 percent lower airflow than a

[2] From correspondence by ANSI/AIHA Z9.5 Standards committee, June 2003.

typical fume hood, based on total exhaust volume. It does not rely on face velocity, in the traditional sense, to maintain fume containment within a hood.

The LBNL containment technology uses a "push-pull" displacement airflow approach to contain fumes and move air through a hood. Displacement air “push” is introduced with supply vents near the hood’s sash opening. Displacement air “pull” is provided by simultaneously exhausting air from the hood. Thus, an “air divider” is created, between an operator and a hood’s contents, that separates and distributes airflow at the sash opening. This air divider technology is simple and increases operator protection.

2.3 Summary of Results

2.3.1 Successful Containment Performance

Table 1 presents the complete results from the ASHRAE 110-1995 Method, including tracer gas containment performance per ANSI/AIHA thresholds. Note that both the conventional and Berkeley hood “pass”, per ANSI Z9.5-2003.

Table 1: ASHRAE 110 Test results for Side-by-side Conventional and Berkeley hoods

Run	*Test Procedure*	*Detection Medium*	*Test Conditions*	*Conventional Hood Containment AI (as installed)*	*Conventional Hood Containment AM (as mf'g)*	*Berkeley Hood Containment AI (as installed)*	*Berkeley Hood Containment AM (as mf'g)*
1	Local Flow Visualization	Small volume Smoke tube	Visual observation	Good	Good	Good	Good
2	Large-volume Flow Visualization	Large volume Smoke	Visual observation; no mannequin	Good	Good	Good	Good
3	Face Velocity	N/A	Velocity meter	Pass	Pass	N/A	N/A
4	Static Mannequin	Tracer gas	Ejector Center position; Sash full open	Pass [a]	Pass [a]	Pass [a]	Pass [a]
5	Static Mannequin	Tracer gas	Ejector Left position; Sash full open	Pass [a]	Pass [a]	Pass [a]	Pass [a]
6	Static Mannequin	Tracer gas	Ejector Right position Sash full open	Pass [a]	Pass [a]	Pass [a]	Pass [a]
7	Sash Movement Effect (SME)	Tracer gas	Ejector Center position Sash operated	Pass [b]	Pass [b]	Pass [b]	Pass [b]
8	Sash Movement Effect (SME)	Tracer gas	Ejector Left position Sash operated	Pass [b]	Pass [b]	Pass [b]	Pass [b]
9	Sash Movement Effect (SME)	Tracer gas	Ejector Right position Sash operated	Pass [b]	Pass [b]	Pass [b]	Pass [b]
10	Periphery Traverse	Tracer gas	Ejector Center position; Sash full open; no mannequin	Pass [b]	Pass [b]	Pass [b]	Pass [b]

a. Tracer gas Pass/Fail criterion per ANSI Z9.5 2003.

b. No specified Tracer gas Pass/Fail criterion per ANSI Z9.5 2003; however, compared to static mannequin guidelines and an averaged value during the test, a pass rating was achieved.

2.3.2 Superior Containment Performance

Examining quantitative data, in Table 2, shows that the Berkeley hood provides superior containment performance, per ANSI Z9.5-2003, to the conventional hood.

Table 2: ASHRAE 110 Test results for Side-by-side Conventional and Berkeley hoods

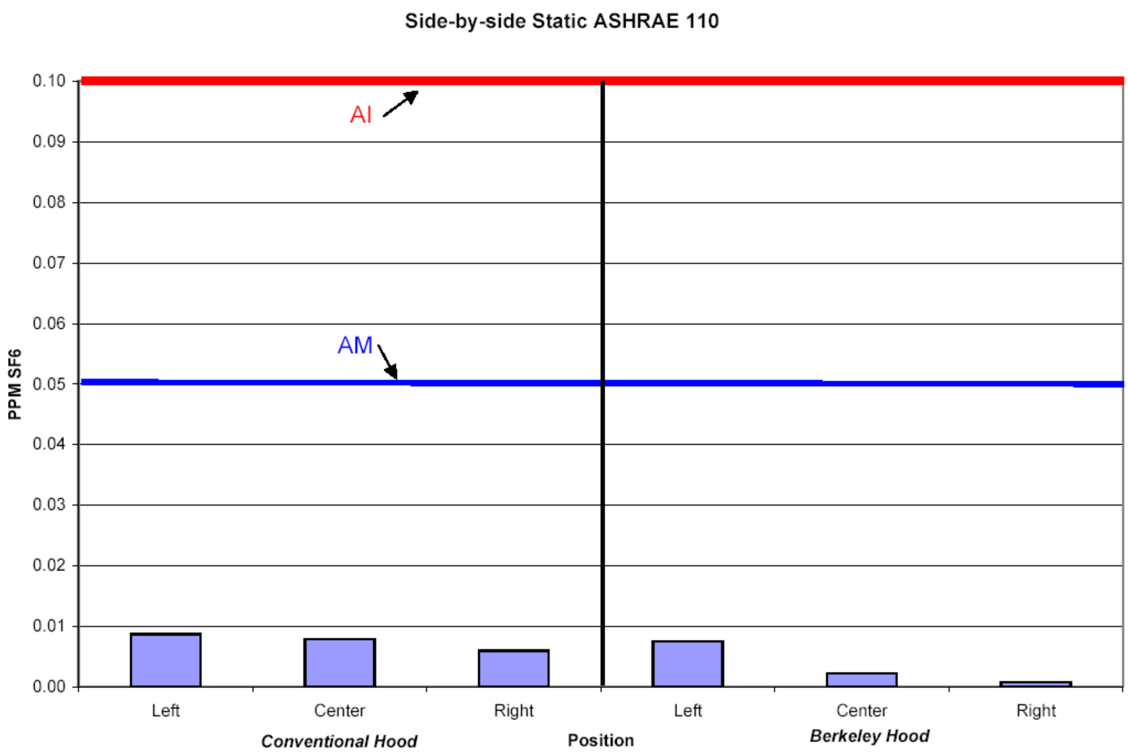
Tracer Gas Test Position/Type	Conventional (Aver PPM for 5 Min.)	Berkeley (Aver PPM for 5 Min.)
Center	0.008	0.002
Left	0.009	0.007[a]
Right	0.006	0.001
SME Center	0.025	0.001
SME Left	0.021	0.002
SME Right	0.012	0.001[b]
Periphery Traverse	0.022	0.001

a.) Includes unscheduled AI door opening and closing during test run.
b.) Corrected for increasing level of background SF6 tracer gas (0.006 without correction).

2.3.3 Containment Performance Comparison

Chart 1 presents comparative results for the ASHRAE 110 tracer gas containment tests averaged over a 5-minute interval. Note that both the conventional hood and the Berkeley hood performed very well by providing containment far below the ANSI Z9.5 2003 threshold for an as-installed (AI) hood of < 0.10 PPM. Importantly, the ANSI containment threshold for the more stringent as-manufactured limit of <0.05 PPM was also achieved by both hoods.

Chart 1: Comparative containment for Side-by-side Conventional and Berkeley hoods



3 Test Procedure

3.1 Test Description

All tests followed ASHRAE's 110-1995 test methods for flow visualization and tracer gas tests, Section 6.1 and Section 7, respectively. Face velocity tests were performed on each hood; however, the Berkeley hood face velocity tests were performed without the hood's supply fans in operation. Refer to ANSI/ASHRAE 110-1995 for specific information regarding its Purpose (Section 1), Scope (Section 2), Definitions (Section 3), Instrumentation and Equipment (Section 4), and Test Conditions (Section 5). The tests, referenced below, used the ASHRAE 110 method's Section 6.1, Flow Visualization and Section 7 (7.1 through 7.10), Tracer Gas Testing Procedure to evaluate containment performance. A general overview of these tests is provided:

1) Flow visualization tests can be performed with various smoke-generating substances. Theatrical smoke, superheated glycol, smoke "sticks", titanium tetrachloride, and dry ice, solid-phase CO_2, are examples of smoke sources. A qualitative understanding of containment is gained from conducting smoke tests. A rating system has been devised for "poor- to-good" patterns of smoke containment by Tom Smith[3]. However,

[3] Tom Smith, President of Exposure Control Technologies, Inc. 231-C East Johnson St. Cary, NC 27513 ph: 919.319.4290

these tests are only used as indicators of containment. When satisfactory results are observed, they should be followed by tracer gas testing. Both small and large volume smoke tests were performed on each hood with full containment of all smoke clearly moving towards the rear of the hood without any "reverse return" flow noted.

2) Face velocity measurements are performed by using a "hot wire" velocity meter with its probe held fast in a stand. This removes any variability that a person may introduce into the data. An imaginary grid of one-foot squares provide the location for the meter's probe, which is centrally located in each square foot area. For the side-by-side tests, each hood's grid had three rows and five columns, yielding fifteen readings that were averaged. Each hood's averaged reading compared well to the exhaust volume, as determined by a calibrated pitot tube in its exhaust stack.

3) Tracer gas testing is the most reliable test for determining a fume hood's containment performance. A highly generalized overview of the test is provided. The gas typically used is sulfur hexafluoride, or SF_6. This gas flows into a fume hood being tested through a specially constructed "ejector." The ASHRAE 110 guideline includes engineering drawings to fabricate this ejector. SF_6 flow rate is set at four liters per minute (LPM). A mannequin is placed in front of the hood being tested to simulate an operator. An inlet port to a detector device is placed at the "breathing zone" (the nose) of the mannequin. This breathing zone is set a height of 26 inches above the hood's work surface. Tracer gas is allowed to flow for five minutes and spillage levels are recorded by the detector. The mannequin and the tracer gas ejector are located in three positions: center, left, and right to determine containment. Ratings can be provided for a hood at three levels of hood installation:

- "As manufactured" (AM) — initial test of performance of a hood in a highly controlled/idealized setting at the manufacturer's facility.
- "As installed" (AI) — hood testing is completed in the actual, fully operating facility, potentially more difficult conditions than the manufacturers' facility.
- "As used" (AU) — hood testing is performed by adding a hood operator's experimental equipment, a.k.a., "clutter", to the "as installed" hood, making the test conditions even more difficult.

3.2 Instrumentation

3.2.1 Total Exhaust Flow Measurement

Total exhaust flow was verified by measuring pressure readings from a pitot tube located in a straight run of each hood's exhaust stack. The volumetric flow was verified with a calibrated flow meter with an accuracy of better than ±3 percent for each hood's pitot tube and a calibration curve was generated using a least squares second-order method. Each hood's calibration curve was plotted and attached to the hood for easy reference during hood setup.

3.2.2 Face Velocity Meter

Face velocities were tested with a TSI velocity meter, model 8360. Readings were averaged with fifteen points. Volumetric flow, from pitot tube readings, correlated well with face velocity readings measured in each hood. However, face velocity readings indicated some level of turbulence not quantified in this study. This is a typical situation for most conventional hoods and is being addressed by many hood manufacturers with advanced design methods and construction enhancements. In the case of the Berkeley hood, the air divider technique addresses this situation by gently pushing air into the hood with low turbulence intensity.

