



UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

OFFICE OF
SOLID WASTE AND
EMERGENCY RESPONSE

MEMORANDUM

SUBJECT: *Mercury Lamp Drum-Top Crusher Study*
Document Number: [REDACTED]

FROM: Matt Hale, Director
Office of Solid Waste
Marie Pausi Dickey for

TO: State and Regional RCRA Waste Management Directors
Users and Potential Users of Drum-Top Crusher Devices
Lamp Recyclers and Manufacturers

As part of ongoing efforts to encourage safe management of mercury-containing equipment and fluorescent lamps, the Environmental Protection Agency (EPA) is releasing a *Mercury Lamp Drum-Top Crusher Study* on the performance of mercury lamp drum-top crusher (DTC) devices. DTC devices fit on the top of a 55 gallon drum and crush fluorescent lamps into the drum below. DTC devices are designed to reduce the volume of waste lamps, while controlling the release of mercury vapors from crushed lamps. This volume reduction can facilitate storage and handling, decrease the possibility of subsequent breakage and release, and reduce shipping costs associated with fluorescent lamp recycling.

We conducted the *Mercury Lamp Drum-Top Crusher Study* in order to gain more information about the performance of DTC devices. The objective of the study was to evaluate how well four DTC devices contained mercury releases from crushed lamps, focusing on worker exposure to airborne mercury. The study provides current information on the performance of DTC devices. The report presents our findings, which we believe will be helpful to states, users of fluorescent lamps, and lamp recyclers in making more informed management decisions when recycling fluorescent lamps. For more information and a copy of the *Study*, visit <http://www.epa.gov/epaoswer/hazwaste/id/univwast/drumtop/drum-top.htm>. If you have any questions, please contact Greg Helms at (703) 308-8845 or Cathy Davis at (703) 308-7271.



Mercury Lamp
Drum-Top Crusher
Study

Mercury Lamp Drum-Top Crusher Study

TABLE OF CONTENTS

1.	EXECUTIVE SUMMARY.....	1
1.1	Study Overview	1
1.2	Observations	3
2.	SCOPE OF STUDY.....	5
2.1	Mercury Fluorescent Lamp Disposal.....	5
2.2	Study Overview	5
2.2.1	Study Location.....	5
2.2.2	Containment Structure.....	6
2.2.3	General Procedures.....	8
2.2.4	Study Components	9
2.2.5	Equipment.....	10
2.3	Testing Locations and Study Chronology.....	13
3.	DATA COLLECTION METHODOLOGY.....	15
3.1	Analytical Air Samples.....	16
3.1.1	Performance Validation Study.....	19
3.1.2	Extended Field Test #1.....	21
3.1.3	Extended Field Test #2.....	22
3.1.4	Extended Field Test #3.....	24
3.2	Jerome Mercury Vapor Analyzer Samples.....	26
3.3	Bulk Samples	27
3.3.1	Unbroken Spent Lamps.....	27
3.3.2	Pollution Control Media	28
3.3.3	Crushed Lamps	28
3.4	Wipe Samples	29
3.5	Test Protocol Deviations and Modifications.....	30
4.	RESULTS AND DATA EVALUATION.....	32
4.1	Exposure Evaluation Criteria	32
4.2	Background Air Samples	33
4.3	Blank Air Samples.....	36
4.4	Performance Validation Study.....	37
4.4.1	Performance Validation Study - Phase I.....	37
4.4.2	Performance Validation Study - Phase II.....	40
4.4.3	Comparison of Performance Validation Study Phases I and II.....	43
4.5	Extended Field Test Study	45
4.5.1	Extended Field Test #1.....	45
4.5.2	Extended Field Test #2.....	50
4.5.3	Extended Field Test #3.....	55
4.5.4	Comparison of Extended Field Tests	59
4.6	Box Tests.....	61
4.6.1	AERC Melbourne Box Test.....	62
4.6.2	AERC Ashland Box Test	63
4.7	Overnight Samples	63
4.8	U-Tube Test.....	65

5.	MASS BALANCE STUDY	66
5.1	Mass Balance Equation.....	66
5.2	Estimating Total Mercury Content of Unprocessed Lamps (Hg _T)	66
5.3	Estimating Mercury Mass Captured in the DTC Devices (Hg _C).....	69
5.4	Estimated Mercury Released To The Ambient Air (Hg _R)	72
5.5	Mass Balance Results.....	73
5.6	Mass Balance Discussion.....	74
5.6.1	Mercury Mass in Crushed Lamps	74
5.6.2	Mercury Mass in Air Filtration System Elements	75
5.6.3	Mercury Mass Adhering to Surfaces.....	77
5.6.4	Mercury Mass in Ambient Air	77
5.7	Mass Balance Study Observations.....	77
6.	LIMITATIONS.....	79
6.1	Background Levels of Mercury	79
6.2	Experimental Conditions	80
6.3	Contamination from Lamps Broken During Shipment.....	80
6.4	Contamination from Lamps Broken During DTC Device Operation	81
7.	DISCUSSION	82
7.1	Summary of Results.....	82
7.1.1	Exposures during Routine Crushing Operations.....	83
7.1.2	Exposures during Routine Drum and Filter Changes.....	84
7.1.3	Exposures Resulting From DTC Device Malfunction	84
7.1.4	Changes in DTC Performance over Time.....	85
7.1.5	Overnight Tests	86
7.1.6	U-Tube Test.....	86
7.1.7	Exposures Resulting from Lamp Breakage.....	86
7.2	Safety Concerns when Operating DTC Devices.....	87
7.2.1	Operator Safety.....	87
7.3	Potential DTC Design Modifications	89
7.4	Future Areas for Study	90
7.5	Conclusions.....	91

LIST OF FIGURES

Figure 3. 1: Sampling Locations for the Performance Validation Study and Extended Field Test #3.....	21
Figure 3. 2: Sampling Locations for Extended Field Test #1	22
Figure 3. 3: Sampling Locations for Extended Field Test #2	23
Figure 3. 4: Box Test Configuration, AERC Melbourne	24
Figure 3. 5: Box Test Configuration, AERC Ashland.....	25
Figure 4. 1: Analytical Air Sampling Results, Performance Validation Study I.....	39
Figure 4. 2: Analytical Air Sampling Results, Performance Validation Study II.....	41
Figure 4. 3: Jerome Results - Inside Containment, Performance Validation Study II	42
Figure 4. 4: Analytical Air Sampling Results, Performance Validation Study - Phases I & II	43
Figure 4. 5: Analytic Air Sampling Results, All Devices, Extended Field Test #1	48
Figure 4. 6: Jerome Results - Inside the Containment, Extended Field Test #1	49
Figure 4. 7: Analytic Air Sampling Results, All Devices, Extended Field Test #2	53
Figure 4. 8: Jerome Results - Inside the Containment, Extended Field Test #2	54
Figure 4. 9: Analytical Air Sampling Results, All Devices, Extended Field Test #3 ..	57
Figure 4. 10: Jerome Results - Inside the Containment, Extended Field Test #3	58
Figure 4. 11: Analytical Air Sampling Results, Extended Field Test Study - Manufacturer A	60
Figure 4. 12: Analytical Air Sampling Results, Extended Field Test Study - Manufacturer B.....	60
Figure 4. 13: Analytical Air Sampling Results, Extended Field Test Study - Manufacturer C	61
Figure 4. 14: Jerome Results - Inside Containment, AERC Melbourne Box Test.....	62
Figure 4. 15: Overnight Test Sample Results	64
Figure 4. 16: U-tube Test Sample Results	65

LIST OF PHOTOGRAPHS

Photograph 2. 1: AERC Ashland Facility – Containment Structure – First Visit.....	7
Photograph 2. 2: EPSI Phoenix Facility – Containment Structure	7
Photograph 2. 3: AERC Melbourne Facility – Containment Structure	7
Photograph 2. 4: AERC Ashland Facility – Containment Structure – Second Visit.....	7
Photograph 2. 5: Manufacturer A Device	10
Photograph 2. 6: Manufacturer B Device.....	10
Photograph 2. 7: Manufacturer C Device	11
Photograph 2. 8: Manufacturer D Device	11
Photograph 3. 1: Air Sampling Pumps and Jerome Mercury Vapor Analyzer	15
Photograph 3. 2: Sensidyne Air Sampling Pumps	16
Photograph 3. 3: Feeding Bulbs into the Manufacturer A Device	18
Photograph 3. 4: Feeding Bulbs into the Manufacturer B Device.....	18
Photograph 3. 5: Feeding Bulbs into the Manufacturer C Device.....	18
Photograph 3. 6: Crushing of U-Tubes – Manufacturer C Device.....	26
Photograph 3. 7: Placement of Air Sampling Pump & Jerome Analyzer in Relation to DTC Device	27
Photograph 3. 8: Wipe Sample Media.....	29
Photograph 7. 1: Clearing Jammed Feed Tube of Manufacturer A Device.....	88

LIST OF TABLES

Table 2. 1: DTC Device Equipment Operating Manual Comparison.....	11
Table 2. 2: Order of Device Testing for DTC Device Study	14
Table 3. 1: Analytical Air Samples Collected during the Performance Validation Study	20
Table 3. 2: Air Samples Collected during Extended Field Test #1.....	21
Table 3. 3: Air Samples Collected during Extended Field Test #2 and #3	23
Table 3. 4: Air Samples Collected during U-tube Evaluation.....	26
Table 4. 1: Background Mercury Results – Analytical Air Samples	34
Table 4. 2: Background Mercury Results – Jerome Analyzer Measurements	34
Table 4. 3: Trip Blank Results	36
Table 4. 4: Field Blank Results.....	36
Table 4. 5: Total Lamps Processed in Each Device, Performance Validation Study I	38
Table 4. 6: Jerome Analyzer Measurements - Inside Containment, Performance Validation Study I.....	39
Table 4. 7: Total Lamps Processed in Each Device, Performance Validation Study II	40
Table 4. 8: Jerome Analyzer Measurements - Inside Containment, Performance Validation Study II.....	42
Table 4. 9: Performance Validation Study Air Sampling Data Comparison ^{a, b}	44
Table 4. 10: Total Lamps Processed in Each Device, Extended Field Test #1	46
Table 4. 11: Jerome Analyzer Measurements, Extended Field Test #1	47
Table 4. 12: Total Lamps Processing in Each Device, Extended Field Test #2.....	50
Table 4. 13: Jerome Analyzer Measurements, Extended Field Test #2	51
Table 4. 14: Total Lamps Processed in Each Device During Extended Field Test #3	55
Table 4. 15: Jerome Analyzer Measurements, Extended Field Test #3	56
Table 4. 16: Mean Background Mercury Concentrations, Extended Field Test Study	59
Table 4. 17: Results for AERC Ashland Box Test.....	63
Table 5. 1: Mass of Mercury in Philips Lighting Alto® Fluorescent Lamps	67
Table 5. 2: Total Mercury in Spent Philips Lighting Alto® Fluorescent Lamps ^a	68
Table 5. 3: Mass of Mercury Processed for Each DTC (Hg _T)	69
Table 5. 4: Samples Collected for the Mass Balance Study	69
Table 5. 5: Mass Balance Study Sample Results.....	70
Table 5. 6: Total Weights, Areas, and Blank Mercury Concentrations of Bulk Sample Media	71
Table 5. 7: Estimated Mercury Mass Captured inside DTC Devices (Hg _C).....	71
Table 5. 8: Mercury Released from DTC Devices (Hg _R).....	72
Table 5. 9: Summary of Mercury Mass Contributions, By Source	73
Table 5. 10: Mass Balance Calculation Results.....	73
Table 5. 11: Spike and Blank Analytical Results for Pollution Control Media.....	76

LIST OF APPENDICES

- Appendix A: Air and Wipe Sample Results
- Appendix B: Air Sampling Data Forms
- Appendix C: Data Chem Laboratories Reports
- Appendix D: Drum-Top Crushing Device Sampling and Study Plan
- Appendix E: Laboratory Methods and Modifications
- Appendix F: Wipe Sample Data and Discussion
- Appendix G: Sampling Error and Correction Efforts for Mass Balance Study
- Appendix H: Procedure for Collection of Samples from Pollution Control Media
- Appendix I: Letter from EPA Documenting Problems with Manufacturer D Device
- Appendix J: Peer Review of Mercury Lamp Drum-Top Crusher Study: Response to Comments

ACKNOWLEDGEMENTS

DTC Study Team

Paul Abernathy, ALMR
Catherine Bodurow, National Academy Institute of Medicine
Noah Borenstein, EPA Region 3
Alexis Cain, EPA Region 5
Stephen Coffee, CIH, Booz Allen Hamilton
Cathy Davis, EPA Office of Solid Waste
Suzanne Davis, California EPA Department of Toxic Substance Control
Mark Hanrahan, Booz Allen Hamilton
Greg Helms, EPA Office of Solid Waste
Jordan Murphy, Booz Allen Hamilton
Wayne Naylor, EPA Region 3
Tad Radzinski, EPA Region 3
Betty Ann Quinn, EPA Region 3
John Wesnousky, California EPA Department of Toxic Substance Control

Lamp Crushing Facilities

AERC Recycling Solutions
Earth Protection Services, Inc.

Equipment Manufacturers

Rick Beierwaltes, Air Cycle Corporation
Scott Beierwaltes, Air Cycle Corporation
Edward Domanico, Hazardous Material Specialist
David Dougall, Dextrite, Inc.
Albert Greene, Dextrite, Inc.
Don Seiler, Resource Technology, Inc.
Mike Seiler, Resource Technology, Inc.

Philips Lighting

Steve McGuire, Philips Lighting

Peer Reviewers

Dr. Carl Hebrandson, Minnesota Department of Health
Dr. Steven Lindberg, Oak Ridge National Laboratory
Michael McLinden, CIH, New Jersey Department of Environmental Protection

ACRONYMS

ACGIH	American Conference of Governmental Industrial Hygienists
ANOVA	Analysis of Variance
cc/min	Cubic Centimeters per Minute
DTC	Drum Top Crusher
EFT	Extended Field Test
EFTS	Extended Field Test Study
EPA	Environmental Protection Agency
EPSI	Earth Protection Services, Inc.
Hg	Mercury
LOEL	Lowest Observed Effect Level
MCE	Mixed Cellulose Ester
mg	Milligrams
mg/m ³	Milligrams per Cubic Meter
min	Minutes
mm	Millimeters
NA	Not Applicable
ND	Not Detected
NIOSH	National Institute for Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
PEL	Permissible Exposure Limit
PPE	Personal Protective Equipment
PVS	Performance Validation Study
RCRA	Resource Conservation and Recovery Act
REL	Recommended Exposure Limit
RfC	Reference Concentration
TLV	Threshold Limit Value
TSDF	Treatment, Storage, and Disposal Facility
TWA	Time Weighted Average
µg	Microgram

1. EXECUTIVE SUMMARY

The increasingly wide-spread use of energy-efficient, fluorescent lamps has had tremendous environmental benefits. However, mercury, a toxic chemical, is an essential component of fluorescent lamps. When lamps are broken, whether during storage, transport, disposal, or crushing, a substantial portion of the mercury contained in the lamp is released as mercury vapor. If the mercury vapor is not controlled or contained, it could be readily inhaled by anyone in the area and be hazardous to the health of those exposed individuals. Additionally, mercury released from broken lamps is persistent in the environment, where it can be chemically transformed to methylmercury, which is more toxic than elemental mercury and which bioaccumulates up the food chain.

When lamps are disposed of in a landfill, rather than recycled, a substantial percentage of the lamps are broken and virtually all of the mercury contained in the lamps is released into the environment. In addition, lamps may be broken during collection, shipping, or handling. Therefore, in order to protect human health and the environment, the Environmental Protection Agency (EPA) strongly encourages the safe handling and recycling of fluorescent lamps.

Lamp recycling can be done either by sending whole, boxed lamps to a recycler or by using a drum top crusher (DTC) device at the point where lamps are removed from service. DTC devices are designed to fit on the top of a 55 gallon drum in order to prevent the release of mercury vapors while crushing the fluorescent lamps into the drum below. These devices are used to reduce the volume of waste lamps so as to improve storage and handling and reduce shipping costs associated with fluorescent lamp recycling. Each method of recycling has potential benefits and draw-backs. This report examines DTC devices only and does not address whole lamp recycling or disposal of lamps.

As part of ongoing efforts to encourage safe management of mercury-containing equipment and fluorescent lamps, EPA conducted the Mercury Lamp Drum-Top Crusher Study (the Study). The objective of the Study was to evaluate the ability of four DTC devices to contain the mercury released from crushed lamps in terms of preventing worker exposure to adverse levels of airborne mercury resulting from the operation of these devices. The scope of the Study did not include evaluating other lamp handling methods or comparing other lamp handling methods to the use of DTC devices. This report presents the findings of the Study; the purpose of this report is not to endorse or discourage the use of DTC devices.

1.1 Study Overview

The original study design called for testing of four DTC devices from four different manufacturers: A, B, C, and D.¹ However, the Manufacturer D device was removed from the Study after two rounds of testing because of its inability to maintain

¹ *The focus of the Study was on DTC devices in general. It was not the intent of the study team to find the "best" manufacturer or to recommend a certain device. The manufacturers that participated in the Study may choose to identify themselves; however, for the purposes of this report, Manufacturer A, B, C, and D will not be identified.*

mercury vapor concentrations below the Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL) of 0.1 milligrams per cubic meter (mg/m³) during device operation (*refer to Section 3.5.3 and Appendix I*). Therefore, the executive summary focuses primarily on the three other DTC devices that completed the entire Study. A large amount of data was collected and analyzed throughout the Study. To fully understand the information gained, this report should be reviewed in its entirety.

Testing of the DTC devices was performed in a confined space, constructed for the Study, at three separate commercial lamp recycling facilities (the AERC Recycling Solutions facility in Ashland, VA, was used twice during the Study). Lamp recycling facilities were used as the sites for the Study to ensure compliance with all state requirements, to take advantage of the availability of spent lamps that were sent to them for recycling, and to facilitate appropriate recycling of the lamps crushed during the Study. The containment structure was used in order to isolate the Study from background mercury present in the facilities due to regular lamp recycling operations (*refer to Sections 4.2 and 6.1 for information about background mercury levels*) and also to test a “worst-case” scenario for the type of environment in which a DTC device may be operated (i.e., a room with low ventilation rates). Operator exposures would be expected to be lower than found in this Study if a DTC device is operated in a room with higher ventilation rates than used in this Study.

Concentrations of mercury in the air were measured using two Jerome Mercury Vapor Analyzers (Jerome analyzers) and using National Institute for Occupational Safety and Health (NIOSH) Analytical Method N6009 and Draft Analytical Method N9103 (*refer to Appendix E*). Surface wipe samples (from the inside of the containment structure), unbroken lamps, and bulk samples of crushed lamps and pollution control media were also collected and analyzed for mercury using procedures described in Appendix E. A number of observations about possible mercury exposure, DTC operation, and operational problems with the devices tested were made based on data collected over a range of conditions, including:

- Operational period – normal crushing
- Operational period – drum changes and filter changes
- Operational period – improper assembly/leakage of seals
- Non-operational period – broken lamps staged for crushing
- Non-operational period – overnight (full, or partially-full, 55-gallon drum)

After the Study was completed, each manufacturer was able to review the results specific to their device. The purpose of this was to make it possible for the manufacturers to consider the results of the Study and make any modifications to their devices based on these results.

In September 2004, EPA prepared a draft report for the Study, and RTI International, under contract to EPA, arranged for an independent review of the draft report, by recognized technical experts. This review was conducted by letter format in a manner consistent with EPA’s Office of Research and Development and Science Policy Council *Peer Review Handbook* (December 2000). Many substantive comments

were made by the reviewers. As a result of these comments, EPA extensively revised this report (*refer to Appendix J for the peer review comments and EPA's responses to the comments*).

1.2 Observations

All three of the devices that completed the Study usually maintained mercury levels below the OSHA PEL within the containment structure and in the operator breathing zone, and one device generally maintained mercury levels below the American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit value (TLV) of 0.025 mg/m³ during normal lamp crushing operations.² However, this Study also demonstrated that during operation of a DTC device, under the operating conditions that existed during the Study, the operator can be exposed to levels of mercury above the TLV and the PEL. Specifically:

- Operator exposure only remained below the OSHA PEL and ACGIH TLV values when the three well-designed DTC devices were operated optimally. That is, when a sub-standard device was used, and when the well-designed devices were not performing optimally or were improperly assembled, operator exposures increased above these levels. (Note: In most of the cases of potential mercury exposure experienced in this Study, the operator only realized that the device being used was not effectively containing mercury because a real-time mercury vapor monitor, equipped with an alarm, was used. The exception to this was that when one of the DTC devices was incorrectly assembled and was, therefore, releasing much more mercury than it would have under normal operating conditions, the operator noted white powder coming out of the connection between the feed tube and the main device assembly that was missing a seal.)
- Measurable concentrations of mercury were detected in the air in the lamp recycling facilities (background air sample results ranged from 0.00052 mg/m³ to 0.044 mg/m³).
- There is an increased risk of mercury exposure when full drums are replaced with empty ones, an operation inherent in the use of a DTC device. Drum changes typically resulted in short-term excursions above the PEL. These high mercury levels decreased after the drum changes were complete. Several short-duration, high-volume air samples were taken during drum changes to estimate maximum possible worker exposure. Over 70 percent of these samples were above the PEL.
- Performance of DTC devices may change over the lifetime of the device and under varying environmental conditions. Two of the devices showed a significant

² Throughout this report the ACGIH TLV is used as a point of reference with which the analytical air samples are compared. The TLV is an eight-hour, time-weighted average; however, the analytical air samples generally represent one to three hour sampling periods (*refer to Section 3.1 for a description of the analytical air samples and Appendix A, Table 1 for individual sample durations*). Sample results that are greater than the TLV should not necessarily be interpreted to indicate that use of one of the DTC devices included in the Study would result in operator exposure above the TLV because exposure would need to be averaged over an eight-hour day and a 40-hour week.

decrease in their ability to contain mercury after being used to crush eight drums of lamps. (Note that changes in the test environment, such as increased ambient temperature, may have had some affect on device performance.)

- Minor mistakes in assembly of a DTC device can significantly affect its ability to capture mercury. A leak on one device notably raised mercury levels for the samples in the operator's breathing zone and caused mercury concentrations to exceed the PEL for the area sample collected near the leak. The leak was located at one of the seals and was due to improper device assembly.
- Overnight tests, which were performed during non-operational periods, were inconclusive. Further study would be needed to determine whether or not drums containing crushed lamps with the DTC device attached to the top of the drum, but not in operation, would release mercury in quantities that pose a risk.
- Finally, in one test, the operation of the Manufacturer D device resulted in ambient mercury concentrations of 0.89 mg/m³, nine times the OSHA PEL, even though exclusively low mercury, Alto® lamps, manufactured by Phillips Lighting, were used.³ The results from this test illustrate that mercury vapor can exceed established levels even if the lamps being crushed in the DTC device (i.e., low-mercury lamps) are not identified as hazardous wastes.

Use of DTC devices allows several hundred crushed lamps to occupy the space that 40 or 50 whole lamps would occupy, thereby reducing storage and shipping costs. This leads to a reduction in recycling costs on a per-lamp basis. Crushing lamps before shipment also has the advantage of allowing the lamps to be shipped to the recycler in a well-sealed, durable container that is unlikely to release substantial amounts of mercury. Shipping whole lamps inevitably leads to some breakage and potential release; with careful handling, the amount of breakage can be reduced.

The DTC devices evaluated as part of this Study all released some mercury when used. The mercury released during DTC device use will create certain new mercury exposure situations. Exposure will be experienced by the DTC device operator and any assistants handling lamps or working directly with the DTC device. Less direct mercury exposures that could be created by DTC device use include anyone working in or visiting buildings in which DTC devices are used. To eliminate these unnecessary indirect mercury exposures, the ventilation of the lamp crushing room would need to be separate from the general building ventilation system, as is done at industrial lamp recycling facilities.

Additional findings regarding the design and operation of DTC devices, and future areas of study, are discussed in Chapter 7.

³ The Alto® lamps typically contain three to five mg of mercury per lamp and are advertised as "TC compliant" by the manufacturer, meaning that the lamps would generally not be classified as hazardous waste when discarded.

2. SCOPE OF STUDY

2.1 Mercury Fluorescent Lamp Disposal

On May 11, 1995, EPA adopted new streamlined hazardous waste management regulations under the Resource Conservation and Recovery Act (RCRA) governing the collection and management of certain widely generated hazardous wastes termed “universal wastes” (60 FR 25491). The new hazardous waste management regulations were designed to facilitate the environmentally-sound collection and proper management of certain hazardous waste batteries, pesticides, and mercury-containing thermostats. Hazardous waste lamps were added to the federal list of universal wastes on January 6, 2000 (64 FR 36465). On August 5, 2005, the category of mercury-containing thermometers was removed from the federal list, and a broader category, mercury-containing devices, was added to the federal list of universal waste (70 FR 45508).⁴ The universal waste regulations are set forth in 40 CFR Part 273.

By introducing flexibility into the storage, transport, and collection of universal hazardous wastes, the universal waste rule seeks to encourage the development of programs to reduce the quantity of hazardous wastes going to municipal solid waste landfills or combustors and to assure that wastes subject to the universal waste system go to appropriate hazardous waste recycling facilities or treatment, storage and disposal facilities (TSDF). Handlers of universal wastes are subject to more flexible standards for storing, transporting, and collecting these wastes than under full Subtitle C regulation. Hazardous waste lamps are regulated as a universal waste in order to encourage lamp recycling, facilitate better lamp management, and improve compliance with the hazardous waste regulations.

2.2 Study Overview

The Study was performed at three different existing, large-scale lamp recycling facilities. Four DTC devices were originally included in the Study, but only three of the devices completed the Study (*refer to Section 3.5.3*). Analytical air samples were collected to quantify mercury concentrations inside the containment structure and operator exposure to mercury, and a Jerome Mercury Vapor Analyzer was employed to provide real-time measurements of ambient mercury vapor concentrations. Additional samples were collected for the Mass Balance Study.