3.2.3 Tracer Gas Ejector

A standard ASHRAE 110 ejector, manufactured by Air Flow Tech Products, Inc., was used during the test runs. A BIOS Dry-Cal DC-1 Flow calibrator was used to verify SF_6 volumetric flow at 4 LPM. A pressure gauge attached to the ejector was monitored during the flow calibration sequence at 23.5 psig and maintained throughout the test runs.

3.2.4 Tracer Gas Detector

Test instrument used to detect SF_6 was a ITI-Qualitek Leakmeter 120. Inlet tube was located at nose of mannequin. Calibration was verified frequently with known concentrations of SF_6 in "cal bags." Analog output readings (voltage) from the ITI-Qualitek Leakmeter were recorded with an A-to-D converter (a voltage-ohm-meter, VOM) and stored on a personal computer. Later these data were graphed with Microsoft Excel™ for presentation.

3.3 Acceptability Level

The LBNL test/fabrication laboratory is not a highly controlled/idealized setting as would be found in a manufacturer's facility. Therefore, due to the environment where the hoods were installed, test criterion for the "as installed" (AI) designation was used from ANSI/AIHA Standard Z9.5 (2003). The acceptability level required for AI designation is 0.10 PPM, or less, averaged over five minutes. However, the acceptability level required for AM designation, which is 0.05 PPM, or less, for five minute average, was not exceed by either hood during testing. It is noteworthy that both hoods met the more stringent AM threshold even though the test site was less than an ideal environment.

3.4 Deviations from ASHRAE 110 Test Procedure

None.

4 Side-by-side Setup

4.1 Conventional hood configuration

The conventional hood is produced by Jamestown Metal Products. It is a nominal six-foot wide hood. The hood was installed with a dedicated exhaust fan and operates in a conventional manner.

The depth of the nominal six-foot-wide hood is 32.5 inches from the sash to the rear baffle. The fully open sash dimensions are 61.75 inches wide by 26.5 inches high, for a total open area of 11.36 square feet. Testing was conducted with total exhaust flow of 1136 CFM. This corresponds to a 100 FPM face velocity.

4.2 Berkeley hood configuration

The nominal six-foot-wide version of the Berkeley hood is 30.5 inches from the sash to the rear baffle. The fully open sash dimensions are 61.75 inches wide by 30 inches high, for a total open area of 12.87 square feet. Testing was conducted with total exhaust flow of 643 CFM. This corresponds to 50 percent flow in a standard hood operating at a 100 FPM face velocity, respectively.

4.2.1 Push/Pull System

This six-foot version of the Berkeley hood uses four fans to push room air into the hood's cabinet. The "top" plenum fan pushes air from behind the top of the sash towards the rear baffle. The "front" plenum fan blows air from the top of the face area down (and across the front of the sash when it is closed). The "lower" plenum fans (two) push air from behind the lower airfoil towards the rear of the cabinet. All three plena have individual rheostats to manually adjust fan speed. These fans produce a vectored airflow (push) that provides containment at lower than normal exhaust airflow (pull). The push air is introduced at or inside the sash (face) that creates an “air divider.” Consequently, face velocity measurements are irrelevant.

4.2.2 Supply Airflow Rate

Each supply grill/screen was measured with a hot wire anemometer with the results provided in Table 3. The velocity of the Front and Top plena was recorded in a vertical orientation at intervals of every two inches. The velocity of the Bottom plenum was recorded in a horizontal orientation every inch. Conversion from velocity to volumetric flows from the supply outlets is approximate.

Table 3: Configuration of CEC Six-foot Berkeley hood at LBNL.

Supply	Approx. Outlet Area Sq. ft.	Average Velocity FPM	Estimated Volume CFM
Front	1.6	57.8	92.5
Top	2.64	35.6	94.0
Bottom	0.65	71.0	45.9
Total	5.89		232

4.3 Mannequin Setup

In the following, Figures 1 & 2 show the typical mannequin positioned in front of the conventional hood prior to installing the tracer gas ejector and the ITI detector. Figures 3, 4, and 5 (center, left, and right positions) show the mannequin positioned in front of the Berkeley hood with both the tracer gas ejector and ITI detector installed.

Fig. 1 – Right view of mannequin position for standard Center ASHRAE 110 SF6 test; 26 inches above work surface, conventional hood.

Fig. 2 – Left view of mannequin position for standard Center ASHRAE 110 SF6 test; 26 inches above work surface, conventional hood.

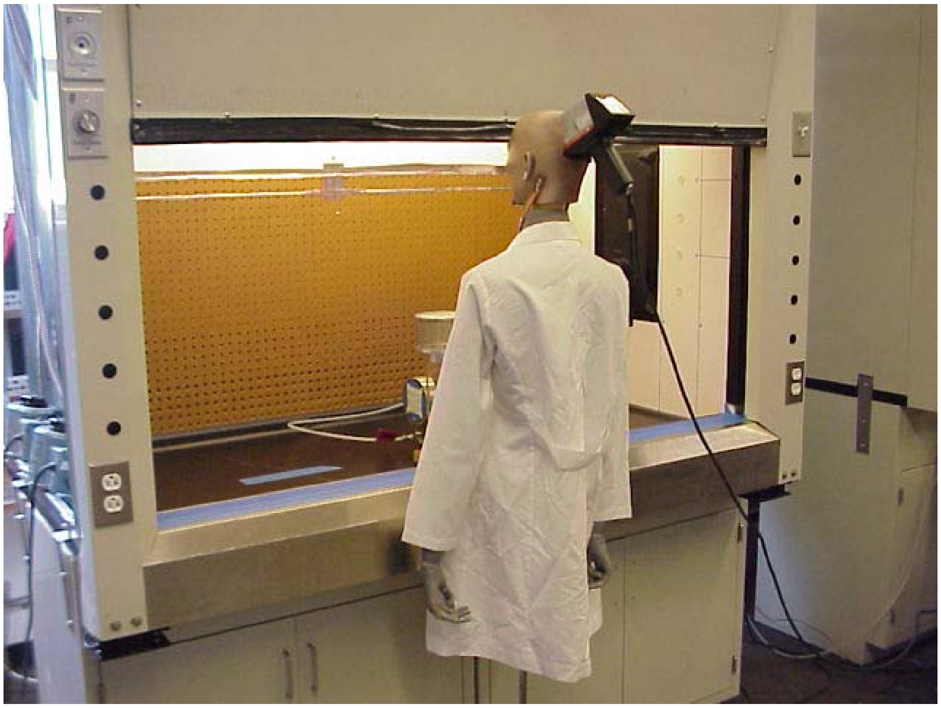


Fig. 3 - Mannequin in position for standard Center ASHRAE 110 SF6 test; 26 inches above work surface with ejector and detector, Berkeley hood.

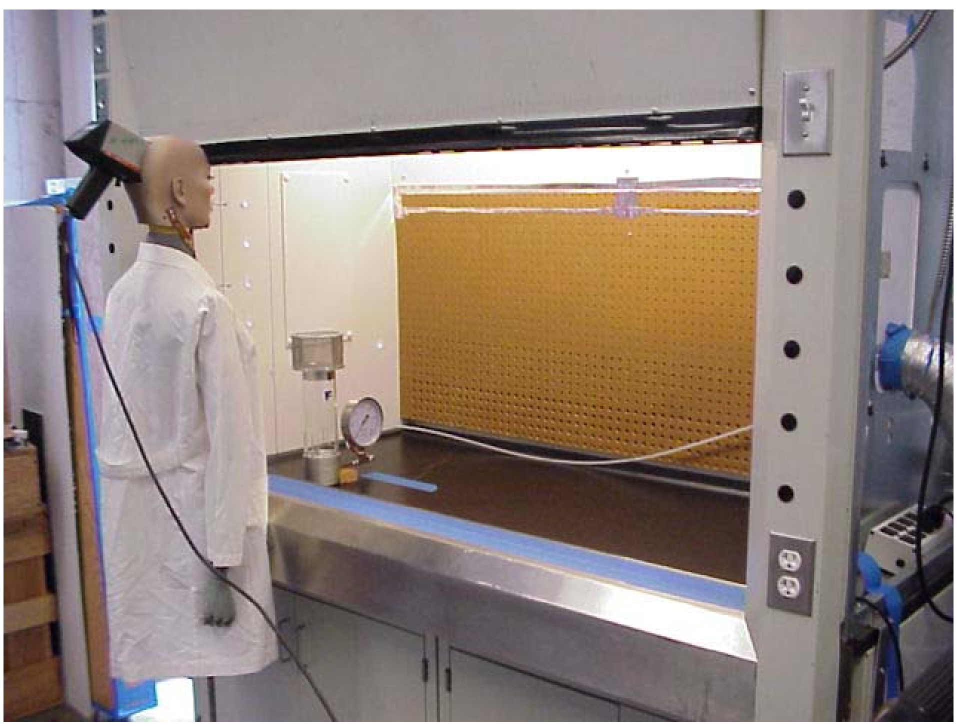


Fig. 4 - Mannequin in position for standard Left ASHRAE 110 SF6 test; 26 inches above work surface with ejector and detector, Berkeley hood.

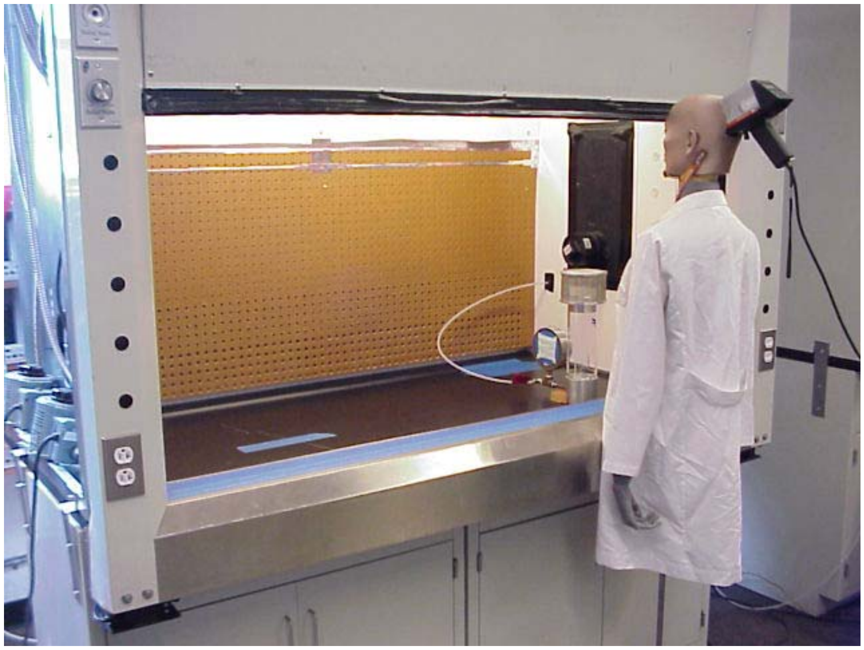


Fig. 5 - Mannequin in position for standard Right ASHRAE 110 SF6 test; 26 inches above work surface with ejector and detector, Berkeley hood.