2.2.1 Study Location

The Study was conducted at mercury lamp recycling facilities for a number of reasons. One critical reason was that these facilities are permitted for hazardous waste lamp processing. Because some states require permits for the use of a DTC device, reliance on the facilities’ existing permits allowed the Study to be conducted more quickly and inexpensively and was a key factor in the decision to fund and

⁴ *Mercury-containing thermometers are a type of mercury-containing devices, and thus, are still included in the federal list of universal waste under the broader category.*

conduct the Study. The lamp recycling facilities also provided sufficient numbers of fluorescent lamps to complete each phase of the Study, as well as valuable assistance by receiving and storing the DTC devices, providing sufficient space to conduct the Study, and recycling the crushed lamps generated in the course of the Study.

The disadvantage of conducting the Study at lamp recycling facilities was that each facility had existing background concentrations of mercury that could potentially confound study results. The detected background concentrations are presented in Section 4.2, and apparent effects on study results are further discussed in Section 6.1.

In each facility, the office space was segregated from the work area for the industrial lamp crushing activities. However, the facility layout was different at each study location, which affected facility background mercury levels. AERC Ashland had two large bays, one of which housed an industrial lamp crusher while the other bay was used for the Study. A large doorway separating the two bays was kept closed for most of the study duration. This allowed the DTC crushing activities to be isolated from direct mercury emission sources, but fugitive emissions from the industrial recycling operations were present in the bay used for the Study. AERC Melbourne provided an isolated bay for the Study, and the door between this bay and the main bay where AERC operations took place was closed for the duration of the Study. At EPSI Phoenix, the Study was conducted in the same bay as the facility's industrial-size lamp crusher, resulting in somewhat higher mercury background concentrations, as compared to the other test sites (refer to Sections 4.2 and 6.1).

2.2.2 Containment Structure

During the Study, the DTC devices were operated inside a fabricated containment structure. This structure provided a "worst case" environment in which to evaluate the performance of each device by minimizing ventilation and containing mercury emissions in an enclosed space.⁵ The structure was also intended to isolate the DTC operations from the background mercury present in the lamp recycling facilities, although it did so only to a limited extent. The containment structure consisted of a frame constructed from ¾ inch PVC tubing and covered with a single layer of four-millimeter (mm) thick polyethylene sheeting on the walls, floor, and ceiling (refer to *Photograph 2. 1, Photograph 2. 2, Photograph 2. 3, and Photograph 2. 4*).⁶

⁵ Operator exposures would be expected to be lower than found in this Study if a DTC device is operated in a room with higher ventilation rates than used in this Study.

⁶ Mercury has been shown to sorb onto and permeate through polyethylene. Another material, such as vinyl, may have been more appropriate for this Study. During the first set of tests in Ashland, VA, the measurements of the containment structure were 12 feet (ft.) by 12 ft. by 10 ft. high to ensure that there was adequate space to operate each device properly. The containment structure ceiling height was lowered to 8 ft. in Phoenix, AZ, to expedite test set-up. However, three of the devices had feed chutes angled upward, and, as lamps were being fed into the device, they scraped against the ceiling of the containment area. Therefore, containment structures measuring 10 ft. in height were utilized in Melbourne, FL, and the second set of tests in Ashland, VA.



Photograph 2.1: AERC Ashland Facility - Containment Structure - First Visit



Photograph 2.2: EPSI Phoenix Facility - Containment Structure



Photograph 2.3: AERC Melbourne Facility - Containment Structure



Photograph 2.4: AERC Ashland Facility - Containment Structure - Second Visit

The polyethylene walls, floor, and ceiling were changed before testing each device at each location. The containment structure used a “flap” door to allow entry and exit by the operators. This door, which overlapped the walls, limited the amount of air exchanged between inside and outside the containment structure; however, it was not possible to entirely eliminate air exchanges.

In the initial parts of the Study, the polyethylene was measured and cut inside the facility, next to the containment frame. This was done during Phase I of the Performance Validation Study in Ashland, Virginia and in the first Extended Field

Test in Phoenix, Arizona. However, results from the pre-test wipes of surfaces within the containment structure (taken prior to crushing any bulbs in the DTC device) indicated that mercury was detected on the polyethylene sheeting (*refer to Appendix A, Table 2*). The field team determined that the mercury contamination on the sheeting was most likely attributable to measuring and cutting the polyethylene on the contaminated floor inside the recycling facility, as well as deposition of background airborne mercury from ongoing facility operations. To reduce the potential for contaminating the polyethylene sheeting during construction of the containment structure, staging areas for measuring and cutting the polyethylene sheets were established in the parking lot outside the facility for the second Extended Field Test in Melbourne, Florida and used for all of the remaining tests.

2.2.3 General Procedures

At each stage of the Study, the DTC devices were generally operated in conformance with the manufacturer's operating manual. The only deviation from the operating manual was that more lamps than recommended by one manufacturer (Manufacturer C) were crushed during each round of the Extended Field Test Study.⁷ DTC device operations included device assembly and placement on the drum, routine lamp crushing operations, and drum and filter changes. When the DTC device manufacturer representatives were available and on-site, they were allowed to provide further operational instructions specific to their device. In the first phase of the Performance Validation Study, representatives of the four manufacturers were required to be present during the operation of their device. For the remainder of the Study, DTC device representatives were invited to observe, but their presence was not required to include their device in the Study.

Each DTC device was operated according to the following procedure:

1. Construct the containment structure (*described in Section 2.2.2*);
2. Calibrate the Jerome analyzer and take background readings;
3. Equip the operator with required personal protection equipment (PPE), Tyvek® coveralls, respirator, Kevlar® gloves, etc., and personal air samplers;
4. Assemble the DTC device on top of the collection drum inside the containment structure;
5. Ensure that the device is properly assembled and the filter is in place;
6. Collect pre-test wipe samples.
7. Bring spent lamps into the containment structure;

⁷ The operator's manual for the Manufacture C device specifies that the device should only be used to crush one drum of lamps per eight-hour period in order meet with OSHA safety standards.

8. Power up the device (runs off of 110-volt, single-phase service) and ensure negative pressure inside the device has been activated;
9. Begin feeding lamps (feed rate during the test was between 30 and 40 bulbs per minute using a two-person crew; for a one-person crew, the rate is expected to be closer to 20 to 25 bulbs per minute).
10. After filling the prescribed number of drums, collect post-test wipe samples from the device and from the walls, ceiling, and floor of the containment structure.

The specific methodologies employed during each of the three studies are discussed in detail in Chapter 3 of this report.

2.2.4 Study Components

The DTC Device Study was divided into three distinct studies.⁸ The basic elements of each study are described below.

- Performance Validation (PVS) – sought to (1) quantify ambient mercury vapor concentrations inside the containment structure and personnel exposure during the operation of several DTC devices, and (2) establish initial baseline air concentrations of mercury (Phase I) for comparison to air concentration measurements after DTC devices have processed enough fluorescent lamps to fill approximately eight 55-gallon drums (Phase II).
- Mass Balance Study – sought to estimate the overall capture efficiency of each device by quantifying (1) the total mass of mercury contained in the lamps fed into the DTC device, and (2) the masses of mercury retained in the drum, captured by the DTC device’s pollution control equipment, and released into the ambient environment as mercury vapors, aerosols, and particulates containing mercury. Samples for the Mass Balance Study were collected during Phase I of the PVS.
- Extended Field Test Study (EFTS) – sought to quantify and compare ambient mercury concentrations and worker exposure during the operation of the different DTC devices at several different locations, which represented a range of potential operating conditions. The EFTS was designed to evaluate the mercury vapor capture efficiency of each DTC device in a simulated occupational environment, with a focus on assessing the potential for human (operator) exposure to mercury as a result of DTC use. The following tests were performed as additional components to the EFTS.
 - Overnight Test – was conducted during EFT #1, EFT #2, and EFT #3 and sought to quantify the amount of mercury that may escape the DTC device and full drum assembly when the device is not in operation.

⁸ Because of the exploratory nature of the Study and the desire to maximize data collection while in the field, certain ad hoc changes to the original sampling plan were introduced not always with the ability to pre-define data quality objectives such as sample sizes or acceptable error ranges.

- “U” Shaped Lamp Test - was conducted during EFT #3 and sought to evaluate airborne mercury levels from two DTC devices, while processing “U” shaped lamps (U-tubes).
- Box Test - was conducted during EFT #2 and EFT #3 and sought to determine the degree to which shipping boxes containing broken lamps located inside the containment structure contributed to elevated mercury concentrations detected during early phases of the DTC Study.

2.2.5 Equipment

The DTC Device Study evaluated crushers from four different manufacturers:

- Manufacturer A (*Photograph 2. 5*)
- Manufacturer B (*Photograph 2. 6*)
- Manufacturer C (*Photograph 2. 7*)
- Manufacturer D (*Photograph 2. 8*)

All manufacturers except Manufacturer A provided new, unused DTC devices for the Study. Manufacturer A provided a prototype machine that was used prior to the Study, but was cleaned and decontaminated by the manufacturer before it was sent for testing in the Study. For reasons that are discussed in Section 3.5.1 of this report, the Manufacturer D device was tested only during Phase I of the PVS and the first round of the EFTS.



Photograph 2. 5: Manufacturer A Device



Photograph 2. 6: Manufacturer B Device



Photograph 2.7: Manufacturer C Device



Photograph 2.8: Manufacturer D Device

Table 2.1 summarizes the manufacturer information contained in the operating manual that was provided with each machine.

Table 2.1: DTC Device Equipment Operating Manual Comparison

	Manufacturer A	Manufacturer B	Manufacturer C	Manufacturer D
Filter Maintenance Change Frequency				
Particulate Filter	Change every 100,000 Lamps	Change Every 2,400 Lamps	Change Every Full Drum	Change Every 300 Lamps
HEPA Filter	NA	NA	Change Every 10 Drums	Change Every 10 Particulate Filters or 3,000 Bulbs
Carbon Filter (quantity)	85 lbs	Not Specified (Approx. 13 oz)	22 lbs	Not Specified (Approx. 5 lbs)
Filter Change Frequency	Change After 750,000 Lamps	Change Every 2,400 Lamps. Lamp Counter Shuts Down Motor at Lamp Count of 2,400	No Change Frequency Specified	Change Annually or Every 10,000 Lamps
Operating Manual has Filter Change Instructions or Procedure For:	Particulate and Carbon Filter	Filter Cartridge (Contains Particulate and Carbon)	Particulate and HEPA Filter	Particulate, HEPA and Carbon
Operating Manual has a Log Form to Document Filter Maintenance	No	No	Yes	No
Health and Safety				
Operating Manual Specifies Operational Time Limits	No	No	Do not crush more than one drum per Eight-Hour Shift	No
Operating Manual Requires/Recommends Respirator	Required If indicated by Direct Reading Mercury Vapor Instrument Results	No	No	Required (Half Face Respirator)
Operating Manual Requires/Recommends Safety Glasses	Required	Required	Required	Required

	Manufacturer A	Manufacturer B	Manufacturer C	Manufacturer D
Operating Manual Requires/Recommends Gloves	Recommended	No	Required	Required
Operating Manual Requires/Recommends Hearing Protection	Recommended	No	No	No
Operating Manual Requires/Recommends Coveralls	Required	No	No	No
Operating Manual Requires/Recommends Air Monitoring for Mercury Vapor	Recommended	No	No	No
Operation				
Operating Manual has Equipment Operating Instructions or Procedure	Yes	Yes	Yes	Yes
Operating Manual has Shutdown Instructions or Procedure	Yes	Yes	Yes	Yes
Operating Manual Shutdown Instructions or Procedure Requires use of Vacuum System During Equipment Shutdown	Automatic Operation of Vacuum System Continuously while Device is attached to Drum of Crushed Lamps	Manually Allow Disposer to Run for 2 to 3 Minutes When Finished Using Machine	Automatic Purge for 10 Seconds after Shutdown	NA
Operating Manual has Drum Change Instructions or Procedure	Yes	Yes	No	Yes
Features and Controls				
Device Has a Drum Full Indicator	Yes	No	Yes	No
Device has Automatic Lamp Counter	No	Yes - Shuts Down Motor and provides Audible and Visual Alarm at 800 Count	No	No
Device has Lid Open Indicator/Interlock	Yes Indicator with Interlock to Prevent Motor Start	No	Yes Indicator with Interlock to Prevent Motor Start	No
Device has Programmable Logic Controller (PLC)	Yes	No	No	No
Device has Emergency Stop Switch	Yes - Crushing head will not engage unless negative pressure system is operating	No	Yes	No
Listed Lamp Capacity	400- 500 Lamps (T8 or T12 type)	800 Four-Foot Lamps	NA	1200 Four-Foot Lamps
Mercury Hazard Information				
Operating Manual Contains Mercury Hazard Information and Reference To OSHA Mercury Exposure Limits	Mercury Hazard	NA	Mercury Hazard	Mercury Hazard OSHA
Regulatory Information				

	Manufacturer A	Manufacturer B	Manufacturer C	Manufacturer D
Operating Manual Provides Information on Universal Waste	Yes	No	Yes	Yes
Operating Manual Provides Information on Lamp Recycling	Yes (Minimal)	No	Yes (Comprehensive)	Yes
Operating Manual Identifies Spent Pollution Control Media as Hazardous Waste	Specified for Filter and Carbon	Not Specified	Specified for Spent Particulate and HEPA Filters Only	Specified for Particulate, HEPA, and Carbon Filter
Operating Manual Provides Disposal Instructions for Spent Pollution Control Media	General Instruction	General Instruction	Place in Drum for Disposal with Crushed Lamps	Not Specified
Air Emissions				
Operating Manual Contains a Statement about the Device's Ability to Control Mercury Emissions	Yes "...is equipped with state of the art components to capture mercury vapors generated by crushing lamps to ensure a safe environment surrounding your drum top crusher."	No	Yes "...will remove virtually all airborne powder and mercury vapor (well over 99%)."	Yes "Crushes any length of fluorescent lamp in seconds into fragments while recovering 100% of the hazardous mercury vapors."

2.3 Testing Locations and Study Chronology

The Study was conducted at three locations over approximately five months. Table 2. 2 provides the order in which the devices were tested at each location. The following is a chronology of the DTC Device Study:

- Performance Validation Study, Phase I, AERC Recycling Solutions facility in Ashland, Virginia (AERC Ashland), from February 24, 2003 through February 28, 2003.
- Mass Balance Study, AERC Recycling Solutions facility in Ashland, Virginia (AERC Ashland), from February 24, 2003 through February 28, 2003.
- Extended Field Test Study, Test #1, Earth Protection Services, Inc. (EPSI) facility in Phoenix, Arizona (EPSI Phoenix), from March 24, 2003 through March 28, 2003.
- Extended Field Test Study, Test #2, AERC Recycling Solutions facility in Melbourne, Florida (AERC Melbourne), from April 28, 2003 through May 2, 2003.
- Extended Field Test Study, Test #3, AERC Recycling Solutions facility in Ashland, Virginia, from June 9, 2003 through June 13, 2003.

- Performance Validation Study, Phase II, AERC Recycling Solutions facility in Ashland, Virginia, from June 9, 2003 through June 13, 2003.

Table 2. 2: Order of Device Testing for DTC Device Study

Study	Date	Device
Performance Validation I	2/26/2003	C
	2/27/2003	A
	2/27/2003	D
	2/28/2003	B
Extended Field Test #1	3/24/2003	A
	3/25/2003	B
	3/26/2003	D
	3/27/2003	C
Extended Field Test #2	4/29/2003	B ^a
	4/30/2003	C
	5/1/2003	A
	5/2/2003	B ^a
Extended Field Test #3 & Performance Validation II	6/10/2003	A
	6/11/2003	B
	6/12/2003	C

^a The device from Manufacturer B was tested twice during EFT #2. Refer to Section 3.5.1.

3. DATA COLLECTION METHODOLOGY

This chapter describes the procedures used to collect the various study samples, including descriptions of sampling and analysis methods and sample locations. Airborne mercury was tested using two methods:

- Analytical Air Samples – known quantities of air drawn through collection media designed to capture airborne mercury particulates and mercury vapor over extended periods of time and
- Jerome Analyzer Measurements – direct reading air samples of ambient mercury concentrations using the Jerome Mercury Vapor Analyzer.

Air samples were collected in the operator's breathing zone during normal operation, filter changes and drum changes, and in selected locations within the containment structure. Jerome measurements were taken both inside and outside the containment structure. Photograph 3. 1 shows the air sampling pump and Jerome analyzer inside the containment structure.



Photograph 3. 1: Air Sampling Pumps and Jerome Mercury Vapor Analyzer

Several additional types of samples were collected for the Mass Balance Study.

- Wipe samples – Wipes of surfaces inside the containment structure were taken to characterize the amount of mercury deposited due to DTC device operation.
- Crushed lamps – Samples were taken out of a full drum after crushing operations (approximately eight inches deep into the drum).
- Pollution control media – Bulk samples were taken of the pollution control media (HEPA filter, pre-filter, and carbon filter) of each DTC device.
- Whole lamps – Samples of the spent, unbroken, Phillips Alto® lamps were taken.

The sample collection methodology, sample analysis, and sampling locations are discussed below. Section 3.1 describes the analytical air samples collected for the Performance Validation Study (PVS), including air samples used in the Mass Balance Study, and the Extended Field Test Study (EFTS). Section 3.2 describes the Jerome

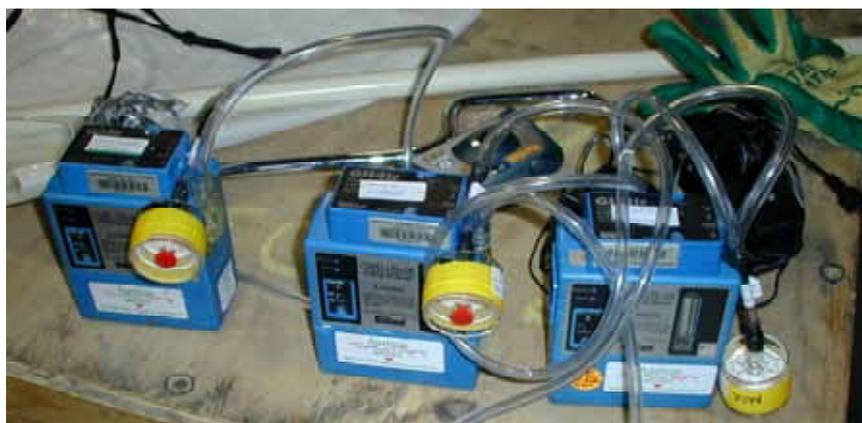
analyzer samples for the PVS and the EFTS. Section 3.3 details the methodology used for collecting the bulk samples used in the Mass Balance Study. Section 3.4 addresses the methodology for measuring surface contamination using wipe samples. Finally, Section 3.5 describes modifications and deviations to the test protocol based on operational difficulties encountered during testing.

3.1 Analytical Air Samples

Personal and area air samples were collected at numerous locations at each facility to support different aspects of the Study. The personal air samples were collected from the operator's breathing zone during operation and during drum changes, and the area samples were collected near the feed tube and the exhaust. Background samples and overnight samples were also collected.

Air samples were collected and analyzed, to measure airborne mercury concentrations in the aerosol and vapor phases, in accordance with the National Institute for Occupational Safety and Health (NIOSH) draft Analytical Method N9103⁹ and NIOSH Analytical Method N6009,¹⁰ respectively. The air samples were collected by drawing a known volume of air through two different media specific to the collection of mercury in each phase. A 37mm mixed cellulose ester (MCE) filter was first in line to capture mercury aerosols, and a Hydrar solid sorbent tube was second in line, attached to the MCE filter, to capture mercury vapors. The reporting limit for both the MCE filter and the Hydrar tube is 0.01 µg /sample. This reporting limit is based on the lowest calibration standard analyzed at the laboratory.

Air samples were collected by drawing known volumes of air through the sampling media using Sensidyne GilAir 5RC air sampling pumps equipped with multi-flow adapters (*refer to Photograph 3. 2*).



Photograph 3. 2: Sensidyne Air Sampling Pumps

The Sensidyne pumps were calibrated on site both before and after use, according to the manufacturers' specifications, using the BIOS DC-Lite calibrator as a primary standard. The calibration data are contained in Appendix B. During calibration, the

⁹ At the time of this Study, Method N9103 (*refer to Appendix E*) was in draft form. It is undergoing approval by NIOSH.

¹⁰ NIOSH Manual of Analytical Methods, 4th ed., Method N6009, Issue 2, 1994. A copy can be found in Appendix E.

airflow was adjusted in order to establish a known flow rate. The flow rates of the pumps varied depending on sample type. Ranges of pump flow rates are listed below in cubic centimeters per minute (cc/min).

- Background Samples: 136 – 221 cc/min
- On Operator, During Drum Filling: 135 – 212 cc/min
- On Operator, Filter Changes and Drum Changes:¹¹ 154 – 261 cc/min
- On Operator, Ceiling Samples: 247 – 260 cc/min
- At Exhaust of the Device: 121 – 253 cc/min
- At Feed Tube of the Device: 125 – 210 cc/min
- Overnight Samples: 100 – 163 cc/min

At each facility, three sets of laboratory blanks were prepared at the beginning of each study. Three MCE filters and three Hydrar-sorbent tubes were labeled and placed in storage in the calibration room. Two sets of field blanks were prepared for each day of sampling at each location. Two MCE filters were labeled, the caps were opened and replaced, and the filters were placed into storage in the calibration room. Two Hydrar-sorbent tubes were labeled, the ends of the tubes were broken and capped, and the tubes were placed into storage in the calibration room.

Upon arrival at each study location, two background area samples were collected just outside the containment structure. These samples were collected for a period of time ranging from 3.5 hours to 5 hours before any of the DTC devices were operated. The purpose of these samples was to provide a measure of background conditions inside the lamp recycling facility.

Personal and area air samples were collected within the containment structure for the entire time it took the operator to fill one to two 55-gallon drums with crushed lamps for each DTC device (approximately 60 to 110 minutes). Personal air samples were collected by placing the air pumps on the operator's belt and securing the collection media on the operator's shoulder in order to collect air from within his/her breathing zone (*refer to Photograph 3. 3, Photograph 3. 4, and Photograph 3. 5*). The personal air samples were collected in order to measure the operator's exposure to airborne mercury during different operational activities.

Groups of personal air samples were also collected separately during the filter change and drum change processes for each device, as appropriate. Once the filter change or drum change, which took between two and 10 minutes, had been completed, the operator remained inside the containment structure to allow at least 12 full minutes for sample collection to ensure that the amount of mercury captured in the sample tube was greater than the detection limit (0.01 µg/sample).

¹¹ *When a sample is referred to as a "Filter Change Sample," it is a personal air sample taken when the DTC device filter was changed at a time other than during a drum change. This sample is specific to the Manufacturer C and Manufacturer D devices. The Manufacturer A device did not require a filter change during the Study. For the Manufacturer B device, the filter was changed at the same time that the drum was changed, so a separate "Filter Change Sample" was not needed. Personal air samples that were taken when the drum was changed are referred to in this report as "Drum Change Samples."*



Photograph 3. 3: Feeding Bulbs into the Manufacturer A Device



Photograph 3. 4: Feeding Bulbs into the Manufacturer B Device



Photograph 3. 5: Feeding Bulbs into the Manufacturer C Device

During portions of the Study, short-term “ceiling” air samples were taken. The ceiling samples were another set of personal air samples, which were collected to attempt to quantify airborne mercury concentrations at the estimated time of

maximum exposure. Readings taken on the Jerome analyzer indicated that maximum exposure conditions most probably occurred during drum changes. Thus, the ceiling samples were collected during one of the drum changes for each device during PVS-Phase II, EFT #2, and EFT #3. Two samples were collected on the operator's shoulder, in sequence; each ceiling sample was collected for four minutes.

Area samples were collected by placing the air pumps and collection media on elevated surfaces in specified areas (*refer to Photograph 3. 1 and Photograph 3. 7*) to measure the general airborne mercury concentration inside the containment structure. During operation of each device, four area samples were collected in each phase of the PVS, and two area samples were collected in all three parts of the EFTS.

In addition to the area samples collected during the operation of each device, overnight samples were collected as part of the EFTS. The purpose of the overnight samples was to measure the release of mercury when the DTC devices were not operating, thus simulating a realistic field scenario. At the end of each day of the EFTS, each DTC device remained inside the containment structure, attached to a drum containing crushed lamps, once crushing activities for the second drum were completed. Two to three area air samples were then collected for six to 18 hours. At EPSI Phoenix, the overnight samples were collected inside the containment structure, near the device exhaust and device feed tube. During EFT #2 and EFT #3, overnight samples were collected outside of the containment structure in addition to the samples collected at the device exhaust and device feed tube inside the containment structure.

At the end of each day of sampling, the sampling pumps were removed from the containment structure and taken to the calibration room to be post calibrated. The sampling trains were taken apart, and the mixed cellulose filters and Hydrar tubes were immediately capped on both ends. All information regarding sample duration and air pump calibrations were recorded on air sampling data forms at that time (*refer to Appendix B*). The capped samples were then placed in labeled re-sealable plastic bags and kept at the facility.

At the completion of the sampling event at each study location, all analytical air samples were collected, packaged, and shipped via Federal Express to Data Chem Laboratories, Inc. (Data Chem), along with the completed chain-of-custody forms. Data Chem is an American Industrial Hygiene Association accredited laboratory located in Salt Lake City, Utah. Air sampling media were supplied by Data Chem.

The following sections provide details on the sampling protocol used for each stage of the DTC Device Study.

3.1.1 Performance Validation Study

Phase I of the PVS was conducted February 24-28, 2003, at the AERC facility in Ashland, Virginia (AERC Ashland), and it included the DTC devices from all four manufacturers. AERC Ashland was also the site location for Phase II of the PVS. This phase was conducted June 9-13, 2003 and included 3 DTC devices

(Manufacturer A, Manufacturer B, and Manufacturer C). (Refer to Section 3.5.3 for a discussion of the exclusion of the Manufacturer D device.)

The PVS was conducted to examine the effectiveness of each device in capturing and retaining mercury vapors and any potential change in effectiveness over time. The Study compared the results among the different devices when new, and after a pre-determined period of operation during which numerous lamps were processed through each device. The analytical air samples collected for PVS-Phase I were also used in the Mass Balance Study to calculate the release of mercury from the devices.

Table 3. 1 lists the air samples collected for the PVS, and the sampling locations are shown in Figure 3. 1.