5 Test Run Narrative

5.1 Flow Visualization test runs

Test Runs #1 and #2 (refer to Table 1, above) are the results for the ASHRAE's 110 protocol, Section 6.1 – Flow Visualization. Specifically, Sections 6.1.1 Local (small) Challenge and 6.1.2 Large-Volume Challenge were performed with passing ratings, per ANSI Z9.5-2003, with no visible escape beyond the plane of either hood's sash.

5.2 Face Velocity measurements

The ASHRAE 110-1995 protocol includes a measurement of the tested fume hood's face velocity. Face velocity is measured in the plane of the sash while fully open or with the sash in its "design position." To simulate a worst-case situation, all measurements were gathered with each hood's sash fully open. This is NOT the recommended position for the sash to be during operator use. The sash should always be lowered to yield the smallest opening that allows the operator to manipulate objects/experiments within the hood's cavity safely. This is true for all fume hoods.

Test Run #3 presents results of ASHRAE's 110 protocol, Section 6.2 – Face Velocity Measurements (refer to Table 1, above). As noted above per the ASHRAE 110-1995 protocol, an imaginary grid of areas of one square foot provided the pattern for measuring the conventional hood's face velocity. The dedicated fan providing airflow into the conventional hood was adjusted until an average face velocity of 100 FPM was attained with no measured point below 70 FPM. This was confirmed by checking the total exhaust volume with a pitot tube device, as noted above.

With the Berkeley hood design, primary contaminant control is provided by the directed laminar to near-laminar air streams, not by the air flowing around the operator. This Hood design does not use the expected high face velocities of conventional fume hoods to achieve containment. Therefore, testing that measures face velocity, rather than containment, does not accurately describe the increased performance and containment achieved by the Berkeley Hood design. With a push/pull hood, much of the supply air is introduced at or inside of the face, so the resulting face velocity is reduced. To verify the Berkeley hood's lower total exhaust airflow, both face velocity and total flow volume were measured and compared with supply fans turned off. An average value of 50 FPM is provided by its dedicated exhaust fan.

5.3 Static Tracer Gas test runs

The ASHRAE 110-1995 protocol includes an evaluation of the tested fume hood's ability to contain a tracer gas. Tracer gas containment is normally measured with the sash in its "design position", which is typically in a position of 18 inches open. To simulate a worst-case situation, all tracer gas tests were performed with each hood's sash fully open. This is NOT the recommended position for the sash to be during operator use. The sash should always be lowered to the yield the smallest opening that allows the operator to manipulate objects/experiments within the hood's cavity safely. This is true for all fume hoods.

Test Runs #4 through #6 presents results of ASHRAE's 110 protocol, Section 7 – Tracer Gas Test Procedures (refer to Table 1, above). Specifically, Sections 7.1 through 7.10

were performed with passing ratings, per ANSI Z9.5-2003, for both "as-manufactured" and "as-installed" conditions. The total exhaust airflow for the Berkeley hood was 643 CFM. This exhaust flow equates to 50 percent of the volume when compared to the hood flowing with a face velocity of 100 FPM. For each hood, tracer gas test runs were performed with the ejector in center, left, and right positions. The SF_6 gas detector, an Ion Tracker Instruments (ITI) Leakmeter 120, was checked with calibrated bags of SF_6 tracer gas just prior to each test, thus ensuring accurate results. Refer to charts in Appendix B.

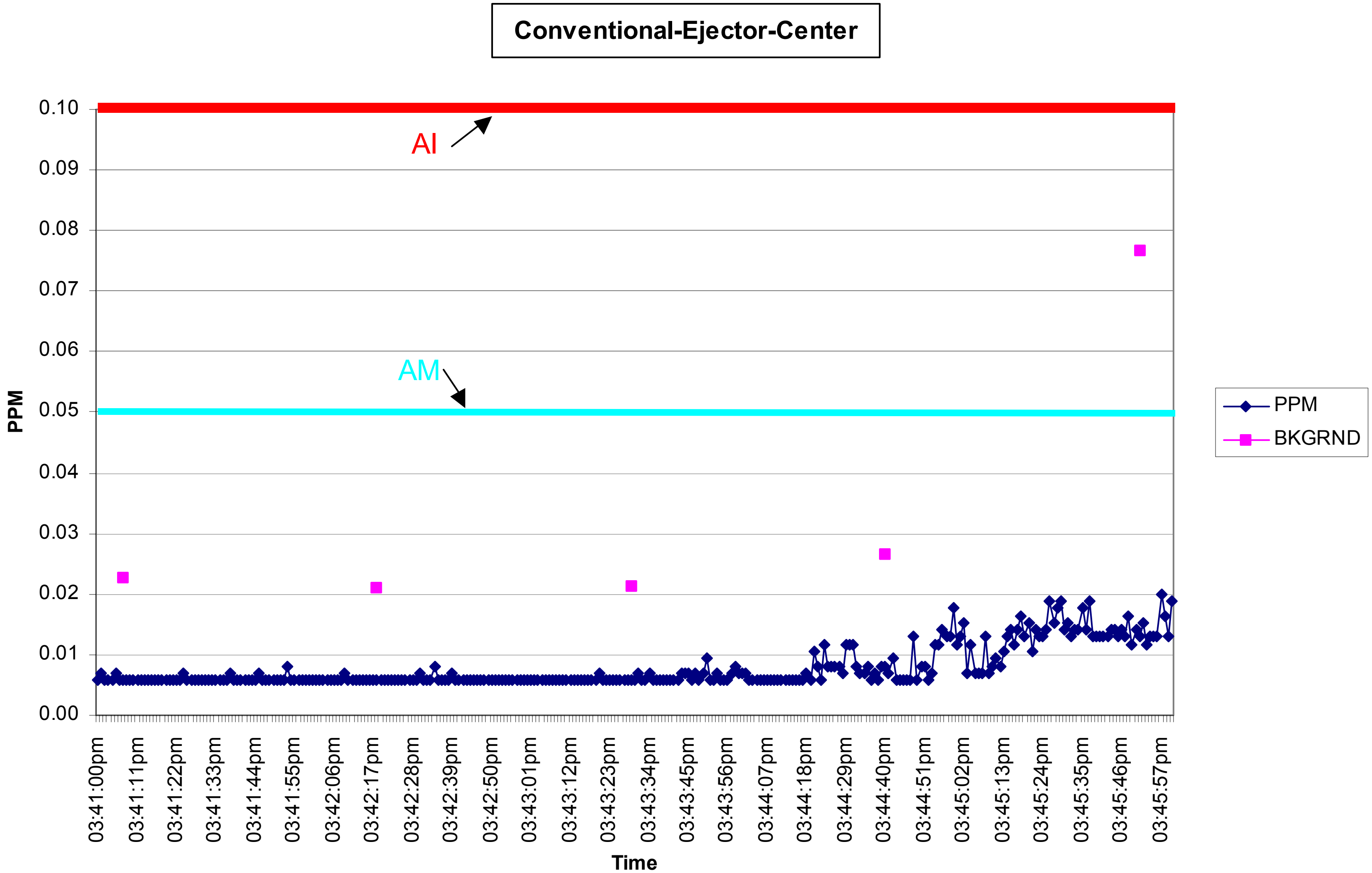
5.4 Sash Movement Effect runs

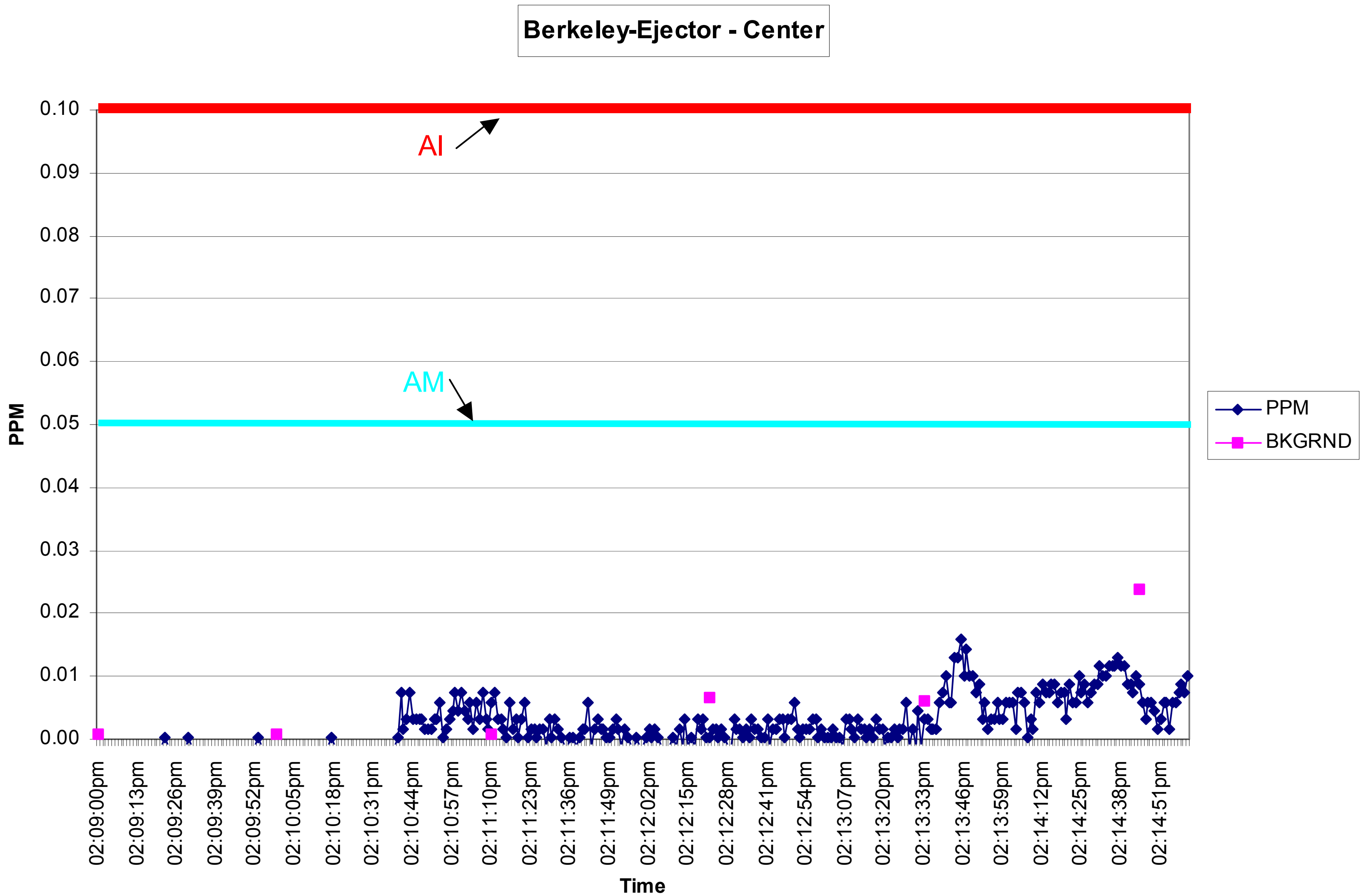
Test Runs #7 through #9 presents results of a Sash Movement Effect (SME) test per ASHRAE 110 Section 7.12 (refer to Table 1, above). Per the protocol with the mannequin present in each case, this challenge involves closing and opening the sash to fully three times for each ejector position; center, left, and right. Refer to charts in Appendix B.