Table 3. 1: Analytical Air Samples Collected during the Performance Validation Study

	Type of Sample	# of Samples	Approximate Duration (min)
Personal Samples	1 on each shoulder – filling the drum	2	50 – 115
	1 on left shoulder – during drum/filter change	1-2 ^{a, b}	6 – 18
Area Samples	Near device exhaust	2	50 – 115
	Near device feed tube	2	50 – 115

^a Manufacturer A: 1 Drum Change Sample

Manufacturer B: 1 Drum Change Sample

Manufacturer C: 1 Filter Change Sample, 1 Drum Change Sample

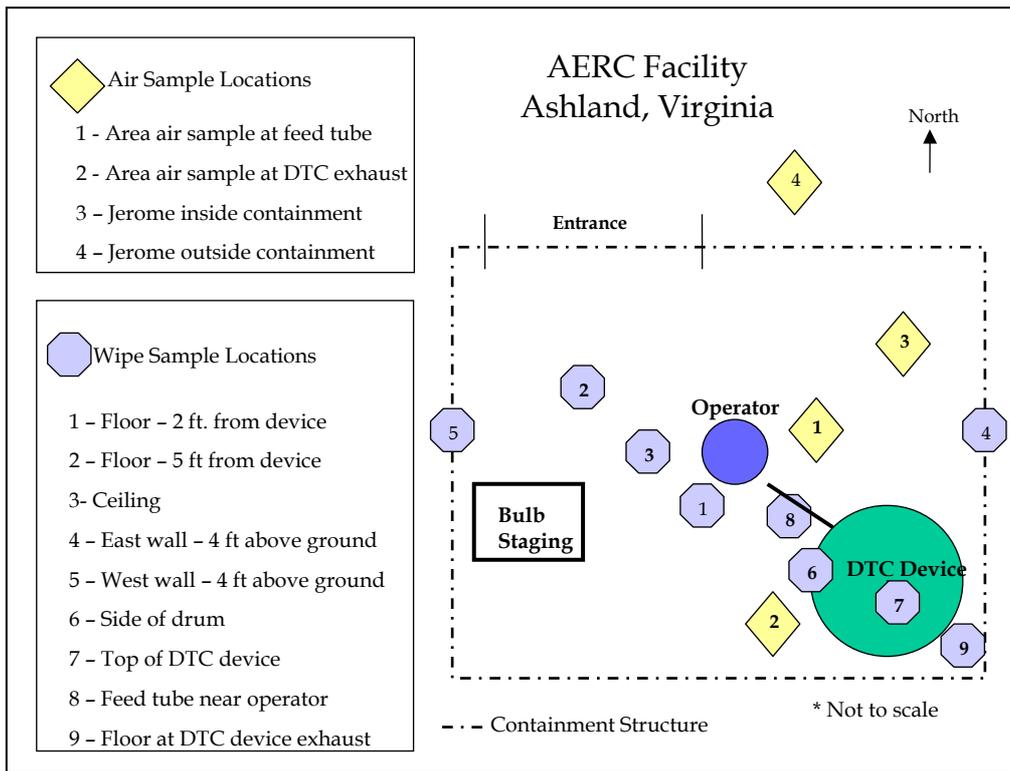
Manufacturer D: 1 Filter Change Sample, 1 Drum Change Sample (only Phase I).

^b The filter change samples for the Manufacturer C device were taken when the drum was half full (~350 bulbs).

Manufacturer C and Manufacturer D devices required one filter change per drum in addition to the filter changes performed during drum changes. The personal sample on the shoulder of the operator during the filter change for the Manufacturer C device was performed when the drum was half full of fluorescent light bulbs, equivalent to approximately 350 crushed bulbs. This was true for all filter change samples collected for the Manufacturer C device throughout the DTC Device Study.

Due to exposure levels significantly above the OSHA PEL, only 276 bulbs were crushed in the Manufacturer D unit during Phase I of the PVS. The Manufacturer D device was removed from the study after EFT #1 (refer to Section 3.5.3), so the samples listed for this device in Table 3. 1 were only collected during PVS – Phase I.

Figure 3. 1: Sampling Locations for the Performance Validation Study and Extended Field Test #3



3.1.2 Extended Field Test #1

The EFTS was conducted to examine the ongoing performance of each device during extended use and over a range of environmental conditions. EFT #1 was conducted at the EPSI facility in Phoenix, Arizona (EPSI Phoenix), March 24-28, 2003, and it included four DTC devices (Manufacturer A, Manufacturer B, Manufacturer C, and Manufacturer D). Air samples collected during EFT #1 are described in Table 3. 2, and Figure 3. 2 shows the sample collection areas.

Table 3. 2: Air Samples Collected during Extended Field Test #1

	Type of Sample	# of Samples	Approximate Duration (min)
Personal Samples	1 on each shoulder - filling the drum	2	125 - 200
	1 on left shoulder - during drum/filter change	1-3 ^{a, b}	12 - 36
Area Samples	Near device exhaust	1	125 - 200
	Near device feed tube	1	125 - 200
Overnight Samples	Near device exhaust	1	440 - 780
	Near device feed tube	1	420 - 780

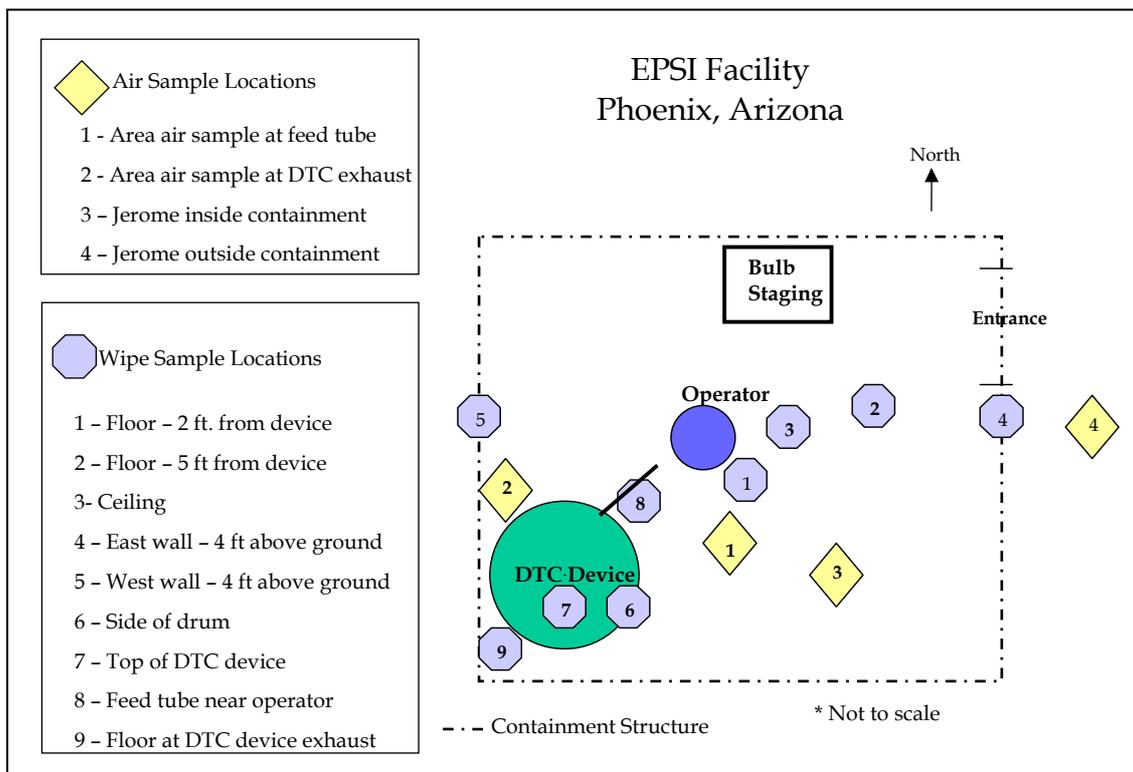
^a Manufacturer A: 1 Drum Change Sample
 Manufacturer B: 2 Drum Change Samples
 Manufacturer C: 2 Filter Change Samples, 1 Drum Change Sample
 Manufacturer D: NONE

^b The filter change samples for the Manufacturer C device were taken when the drum was half full (~350 bulbs).

The Manufacturer D device was removed from the Study during Extended Field Test (EFT) #1 because Jerome measurements of mercury vapor concentrations in the

containment structure reached 0.59 mg/m^3 , nearly six times the OSHA PEL. Further information can be found in Section 3.5.3.

Figure 3. 2: Sampling Locations for Extended Field Test #1



3.1.3 Extended Field Test #2

Air samples were collected during EFT #2 at the AERC facility in Melbourne, Florida (AERC Melbourne), April 28 - May 3, 2003, for three DTC devices (Manufacturer A, Manufacturer B, and Manufacturer C). Short-term ceiling air samples were introduced into the Study during this round of testing. As described above, ceiling samples were air samples collected over a short duration in time in an attempt to quantify airborne concentrations at the estimated time of maximum exposure.

Readings taken on the Jerome analyzer indicated that maximum exposure conditions most probably occurred during drum changes. Drum change sample results from EFT #1 showed that the ambient concentration of mercury is sufficiently high during drum changes such that the samples did not need to be collected for 12 minutes in order to exceed detection limits. Thus, two short-term, personal air samples were collected in sequence during one of the drum changes for each device. The sampling time was four minutes per sample, for a total duration of eight minutes.

Table 3. 3 lists the analytical air samples collected in EFT #2. Sampling locations at the Florida facility are shown in Figure 3. 3.

Table 3. 3: Air Samples Collected during Extended Field Test #2 and #3

	Type of Sample	# of Samples	Approximate Duration (min)
Personal Samples	1 on left shoulder – filling both drums, filter changes, drum changes	1	100 – 160
	1 on each shoulder – filling 1 st drum	2	60 – 80
	1 on each shoulder – filling 2 nd drum	2	40 – 70
	1 on left shoulder – during drum/filter change	2-4 ^{a, b}	12 – 20
Ceiling Samples	1 on shoulder – samples taken in sequence during drum change	2	4
Area Samples	Near device exhaust	1	100 – 160
	Near device feed tube	1	100 – 160
Overnight Samples	Near device exhaust	1	720 – 1080
	Near device feed tube	1	720 – 1080

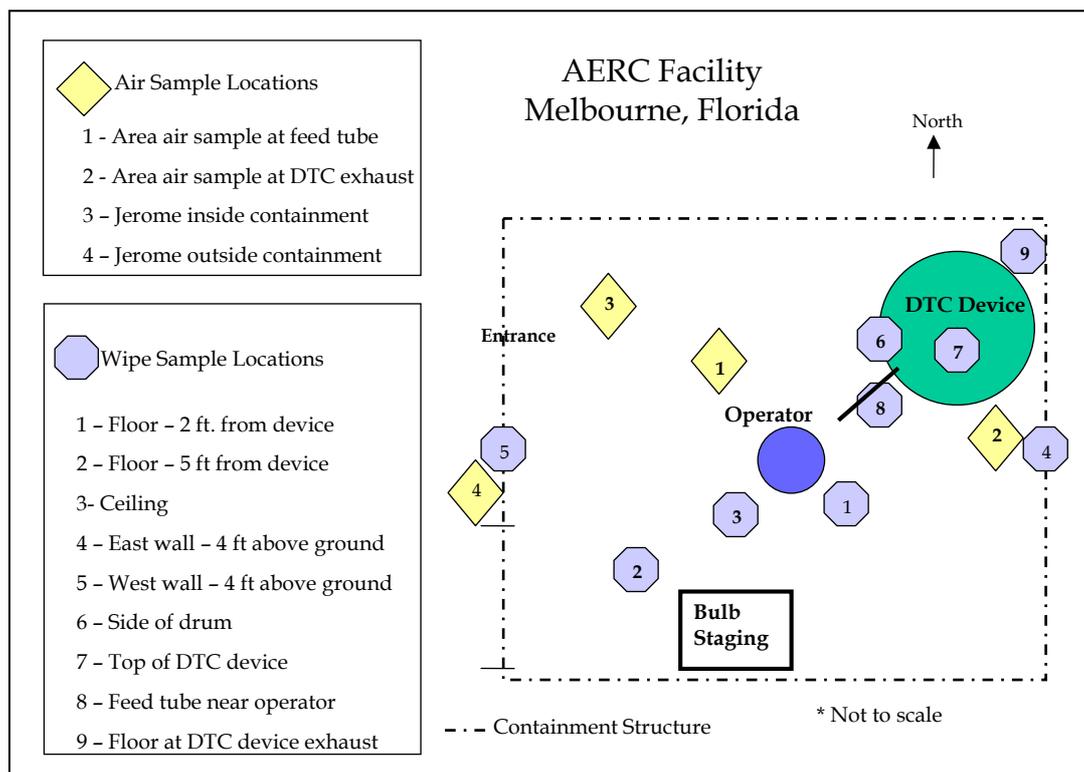
^a Manufacturer A: 2 Drum Change Samples

Manufacturer B: 2 Drum Change Samples

Manufacturer C: 2 Filter Change Samples, 2 Drum Change Samples

^b The filter change samples for the Manufacturer C device were taken when the drum was half full (~350 bulbs).

Figure 3. 3: Sampling Locations for Extended Field Test #2



3.1.3.1 Box Test

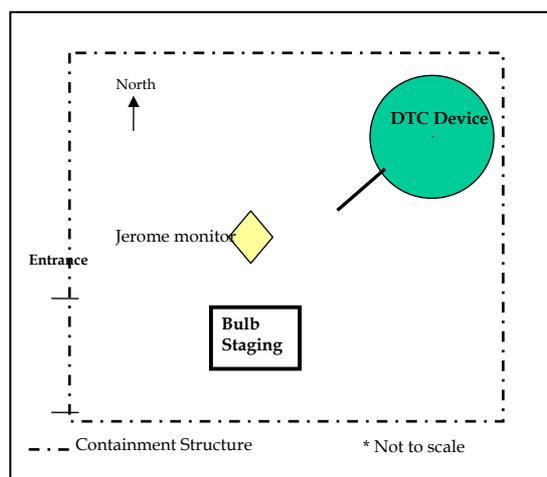
On the first day at AERC Melbourne (EFT #2), the Manufacturer B device was operated and mercury levels were measured. The Jerome analyzer measured airborne mercury levels that exceeded the OSHA PEL: (1) while operating the device to fill the first drum, (2) during the down time taken by the operator after filling and changing out the first drum, and (3) for the first 20 minutes of device operation, while filling the second drum. Because the Manufacturer B Device had previously shown better performance and because mercury levels in the

containment structure had declined during other non-operational periods (i.e., periods during the operator break between drums when devices were not operated), the field team decided to try to evaluate the cause of the high mercury readings.

During Phase I of the PVS and EFT #1 and the beginning of EFT #2, multiple cardboard boxes of fluorescent lamps were brought into the containment structure and kept inside to ensure that the operator had an adequate supply of readily accessible lamps. The field team suspected that the mercury released from the broken lamps in the boxes was contributing to elevated levels inside the containment structure. Based on this concern, testing procedures were revised so that only one box of lamps was kept inside the containment structure.

On April 30 (EFT #2), a test was performed to determine whether the boxes containing broken lamps were contributing to elevated mercury concentrations inside the containment structure (Box Test). Five boxes containing some broken lamps were brought into the containment structure. A Jerome analyzer was also placed inside the containment structure to record the airborne concentrations of mercury. Figure 3.4 shows the layout of the containment area and sampling locations for the mercury emission test from broken boxed lamps.

Figure 3. 4: Box Test Configuration, AERC Melbourne



At the end of the week, the decision was made to repeat a portion of the Manufacturer B device testing, following the new procedure of bringing only one box at a time into the containment structure. Due to time constraints, the repeat test included only one drum, not two drums as in the first test at this location.

3.1.4 Extended Field Test #3

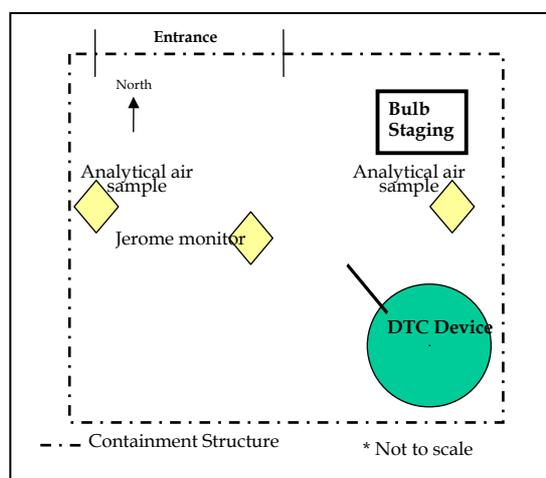
The third EFT was conducted at AERC Ashland, during the same time period as Phase II of the PVS, June 9-13, 2003. Three DTC devices (Manufacturer A, Manufacturer B, and Manufacturer C) were included in this portion of the Study. At the conclusion of EFT #3 for each DTC device, the containment structure polyethylene was replaced with new polyethylene, and Phase II of the PVS for that device began. Table 3.3 lists the samples collected for EFT #3. Because this test was

conducted at AERC Ashland, the sampling locations are the same for PVS Phase I, PVS Phase II, and EFT #3 (refer to Figure 3. 1).

3.1.4.1 Box Test

A Box Test was also conducted at AERC Ashland in a similar manner to the test at AERC Melbourne, with the addition of analytical air samples collected on the east and west sides of the containment structure. Refer to Figure 3. 5 for the containment area layout and sampling areas for the Ashland Box Test. The test was performed at the conclusion of EFT #3 and before the beginning of PVS – Phase II for each device (Manufacturer A, Manufacturer B, and Manufacturer C devices).

Figure 3. 5: Box Test Configuration, AERC Ashland



3.1.4.2 U-Tube Test

The majority of fluorescent lamps processed in the Study were four-foot straight tubes. Although the DTC devices included in the Study were designed to process straight lamps, only two devices (Manufacturer B and Manufacturer C) have attachments that enable them to process “U” shaped fluorescent lamps (U-tubes), as well. At the end of EFT #3 at AERC Ashland, a test was conducted to evaluate airborne mercury levels from the two devices while processing U-tubes. The intent was for both the Manufacturer B and Manufacturer C devices to process enough U-tubes to fill a 55-gallon drum. However, the facility was only able to collect a limited number of U-tubes for the U-tube study. Therefore, the total quantity of U-tubes was divided between the two devices. The Manufacturer B device processed a total of 85 U-tubes, and the Manufacturer C device processed a total of 89 U-tubes.

Table 3. 4 lists the analytical air samples collected during the processing of the U-tubes. Air sample locations correspond to the locations shown in Figure 3. 1; however, there were no wipe samples collected for the U-tube evaluation. Photograph 3. 6 shows the crushing of U-Shaped.

Table 3. 4: Air Samples Collected during U-tube Evaluation

	Type of Sample	# of Samples	Approx. Duration (min)	Air Flow Rate (cc/min)
Personal Samples	1 on each shoulder - filling the drum	2	12 - 14	150
Area Samples	Near device exhaust	1	12 - 14	150
	Near device feed tube	1	12 - 14	150



Photograph 3. 6: Crushing of U-Tubes - Manufacturer C Device

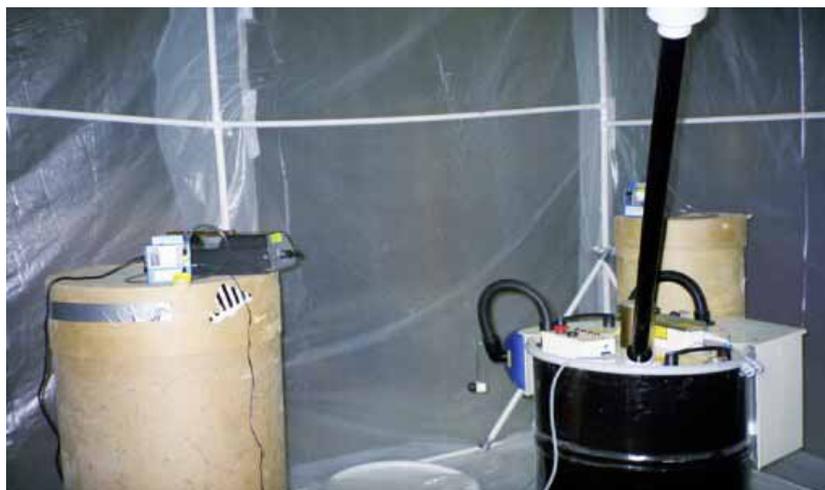
3.2 Jerome Mercury Vapor Analyzer Samples

In addition to measuring mercury concentrations in the air using sampling pumps, two factory-calibrated Jerome Mercury Vapor Analyzers (Model 431-X, Arizona Instrument, LLC) were used to measure real-time mercury concentrations in the ambient air. As shown in Figure 3. 1, Figure 3. 2, and Figure 3. 3, one stationary Jerome analyzer (Jerome #1) remained inside the containment structure (*refer to Photograph 3. 1 and Photograph 3. 7*), while another Jerome analyzer (Jerome #2) was placed outside of the containment structure and brought inside at various times.

Both analyzers were used to identify fluctuations in concentrations while the DTC devices were operated. The Jerome analyzer accurately measures mercury within $\pm 5\%$ in the sensitivity range of 0.003 to 0.999 mg/m³ mercury. Both analyzers were equipped with data loggers, to measure and record the mercury concentrations throughout the day. However, due to problems with the data loggers, the analyzers had to be checked manually and the concentrations recorded in field notebooks.

Jerome #2 was specifically utilized to identify emissions at the carbon filter exhaust, leaks around the seals, emissions/releases at the feed tube, varying concentrations within the containment structure, and background conditions outside the containment structure. This information assisted the operators in determining when personal protective equipment (PPE) was necessary. The mercury vapor analyzer alarms were set to activate at 0.05 mg/m³, to alert the operator of the mercury concentration before the OSHA PEL (0.1 mg/m³) was approached. The project health and safety plan specified that respiratory protection be used inside the containment structure if mercury levels reached or exceeded 0.05 mg/m³. It was

common for mercury concentrations to exceed 0.05 mg/m³ during routine operation; therefore, respiratory protection was employed throughout most of the Study.



Photograph 3. 7: Placement of Air Sampling Pump & Jerome Analyzer in Relation to DTC Device

3.3 Bulk Samples

The Mass Balance Study was intended to account for the fate of the mercury involved in the operation of DTC devices by estimating the total mass of mercury put into the DTC device via crushed lamps and comparing that quantity to the mass of mercury retained by the device plus the mass of mercury released. Samples of unbroken, spent lamps were collected to quantify the average amount of mercury in different types of fluorescent lamps and estimate the total amount of mercury processed by each device. Pollution control media samples and samples of crushed lamps were used in the Mass Balance Study to estimate the amount of mercury retained within the drum and the device assembly for each device.

3.3.1 Unbroken Spent Lamps

During Phase I of the Performance Validation Study (PVS), several unbroken, spent fluorescent lamps were submitted to Data Chem for mercury analysis. Alto® lamps, manufactured by Philips Lighting, were collected and used for this portion of the Study. Specifically, three Alto® T8 lamps, three T12 34-watt lamps, and two Alto® T12 40-watt lamps were obtained from AERC Ashland and analyzed.

Data Chem used a low-temperature drill and acid extraction method to collect the mercury in the lamps, and performed the analysis in accordance with EPA Method 7470. The method used by Data Chem is a non-standardized method based on discussions between Data Chem and Philips Lighting. Philips Lighting shared information with Data Chem on experiments performed to extract mercury from an operating lamp. Data Chem modified the mercury extraction method to extract mercury from a spent lamp rather than an operational lamp (*refer to Appendix E for a description of Data Chem's extraction method*).

Briefly, the method involved packing the lamps in dry ice for approximately one hour, to chill them and condense the mercury vapors inside. A small hole was then drilled into the end cap, and concentrated nitric acid was introduced into the lamps. The hole was filled with a wax plug and the lamps were agitated for approximately 15 minutes, to allow the mercury to react with the acid. The acid was removed from the lamp and analyzed using EPA Method 7470. The results were used to confirm the amount of mercury reported by Philips Lighting and to calculate the quantities of mercury for the Mass Balance Study.

3.3.2 Pollution Control Media

During Phase I of the PVS, bulk samples of various pollution control media were collected from each DTC device after the operator had filled one drum with lamps. Bulk samples were collected from the filter media prior to removing the device from the containment structure (*refer to Appendix H for detailed procedures for the collection of samples from the pollution control media*).

The bulk samples collected from each of the DTC devices included:

- Three samples of particulates from the particulate pre-filters from the Manufacturer B device, Manufacturer C device, and Manufacturer D device (the Manufacturer A device is not equipped with a particulate pre-filter).
- Three samples of particulates from the HEPA filters from all four devices.
- Three samples of particulates from the carbon filters from all four devices.

Clean filter media were submitted by the manufacturers to Data Chem for quality control (QC) samples. These clean materials were used for blank samples and spike samples so that comparisons could be made to the samples of the used filter media. The samples were analyzed in accordance with EPA Method 7470 and EPA Method 7471A, modified slightly by Data Chem to accommodate materials other than soil or sediment, as outlined in Appendix E.

Before the start of lamp crushing operations, the filters (pre-filter, HEPA filter, and carbon filter) and empty drums were weighed for each device. After the drum was completely full, the drum and filters were re-weighed to determine the amount (by weight) of crushed lamps in the drum or particulate on the filters.

3.3.3 Crushed Lamps

After the samples from the pollution control media were collected, the DTC device was removed from the top of the drum. Three samples of crushed lamps were collected for each device to determine the amount of mercury in a drum of crushed lamps for the Mass Balance Study. Approximately 275 to 300 cubic centimeters (cm³) of crushed lamps was collected from each drum using dedicated, disposable plastic spoons that had been decontaminated (prior to use) with HgX® in clean water and

allowed to air-dry.¹² The samples were collected from as deep within the drum as possible to minimize the potential for low-biased results due to vaporization or fugitive particulate emissions of mercury. However, due to the density of the crushed lamps, the sampling depth was limited to approximately eight inches. The samples were sealed in sample containers provided by Data Chem Laboratories.

After collection, all the bulk samples (i.e., unbroken spent lamps, pollution control media, and crushed lamps) were packaged and shipped via Federal Express to Data Chem for analysis along with completed chain-of-custody forms that were signed by the personnel who collected the samples.

3.4 Wipe Samples

Surface wipe samples were collected inside the containment structure on numerous surfaces both before and after lamp crushing, as part of the Mass Balance Study. The wipe samples were collected and analyzed in accordance with N9103 for wipe samples (*refer to Appendix E*). Under this procedure, a 100 square centimeter (cm²) area was wiped using a “Wash N’ Dri” towelette (the liquid component of the wipe is 5 to 10 percent ethanol and 80 to 90 percent water), which was placed into a glass vial. Wipe sample supplies were provided by Data Chem (*refer to Photograph 3. 8*).



Photograph 3. 8: Wipe Sample Media

Wipe samples were collected prior to the start of each DTC device operation and again at the conclusion of the DTC device operation. The pre-test and post-test samples were collected in the same general area; however, the post-test wipe samples may not have been collected in the exact location of the pre-test wipe sample (*refer to Figure 3. 1, Figure 3. 2, and Figure 3. 3 for sample collection areas*).

For the testing conducted at AERC Ashland during PVS – Phase I, a set of two pre-test wipe samples and a set of two post-test wipe samples were collected at each of the nine locations shown in Figure 3. 1. The purpose of this activity was to assess the reproducibility of the results. However, although the testing at AERC Ashland indicated, widely divergent values (i.e., orders of magnitude differences), most likely

¹² HgX® is a sulfiding and chelating agent that contains sodium thiosulfate and EDTA.

attributable to the high background level of airborne and surficial mercury contamination, it was not possible to modify the study design to increase the number of replicates of wipe samples at the other locations.

After sampling was complete at each of the study locations, the wipe samples were collected for shipment to Data Chem. Samples were placed in an oversized sturdy box with packing material to fill voids and protect the samples during shipping. The chain-of-custody forms were then signed by the sampling personnel and placed in the box with the samples. Samples were shipped via Federal Express to the laboratory.

3.5 Test Protocol Deviations and Modifications

Due to circumstances encountered in the field, it was not always possible to follow the initial testing protocol. The following sections describe deviations in device operation and modifications to testing procedures, which were mainly associated with difficulties encountered while processing lamps.

3.5.1 Manufacturer B Device

For EFT #1, the vendor provided the operator with a reducer plate to install in the Manufacturer B device at the carbon filter exhaust. The reducer apparently was designed to throttle airflow through the unit, and was installed at EPSI Phoenix per the vendor's instructions. Increased emissions occurred while the DTC device was being tested, apparently as a consequence of the newly installed reducer. After processing the first full drum of crushed lamps, a representative from Manufacturer B was contacted and a decision was made to remove the reducer plate and then to continue the crushing operations for the second drum without the plate.

3.5.2 Manufacturer C Device

For EFT #1 at EPSI Phoenix, the Manufacturer C device experienced some operational difficulties that delayed the start of testing and may have had an effect on the results measured during the operation. After the first lamp was inserted into the feed tube, the motor on the machine stopped. After troubleshooting the problem, the manufacturer found that the machine would start if the start button were depressed for approximately 10 seconds. Depressing the start button for 10 seconds enabled a safety lock operating off a pressure sensor to be disengaged. The operator proceeded to crush lamps, and changed a filter after 350 lamps were crushed. The drum and filter were changed once the first drum was filled with 750 lamps. During crushing operations for the first drum, the operator noted that the feed tube jammed about every 20 bulbs and had to be cleared by sliding a rod down the feed tube.

Due to on-going operational problems and elevated mercury levels, testing of this device was concluded after only 336 bulbs had been crushed in the second drum. The device was returned to the manufacturer to evaluate the cause of the operational difficulties. The manufacture installed a new control panel for the device and then

shipped the machine to Melbourne, Florida for EFT #2. The device was able to process the required number of lamps during EFT #2, EFT #3, and the PVS.

3.5.3 Manufacturer D Device

During PVS – Phase I, elevated levels of mercury vapor were detected during testing of the Manufacturer D device (*refer to Section 4.4.1.2*). These levels required the temporary suspension of the test to allow the operator to don respiratory protection (after crushing 25-30 fluorescent lamps). The test was permanently suspended (after crushing 276 lamps) at this site because mercury concentrations consistently exceeded the OSHA PEL and continued to increase. The readings on the Jerome analyzer peaked at 0.89 mg/m³, nearly 9 times the OSHA PEL.

The Manufacturer D device was shipped back to the Manufacturer D facility at the manufacturer's request to evaluate the cause(s) of the elevated ambient mercury measurements. EPA requested that the manufacturer prepare a written report detailing the problem(s) and the cause(s); the report was also required to confirm the adequacy of the repairs, including an analysis for mercury vapor by a qualified industrial hygienist.

The device arrived at EPSI Phoenix (EFT #1) for the next round of testing visibly damaged and modified to the extent that it looked like a different device than the device used for Phase I of the PVS. The overall study design required each DTC device vendor to provide one unit that would be used throughout the entire test. Changing the device design violated the study design. There was also a clearly visible crack in the vacuum assembly, preventing adequate negative pressure when the device was turned on, and some of the carbon from the pollution control media spilled out of device during assembly. Even though only 16 lamps were crushed during testing, the ambient mercury concentration inside the containment structure, measured by the Jerome analyzer, reached 0.406 mg/m³ mercury, more than four times the PEL.

None of the analytical air samples taken for this device were below the ACGIH TLV. Eight analytical air samples were collected during PVS – Phase I, and only one was below the PEL. Only two of the four samples collected during EFT #1 (when only 16 lamps were crushed) were below the PEL. It was determined that the use of the Manufacturer D device posed a health risk to study personnel, particularly the operator and assistants. After serious consideration, the unit was eliminated from further testing because of the unauthorized modifications and because of continued elevated mercury levels. Further information can be found in Appendix I.

4. RESULTS AND DATA EVALUATION

The overall objective of the DTC Device Study was to gain insights into the abilities of four different DTC devices to capture and contain mercury, while processing fluorescent lamps. A variety of air and other samples were collected for distinct tests that comprise the DTC Study.¹³ This chapter presents the data collected for the Performance Validation Study (PVS) and the Extended Field Test Study (EFTS) and evaluates those results against study objectives. The next chapter (Chapter 5) presents and evaluates the data collected for the Mass Balance Study. The objectives for the different studies discussed in this chapter are listed below.

- The PVS was conducted to examine the effectiveness of each device in capturing and retaining mercury vapors and to identify any potential change in effectiveness over time. The study compared the results among the different devices when new and after a pre-determined period of operation during which numerous lamps were processed through each device (Section 4.4).
- The EFTS was conducted to examine the ongoing performance of each device during extended use and over a range of environmental conditions (Section 4.5).
- The Box Tests, conducted as part of the EFTS, were performed as an addendum to the EFTS to determine if the presence of broken lamps inside the containment structure confounded the study results (Section 4.6).
- The Overnight Tests were performed as part of the EFTS to evaluate releases of mercury vapor from DTC devices attached to partially filled drums during non-operational periods (Section 4.7).
- The U-tube Test, conducted as part of the EFTS, examined the performance of two of the devices when processing U-shaped fluorescent lamps (Section 4.8).

4.1 Exposure Evaluation Criteria

The results from the analytical air samples and the Jerome analyzers were compared to published mercury exposure limits to assess the performance of the devices in effectively capturing mercury vapors, while processing fluorescent lamps.

OSHA PEL: The federal Occupational Safety and Health Administration (OSHA) has established a maximum work-place regulatory permissible exposure limit (PEL) for inorganic mercury, which is codified in 29 Code of Federal Regulations (CFR) 1910.1000, Table Z-2. The current mercury exposure limit for workers is 0.1 mg/m³ (ceiling). This regulatory exposure limit is established as a “ceiling” value in the

¹³ *It is important to note that, out of the 199 analytical air samples collected, only eight mercury aerosol (MCE filter) samples had values above the detection limit, and all blank MCE filter samples were below the detection limit. All of the mercury vapor (Hydrar tube) samples contained levels of mercury above the detection limit. Because the amount of mercury aerosol was not high enough to measure, the air results discussed in this chapter only address the Hydrar tube samples. The results for the MCE filters can be found in Appendix A, Table 1. Future research may be necessary to determine why aerosols were generally not detected (refer to Section 7.4).*

CFR, meaning that exposure to this value is not to be exceeded during any part of the work day, as opposed to a time weighted average (TWA) that calculates average exposure over the entire work shift.¹⁴ However, in a memo dated September 1996, it states that OSHA currently implements the mercury PEL as an eight-hour TWA rather than as a ceiling value.¹⁵

ACGIH TLV: The other exposure limit that is referenced in this report regarding DTC device performance is a published work-place exposure limit, the threshold limit value (TLV) established by the American Conference of Governmental Industrial Hygienists (ACGIH), which is a professional organization for individuals in the industrial hygiene and occupational health and safety industry. The ACGIH TLV is 0.025 mg/m³ and is a TWA (eight hours per day, 40 hours per week).¹⁶

EPA has established an exposure limit (a reference concentration, or RfC) of 3.0x10⁻⁴ mg/m³ for the general public for chronic exposure to elemental mercury.¹⁷

The data from analytical air samples taken in this Study represent average values for the time periods during which the samples were taken; sampling time was generally between one and three hours for the samples taken during device operation (*refer to Appendix A, Table 1 for sample durations*). Sample results that are greater than the TLV value should not necessarily be interpreted to indicate that use of one of the DTC devices included in the Study would result in operator exposure above the TLV because the device may not be used for eight hours per day, 40 hours per week. The analytical air sample results were not normalized to an eight hour workday because DTC device use patterns may vary significantly (e.g., from a few minutes to eight or more hours per day). More information about the actual use patterns of DTC devices and the mercury exposures experienced by workers during non-operational periods would be necessary in order to calculate an eight hour TWA accurately for any specific pattern of use.

4.2 Background Air Samples

Because the Study was being conducted at commercial lamp recycling facilities, which were expected to have ambient mercury concentrations above those in outdoor air, three types of background samples were collected in order to quantify the mercury present at each site before, during, and after device operation.

¹⁴ Refer to 29 CFR 1910.1000(b).

¹⁵ The PEL for mercury was promulgated as a ceiling value in 1971 (36 FR 10505, May 29, 1971). A memorandum to OSHA compliance personnel was issued on September 3, 1996, that directs compliance officers to issue citations only when an overexposure exceeds 0.1 mg/m³ as an 8-hour TWA.

¹⁶ ACGIH also has a "skin" notation for elemental mercury, indicating that dermal absorption is another possible exposure route. Refer to ACGIH (1994). *1994-1995 Threshold limit values for chemical substances and physical agents and biological exposure indices*. Cincinnati, OH: American Conference of Governmental Industrial Hygienists.

¹⁷ The inhalation Reference Concentration (RfC) is intended to identify a maximum safe level for chronic exposure for the general population and is analogous to the oral RfD. The inhalation RfC considers both toxic effects for the respiratory system and toxic effects peripheral to the respiratory system (extrarrespiratory effects). In general, the RfC is an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily inhalation exposure of the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime. The mercury RfC is based on a human lowest observed effect level (LOEL) of 0.025 mg/m³. See Integrated Risk Information System (IRIS) website (www.epa.gov/iris/index.html) for further discussion.

- On the first day at each site, before performing any crushing activities, two analytical air samples were collected in the vicinity of the study area, to measure ambient mercury concentrations in the lamp recycling facility (*refer to Table 4. 1*).
- During testing at AERC Melbourne and the second round of testing at AERC Ashland, one analytical air sample was taken overnight outside the containment structure at the end of each day of testing (*refer to Table 4. 1 for overnight background results and refer to Section 4.7 for information on overnight tests*).
- Jerome readings from a Jerome analyzer positioned outside the containment structure were manually recorded during PVS – Phase II and during the EFTS as time allowed (*refer to Table 4. 2*).

Table 4. 1: Background Mercury Results - Analytical Air Samples

Studies	Date	Location	Mercury Concentration (mg/m ³)	Mean (mg/m ³)
Performance Validation I	2/25/2003	Middle of E. bay	0.0039	0.0043
	2/25/2003	E. bay by center bay door	0.0047	
Extended Field Test #1	3/24/2003	N. of containment in bay	0.014	0.010
	3/24/2003	E. of containment in bay	0.0059	
Extended Field Test #2	4/29/2003	24 ft. E. of dock door	0.016	0.0164
	4/29/2003	18 ft. N. of dock door	0.012	
	4/29/2003	Outside containment-night	0.021	
	4/30/2003	Outside containment-night	0.016	
	5/01/2003	Outside containment-night	0.017	
Extended Field Test #3 & Performance Validation II	6/09/2003	Middle of E. bay	0.013	0.0166
	6/09/2003	E. bay by center bay door	0.0086	
	6/10/2003	Outside containment-night	0.017	
	6/11/2003	Outside containment-night	0.00052	
	6/12/2003	Outside containment-night	0.044	

Table 4. 2: Background Mercury Results - Jerome Analyzer Measurements

Studies	Date	Location	Mercury Concentration (mg/m ³)	Mean (mg/m ³)
Performance Validation I		No data	No data	
Extended Field Test #1	3/24/2003	Inside containment before crushing	0.020	0.029
	3/24/2003	Inside manager's desk	0.023	
	3/24/2003	Inside manager's desk	0.022	
	3/24/2003	Inside manager's desk	0.023	
	3/24/2003	Minimum outside containment during crushing	0.030	
	3/24/2003	Maximum outside containment during crushing	0.050	
	3/25/2003	Outside containment	0.040	

Studies	Date	Location	Mercury Concentration (mg/m ³)	Mean (mg/m ³)
	3/26/2003	Outside containment	< 0.003	
	3/27/2003	Inside containment before crushing	0.035	
	3/27/2003	Minimum outside containment during crushing	0.035	
	3/27/2003	Maximum outside containment during crushing	0.045	
Extended Field Test #2	4/29/2003	Outside containment	0.007	0.0074
	4/29/2003	Outside containment	< 0.003	
	5/01/2003	Outside containment	0.004	
	5/01/2003	Outside containment	0.017	
Extended Field Test #3 & Performance Validation II	6/10/2003	Outside containment-after EFT #3, before PVS-II	0.008	0.014
	6/10/2003	Inside containment-after EFT #3, before PVS-II	0.009	
	6/10/2003	Inside containment-after EFT #3, before PVS-II	0.012	
	6/11/2003	Outside containment during operation	< 0.003	
	6/11/2003	Outside containment during operation	0.01	
	6/11/2003	Outside containment during operation	< 0.003	
	6/11/2003	Outside containment during operation	0.004	
	6/11/2003	Outside containment during drum change	0.017	
	6/11/2003	Outside containment-after EFT #3, before PVS-II	0.005	
	6/11/2003	Inside containment-after EFT #3, before PVS-II	0.03	
	6/12/2003	Outside containment before starting	0.013	
	6/12/2003	Outside containment before starting	0.014	
	6/12/2003	Inside containment before starting	0.021	
	6/12/2003	Outside containment between drum 1 & 2, during EFT #3	0.014	
	6/12/2003	Minimum outside containment, during PVS-II	0.020	
	6/12/2003	Maximum outside containment, during PVS-II	0.040	

Each facility had measurable concentrations of mercury in the indoor ambient air. According to research by Garetano, et al. outdoor mercury vapor concentrations generally range from $2 \cdot 10^{-6}$ to $2 \cdot 10^{-5}$ mg/m³, with higher concentrations in urban/ industrial areas.¹⁸ None of the analytical air samples were below the detection limit (0.01 µg/sample), and only four of the 31 mercury concentrations taken with the Jerome analyzer were below the instrument detection limit (0.003 mg/m³).

The samples taken at the end of each day of testing during EFT #2 and EFT #3 were compared to the background samples taken at the two sites before the DTC device was operated to determine if the industrial lamp crushing activities at the lamp recycling facilities created a significant increase in the background concentration of mercury throughout the week. Based on the four samples collected before beginning DTC device operation and six samples collected overnight after DTC device operation (N=10), there was no significant correlation between the measured background concentration of mercury and the day of the week that the air sample was collected. The background mercury concentrations are considered in the results

¹⁸ Refer to Garetano, Gary; Gochfeld, Michael; and Stern, Alan H. 2006. *Comparison of Indoor Mercury Vapor in Common Areas of Residential Buildings with Outdoor Levels in a Community Where Mercury Is Used for Cultural Purposes. Environmental Health Perspectives. 114(1): 59-62.*

discussions in this chapter. The overall effect of the elevated background mercury levels on the Study is discussed in Chapter 6.

4.3 Blank Air Samples

As described in Section 3.1, NIOSH Analytical Method N6009 was used for mercury air sampling. Data Chem included in all laboratory air sample reports the fact that each Hydrar tube was contaminated with 0.035 to 0.045 micrograms (μg) of mercury.

At the beginning of each portion of the Study, three Hydrar sorbent tubes were set aside as trip blanks. These tubes were never opened during the field sampling and were submitted to the laboratory for analysis with the air samples to determine the level of mercury present in the sorbent material when no air sampling had occurred.

Additionally, at the beginning of each day of sampling, two Hydrar tubes were removed and designated as field blanks. The ends of the glass tubes were opened for several seconds to expose the sampling media to the air in the calibration room, and then were capped and submitted to the laboratory for analysis.

All blank air samples were only handled in the pump calibration room, a room at each facility that was separate from the areas where lamps were being crushed, such as a conference room or an office. The tubes used as blanks were never in the lamp processing areas. Table 4. 3 summarizes the trip blank data, and Table 4. 4 summarizes the field blank data. The means and standard deviations (Std Dev) are included with the results.

Table 4. 3: Trip Blank Results

Study	Blank 1 (μg)	Blank 2 (μg)	Blank 3 (μg)	Mean (μg)	Std Dev
Performance Validation I	NA	NA	NA	NA	NA
Extended Field Test #1	0.056	0.060	0.065	0.0603	0.00451
Extended Field Test #2	0.046	0.048	0.049	0.0477	0.00153
Extended Field Test #3 & Performance Validation II	0.040	0.047	0.040	0.0423	0.00404

NA - Not Analyzed

The analytical results for the trip blanks confirmed the presence of mercury in the sorbent material and were generally slightly higher than the laboratory-provided information regarding mercury contamination associated with Hydrar sorbent tubes.

Table 4. 4: Field Blank Results

Study	Date	Blank 1 (μg)	Blank 2 (μg)	Daily Mean (μg)	Site Mean (μg)	Std Dev
Performance Validation I	2/26/2003	0.040	0.041	0.0405	0.0403	0.0014
	2/27/2003	0.041	0.038	0.0395		
	2/28/2003	0.042	0.040	0.041		
Extended Field Test #1	3/24/2003	0.078	0.086	0.082	0.118	0.0807
	3/25/2003	0.075	0.071	0.073		

Study	Date	Blank 1 (µg)	Blank 2 (µg)	Daily Mean (µg)	Site Mean (µg)	Std Dev
	3/26/2003	0.28	0.21	0.245		
	3/27/2003	0.073	0.071	0.072		
Extended Field Test #2	4/29/2003	0.046	0.044	0.045	0.0470	0.0020
	4/30/2003	0.045	0.048	0.0465		
	5/1/2003	0.046	0.049	0.0475		
	5/2/2003	0.049	0.049	0.049		
Extended Field Test #3 & Performance Validation II	6/10/2003	0.039	0.041	0.040	0.0395	0.0022
	6/11/2003	0.041	0.038	0.0395		
	6/12/2003	0.040	0.038	0.039		
	6/13/2003	0.036	0.043	0.0395		

The field blank results were similar to the trip blank results for EFT #2 (only 0.7% relative percent difference) and for EFT #3 (only 3.4% relative percent difference). The results for the field blanks from EFT #1 (conducted at the EPSI facility) were much higher than the trip blanks for that test (32% relative percent difference). This suggests possible contamination of Hydrar tubes at this site and is not surprising given that background mercury levels, as measured by the Jerome analyzer, were highest at the EPSI facility.

4.4 Performance Validation Study

The Performance Validation Study (PVS) was conducted to assess the performance of DTC devices over time and determine if they lose efficiency in capturing and retaining mercury after a specified period of routine operation and crushing a substantial number of lamps. This section presents the measurements collected during Phases I and II, and compares these measurements to evaluate the performance of each device. Phases I and II are separated by five months, and each DTC device, except the Manufacturer D device, was used in the EFTS during this time, crushing approximately 3,800 - 4,300 lamps at three locations.

4.4.1 Performance Validation Study - Phase I

Phase I of the PVS was conducted at the AERC facility in Ashland, Virginia (AERC Ashland) during the week of February 24, 2003. As described in Chapter 3, analytical air samples were collected to measure the concentrations of mercury in the containment structure during operation of the new DTC devices,¹⁹ and the Jerome analyzer was used to collect direct-reading measurements.

Temperature and humidity in Richmond, Virginia for each day at this study location were obtained from an online weather service archive. The average outdoor temperatures during this testing interval ranged between 28.4 and 42.6 degrees Fahrenheit. The average outdoor relative humidity ranged between 57.5 and 99.3

¹⁹ The Manufacturer A device is a prototype and, therefore, is not considered a new device.

percent. Due to the cold weather conditions, the bay doors to the outside remained closed during the tests.²⁰

Background measurements of mercury vapor concentrations, as measured using Hydrar tubes, were 0.0039 mg/m³ and 0.0047 mg/m³. These levels were most likely due to the ongoing, high throughput volume crushing of fluorescent bulbs conducted by AERC in the adjacent bay. A large doorway connected the bay where testing was conducted and the bay where AERC operated its industrial-sized bulb crusher. The facility separated the bays by keeping a pull-down door in-between the two bays closed for the majority of testing; however, the pull-down door was opened occasionally to move materials back and forth between bays (e.g., lamps required for the test). The effect of background concentrations on study results is further discussed in Section 6.1.

In this phase of the Study, one drum of lamps was processed through each device. Table 4.5 summarizes the number of Phillips Lighting “Alto®” lamps processed to fill one drum. The number of lamps is specific to each device.

Table 4.5: Total Lamps Processed in Each Device, Performance Validation Study I

Device	Number of Lamps Processed	Type of Lamp
Manufacturer A	637	T-12 fluorescent (3.5-4.2 mg Hg/lamp)
Manufacturer B ^a	611	T-8 fluorescent (3.0 mg Hg/lamp)
Manufacturer B ^a	113	T-12 fluorescent (3.5-4.2 mg Hg/lamp)
Manufacturer C	706	T-12 fluorescent (3.5-4.2 mg Hg/lamp)
Manufacturer D ^b	276	T-12 fluorescent (3.5-4.2 mg Hg/lamp)

^a Manufacturer B device processed mostly T-8 lamps due to a temporary shortage of T-12 lamps.

^b Manufacturer D device was shut-down before processing a full drum. Refer to Section 3.5.3.

It is important to note that during PVS – Phase I, all of the lamps processed were Alto® fluorescent lamps. These lamps were specifically selected for use in Phase I because these data were also used for the Mass Balance Study, and Alto® lamps are manufactured with more precise doses of mercury than other lamps.

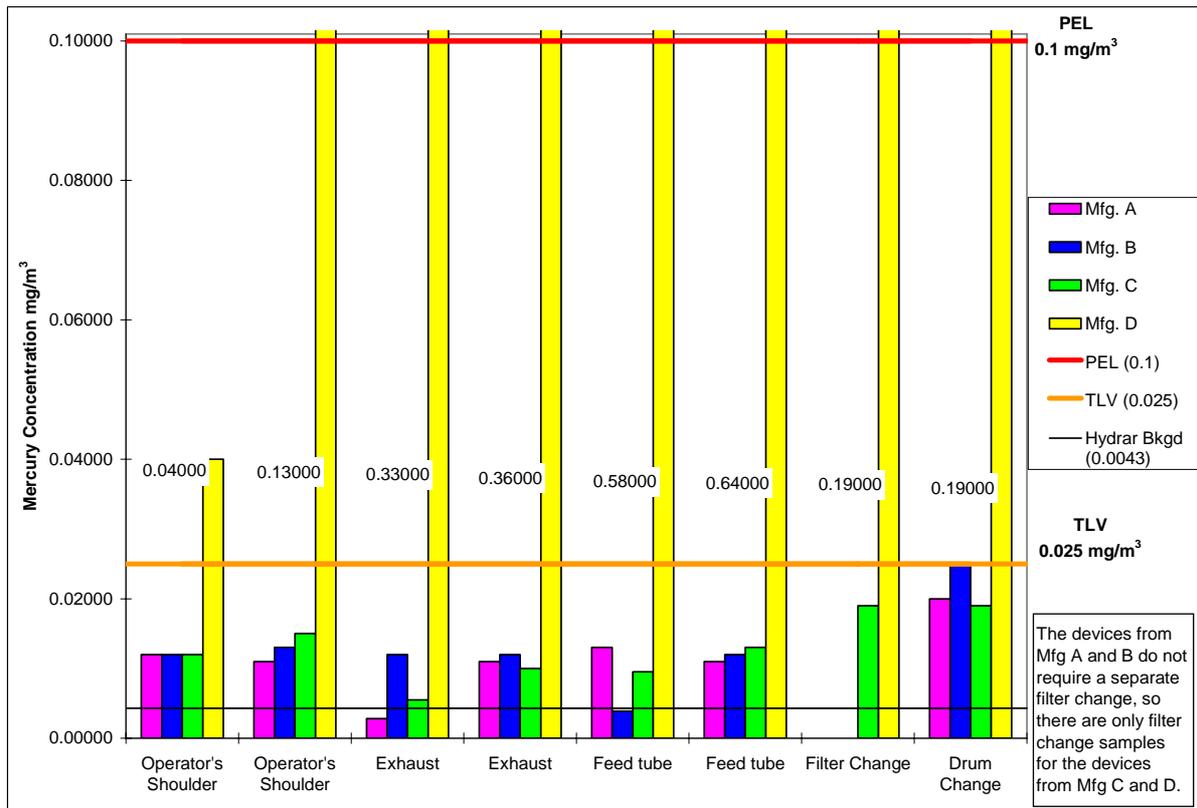
4.4.1.1 Analytical Air Sample Results

The results of the air samples collected during Phase I of the PVS inside the containment structure are presented in Figure 4.1. Air sample results for the Manufacturer A, Manufacturer B, and Manufacturer C devices were generally below both the OSHA PEL and the ACGIH TLV values. The Manufacturer D device exceeded the PEL and the TLV values for seven of the eight samples collected.