5.5 Sash Periphery Traverse test runs

Test Run #10 presents results of ASHRAE's 110 protocol, Section 7 – Tracer Gas Test Procedures, Section 7.11 Sash Periphery Traverse test (refer to Table 1, above). This test was performed twice in each hood. Average containment ratings better than ANSI Z9.5-2003, for both "as-manufactured" and "as-installed" conditions were provided with the Berkeley hood. Excursions were noted with the conventional hood, although time-averaged values can be seen as “passing.” All test runs were performed with the ejector in the hood center position. Refer to charts in Appendix B.

6 Appendix A - Side-by-side Containment Test Runs

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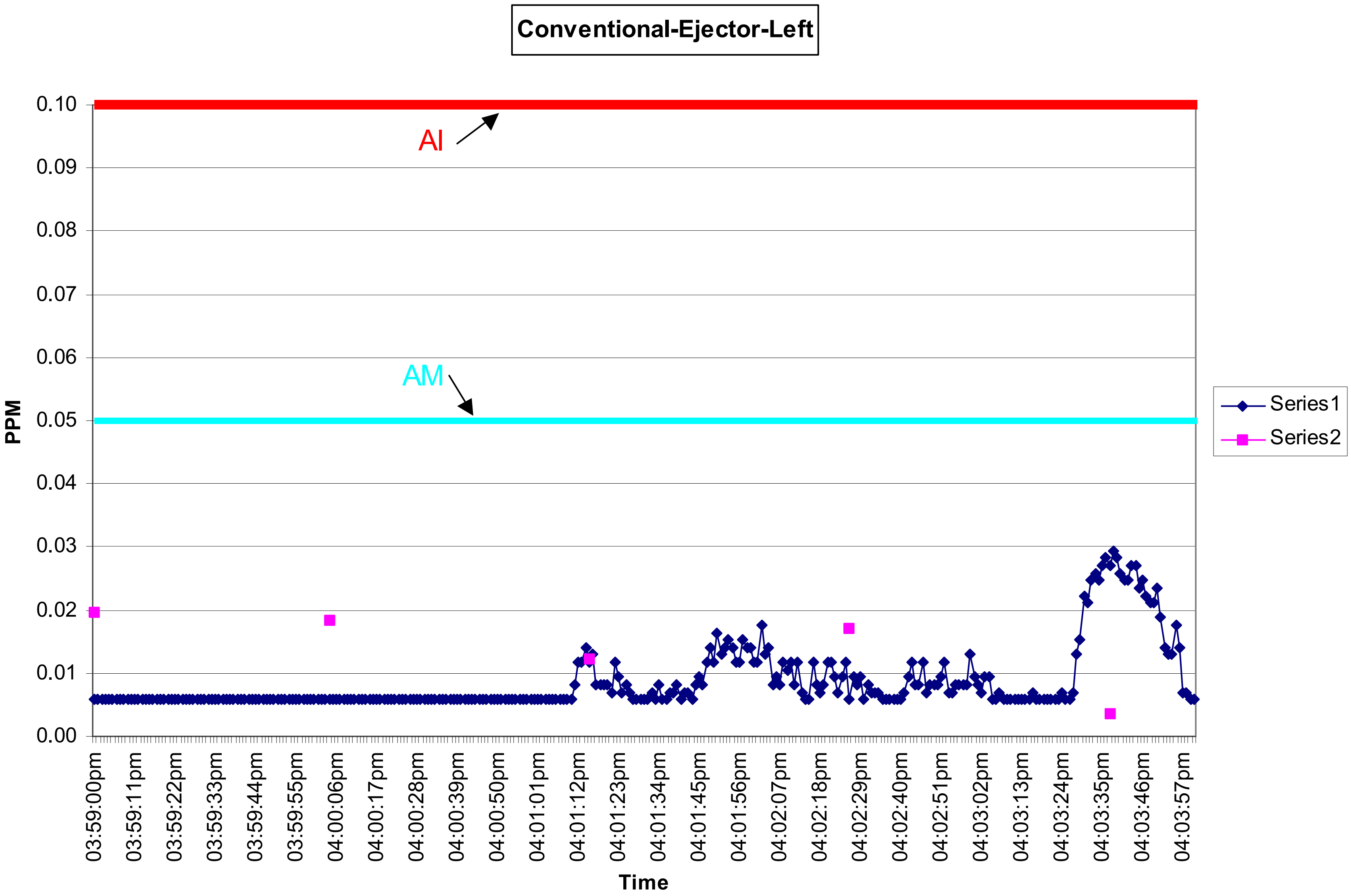
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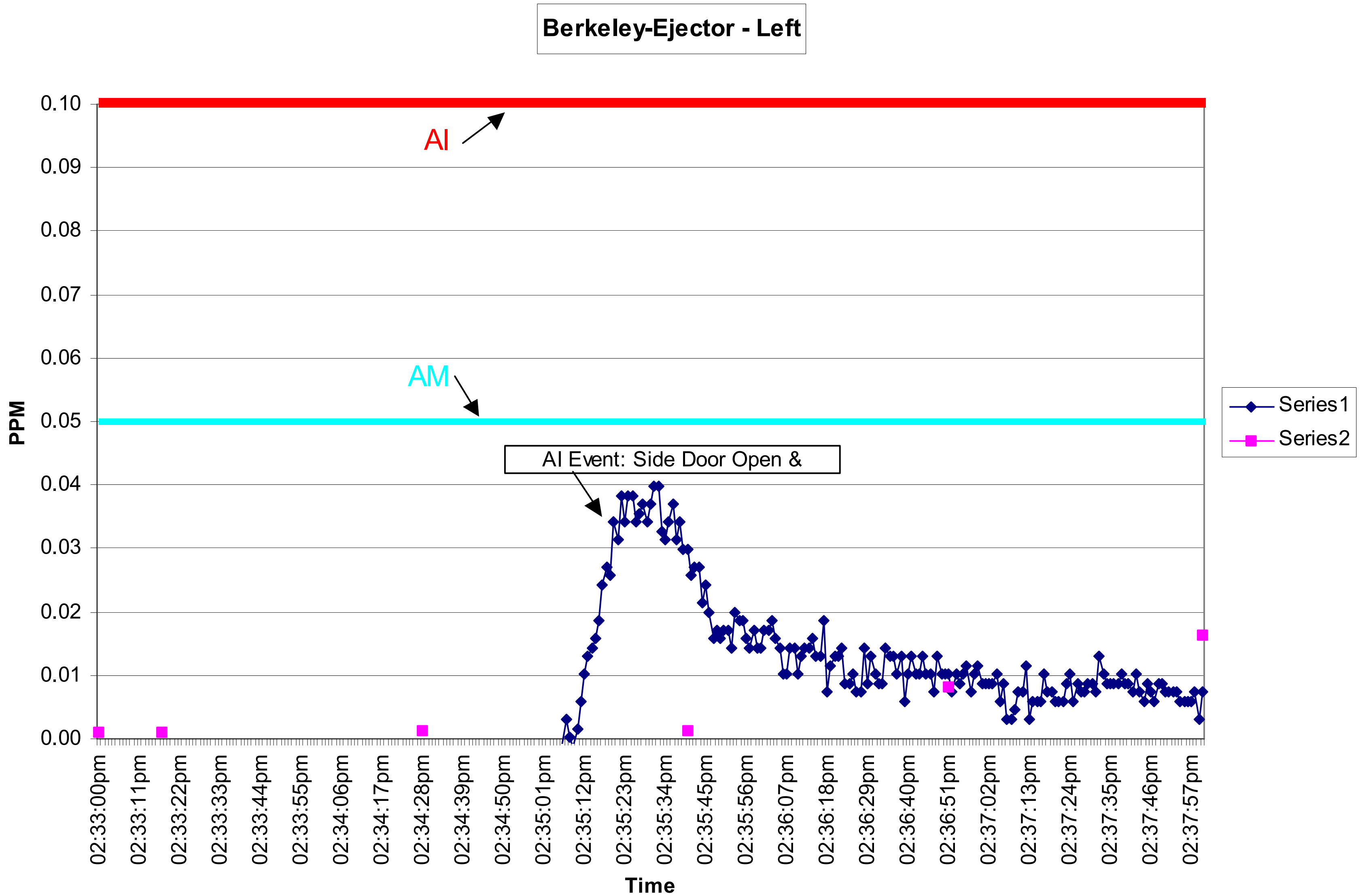