For a separate graphical depiction of the analytical air sample results collected for each DTC device, refer to Appendix A, Figures 1 through 5. To review the actual results for each analytical air sample, refer to Appendix A, Table 1. The Data Chem reports are available in Appendix C.

²⁰ Outdoor temperature and humidity data were collected at the request of the EPA Work Group. While indoor data, when collected, better characterize the operating environment for the devices, the outdoor data are still significant.

Figure 4. 1: Analytical Air Sampling Results, Performance Validation Study I^a



^a The TLV is included on the graph as a point of reference. The analytical air samples shown on this graph do not represent eight-hour TWAs (refer to Appendix A, Table 1 for sample durations).

4.4.1.2 Jerome Mercury Vapor Analyzer Results

The Jerome analyzer results from Phase I of the PVS inside the containment structure are displayed in Table 4. 6.

Table 4. 6: Jerome Analyzer Measurements - Inside Containment, Performance Validation Study I

Device	Jerome Mercury Vapor Analyzer Readings (mg/m ³)		
	During Operation	Filter Change	Drum Change
Manufacturer A	0.005 - 0.009	NA ^d	0.005 - 0.009 ^a
Manufacturer B	0.007 - 0.009	NA ^d	0.026 ^a
Manufacturer C	<0.003 - 0.005	0.008 ^b	0.008 ^b
Manufacturer D	0.44 - 0.89 ^c	No data ^c	No data ^c

NA - Not applicable

^a During the drum change, the measurements were at the maximum levels recorded.

^b During the filter change and the drum change, measurements were at the maximum levels recorded.

^c See paragraph below and Section 3.5.3.

^d The Manufacturer A and Manufacturer B devices do not have a separate filter change.

The real-time mercury vapor concentrations measured inside the containment structure using the Jerome analyzer during operation of the Manufacturer A, Manufacturer B, and Manufacturer C devices were all below the OSHA PEL and the ACGIH TLV values (with the exception of the Manufacturer B device during the drum change, which exceeded the TLV value). The Jerome analyzer readings

collected while operating the Manufacturer D device exhibited a continuous increase in mercury concentrations. After processing approximately 25 to 30 lamps, the Jerome analyzer measured mercury vapor at 0.44 mg/m³, and processing was suspended to allow the operator to don respiratory protection. Crushing operations then continued for approximately 45 minutes, until the Jerome analyzer readings increased to 0.89 mg/m³. Testing of the Manufacturer D device at this facility was permanently suspended after processing a total of 276 lamps, due to the persistent TLV and PEL exceedances in the test area. Further discussion of the Manufacturer D device is provided in Section 3.5.3.

4.4.2 Performance Validation Study – Phase II

Phase II of the PVS was conducted at AERC Ashland during the week of June 9, 2003. The Manufacturer A, Manufacturer B, and Manufacturer C devices were tested during Phase II; as noted earlier, the Manufacturer D device was removed from the Study due to airborne mercury concentrations consistently above the PEL during Phase I. The average outdoor temperature during this testing interval ranged between 70.0 and 79.0 degrees Fahrenheit, and average outdoor relative humidity ranged between 73.0 and 80.6 percent. The indoor temperature and relative humidity were measured using a Velocicalc instrument.

- Temperatures: ranged between 73.0 and 86.2 degrees Fahrenheit, with a weekly average of 81.2 degrees Fahrenheit.
- Relative humidity: ranged between 54.5 and 74.4 percent, with an average of 63.1 percent.

As described in the Sampling and Study Plan (*refer to Appendix D*), the Phase II testing was conducted after each DTC device had processed six to seven drums' worth of lamps.

Table 4. 7 summarizes the number of lamps processed to fill one drum. The number of lamps is specific to the unique operation of each device.

Table 4. 7: Total Lamps Processed in Each Device, Performance Validation Study II

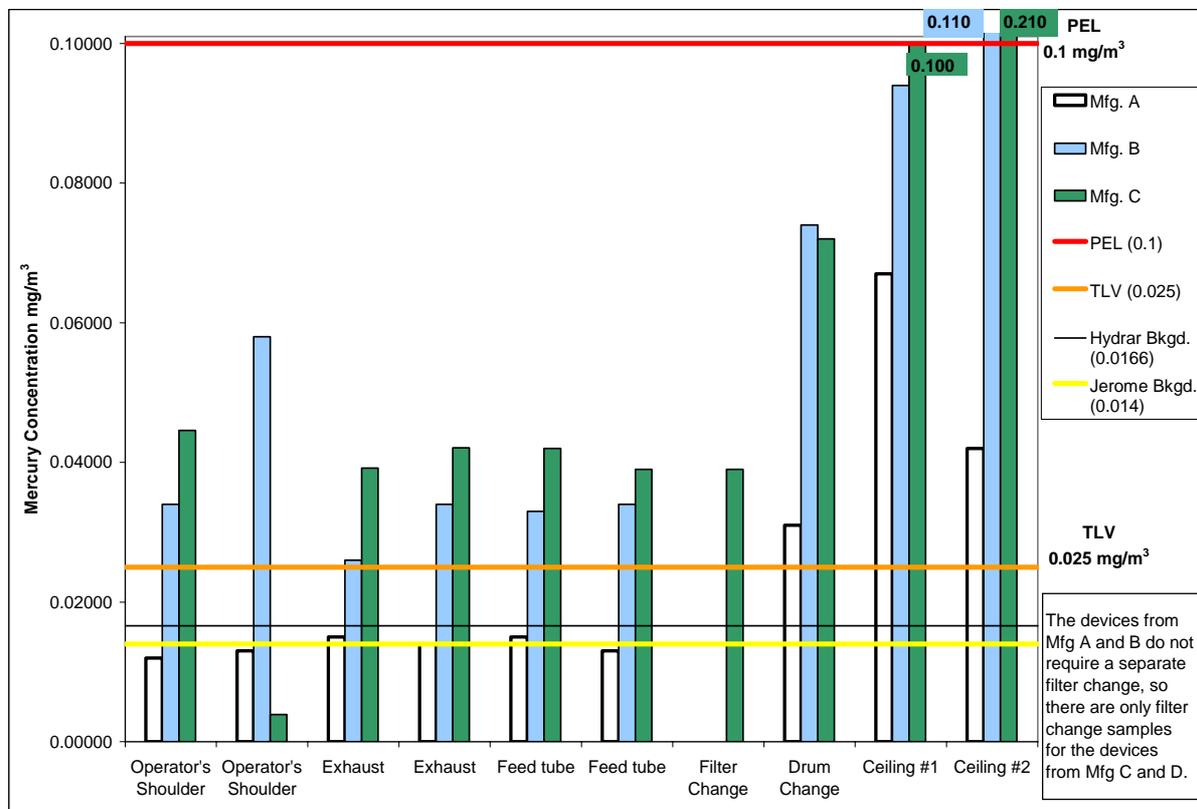
Device	Number of Lamps Processed
Manufacturer A	667
Manufacturer B	617
Manufacturer C	801

During Phase II of the PVS, some of the lamps processed were not Phillips Alto® lamps because there were not enough of them available. The inclusion of conventional lamps in the second phase of the PVS may have affected the measured mercury concentrations because most conventional fluorescent lamps contain more mercury than Alto® lamps.

4.4.2.1 Analytical Air Sample Results

For Phase II, a majority of the results for the analytical air samples were below the OSHA PEL value, but not the ACGIH TLV value, as shown below in Figure 4. 2.

Figure 4. 2: Analytical Air Sampling Results, Performance Validation Study II^a



^a The TLV is included on the graph as a point of reference. The analytical air samples shown on this graph do not represent eight-hour TWAs (refer to Appendix A, Table 1 for sample durations).

The Ceiling #1 sample for the Manufacturer C device met, but did not exceed, the PEL value.²¹ The two samples that exceeded the PEL were two of the three Ceiling #2 samples (Manufacturer B and Manufacturer C devices). Throughout Phase II of the PVS, air sample concentrations for the Manufacturer A device were consistently lower relative to the other two devices, usually below the TLV. To review the results for each analytical air sample, refer to Appendix A, Table 1. For a separate graphical depiction of the air sample results collected for each DTC device, refer to Appendix A, Figures 6 through 9. The Data Chem reports are available in Appendix C.

4.4.2.2 Jerome Mercury Vapor Analyzer Results

The field team experienced software performance problems while attempting to record the mercury concentration on both data loggers attached to the vapor analyzers during Phase II. The only available logged readings were those from

²¹ It is important to note that the drum-change and ceiling samples are not time-weighted averages (TWA) and should not be compared to the TLV, which is a TWA. The PEL for mercury was promulgated as a ceiling value in 1971 (36 FR 10505, May 29, 1971). A memorandum to OSHA compliance personnel was issued on September 3, 1996, that directs compliance officers to issue citations only when an overexposure exceeds 0.1 mg/m³ as an 8-hour TWA.

operation of the Manufacturer A and Manufacturer B devices inside the containment structure. Mercury vapor analyzer measurements for the Manufacturer C device were manually recorded, as time allowed. (Prior to beginning the Phase II test for the Manufacturer C device, the Jerome analyzer recorded 0.008 mg/m³ outside the containment structure and readings between 0.009 mg/m³ and 0.012 mg/m³ inside the containment structure.) Refer to Table 4. 8 for the Jerome analyzer readings taken inside the containment structure during PVS – Phase II.

Table 4. 8: Jerome Analyzer Measurements - Inside Containment, Performance Validation Study II

Device	Jerome Mercury Vapor Analyzer Readings (mg/m ³)		
	During Operation	Filter Change	Drum Change
Manufacturer A	0.007 - 0.013	No data ^a	No data ^b
Manufacturer B	<0.003 - 0.030	No data ^a	No data ^b
Manufacturer C	0.02 - 0.04 ^c	No data ^c	No data ^c

^a The Manufacturer A and Manufacturer B devices do not have a separate filter change.

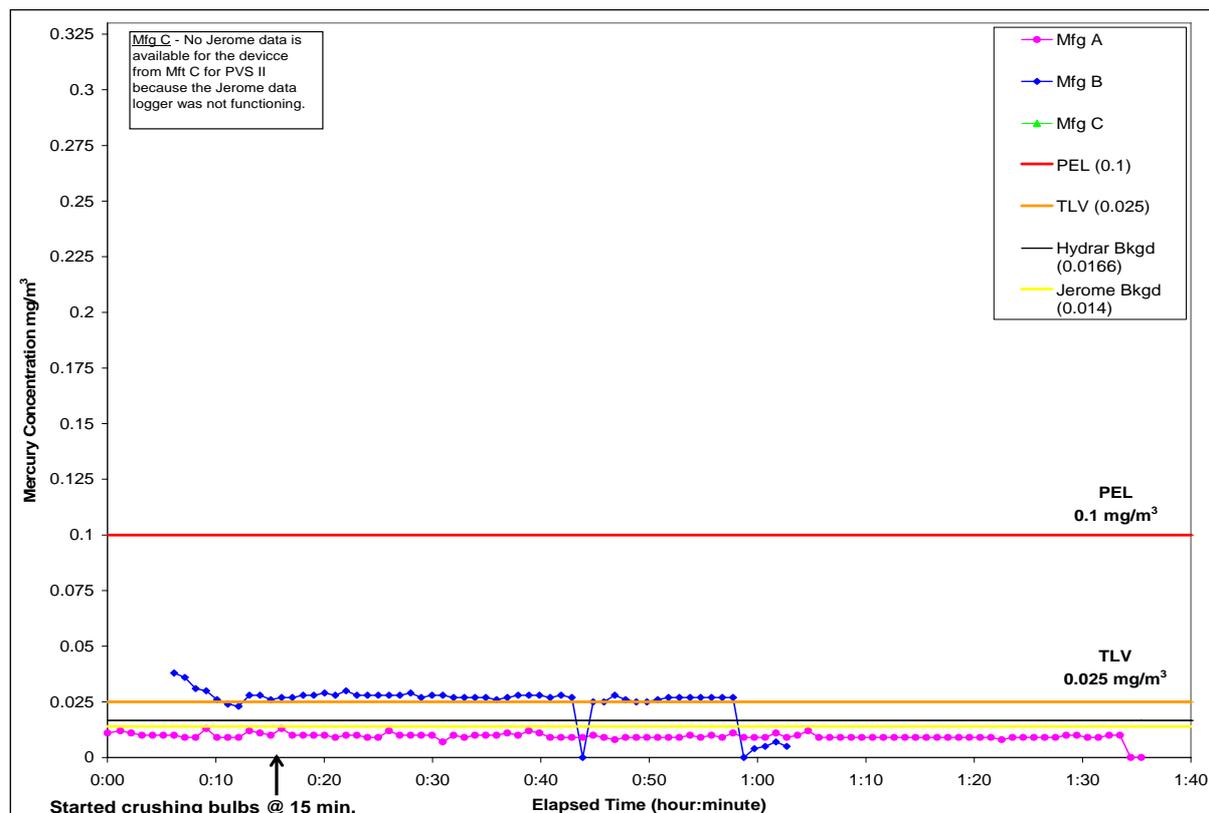
^b Drum was changed the following day.

^c Values were manually recorded, as time permitted, because data logger was not functioning.

^d Data logger was communicating with Jerome analyzer to collect samples but did not record data.

For a graphical depiction of the logged Jerome analyzer data, refer to Figure 4. 3 and Appendix A, Figures 10 through 12.

Figure 4. 3: Jerome Results - Inside Containment, Performance Validation Study II^a

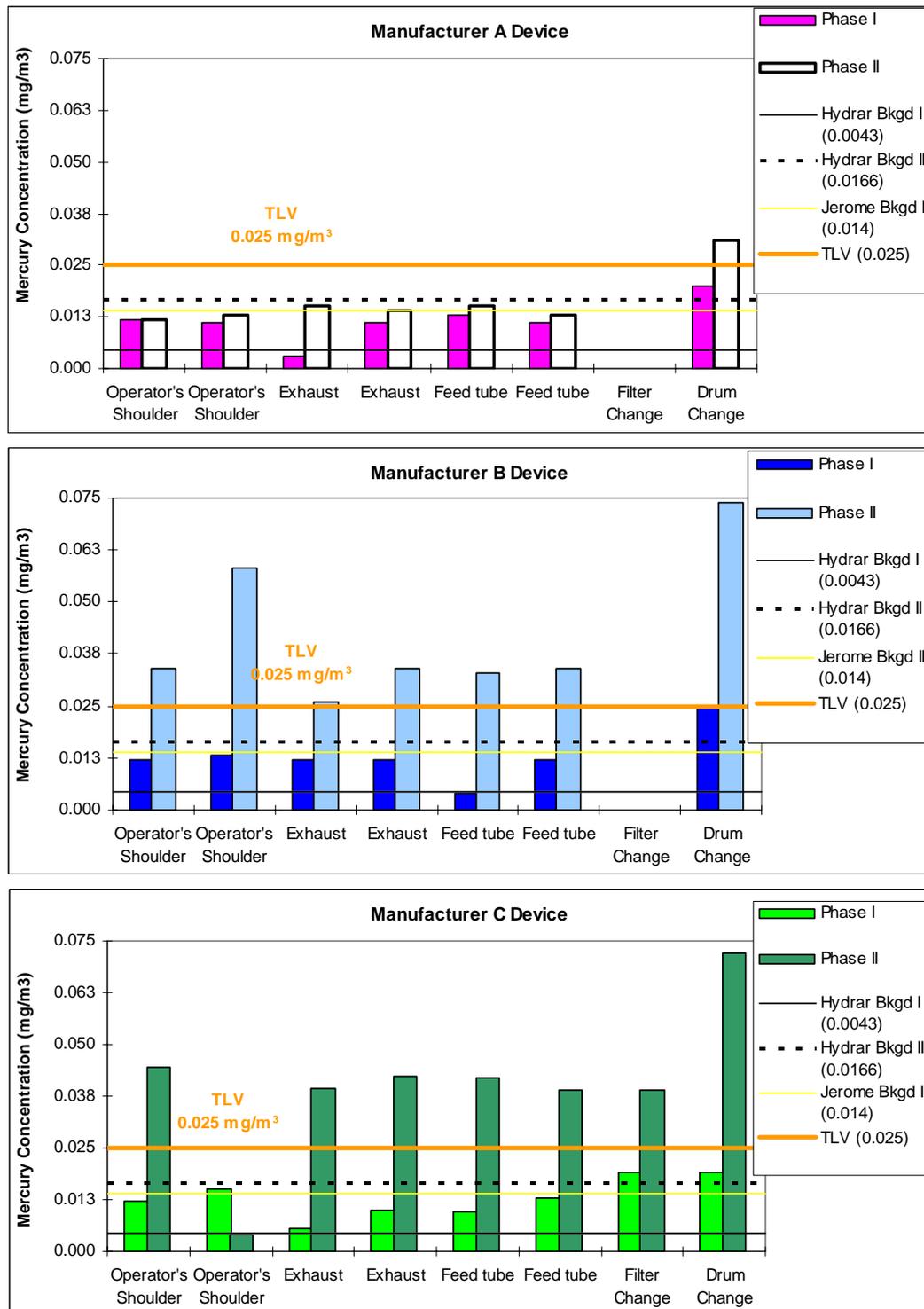


^a The TLV is included on the graph as a point of reference. The mercury concentrations shown on this graph represent instantaneous measurements and do not represent eight-hour TWAs.

4.4.3 Comparison of Performance Validation Study Phases I and II

Overall, analytical air sample results for all three DTC devices during the PVS were higher during Phase II than Phase I (refer to Figure 4. 4 and Figures 13, 14, and 15 in Appendix A). The ceiling samples collected during Phase II are not included in the graphs below because no ceiling samples were collected during Phase I.

Figure 4. 4: Analytical Air Sampling Results, Performance Validation Study – Phases I & II ^a



^a The TLV is included on the graph as a point of reference. The analytical air samples shown on this graph do not represent eight-hour TWAs (refer to Appendix A, Table 1 for sample durations).

Background mercury levels inside the AERC Ashland facility were higher during Phase II than during Phase I. Several one-way Analyses of Variance (ANOVAs) were calculated using the data from Phase I and Phase II. Table 4. 9 compares the results from the Phase I and II PVS tests to background mercury levels and to each other. The ceiling samples are not included in these comparisons because no ceiling samples were taken during Phase I.

Table 4. 9: Performance Validation Study Air Sampling Data Comparison ^{a, b}

Device	Significant Difference from Background Concentrations		Significant Difference between Phase I and Phase II Concentrations	
	Phase I	Phase II	Measured Value	Background Corrected Values ^c
Manufacturer A	yes p-value = 0.0782	no p-value = 0.6682	no ^d p-value = 0.1700	no ^d p-value = 0.5172
Manufacturer B	yes p-value = 0.0432	yes p-value = 0.0402	yes p-value = 0.0013	yes p-value = 0.0076
Manufacturer C	yes p-value = 0.0380	yes p-value = 0.0869	yes p-value = 0.0011	yes p-value = 0.0081

^a Data from limited operation of the Manufacturer D device not included because of failure during Phase I.

^b If p-value < alpha (0.1), the data being compared are significantly different from each other (90% confidence).

^c The mean background concentration of mercury for specific Phase was subtracted from each of the concentrations measured for each of the devices during that Phase of the Study.

^d The comparisons for the Manufacturer A device may not be valid because the concentrations of mercury measured in Phase II were not significantly different from the background concentrations; however, they are given here for reference.

As show in Figure 4. 4, the background levels measured in Phase I using the Hydrar tubes averaged 0.0043 mg/m³, in contrast to the Phase II Hydrar tube background levels, shown in Figure 4. 5, that averaged 0.0166 mg/m³. (Jerome readings are not comparable because no Jerome background data are available for Phase I.) During Phase I, the concentrations of mercury detected using the personal and area air samples were significantly different from the background concentrations for all three devices. During Phase II, the background concentrations were significantly different from the analytical air sample results from the Manufacturer B and Manufacturer C devices, but not significantly different from the analytical air sample results for the Manufacturer A device.

These statistical comparisons are empirically illustrated by the fact that in the second phase of the PVS, during the operation of the Manufacturer B and Manufacturer C devices, most samples exceeded the ACGIH TLV value. However, during the operation of the Manufacturer A device, all samples other than the drum change and ceiling samples were below the TLV value. The Manufacturer A device features a larger particulate filter and a larger carbon absorption bed than the other two devices. The more substantial pollution control equipment could, at least partially, explain why the PEL value was never exceeded by the Manufacturer A device during the PVS, and the TLV value was only exceeded by three samples.

A number of additional factors, external to actual device performance, may have contributed to the differences between the results for the two phases. During the

Phase II tests (performed in June 2003), the outdoor temperature was 25°F-50°F higher than during Phase I (performed in February 2003), which could have elevated the indoor temperature during air volume changes (e.g., doors opening). An increase in temperature, over a range of 40 to 85 degrees Fahrenheit, has been shown to cause an increase in volatilization of mercury, resulting in greater detected concentrations.²² Moreover, the lamps processed in Phase II consisted of a mixture of the Alto® Phillips Lighting lamps (which have lower nominal quantities of mercury per lamp) and ordinary fluorescent lamps, with higher nominal mercury content, whereas the Phase I test used Alto® lamps exclusively. Additionally, the DTC devices were not decontaminated before performing the PVS – Phase II testing, so the results from Phase II may be biased high due to residual mercury that may have been in the device before the testing began. These factors may have contributed to the higher mercury vapor concentrations measured in Phase II. However, these factors may not have significantly affected the outcome of the Performance Validation Study because the results in Phase II for the device from Manufacturer A were not significantly different from the results in Phase I.

Overall, these data suggest possible deterioration in DTC device performance for the devices from Manufacturer B and Manufacturer C from Phase I to Phase II, as measured by the ambient mercury vapor concentration during device operation. For the Manufacturer C device, airborne concentrations increased by factors of between two and five, with the most notable decrease in performance indicated in the device exhaust samples and the drum change samples. For the Manufacturer B device, airborne concentrations increased by factors of between two and four, with the most notable decrease in performance indicated in the device feed tube samples and the drum change samples.

4.5 Extended Field Test Study

4.5.1 Extended Field Test #1

The first Extended Field Test (EFT #1) was conducted at the EPSI facility in Phoenix, Arizona (EPSI Phoenix), during the week of March 23, 2003. Temperature and humidity in Phoenix, AZ for each day of testing were obtained from an on-line weather service archive. The average outdoor temperatures during this testing interval ranged between 63.5 and 73.0 degrees Fahrenheit. The average outdoor relative humidity ranged between 12.1 and 31.5 percent.

As described in Chapter 3, area and personal air samples were collected using sampling pumps, and real-time vapor measurements were recorded on Jerome analyzers. Originally, all four devices were going to be tested during EFT #1. However, the Manufacturer D device testing was terminated when mercury concentrations well above the OSHA PEL value were detected in the device operator's breathing zone after processing 16 lamps. The mercury release was likely

²²Refer to Raposo, Cláudio; Windomöller, Cláudio Carvalhinho; and Júnior, Walter Alves Durão. 2003. *Mercury speciation in fluorescent lamps by thermal release analysis*. *Waste Management*. 23 879-886. and Aucott, et al, 2003. *Release of Mercury from Broken Fluorescent Bulbs*. *J. Air & Waste Manage. Assoc.* 53: 143-151.

due to the fact that the Manufacturer D device arrived at EPSI Phoenix with a large crack in the vacuum assembly (*refer to Section 3.5.3 for further discussion*).

The following table summarizes the number of lamps processed to fill each drum for the Manufacturer A, Manufacturer B, and Manufacturer C devices, by device. The Sampling and Study Plan (*refer to Appendix D*) specified that enough lamps would be crushed to fill two 55-gallon drums for each DTC device during each EFT.

Table 4. 10: Total Lamps Processed in Each Device, Extended Field Test #1

Device	Number of Lamps - 1 st Drum	Number of Lamps - 2 nd Drum
Manufacturer A	684	700
Manufacturer B	534	580
Manufacturer C ^a	750	336
Manufacturer D ^b	16	--

^a Refer to Section 3.5.2 for an explanation of the differences between the 1st and 2nd drums.

^b Refer to Section 3.5.3 for an explanation as to why the Manufacturer D device processed very few lamps.

4.5.1.1 Analytical Air Sample Results

As shown on Figure 4. 5, most of the results for analytical air samples collected during operation of the Manufacturer A, Manufacturer B, and Manufacturer C devices exceeded the ACGIH TLV value, including all samples collected in the breathing zone of the operator. A few results from these three devices also exceeded the OSHA PEL value:

- The Manufacturer A device exceeded the PEL value on a feed tube sample.²³
- The Manufacturer B and Manufacturer C devices exceeded the PEL value in the breathing zone of the operator during the second drum change.

Consistent with the observations made during PVS – Phase I, the Manufacturer D device was unable to control its air emissions in that both samples collected in the operator’s breathing zone during operation of this device exceeded the PEL value.

For a graphical depiction of the air sample results collected for each DTC device, refer to Appendix A, Figures 16 through 20. To review the actual results for each analytical air sample, refer to Appendix A, Table 1. The Data Chem reports are available in Appendix C.

One possible issue with actual mercury emissions from the DTC devices was the large number of broken lamps visually identified in the shipping boxes as they arrived at the facility. The study team suspected that boxes containing broken lamps were contaminated with mercury vapor existing in air spaces inside the corrugated matrix of the cardboard, as well as mercury particles absorbed into the cardboard. Although the broken lamps were recognized as a possible confounding factor during

²³ A visible leak was observed at the feed tube flange of Manufacturer A for the first drum. The cause of the leak was determined to be due to a missing flange gasket that was not installed during assembly. After the first drum was filled, the missing gasket was installed at the feed tube flange for the second drum, and the leak problem was corrected.

EFT #1, no testing to quantify the mercury contribution of the broken lamps and assess this possibility was done until EFT #2 (the box test discussed in Section 4.6).