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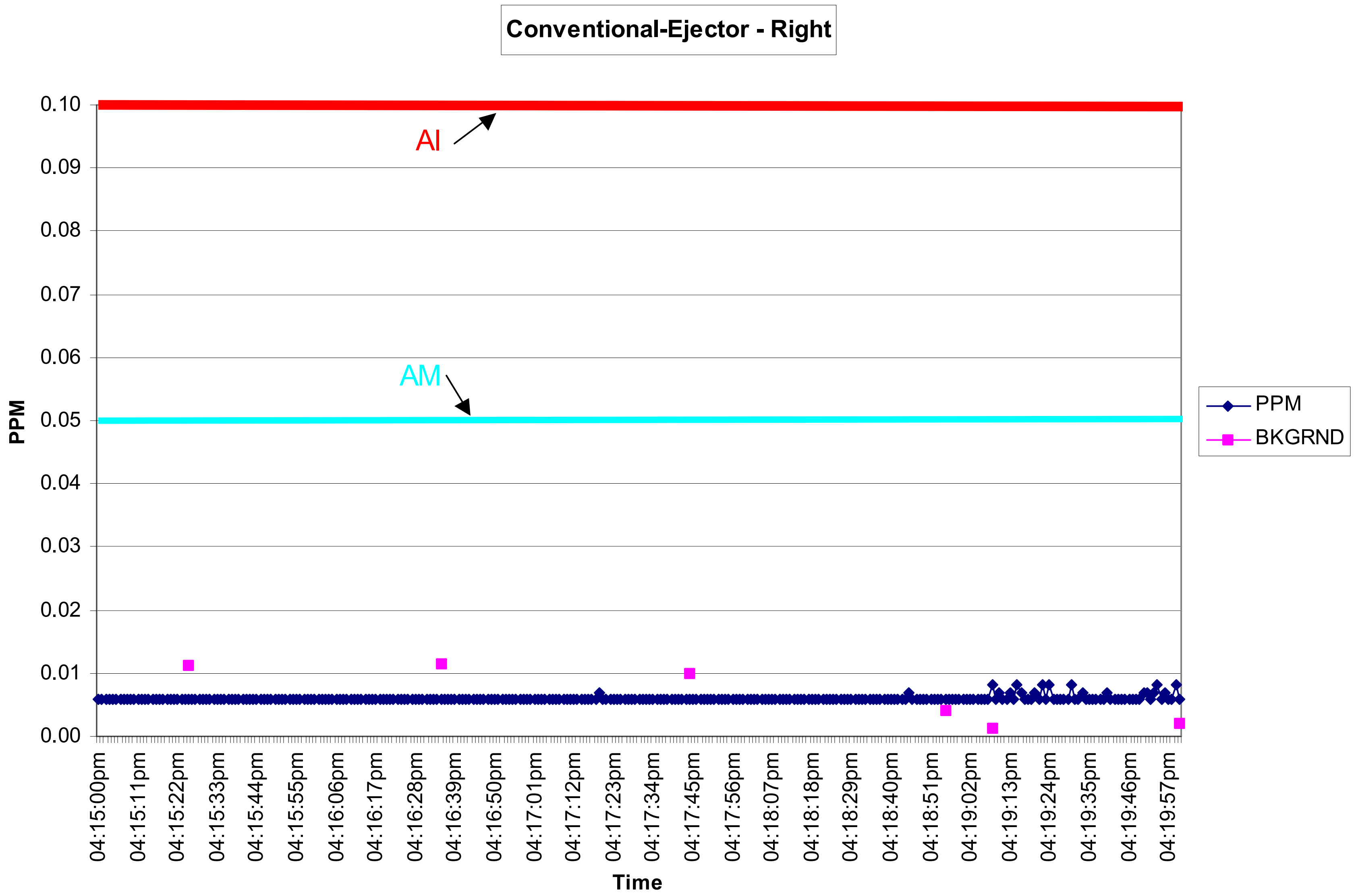
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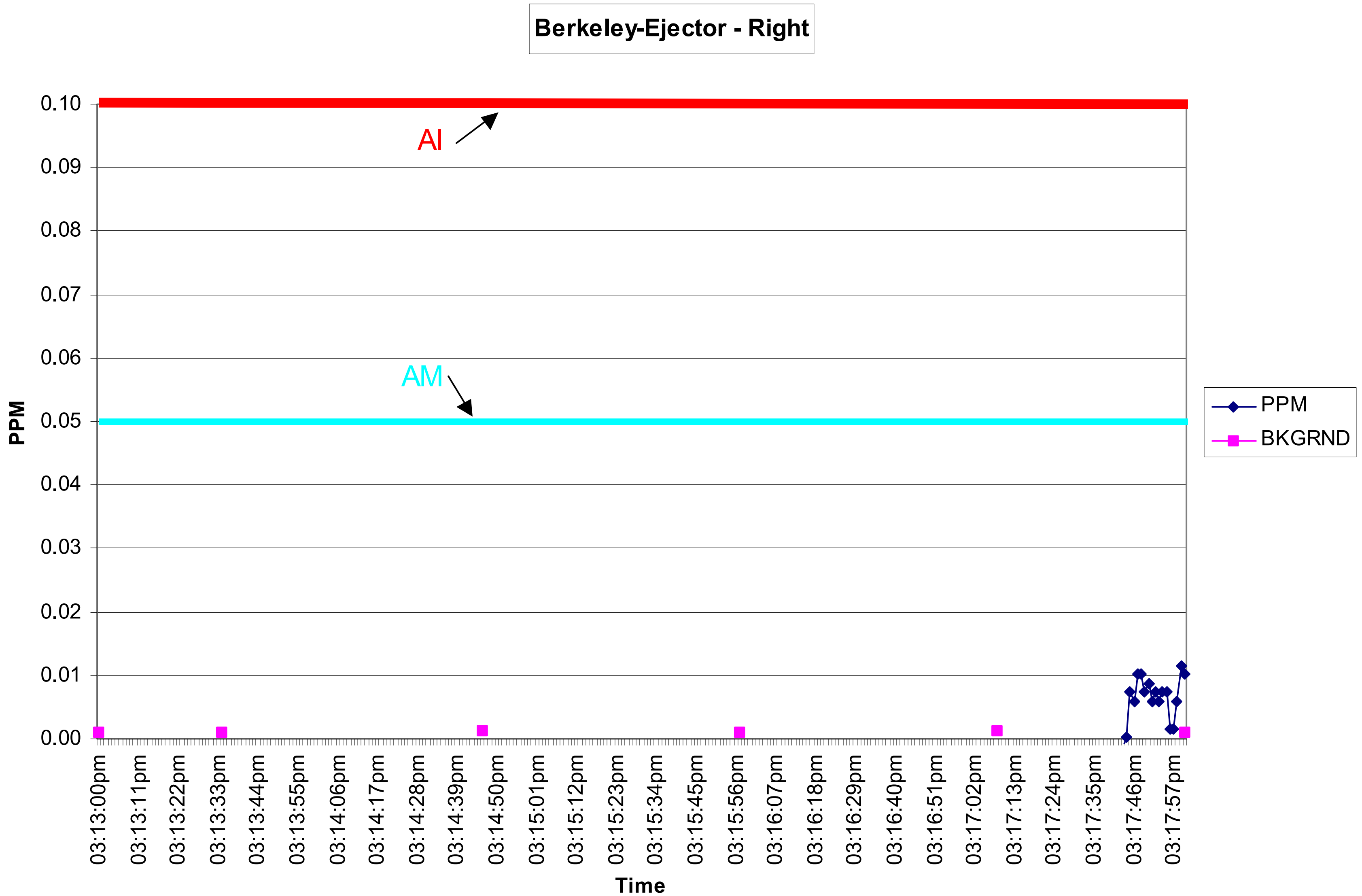
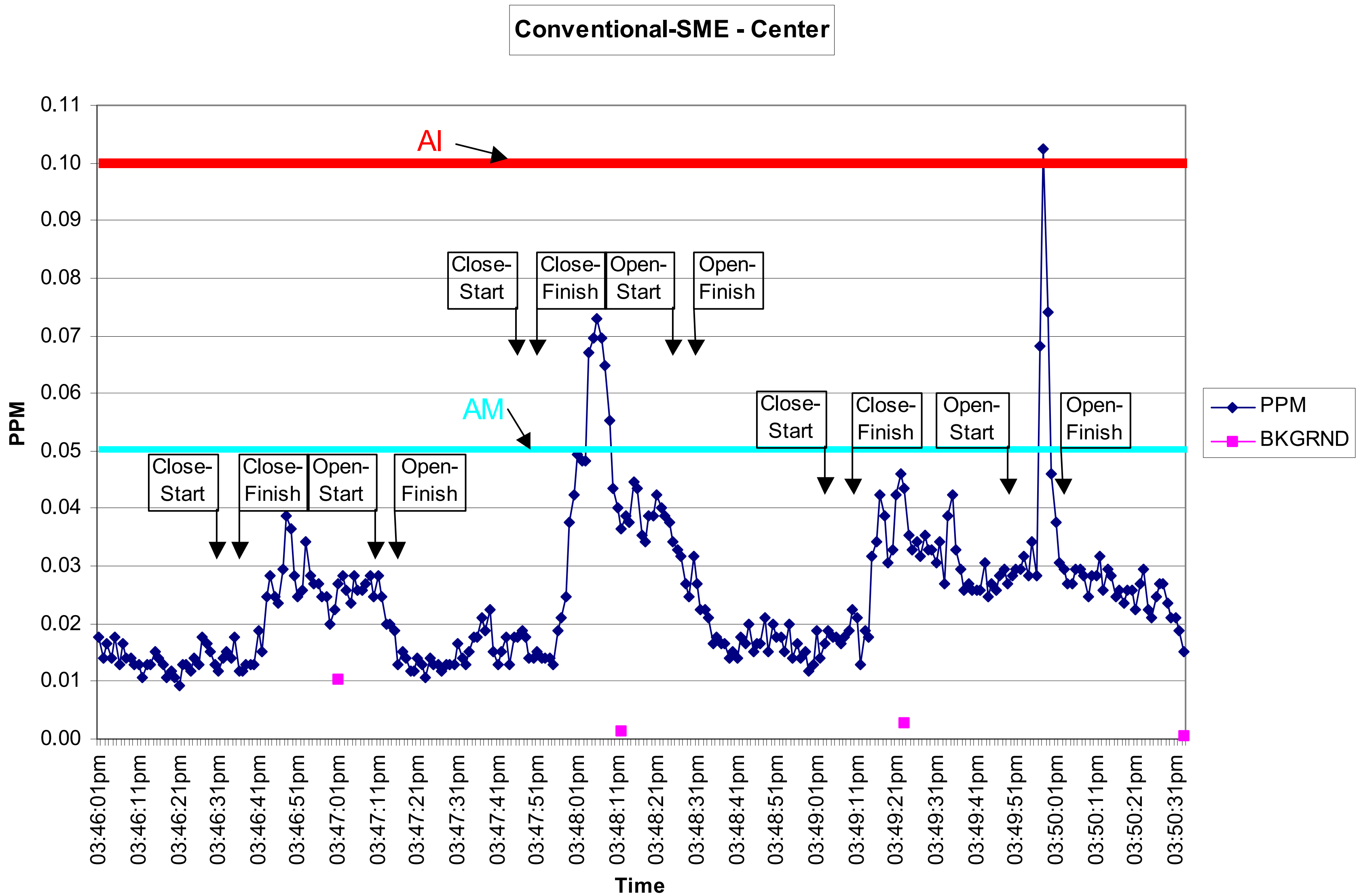
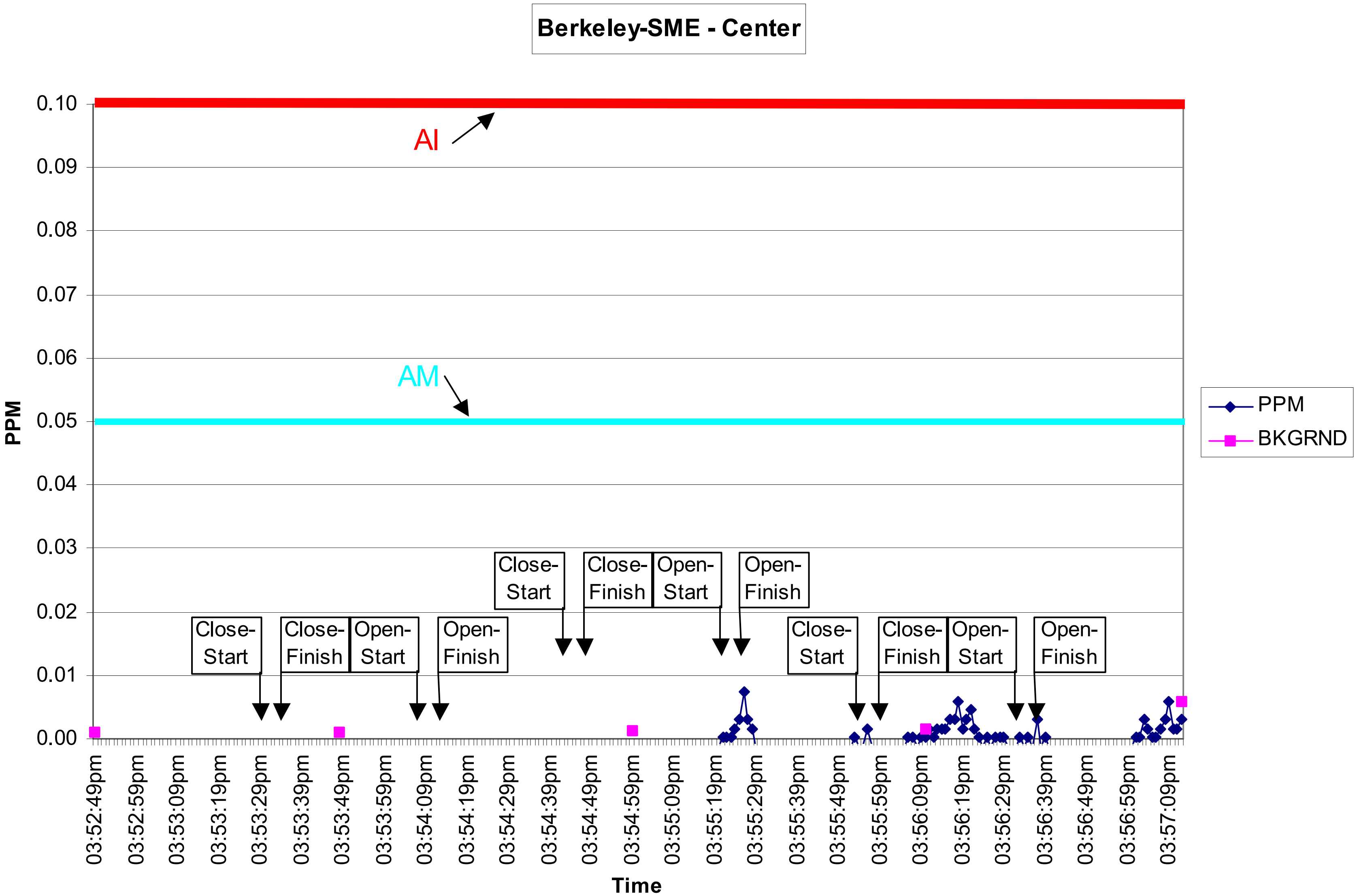
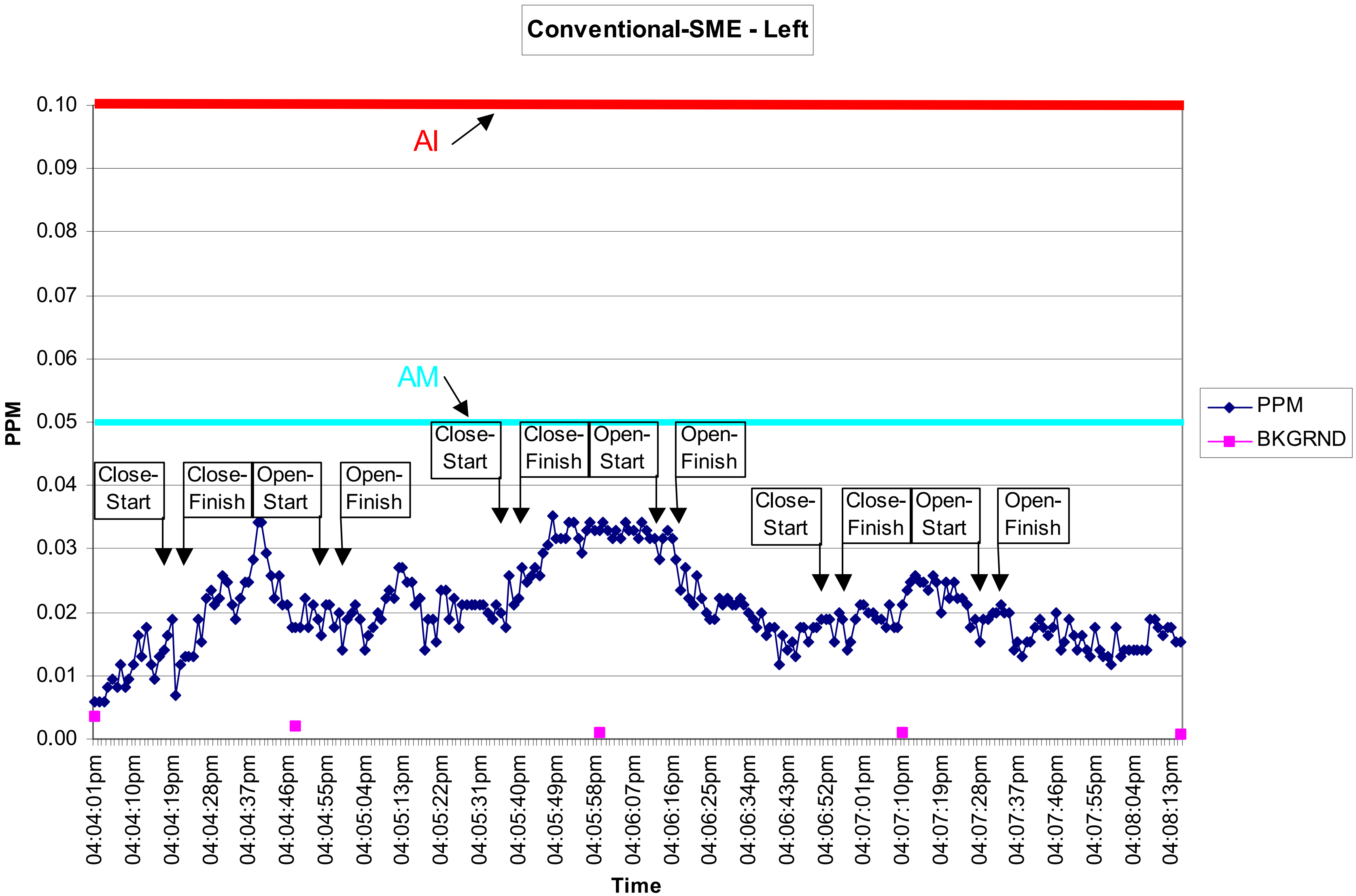
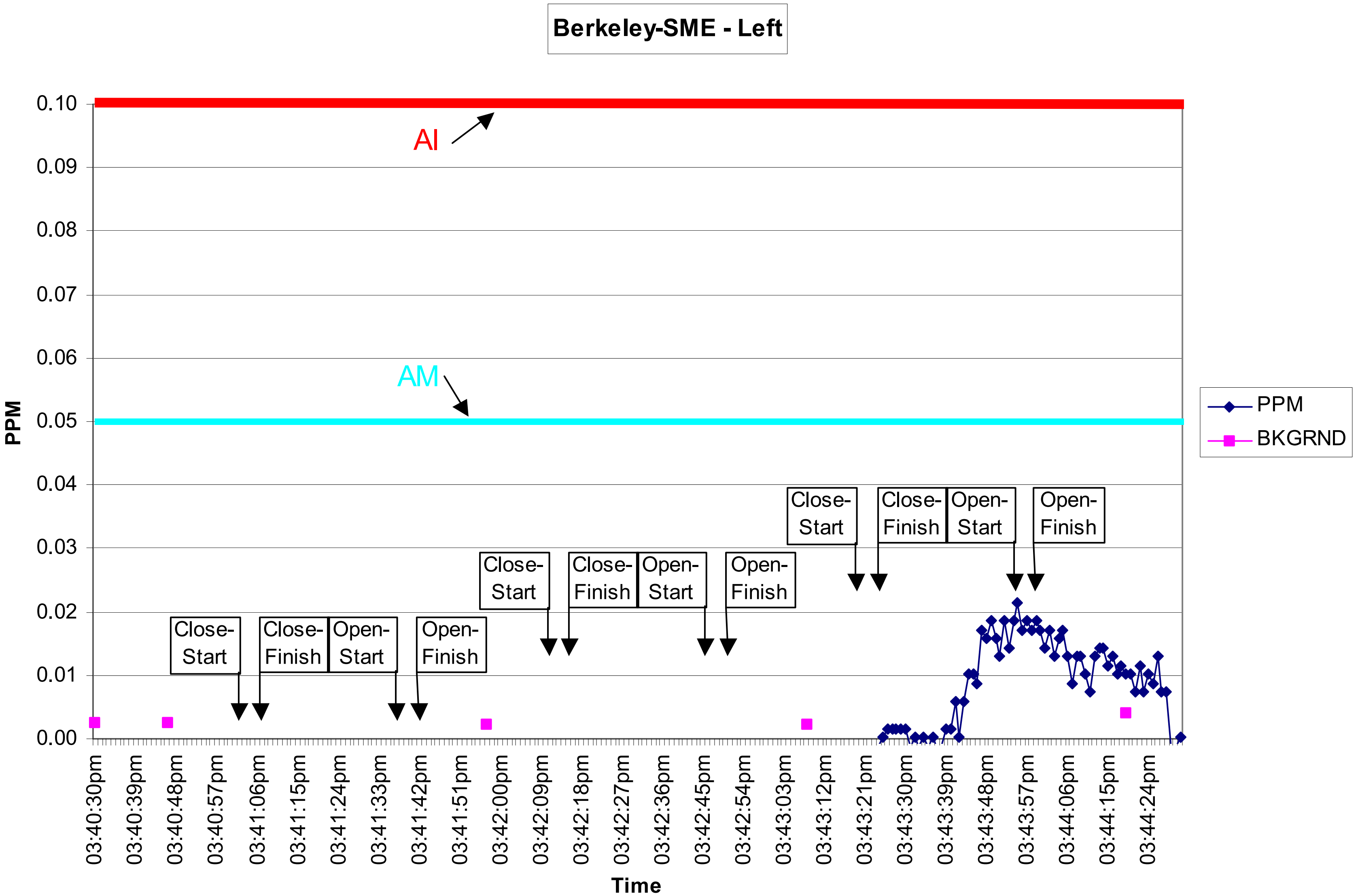
04:19:02pm
04:19:13pm
04:19:24pm
04:19:35pm
04:19:46pm
04:19:57pm
Time
PPM
BKGRND

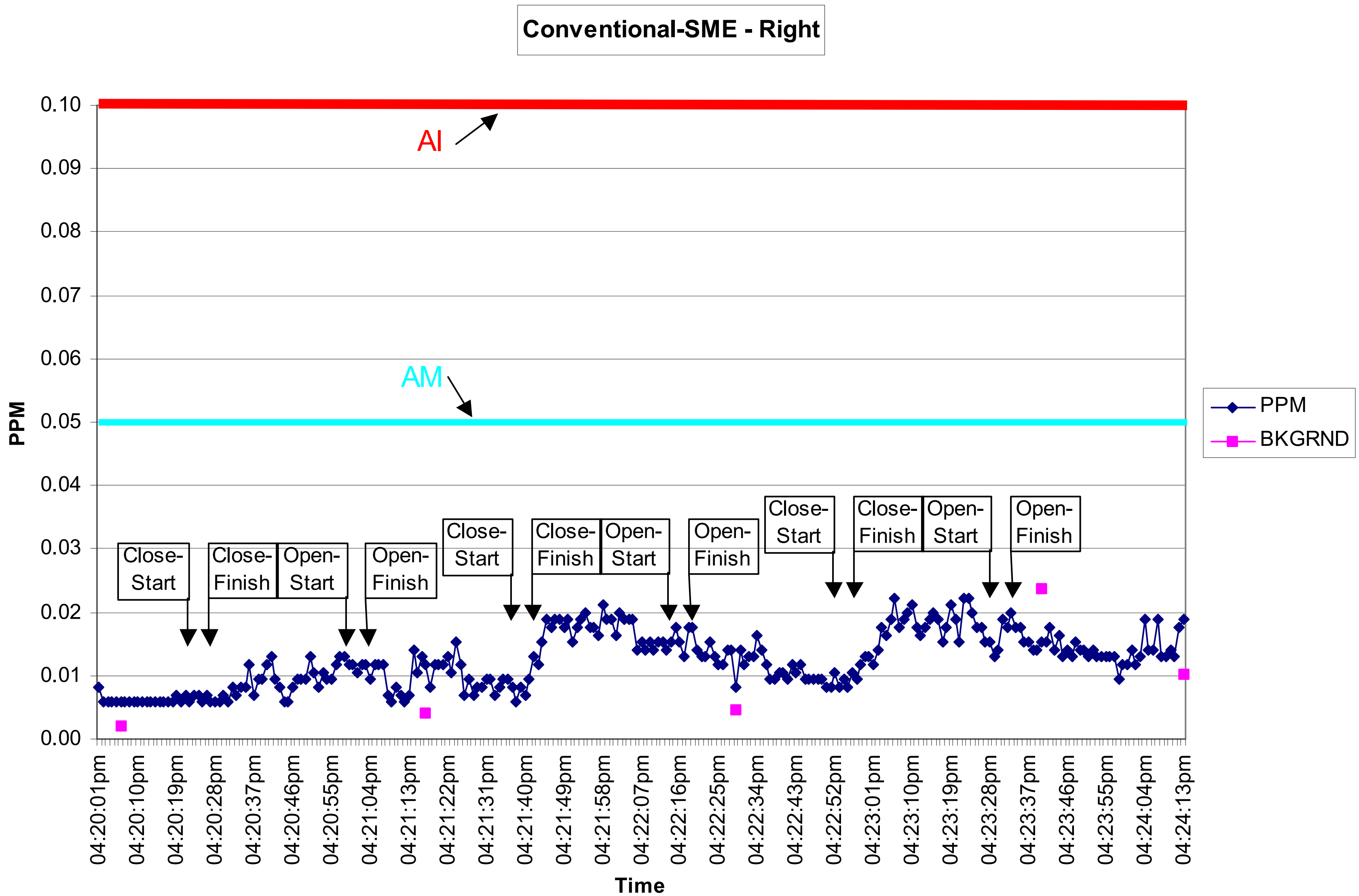

Berkeley-Ejector - Right
PPM
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
AI
AM
Time
03:13:00pm
03:13:11pm
03:13:22pm
03:13:33pm
03:13:44pm
03:13:55pm
03:14:06pm
03:14:17pm
03:14:28pm
03:14:39pm
03:14:50pm
03:15:01pm
03:15:12pm
03:15:23pm
03:15:34pm
03:15:45pm
03:15:56pm
03:16:07pm
03:16:18pm
03:16:29pm
03:16:40pm
03:16:51pm
03:17:02pm
03:17:13pm
03:17:24pm
03:17:35pm
03:17:46pm
03:17:57pm
PPM
BKGRND

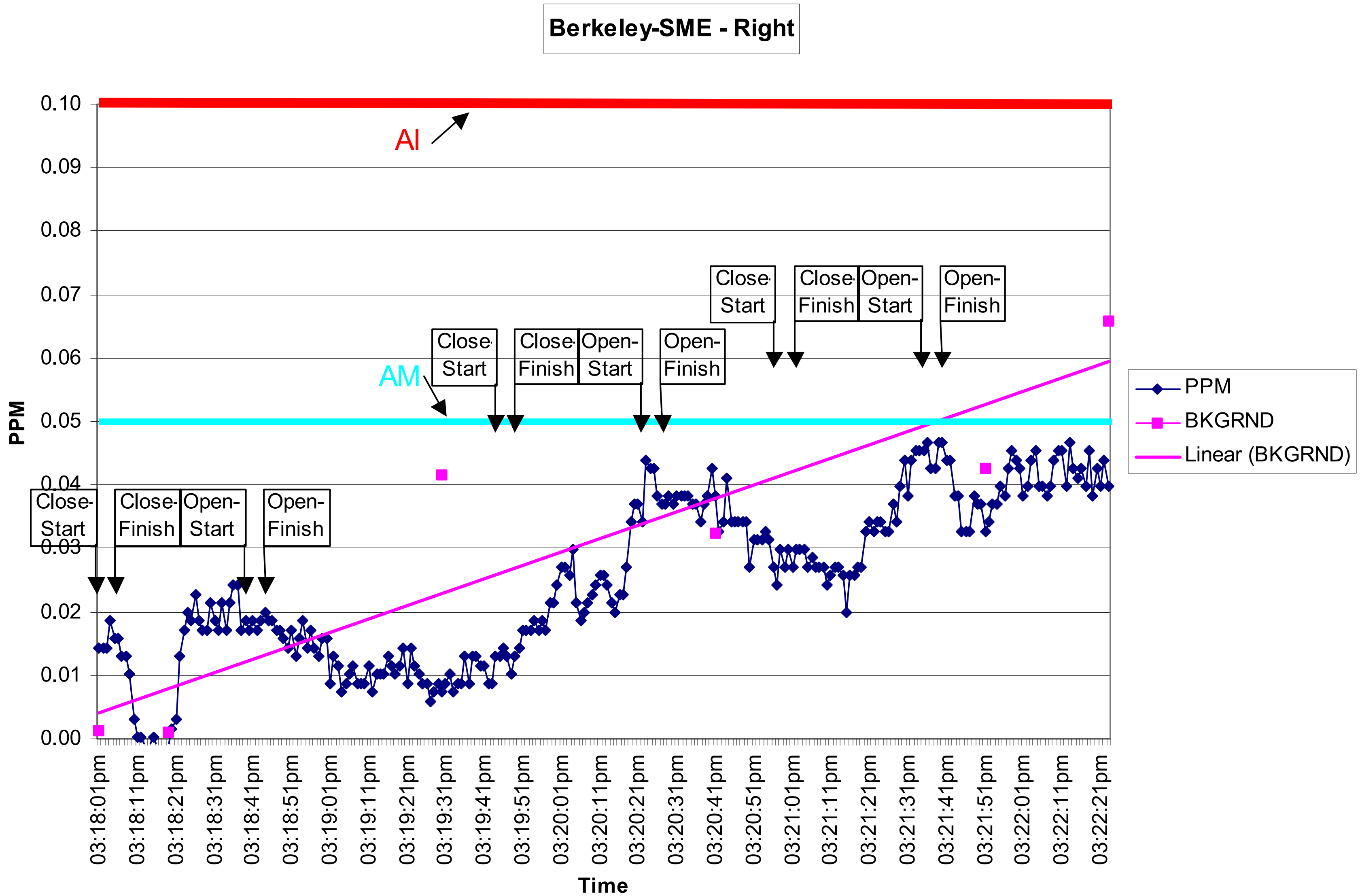

Conventional-SME - Center
0.11
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
PPM
AI
AM
Close-Start
Close-Finish
Open-Start
Open-Finish
Close-Start
Close-Finish
Open-Start
Open-Finish
Close-Start
Close-Finish
Open-Start
Open-Finish
PPM
BKGRND
03:46:01pm
03:46:11pm
03:46:21pm
03:46:31pm
03:46:41pm
03:46:51pm
03:47:01pm
03:47:11pm
03:47:21pm
03:47:31pm
03:47:41pm
03:47:51pm
03:48:01pm
03:48:11pm
03:48:21pm
03:48:31pm
03:48:41pm
03:48:51pm
03:49:01pm
03:49:11pm
03:49:21pm
03:49:31pm
03:49:41pm
03:49:51pm
03:50:01pm
03:50:11pm
03:50:21pm
03:50:31pm
Time