4.5.1.2 Jerome Mercury Vapor Analyzer Results

Review of the Jerome analyzer readings taken inside the containment structure at one-minute intervals indicated a similar pattern of measured mercury concentrations similar to the air sample analytical results (*refer to Appendix A, Figure 26*). Table 4. 11 presents ranges of mercury concentrations measured by both Jerome analyzers, while testing each DTC device.

Table 4. 11: Jerome Analyzer Measurements, Extended Field Test #1

Device	ACGIH TLV (mg/m ³)	OSHA PEL (mg/m ³)	Jerome Mercury Vapor Analyzer Results (mg/m ³)			
			# of Samples	Jerome #1		Jerome #2
				Range	Mean	Range ^a
Manufacturer A	0.025	0.1	212	0.017 - 0.041	0.027	0.029 - 0.060
Manufacturer B	0.025	0.1	121	0.021 - 0.102	0.049	0.026 - 0.131
Manufacturer C	0.025	0.1	140	0.036 - 0.211	0.074	0.0 - 0.102
Manufacturer D	0.025	0.1	11	0.011 - 0.406 ^b	0.175	0.0 - 0.580 ^c

^a Jerome #2 was used to measure the concentrations at the device exhaust, at the seal around the drum, adjacent to the feed tube, and in the operator's breathing zone.

^b When the unit was started, the readings immediately increased to concentrations above the PEL, and testing was concluded after processing only 16 fluorescent lamps.

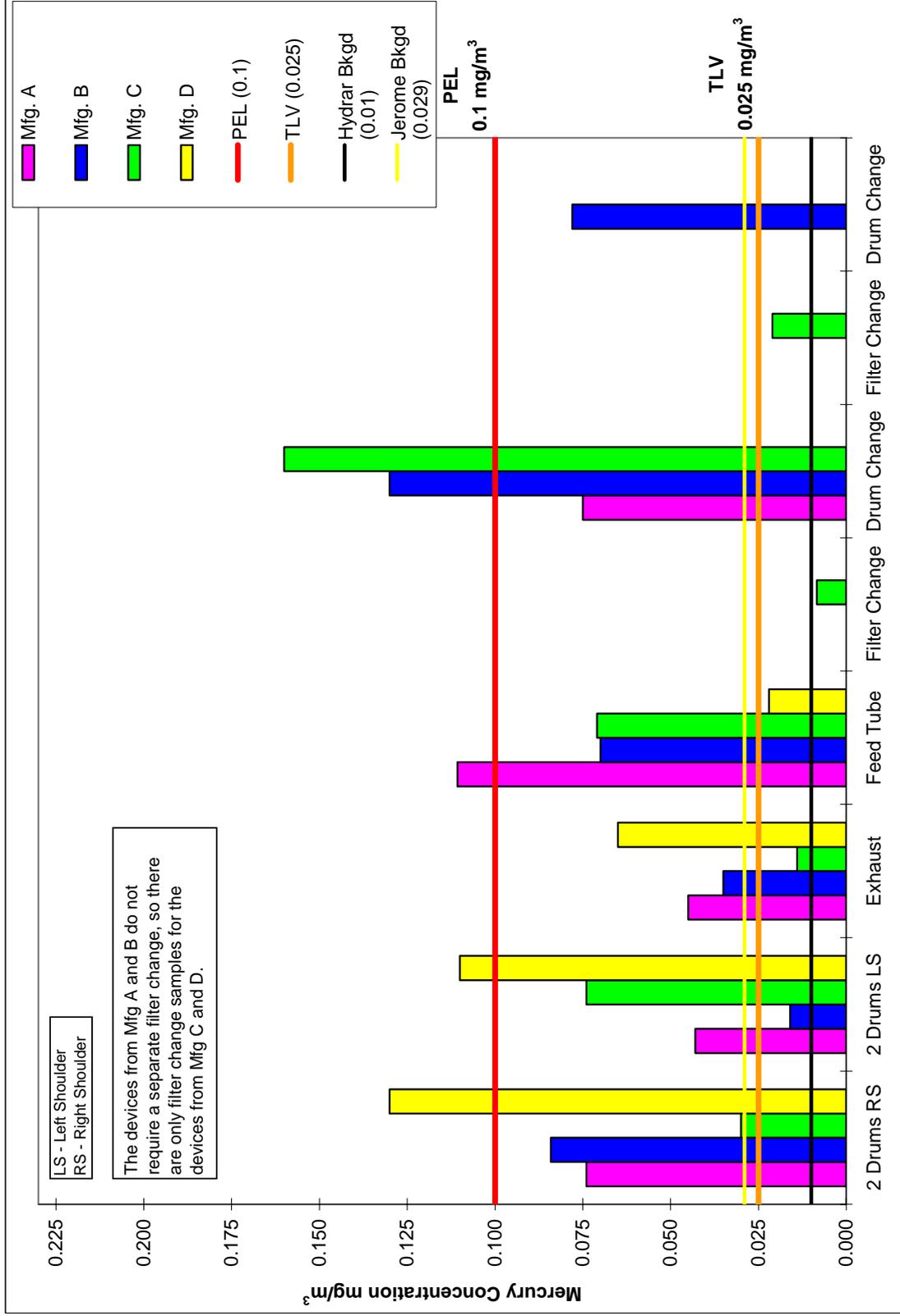
^c Jerome #2 was stationed inside the containment structure and recorded similar readings above the PEL.

Mercury concentrations in the ambient air in the headspace of a representative drum of crushed lamps were also measured using the Jerome analyzer. This activity was not in the Sampling and Study Plan, but was added in the field. Not unexpectedly, a headspace reading of 0.909 mg/m³ was registered above a full drum immediately after the DTC device was removed from on top of the drum. A reading taken next to the drum after removing the DTC device from the top of the drum and affixing the drum lid was considerably lower, as expected (0.03 mg/m³).

While operating the Manufacturer C device, some operational difficulties delayed the start of testing and may have had an effect on the concentrations measured on the Jerome analyzers (*refer to Section 3.5.2 for further discussion regarding the operational problems*). The Jerome results were above the TLV value and below the PEL value at the beginning, but increased to exceed the PEL value toward the end of testing. During the first drum change, the Jerome readings inside the containment structure slightly exceeded the PEL value; once the drum was changed, readings reverted to levels between the TLV and PEL values. During the second drum change, readings were already elevated above the PEL value, and the test was therefore terminated.

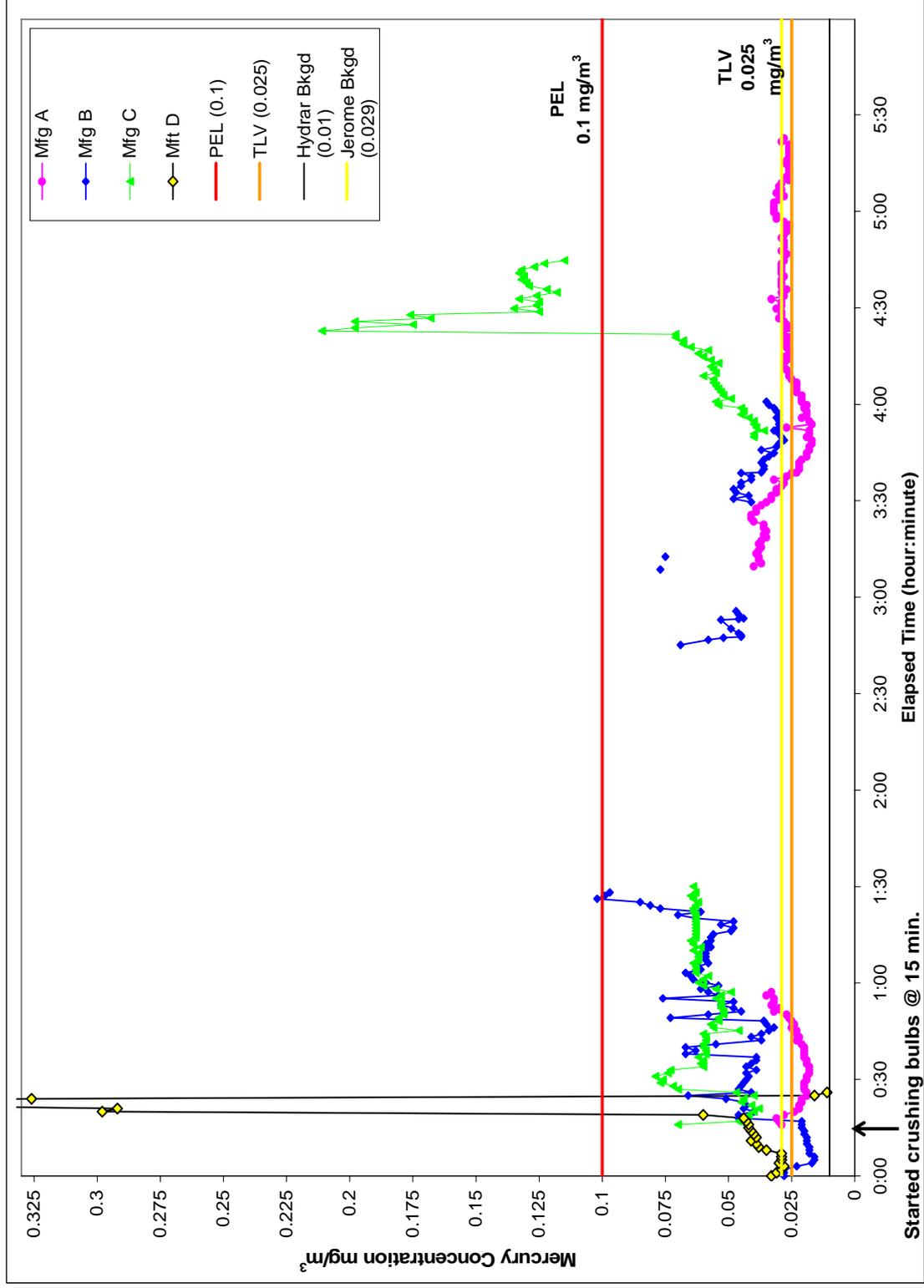
For a graphical depiction of each measurement, refer to Figure 4. 6 and Appendix A, Figures 21 through 25. The graphs also include significant milestones encountered during the device operation to better understand and interpret the measurements.

Figure 4.5: Analytic Air Sampling Results, All Devices, Extended Field Test #1^a



^a The TLV is included on the graph as a point of reference. The analytical air samples shown on this graph do not represent eight-hour TWAs (refer to Appendix A, Table 1 for sample durations).

Figure 4. 6: Jerome Results - Inside the Containment, Extended Field Test #1^a



^a The TLV is included on the graph as a point of reference. The mercury concentrations shown on this graph represent instantaneous measurements and do not represent eight-hour TWAs.

4.5.2 Extended Field Test #2

The second Extended Field Test (EFT #2) was conducted at the AERC facility in Melbourne, Florida (AERC Melbourne) during the week of April 28, 2003. The temperature and relative humidity was measured using a Velocicalc instrument. The average outdoor temperatures during this testing interval ranged between 73.6 and 77.4 degrees Fahrenheit. The average outdoor relative humidity ranged between 73.9 and 84.4 percent. Indoor temperatures and relative humidity were also measured and recorded during this test and were as follows:

- Temperatures: ranged between 80.1 and 89.4 degrees Fahrenheit, with an average of 84.9 degrees Fahrenheit.
- Relative humidity: ranged between 68 and 85.5 percent, with an average of 75.2 percent.

As described in Chapter 3, analytical air samples were collected with sample pumps and Jerome analyzers. DTC devices from Manufacturer A, Manufacturer B, and Manufacturer C were tested during the EFTS at AERC Melbourne. Table 4. 12 summarizes the number of lamps processed to fill each drum, by device. The number of lamps is specific to the unique operation of each device.

Table 4. 12: Total Lamps Processing in Each Device, Extended Field Test #2

Device	Number of Lamps - 1 st Drum	Number of Lamps - 2 nd Drum
Manufacturer A	721	678
Manufacturer B #1 ^a	658	609
Manufacturer B #2 ^a	554	--
Manufacturer C	660	639

^a Refer to Section 3.5.1.

4.5.2.1 Air Sample Results

Several analytical air sample results collected for all three DTC devices during EFT #2 exceeded the OSHA PEL value, and most of the samples exceeded the ACGIH TLV value (*refer to Figure 4. 7*).²⁴

For the Manufacturer A device, the sample on the operator's right shoulder, collected while filling the first drum, exceeded the TLV value. Also, the two ceiling samples exceeded the PEL value.

For the Manufacturer B device, the only sample collected that did not exceed the TLV value was the one collected during the first drum change. Both ceiling samples taken during the first test of the Manufacturer B device were above the PEL value. No ceiling samples were taken during the second Manufacturer B test. Six personal

²⁴ It is important to note that the drum-change and ceiling samples are not time-weighted averages (TWA) and should not be compared to the TLV, which is a TWA. The PEL for mercury was promulgated as a ceiling value in 1971 (36 FR 10505, May 29, 1971). A memorandum to OSHA compliance personnel was issued on September 3, 1996, that directs compliance officers to issue citations only when an overexposure exceeds 0.1 mg/m³ as an 8-hour TWA.

and area air samples were collected during Manufacturer B test #1, and five were collected during Manufacturer B test #2. For the first test, four of these samples were above the PEL value, while only one sample was above the PEL value during the second Manufacturer B test (*refer to Section 3.5.1 for a description of the two tests*).

The samples that exceeded the PEL value during the first test of the Manufacturer B device included both operator shoulder samples collected during filling of first drum, the exhaust area sample during filling of two drums, and the feed tube area sample during filling of two drums. The only sample that exceeded the PEL value during the second test of the Manufacturer B device was the drum change sample.

For the Manufacturer C device, the only sample that did not exceed the TLV value was the one collected on the operator’s right shoulder, while filling the first drum. The first drum change sample and both ceiling samples exceeded the PEL value.

For a graphical depiction of the air sample results collected for each DTC device, refer to Appendix A, Figures 27 through 30. To review the actual results for each analytical air sample, refer to Appendix A, Table 1. The Data Chem reports are available in Appendix C.

4.5.2.2 Jerome Mercury Vapor Analyzer Results

Review of the Jerome analyzer readings taken at one-minute intervals indicated a pattern of concentrations similar to the air sample analytical results (*refer to Appendix A, Figure 35*).

The Jerome analyzer was also used to take direct readings of ambient air in the headspace of a representative drum of crushed lamps. This activity was not in the Sampling and Study Plan but was added in the field. A headspace reading of 0.619 mg/m³ was registered above a full drum on the morning after lamp crushing, and a reading of off-scale (>0.999 mg/m³) was registered above a full drum immediately after filling the drum. (These data do not directly relate to operator health and safety because they were not measurements of the air in or near the operator breathing zone.) Table 4. 13 presents the range of mercury concentrations detected by both Jerome analyzers for each device during EFT #2.

Table 4. 13: Jerome Analyzer Measurements, Extended Field Test #2

Device	ACGIH TLV (mg/m ³)	OSHA PEL (mg/m ³)	Jerome Mercury Vapor Analyzer Results (mg/m ³)			
			# of Samples	Jerome #1		Jerome #2
				Range	Mean	Range
Manufacturer A	0.025	0.1	347	0.003 – 0.046	0.013	0.006 – 0.06 ^a
Manufacturer B #1	0.025	0.1	296	0.00 – 0.328	0.078	0.004 – 0.045 ^c
Manufacturer B #2	0.025	0.1	74	0.021 – 0.177	0.066	0.004 – 0.017 ^b
Manufacturer C	0.025	0.1	430	0.008 – 0.128	0.034	0.008 – 0.154 ^c

^a Jerome #2 was used to measure concentrations outside the containment structure, the operator’s breathing zone, the device exhaust, and at the feed tube connection to the device.

^b Jerome #2 was used to measure concentrations outside the containment structure.

^c Jerome #2 was used to measure concentrations outside the containment structure, in the operator’s breathing zone, at the device exhaust, and on top of the device.

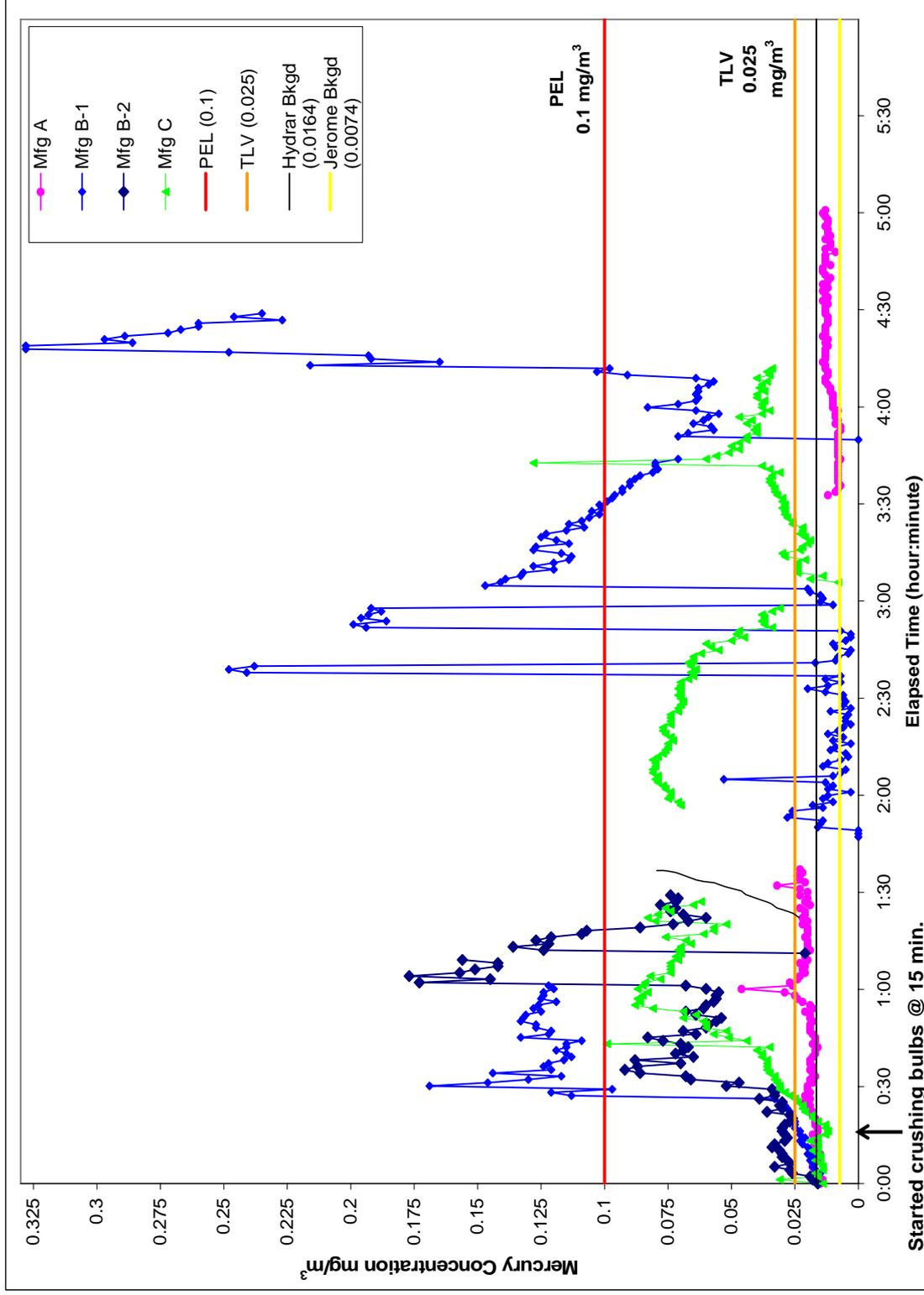
Most of the Jerome readings taken inside the containment structure for the Manufacturer A unit were below the TLV value, with no readings inside the containment structure above the PEL value. The highest reading (0.046 mg/m³) was measured during the first drum change. The average concentration was 0.013 mg/m³. Most readings for the Jerome analyzer located outside the containment structure were below the TLV value, and none exceeded the PEL value.

For the Manufacturer B #1 test, the readings from the Jerome analyzer located inside the containment structure were consistently above the TLV and PEL values. In contrast, most of the readings taken with the Jerome analyzer inside the containment structure during the Manufacturer B #2 test were above the TLV value, but below the PEL value. When the drum was changed during the Manufacturer B #2 test, levels inside the containment structure began to exceed the PEL value.

While bulbs were being crushed in the Manufacturer C device, the readings inside the containment structure were consistently above the TLV value but remained below the PEL value, with the exception of the reading taken during the third filter change. The highest reading (0.154 mg/m³) was obtained after the third filter change and adjacent to a full drum of crushed lamps. The average Jerome analyzer reading inside the containment structure was 0.034 mg/m³. Measurements recorded by the Jerome analyzer outside the containment structure were below both the TLV and the PEL values and generally did not exceed 0.010 mg/m³.

For a graphical depiction of each measurement refer to Figure 4. 8 and Appendix A, Figures 31 through 34. The graphs also include significant milestones encountered during the operation of the devices to better understand and interpret the measurements.

Figure 4. 8: Jerome Results - Inside the Containment, Extended Field Test #2^a



^a The TLV is included on the graph as a point of reference. The mercury concentrations shown on this graph represent instantaneous measurements and do not represent eight-hour TWAs.

4.5.3 Extended Field Test #3

EFT #3 was conducted at AERC Ashland during the week of June 9, 2003. The average outdoor temperatures during this testing interval ranged between 70.0 and 79.0 degrees Fahrenheit. The average outdoor relative humidity ranged between 73.0 and 80.6 percent. The indoor temperature and relative humidity were measured using a Velocicalc instrument.

- Temperatures: ranged between 73.0 and 86.2 degrees Fahrenheit, with a weekly average of 81.2 degrees Fahrenheit.
- Relative humidity: ranged between 54.5 and 74.4 percent, with an average of 63.1 percent.

As described in Chapter 3, ambient mercury concentrations were measured using sample pumps and Jerome analyzers, and wipe samples were collected inside the containment structure on nine surfaces for the Mass Balance Study (*refer to Appendix F for wipe sample results*). DTC devices from the following manufacturers were tested during EFT #3: Manufacturer A, Manufacturer B, and Manufacturer C. Table 4. 14 summarizes the number of lamps processed to fill each drum, by device. The number of lamps is specific to the unique operation of each device.

Table 4. 14: Total Lamps Processed in Each Device During Extended Field Test #3

Device	Number of Lamps - 1 st Drum	Number of Lamps - 2 nd Drum
Manufacturer A	767	719
Manufacturer B	594	539
Manufacturer C	794	689

4.5.3.1 Air Sample Results

The air sampling results from the Manufacturer B and Manufacturer C devices were consistently greater than the ACGIH TLV value (*refer to Figure 4. 9*). Air sampling results also indicated that the Manufacturer C device and, to a lesser extent, the Manufacturer B device were prone to excursions above the OSHA PEL value during EFT #3. This occurred most frequently during drum changes and in ceiling samples. With the exception of one sample for the Manufacturer B device, the air samples within the operator's breathing zone (shoulder samples) were the TLV and PEL values during the Manufacturer B and Manufacturer C tests. In contrast, during the Manufacturer A test, breathing zone concentrations remained below the TLV value.

²⁵ No samples taken during the Manufacturer A test exceeded the PEL value.

For a graphical depiction of the air samples collected for each DTC device, refer to Appendix A, Figures 36 through 39. To review the actual results for each analytical

²⁵ It is important to note that the drum-change and ceiling samples are not time-weighted averages (TWA) and should not be compared to the TLV, which is a TWA. The PEL for mercury was promulgated as a ceiling value in 1971 (36 FR 10505, May 29, 1971). A memorandum to OSHA compliance personnel was issued on September 3, 1996, that directs compliance officers to issue citations only when an overexposure exceeds 0.1 mg/m³ as an 8-hour TWA.

air sample, refer to Appendix A, Table 1. The Data Chem reports are available in Appendix C.

4.5.3.2 Jerome Mercury Analyzer Results

The field team experienced software performance problems while attempting to record the mercury concentration on both data loggers attached to the vapor analyzers during EFT #3. During testing of the first device (from Manufacturer A), the Jerome analyzer appeared to be communicating properly with the data logger (i.e., it was automatically collecting samples at one minute intervals); however, upon downloading the data from the data logger, it was discovered that the data logger had not recorded any measurements. Therefore, there are no logged readings or manual readings for the Jerome analyzer for the Manufacturer A device for EFT #3. Also, due to time constraints, the study team was not able to take readings of the mercury concentration in the head space of a full drum as was done previously.

Review of the Jerome analyzer readings indicate a similar pattern of measured mercury concentrations, compared with the analytical air sample results (*refer to Appendix A, Figure 43*). Table 4. 15 presents a range of results from both Jerome analyzers for the devices from Manufacturer B and Manufacturer C.