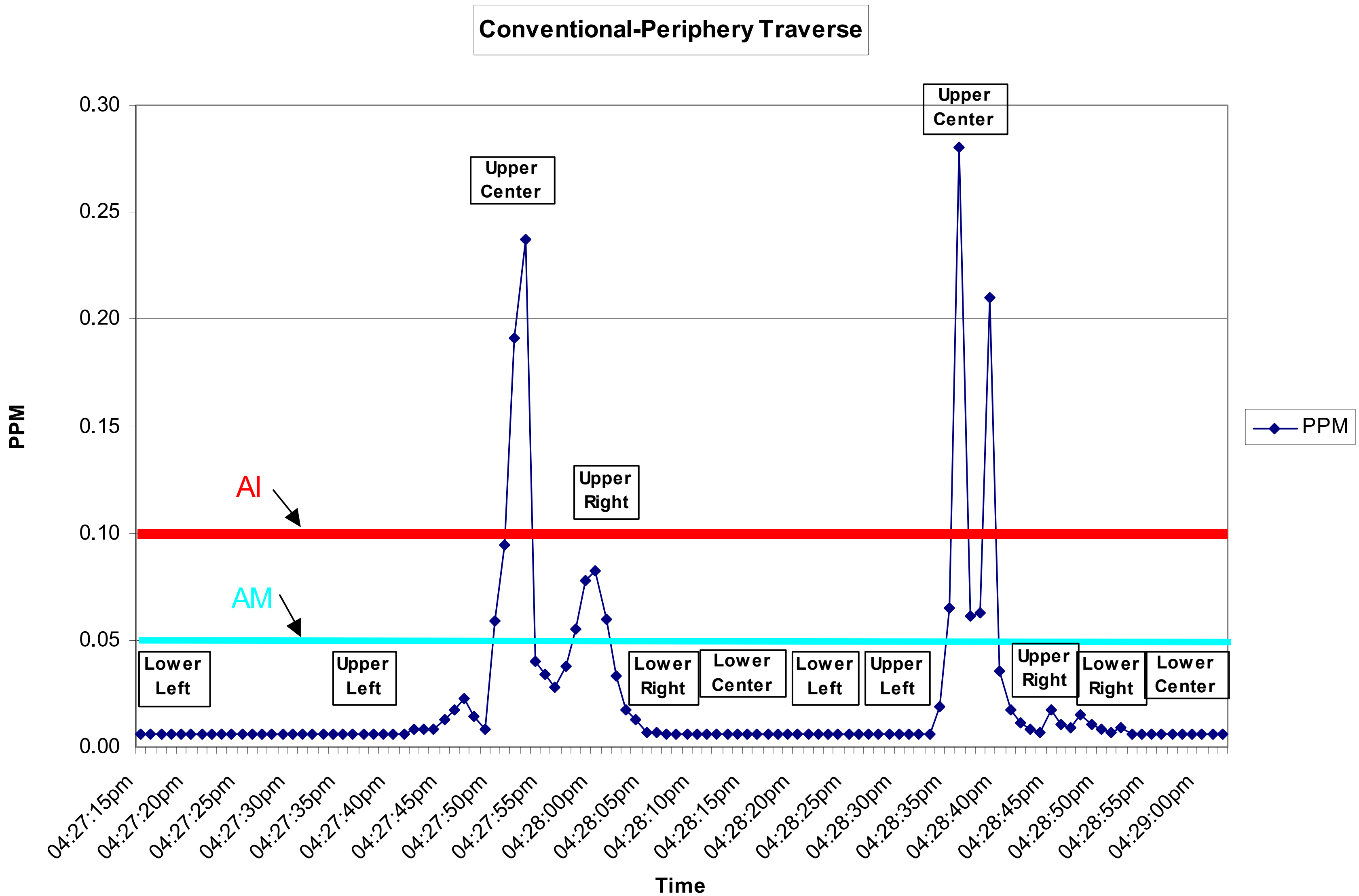

Berkeley-SME - Center
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
PPM
AI
AM
Close-Start
Close-Finish
Open-Start
Open-Finish
Close-Start
Close-Finish
Open-Start
Open-Finish
Close-Start
Close-Finish
Open-Start
Open-Finish
03:52:49pm
03:52:59pm
03:53:09pm
03:53:19pm
03:53:29pm
03:53:39pm
03:53:49pm
03:53:59pm
03:54:09pm
03:54:19pm
03:54:29pm
03:54:39pm
03:54:49pm
03:54:59pm
03:55:09pm
03:55:19pm
03:55:29pm
03:55:39pm
03:55:49pm
03:55:59pm
03:56:09pm
03:56:19pm
03:56:29pm
03:56:39pm
03:56:49pm
03:56:59pm
03:57:09pm
Time
PPM
BKGRND

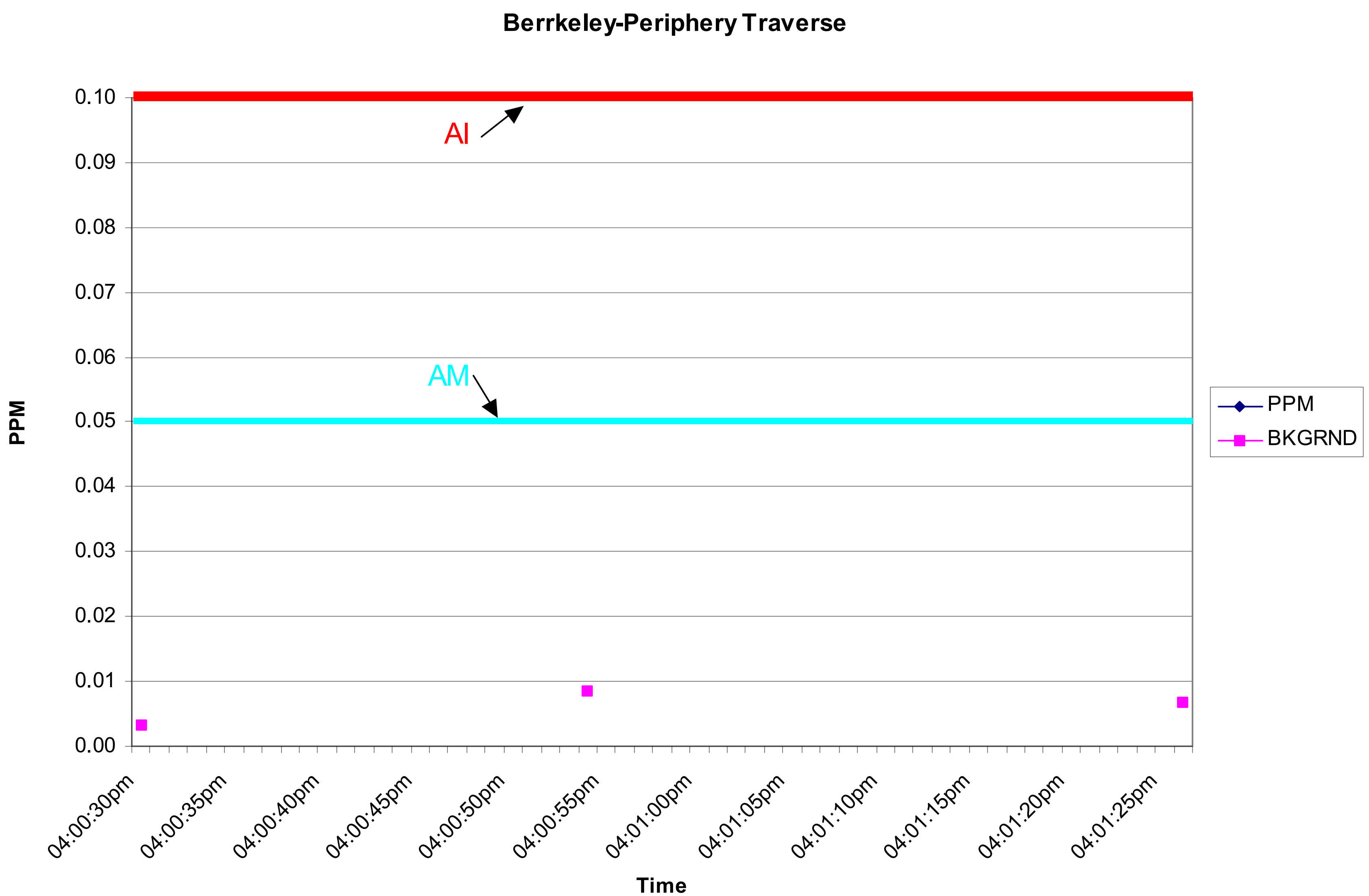

Conventional-SME - Left
AI
AM
Close-Start
Close-Finish
Open-Start
Open-Finish
Close-Start
Close-Finish
Open-Start
Open-Finish
Close-Start
Close-Finish
Open-Start
Open-Finish
PPM
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
04:04:01pm
04:04:10pm
04:04:19pm
04:04:28pm
04:04:37pm
04:04:46pm
04:04:55pm
04:05:04pm
04:05:13pm
04:05:22pm
04:05:31pm
04:05:40pm
04:05:49pm
04:05:58pm
04:06:07pm
04:06:16pm
04:06:25pm
04:06:34pm
04:06:43pm
04:06:52pm
04:07:01pm
04:07:10pm
04:07:19pm
04:07:28pm
04:07:37pm
04:07:46pm
04:07:55pm
04:08:04pm
04:08:13pm
Time
PPM
BKGRND


Berkeley-SME - Left
AI
AM
PPM
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
Close-Start
Close-Finish
Open-Start
Open-Finish
Close-Start
Close-Finish
Open-Start
Open-Finish
Close-Start
Close-Finish
Open-Start
Open-Finish
PPM
BKGRND
03:40:30pm
03:40:39pm
03:40:48pm
03:40:57pm
03:41:06pm
03:41:15pm
03:41:24pm
03:41:33pm
03:41:42pm
03:41:51pm
03:42:00pm
03:42:09pm
03:42:18pm
03:42:27pm
03:42:36pm
03:42:45pm
03:42:54pm
03:43:03pm
03:43:12pm
03:43:21pm
03:43:30pm
03:43:39pm
03:43:48pm
03:43:57pm
03:44:06pm
03:44:15pm
03:44:24pm
Time


Conventional-SME - Right
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
PPM
AI
AM
Close-Start
Close-Finish
Open-Start
Open-Finish
Close-Start
Close-Finish
Open-Start
Open-Finish
Close-Start
Close-Finish
Open-Start
Open-Finish
04:20:01pm
04:20:10pm
04:20:19pm
04:20:28pm
04:20:37pm
04:20:46pm
04:20:55pm
04:21:04pm
04:21:13pm
04:21:22pm
04:21:31pm
04:21:40pm
04:21:49pm
04:21:58pm
04:22:07pm
04:22:16pm
04:22:25pm
04:22:34pm
04:22:43pm
04:22:52pm
04:23:01pm
04:23:10pm
04:23:19pm
04:23:28pm
04:23:37pm
04:23:46pm
04:23:55pm
04:24:04pm
04:24:13pm
Time
PPM
BKGRND


Berkeley-SME - Right
AI
AM
PPM
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
Close-Start
Close-Finish
Open-Start
Open-Finish
PPM
BKGRND
Linear (BKGRND)
03:18:01pm
03:18:11pm
03:18:21pm
03:18:31pm
03:18:41pm
03:18:51pm
03:19:01pm
03:19:11pm
03:19:21pm
03:19:31pm
03:19:41pm
03:19:51pm
03:20:01pm
03:20:11pm
03:20:21pm
03:20:31pm
03:20:41pm
03:20:51pm
03:21:01pm
03:21:11pm
03:21:21pm
03:21:31pm
03:21:41pm
03:21:51pm
03:22:01pm
03:22:11pm
03:22:21pm
Time


Conventional-Periphery Traverse
PPM
0.30
0.25
0.20
0.15
0.10
0.05
0.00
AI
AM
Upper Center
Upper Right
Lower Left
Upper Left
Lower Right
Lower Center
Lower Left
Upper Left
Upper Center
Upper Right
Lower Right
Lower Center
PPM
04:27:15pm
04:27:20pm
04:27:25pm
04:27:30pm
04:27:35pm
04:27:40pm
04:27:45pm
04:27:50pm
04:27:55pm
04:28:00pm
04:28:05pm
04:28:10pm
04:28:15pm
04:28:20pm
04:28:25pm
04:28:30pm
04:28:35pm
04:28:40pm
04:28:45pm
04:28:50pm
04:28:55pm
04:29:00pm
Time



Note: Hood passes containment test if average concentration below limits shown for five minutes.