Table 4. 15: Jerome Analyzer Measurements, Extended Field Test #3

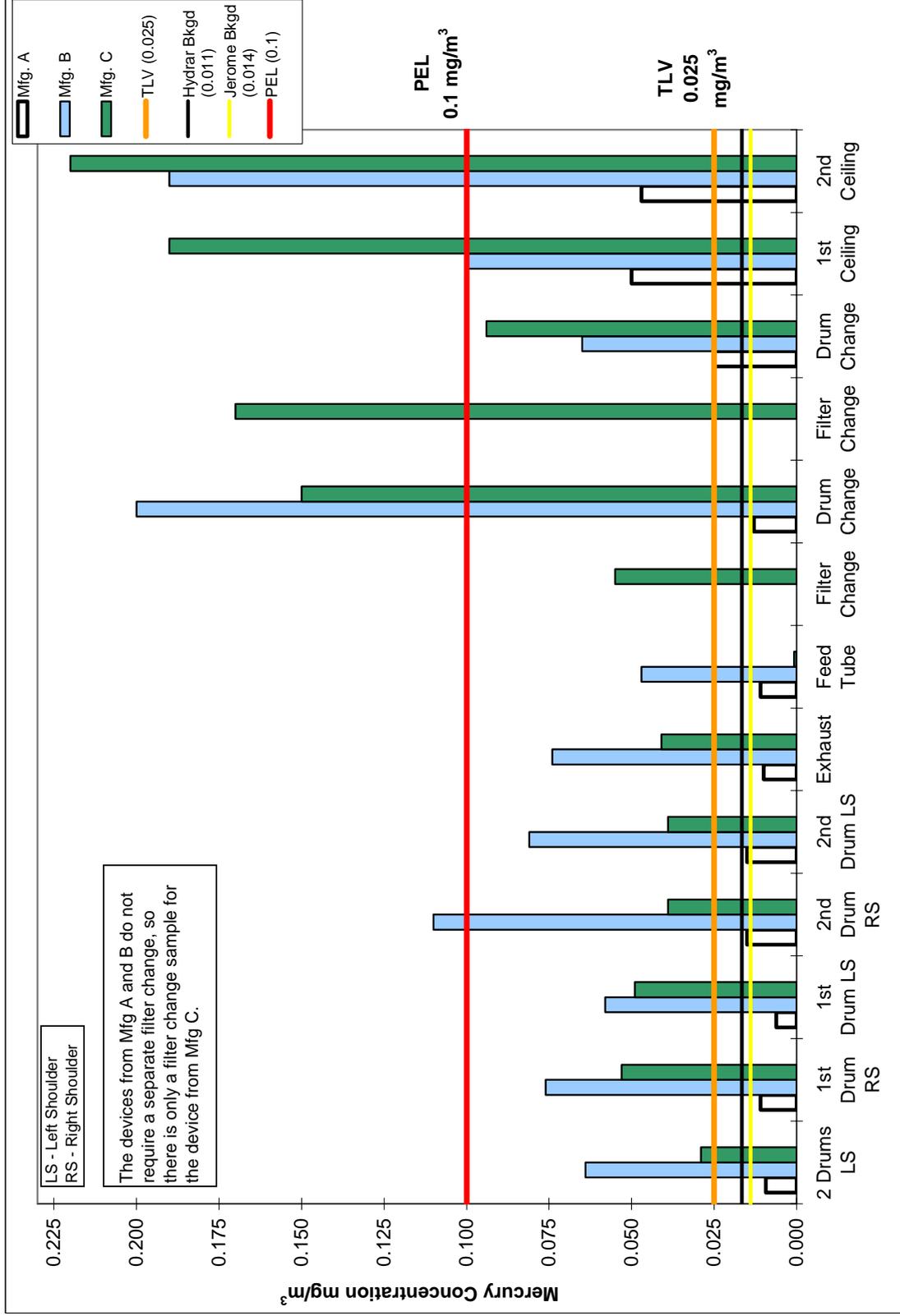
Device	AGCIH TLV (mg/m ³)	OSHA PEL (mg/m ³)	Mercury Vapor Analyzer Results (mg/m ³)			
			# of Samples	Jerome #1		Jerome #2 ^a
				Range	Mean	Range
Manufacturer B	0.025	0.1	234	0.009 – 0.258	0.051	<0.003 – 0.017
Manufacturer C	0.025	0.1	218	0.008 – 0.121	0.040	0.008 – 0.02

^a Jerome #2 unit was kept outside of the containment structure during EFT #3.

For the Manufacturer B device, most measurements (except right after startup) were above the TLV value. There were two sets of excursions above the PEL value. After approximately one hour of operation, readings increased to a maximum of 0.26 mg/m³ and remained above the PEL value until the first drum change (10 readings within nine minutes). After the drum change, a total of four exceedances were recorded before levels dropped to between the PEL and TLV values and then stabilized. Just before the second drum change, a reading of 0.13 mg/m³ was registered. After the second drum change, all levels remained below the PEL value and stabilized in a range just above the TLV value, until the conclusion of the test. During operation of the Manufacturer C device, nearly all of the readings (except right after startup, including startup after the first drum change) were above the TLV value. There was also a brief excursion above the PEL value, three readings within an eight-minute period, right before the first drum change. The highest reading registered during this period was 0.12 mg/m³.

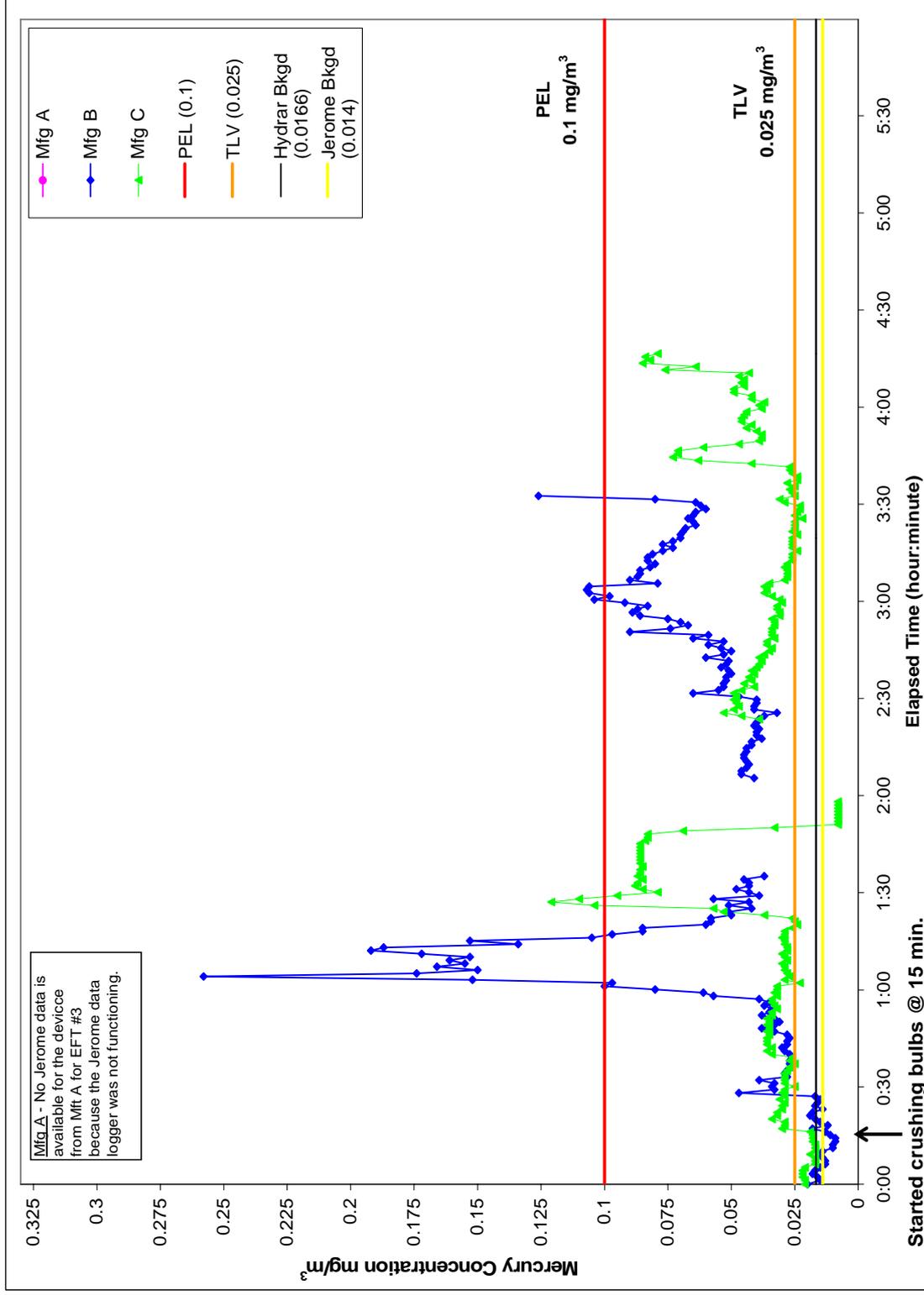
For a graphical depiction of each measurement, refer to Figure 4. 10 and Appendix A, Figures 40 through 42. The graphs also include significant milestones encountered during the operation of the devices to better understand and interpret the measurements.

Figure 4. 9: Analytical Air Sampling Results, All Devices, Extended Field Test #3^a



^a The TLV is included on the graph as a point of reference. The analytical air samples shown on this graph do not represent eight-hour TWAs (refer to Appendix A, Table 1 for sample durations).

Figure 4. 10: Jerome Results – Inside the Containment, Extended Field Test #3^a



^a The TLV is included on the graph as a point of reference. The mercury concentrations shown on this graph represent instantaneous measurements and do not represent eight-hour TWAs.

4.5.4 Comparison of Extended Field Tests

The EFTS was designed to evaluate the mercury vapor capture efficiency of each DTC device in a simulated occupational environment, with a focus on assessing the potential for human exposure to mercury as a result of DTC use.

Unlike the PVS, there were not extreme differences in outside air temperature during the EFTS. The range of outside air temperatures was 63.5°F-79.0°F. This may have reduced the potential variation in test results due to increased volatilization of mercury at increased temperatures (*as discussed in Section 4.4.3*). At EPSI Phoenix, testing was conducted in the same bay as the facility's industrial size lamp crusher. As a result, there was an elevated background concentration of mercury vapor in the bay, most likely due to the ongoing crushing of fluorescent bulbs being conducted by EPSI. The mean background samples collected using the air sample pumps and using Jerome #2 are shown in Table 4. 16.

Table 4. 16: Mean Background Mercury Concentrations, Extended Field Test Study

Facility	Air Samples (mg/m ³)	Jerome Samples (mg/m ³)
EPSI Phoenix (EFT #1)	0.010	0.029
AERC Melbourne (EFT #2)	0.0164	0.007
AERC Ashland (EFT #3)	0.0166	0.014

Based on single-factor ANOVAs calculated for each device at each site, the concentrations measured during operation of each device were significantly different from background concentrations in all cases (95 percent confidence), except the Manufacturer A test at AERC Ashland (EFT #1).

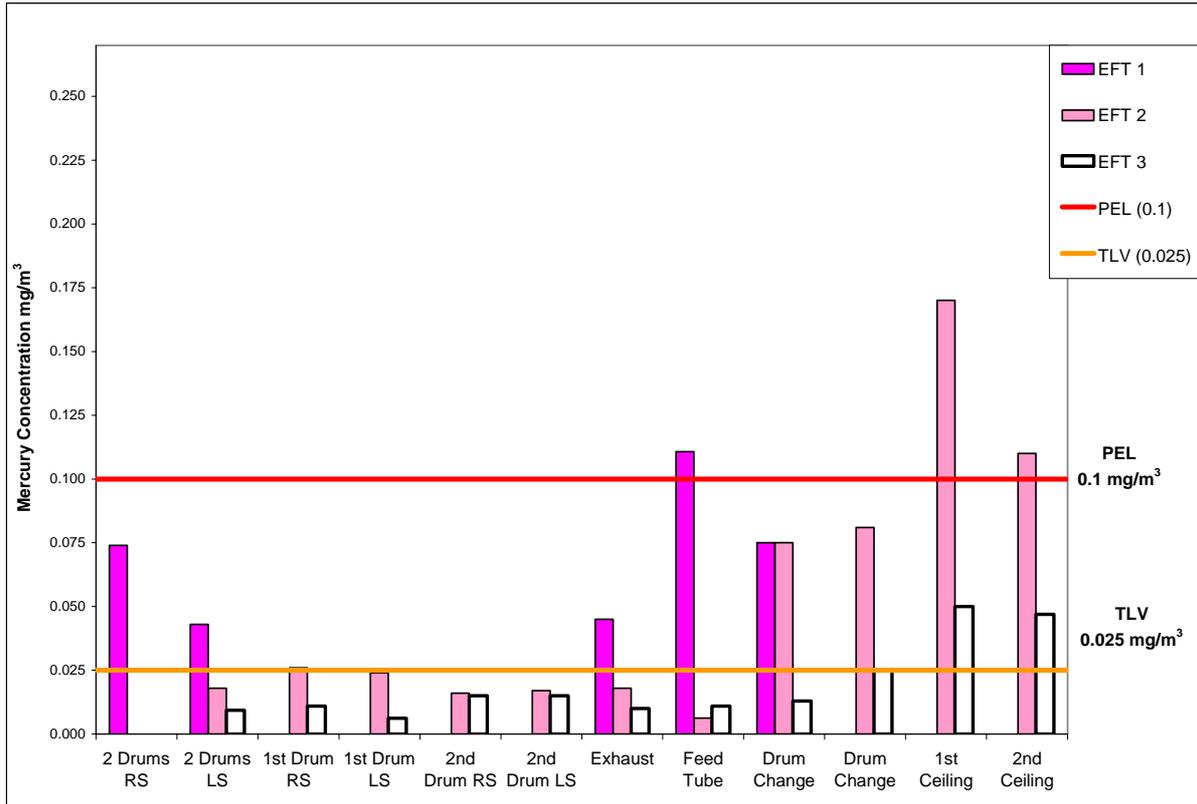
Comparison Across Devices

Devices were compared to each other for each EFT. During EFT #1 and EFT#2, there was no significant difference among the results from the analytical air samples (Hydrar tubes) collected inside the containment structure when each of the three devices were being operated. However, during EFT #3, the results from the analytical air sample collected while operating the Manufacturer A device were significantly lower than those collected while operating Manufacturer B or Manufacturer C devices (95 percent confidence). There was no significant difference between the Manufacturer B device and the Manufacturer C device during EFT #3. Figure 4. 5, Figure 4. 7, and Figure 4. 9 show the results for each EFT.

Performance of Each Device

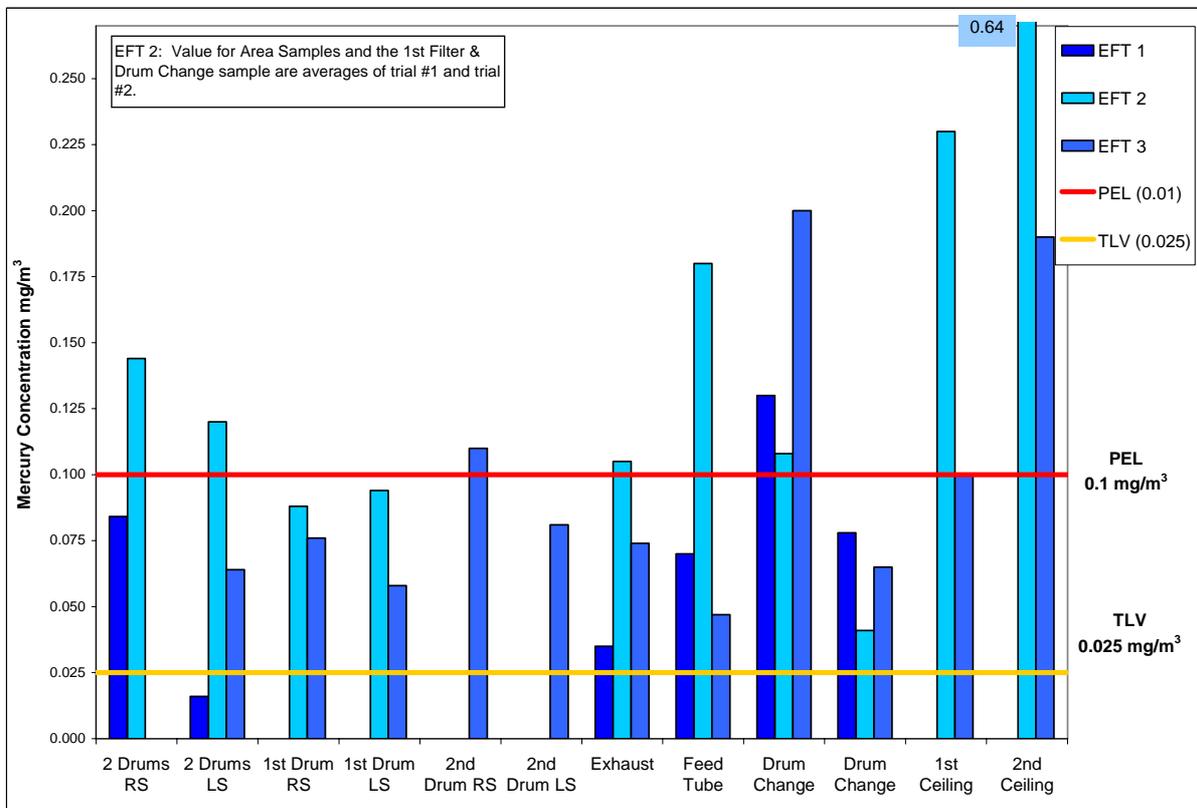
The variability of performance for each device was assessed by comparing the measured mercury concentrations from each field test; Figure 4. 11, Figure 4. 12, and Figure 4. 13 show the results from the EFTS for the devices from Manufacturer A, Manufacturer B, and Manufacturer C.

Figure 4. 11: Analytical Air Sampling Results, Extended Field Test Study - Manufacturer A ^a



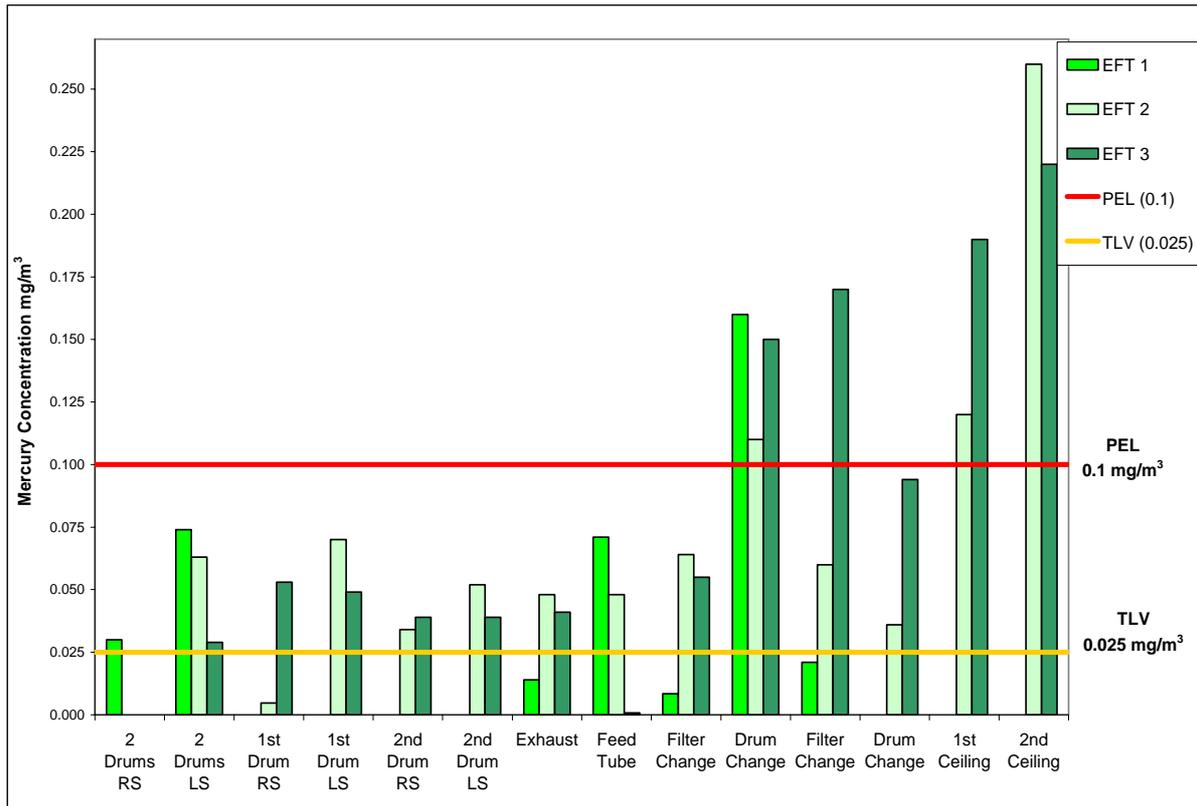
^a The TLV is included on the graph as a point of reference. The analytical air samples shown on this graph do not represent eight-hour TWAs (refer to Appendix A, Table 1 for sample durations).

Figure 4. 12: Analytical Air Sampling Results, Extended Field Test Study - Manufacturer B ^a



^a The TLV is included on the graph as a point of reference. The analytical air samples shown on this graph do not represent eight-hour TWAs (refer to Appendix A, Table 1 for sample durations).

Figure 4. 13: Analytical Air Sampling Results, Extended Field Test Study - Manufacturer C ^a



^a The TLV is included on the graph as a point of reference. The analytical air samples shown on this graph do not represent eight-hour TWAs (refer to Appendix A, Table 1 for sample durations).

In comparing performance over time (i.e., EFT #1, EFT #2, and EFT #3), not all of the air samples could be included. This was because no ceiling samples were taken for EFT #1. The ceiling samples were designed to assess maximum operator exposure. Therefore, inclusion of the samples would skew any statistical comparisons. Comparisons were based on the personal samples during operation and during filter changes and drum changes, the area samples within the containment structure, and the overnight samples within the containment structure (refer to Section 4.7).

The Manufacturer A device had significantly poorer performance during EFT #1 than during EFT #2 and EFT #3 (95 percent confidence). This was most likely due to a problem with assembly of the device in that test (refer to footnote 23 in Section 4.5.1.1). There was no significant difference in the performance of the Manufacturer B device or the Manufacturer C device during the EFTS.

4.6 Box Tests

During the first two portions of the Study (PVS I and EFT #1), the study team recognized that lamps that were broken in their shipping boxes could contribute mercury to the air in the containment structure during operation of the DTC devices and confound the air sample results. In order to evaluate and quantify the contribution of mercury to ambient mercury concentrations inside the containment structure by broken lamps, air samples were collected at AERC Melbourne and AERC Ashland, during EFT #2 and EFT #3, respectively.

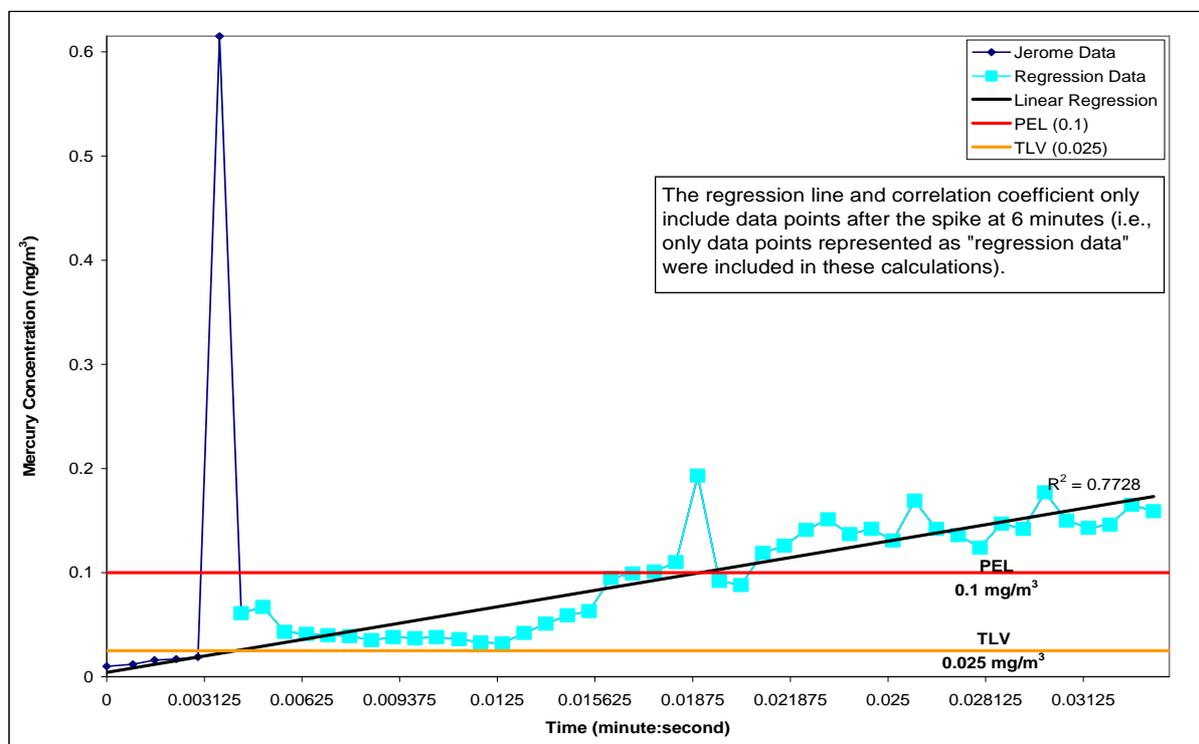
4.6.1 AERC Melbourne Box Test

As described in Section 3.5.1, the Manufacturer B device was tested twice during EFT #2. The first test was performed with boxes of broken lamps inside the containment structure, while the second test was performed without the boxes of broken lamps inside the containment structure. During both tests, personal air samples were collected during drum filling and drum changes, and area samples were collected near the device exhaust and near the device feed tube.

Four out of six sample results collected during the Manufacturer B #1 test exceeded the PEL value, and one out of the five sample results collected during the Manufacturer B #2 test exceeded the PEL value. The fact that 66.7 percent of the samples in test #1, when there were boxes with broken bulbs inside the containment structure, exceeded the PEL value, while only 20 percent of the samples in test #2, when there were not boxes inside the containment structure, exceeded the PEL value suggests a relationship between storing boxes of broken lamps inside the containment structure and elevated mercury concentrations.

The Jerome analyzer was used to measure mercury concentrations when the crushing activity had ceased and when boxes of broken bulbs were present inside the containment structure (refer to Figure 4. 14).

Figure 4. 14: Jerome Results - Inside Containment, AERC Melbourne Box Test ^a



^a The TLV is included on the graph as a point of reference. The mercury concentrations shown on this graph represent instantaneous measurements and do not represent eight-hour TWAs.

After an initial spike in mercury concentration to 0.6 mg/m³, measurements dropped below the PEL and then steadily increased over time. After 30 minutes, all readings were above the PEL. There was a positive correlation ($R^2 = 0.7728$) between

mercury concentrations and time. These results show that it is highly likely that the boxes containing broken lamps did contribute to increases in mercury concentrations within the containment structure.

4.6.2 AERC Ashland Box Test

For each device, after conducting EFT #3, two new air sampling pumps were set up in the containment structure. Boxes containing broken bulbs were placed in the containment structure, but no crushing activities were performed. One analytical air sample was collected on the east side of the containment structure, next to the boxes, and one was collected on the west side of the containment structure, away from the boxes. Samples were collected for 36 – 64 minutes (*refer to Appendix A, Table 1 for sample durations*). Table 4. 17 contains the air sampling results for the box test conducted at AERC Ashland.

Table 4. 17: Results for AERC Ashland Box Test

Device	East Side of Containment (Next to Boxes)	West Side of Containment (Away from Boxes)	Sample Duration (min)
Manufacturer A	0.018 mg/m ³	0.10 mg/m ³	64
Manufacturer B	0.12 mg/m ³	0.12 mg/m ³	36
Manufacturer C	0.050 mg/m ³	0.014 mg/m ³	45

While three of the six samples met or exceeded the OSHA PEL, there was no correlation between sample location (proximity to boxes with broken lamps) and mercury concentration. The Jerome analyzer was used at the same time as the analytical air samples, but the readings are not available due to data logger failure. No manual Jerome readings were taken because there was not anyone in the containment structure during the box tests.

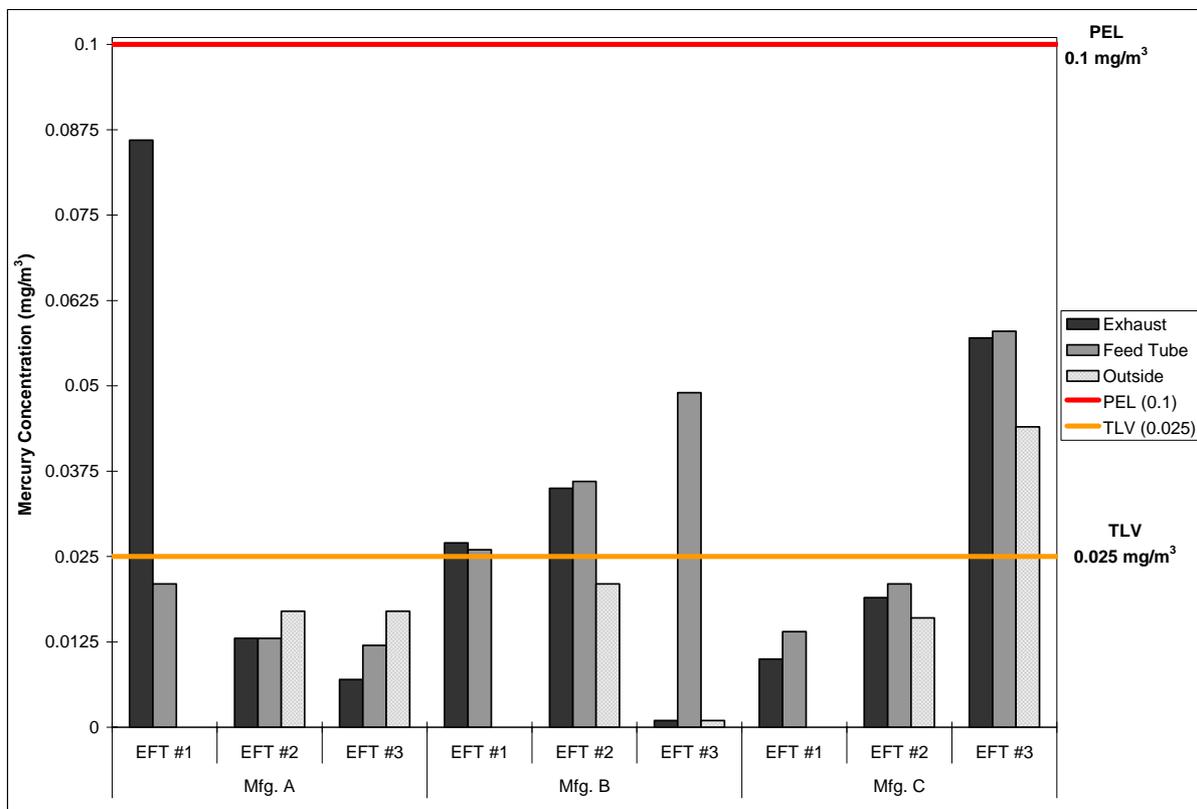
The results from the AERC Ashland box test do not suggest that the broken bulbs in the boxes contribute to elevated mercury concentrations because there was no relationship between the concentration of mercury in the air and the proximity of the air sampling pump to the boxes of broken lamps. However, direct-reading data are not available, so it is not possible to determine whether or not the trend of increasing mercury concentrations in the containment structure over time that was observed in the AERC Melbourne box test is truly representative of what would happen in such a scenario (i.e., boxes containing broken bulbs being stored in a confined space). Therefore, this is an area where future research may be appropriate.

4.7 Overnight Samples

In order to ascertain whether measurable amounts of mercury escaped from the DTC devices during non-operational periods when the devices were assembled on the top of a drum full of crushed lamps, analytical air samples were collected overnight after the operation of each DTC device. The Manufacturer A device blower was kept running (per the manufacturer’s instructions) during the overnight test. In accordance with the manufacturers’ instructions, the power to the Manufacturer B

and Manufacturer C devices were shut down when the devices were not in use. The results of the overnight tests are presented in Figure 4. 15.

Figure 4. 15: Overnight Test Sample Results



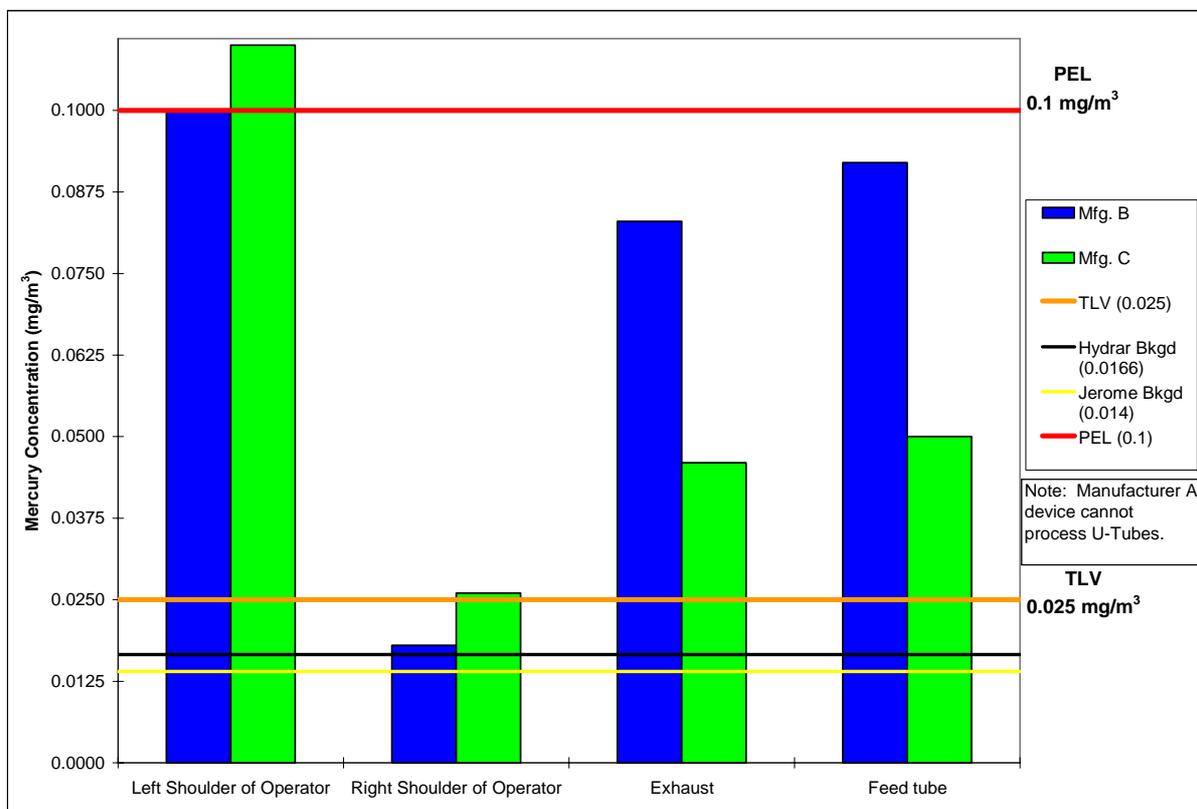
Because overnight samples were collected to assess general release during non-operational periods, values should not be compared to the OSHA PEL or the ACGIH TLV, which is a standard for worker exposure during a regular work day. The lines for the PEL and the TLV are included on the graph as points of reference. The overnight sampling was inconclusive as to whether idle DTC devices attached to partially filled drums of lamps leaked mercury vapors. The concentrations measured overnight were variable. In EFT #1, the overnight sample collected for the Manufacturer A device near the exhaust was much higher than any of the other samples. This may somehow relate to the fact that the Manufacturer A device was the only device that was left on overnight, per instructions in the operations manual.

In EFT #2 and EFT #3, air samples were collected outside the containment structure, as well as inside the containment structure. The overnight samples collected in the containment structure after operating the Manufacturer A device were below the values measured outside the containment structure. Three of the four overnight samples collected inside the containment structure after crushing lamps for the Manufacturer B device measured above the levels measured outside the containment structure. All four of the overnight samples collected inside the containment structure during EFT #2 and EFT #3 for the Manufacturer C device were higher than the outside samples.

4.8 U-Tube Test

The Manufacturer B and Manufacturer C devices have attachments that enable them to process “U” tube lamps (U-tubes). As discussed in Section 3.1.4.2, at the end of EFT #3 at AERC Ashland, a test was conducted to evaluate the airborne mercury levels from the two devices while processing U-tubes. The intent was for both the Manufacturer B and Manufacturer C devices to process enough U-tubes to fill a 55-gallon drum. However, the facility was only able to collect a limited number of U-tubes for the U-tube study, so the available U-tubes were divided between the two devices. The Manufacturer B device processed a total of 85 U-tubes, and the Manufacturer C device processed a total of 89 U-tubes. The sampling duration was 12 minutes for the Manufacturer B device and 14 minutes for the Manufacturer C device. The U-tube air sampling results are presented in Appendix A, Table 1 and shown in Figure 4. 16.

Figure 4. 16: U-tube Test Sample Results^a



^a The TLV is included on the graph as a point of reference. The analytical air samples shown on this graph do not represent eight-hour TWAs (refer to Appendix A, Table 1 for sample durations).

All samples, except for the Manufacturer B sample on the operator’s right shoulder, were above the TLV value. Furthermore, two of the operator breathing zone samples (one for the Manufacturer B device and one for the Manufacturer C device) equaled or slightly exceeded the PEL value. These levels are generally higher than the results from processing the straight lamps, especially in light of the fact that so few U-tubes were processed by each device. A possible explanation for the high mercury levels is the fact that the opening for the U-tube attachment was much larger than the opening for the feed tube for the straight lamps.

5. MASS BALANCE STUDY

The goal of the Mass Balance Study was to estimate for each DTC device its effectiveness in capturing and retaining mercury in the device, expressed as a percent of the total mass of mercury fed into the DTC device. A successful Mass Balance Study would also allow assessment of the total mercury released to the environment due to DTC use, and also to support assessment of potential secondary exposures to mercury from lamp crushing. For each DTC device, the total mercury contained in enough lamps to fill one drum was estimated, and this quantity was then compared with the total mercury detected in samples collected during PVS – Phase I, including: crushed lamps from the drum, DTC pollution control media (particulate, HEPA, and carbon filters), and analytical air samples. See Section 5.1 for the mathematical mass balance equation.

The following sections describe the methodology for, and present the results of, the Mass Balance Study. Note that these results represent the best achievable efforts based on the techniques, methods, equipment, and conditions tested. In some cases (e.g., estimating the quantities of mercury in the unprocessed lamps), there are no agency-approved test methods; therefore, it was necessary to rely on either the manufacturer’s internal testing results (i.e., QC testing) or on the results from the methods improvised by the project laboratory, which were intended to simulate the manufacturer’s test apparatus. The objectives of this project were strictly research and investigation, and the data generated may or may not be suitable for other purposes, such as human health risk assessment.

5.1 Mass Balance Equation

The mass balance mathematical equation is:

$$\text{Hg}_T = \text{Hg}_C + \text{Hg}_R \quad \text{Equation 5.1}$$

where: Hg_T is the estimated total mercury content of unprocessed lamps
 Hg_C is mercury captured in the DTC device (specifically within the air filter media or “filters” and crushed lamps)
 Hg_R is mercury released to the ambient air from the DTC device

Hg_T is determined by the average quantity of mercury in a typical fluorescent lamp, multiplied by the number of lamps processed in the DTC device (*refer to Section 5.2*). Hg_C is determined by the quantity of mercury measured in the crushed lamps and in the various filters (*refer to Section 5.3*). Hg_R is determined by the quantity of mercury measured in the ambient air within the containment structure, as determined by area and personnel air samples (*refer to Section 5.4*).

5.2 Estimating Total Mercury Content of Unprocessed Lamps (Hg_T)

As mentioned above, the first important step in the Mass Balance Study was to estimate the input mercury, or the quantity of mercury contained in a typical set (i.e., one drum’s worth) of unprocessed lamps. In theory, this amount should be 100 percent of the total mercury available for potential release to the crushed lamps, the

air filtration system, and as fugitive emissions to the surrounding indoor air. Any difference between this amount and the total of the component terms on the right-hand side of Equation 5.1 thus is a measurement of the potential error in this study.

Philips Lighting (Philips) “Alto®” fluorescent lamps (also referred to as “green tip” lamps) were used during this part of the DTC Study. According to e-mail correspondence from Mr. Steve McGuire of Philips to Mr. Tad Radzinski of EPA, these lamps are manufactured to achieve a specific mass content of mercury, depending on the type of lamp (Table 5. 1), and the tolerance on the mercury content is +/- 0.1 mg of mercury. The mercury content is determined using a test procedure and testing apparatus that Philips has developed specifically for this purpose. Energized (lighted) mercury lamps are attached to the testing apparatus and then chilled using dry ice or other super-cooled vapor. The cooling process condenses the mercury vapor, eventually causing the light to be extinguished. After cooling, a hole is drilled in the metal end cap of the lamp, and an acid extraction method is used via the hole in the metal end cap to recover the mercury for quantitative analysis (*refer to Appendix E*).

Table 5. 1: Mass of Mercury in Philips Lighting Alto® Fluorescent Lamps

Type of Lamp	Mass of Mercury Per Lamp (mg)	Manufacturer’s Tolerance (mg)
T-8	3.5	+/- 0.1
T-12 (34 Watt)	4.4	+/- 0.1
T-12 (39 Watt)	3.5	+/- 0.1
T-12 (40 Watt)	4.4	+/- 0.1

In order to approximate real-world operating conditions for the DTC Device Study, spent lamps were processed. To obtain data regarding the mercury content of the spent lamps, a sample of unbroken, Alto® lamps were removed from the stockpile and submitted to Data Chem for analysis of total mercury. These results are contained in Table 5. 2. The data are generally lower than the results provided by Philips for new lamps. This difference is possibly due to small leaks of mercury that occurred during the operating lives of the lamps. Other factors, such as reaction of mercury vapor with lamp components leading to conversion of elemental mercury into salts, dissolution of the mercury into the lamp glass, or binding of mercury to other lamp components, might contribute to this disparity but were not a subject of this study. (The reaction of mercury vapor with lamp components was studied by Hildenbrand, et al.²⁶ and Jang, et al.²⁷)

²⁶ Refer to Hildenbrand, V. D.; Denissen, C. J. M.; Geerdinck, L. M.; van der Marel, C.; Snijders, J. H. M.; and Tamminga, Y. 2000. *Interactions of thin oxide films with low-pressure mercury discharge*. *Thin Solid Films*. 371: 295-302.

²⁷ Refer to Jang, Min; Hong, Seung Mo; and Park, Jae K. 2005. *Characterization of recovery of mercury from spent fluorescent lamps*. *Waste Management*. 25: 5-14.

Table 5. 2: Total Mercury in Spent Philips Lighting Alto® Fluorescent Lamps ^a

Type of Lamp	Fluorescent Lamp Mercury Quantity (mg)	Mean Mercury Quantity (mg)	Standard Deviation
T-8	3.0	3.0 (10 - 15 mg/kg)	0.082
	2.9		
	3.1		
T-12 (34 Watt)	4.2	4.2 (14 - 21 mg/kg)	0.12
	4.4		
	4.1		
T-12 (40 Watt)	4.3	3.6 (12 - 18 mg/kg)	0.75
	2.8		

^a No samples of T-12 39 Watt lamps were available for this analysis.

The total mass of mercury in the lamps processed in each DTC device was estimated using the total number of each type of lamp processed and the mean mercury content of each lamp, as shown in Equation 5.2.

$$Hg_T = N_L * Hg_L \quad \text{Equation 5. 2}$$

where: Hg_T is the estimated total mercury content of unprocessed lamps
 N_L is the total number of lamps processed
 Hg_L is the mean mercury content of a single lamp

Means for mercury content for each lamp type were determined from either the unbroken lamp samples collected during the study or the information provided by Philips Lighting. In general, use of the study sampling results was preferred, except in the case of the T-12 39 Watt lamp type, where no data were available (*see footnote to Table 5. 2*). The rationale for using the study data over the manufacturer's averages was that the unbroken lamps were obtained from the broader collection of actual used lamps arriving at the respective facilities and thus were believed to be more representative for this study.

After the conclusion of the DTC Study, research was published regarding the efficacy of acid extraction of mercury from fluorescent bulbs (*refer to footnote 27 in Section 5.2*). This issue is discussed further in Sections 5.6 and 5.7.

Table 5. 3 provides an inventory of the types of lamps processed by each device and the estimated total mass of mercury processed through each device during the Mass Balance Study (Hg_T).

Table 5. 3: Mass of Mercury Processed for Each DTC (Hg_T)

Device	Lamp Type	Number of Lamps	Amount of Mercury per Lamp (mg/lamp)	Total Quantity of Mercury (mg)
Manufacturer A	T-12 (34 Watt)	637	4.2	2,675
Total - Hg_T				2,675 mg
Manufacturer B	T-12 (34 Watt)	113	4.2	475
	T-8	611	3.0	1,833
Total - Hg_T				2,308 mg
Manufacturer C	T-12 (34 Watt)	621	4.2	2,608
	T-12 (39 Watt)	49	3.5	172
	T-12 (40 Watt)	36	3.6	130g
Total - Hg_T				2,910 mg

5.3 Estimating Mercury Mass Captured in the DTC Devices (Hg_C)

Mercury was captured inside the DTC devices in either one of two ways:

- Contained within the crushed lamps collected inside the 55-gallon drum beneath the device; or
- Retained as particulate or vapor air emissions retained within the air filtration system that was supplied with the particular device (listed in Table 5. 4).

Section 3.3 provides details regarding the collection of bulk samples, including crushed lamps and pollution control media, for each device. Table 5. 4 summarizes the number and type of bulk samples.

Table 5. 4: Samples Collected for the Mass Balance Study

Manufacturer A Device	Manufacturer B Device	Manufacturer C Device
Crushed lamps - 3 samples	Crushed lamps - 3 samples	Crushed lamps - 3 samples
Top carbon canister - 3 samples	Pre-filter - 1 sample	Pre-filter - 3 samples
Middle carbon canister - 3 samples	Carbon canister - 3 samples	Carbon canister - 3 samples
HEPA filter - 3 samples		HEPA filter - 1 samples

The analytical results for the samples collected for Manufacturer A, Manufacturer B, and Manufacturer C devices are provided in Table 5. 5. Samples from the Manufacturer D device are not presented below because the Manufacturer D device was removed from the Study (*refer to Section 3.5.1*).²⁸

²⁸ During the Mass Balance Study, when only “low mercury” lamps were used and outdoor temperatures were low, operation of the Manufacturer D device resulted in ambient mercury concentrations nearly 9 times the OSHA PEL, highlighting the problems inherent in the use of a poorly designed DTC device.

Table 5. 5: Mass Balance Study Sample Results

DTC Device	Sample Material	Result (w/w) ^a	Result (w/a) ^b	Mean Result	Std. Dev.
Manufacturer A	Crushed Lamps	5.84 µg/g	NA	3.70 µg/g	1.852
Manufacturer A	Crushed Lamps	2.70 µg/g	NA		
Manufacturer A	Crushed Lamps	2.57 µg/g	NA		
Manufacturer A	Carbon Canister (top)	84 µg/g	NA	62 µg/g	25.534
Manufacturer A	Carbon Canister (top)	34 µg/g	NA		
Manufacturer A	Carbon Canister (top)	68 µg/g	NA		
Manufacturer A	Carbon Canister (middle)	39 µg/g	NA	15 µg/g	20.649
Manufacturer A	Carbon Canister (middle)	5.0 µg/g	NA		
Manufacturer A	Carbon Canister (middle)	1.7 µg/g	NA		
Manufacturer A	HEPA Filter	NA	4.2 µg/100 cm ²	5.5 µg/100cm ²	1.253
Manufacturer A	HEPA Filter	NA	6.7 µg/100cm ²		
Manufacturer A	HEPA Filter	NA	5.6 µg/100cm ²		
Manufacturer B	Crushed Lamps	5.17 µg/g	NA	5.11 µg/g	0.4880
Manufacturer B	Crushed Lamps	4.59 µg/g	NA		
Manufacturer B	Crushed Lamps	5.56 µg/g	NA		
Manufacturer B	Pre-Filter ^c	490 µg/g	NA	490 µg/g	N/A
Manufacturer B	Carbon Canister	11 µg/g	NA	22 µg/g	12.220
Manufacturer B	Carbon Canister	19 µg/g	NA		
Manufacturer B	Carbon Canister	35 µg/g	NA		
Manufacturer C	Crushed Lamps	6.07 µg/g	NA	4.69 µg/g	1.975
Manufacturer C	Crushed Lamps	5.58 µg/g	NA		
Manufacturer C	Crushed Lamps	2.43 µg/g	NA		
Manufacturer C	Pre-Filter ^c	180 µg/g	NA	180 µg/g	0.0
Manufacturer C	Pre-Filter ^c	180 µg/g	NA		
Manufacturer C	Pre-Filter ^c	180 µg/g	NA		
Manufacturer C	Carbon Canister	2.7 µg/g	NA	5.8 µg/g	3.053
Manufacturer C	Carbon Canister	6.0 µg/g	NA		
Manufacturer C	Carbon Canister	8.8 µg/g	NA		
Manufacturer C	HEPA Filter	NA	2.3 µg/100 cm ²	2.3 µg/100 cm ²	N/A

^a Result w/w column of the Bulk Sample Results table is a proportion of weight per weight.

^b Result w/a column of the Bulk Sample Results table is a proportion of weight per area.

^c "Pre-filter" primarily consisted of phosphor with a few glass fines. The pre-filter was collected off a paper sock filter (Manufacturer B device) or a vacuum-bag type filter (Manufacturer C device).

NA - Not applicable

µg/g - micrograms per gram

µg/100 cm² - micrograms per 100 square centimeters

The device manufacturers were instructed to submit clean filter media to Data Chem for quality control (QC) samples. These clean materials were used for laboratory blanks and matrix spikes. The blank sample values are shown in Table 5. 6. The spike values and recoveries are listed in Table 5. 11 and discussed in Section 5.6.2. Table 5. 6 also presents the weight or area information for the samples, as applicable. Results are reported as either a mass of mercury per weight or a mass of mercury per area. The methods used to measure the weight of the samples are described in Section 3.3. The manufacturers provided the nominal areas of each type of filter used in the various devices. Prior to performing the mass balance calculations, all values were converted from standard units (i.e., pounds [lb] or square inches [in²]) to metric units (i.e., grams [g] or square centimeters [cm²]). Table 5. 7 presents the measured mass of mercury captured in each of the different media (i.e., [mean concentration]*[applicable weight or area]), in milligrams (mg).

Table 5. 6: Total Weights, Areas, and Blank Mercury Concentrations of Bulk Sample Media

Device	Weight of Crushed Lamps		Weight of Pre-Filter		Area of HEPA Filter Media		HEPA Filter Blank (µg/sample)		Weight of Carbon Canister		Carbon Canister Blank (µg/g)	
	lb ^(a)	g	lb ^(a)	g	in ^{2(a)}	cm ²			lb ^(a)	g		
Manufacturer A	466	211,374	NA	NA	7,632	49,239	ND	ND	29/bag	13,154	7.4	20.0
Manufacturer B	331	150,139	0.056	25.4	NA	NA	NA	NA	0.742	337	ND	ND
Manufacturer C	436	197,766	0.58	263	194	1,250	ND	ND	22	9,979	ND	ND

^a Actual measured weight or area of the media.

NA - Not applicable

ND - Not detected

Table 5. 7: Estimated Mercury Mass Captured inside DTC Devices (Hg_c)

Device	Sample Type	Concentration	Weight or Area	Total Hg (mg)
Manufacturer A	Crushed Lamps	3.70 µg/g	211,374 g	782
	HEPA Filter	5.5 µg/100 cm ²	49,239 cm ²	2.7
	Carbon Canister (top)	62 µg/g	13,154 g	816
	Carbon Canister (middle)	15 µg/g	13,154 g	197
Total - Hg_T				1,798
Manufacturer B	Crushed Lamps	5.11 µg/g	150,139 g	767
	Pre-Filter	490 µg/g	25.4 g	12
	Carbon Canister	22 µg/g	337 g	7.4
Total - Hg_T				786
Manufacturer C	Crushed Lamps	4.69 µg/g	197,766 g	928
	Pre-Filter	180 µg/g	263 g	47.3
	HEPA Filter	2.3 µg/100 cm ²	1,250 cm ²	0.029
	Carbon Canister	5.8 µg/g	9,979 g	58
Total - Hg_T				1,033

5.4 Estimated Mercury Released To The Ambient Air (Hg_R)

The total mass of mercury released to the ambient air from each DTC device (Hg_R) was estimated using the air sampling data collected during PVS - Phase I. The method for calculating Hg_R is shown in Equation 5.3.

$$Hg_R = N_{AE} * [Hg] * V \quad \text{Equation 5.3}$$

where: Hg_R is mercury released to the ambient air from the DTC device
 N_{AE} is the estimated number of air exchanges
 $[Hg]$ mean air concentration in containment structure during PVS I
 V is the volume of the containment structure

The mean of the four area air sample results (two samples at the feed tube and two samples at the device exhaust) was calculated for each DTC device. The containment structure measured 12 feet by 12 feet by 10 feet, for a volume of 1,440 cubic feet (ft^3), which converts to 40.78 cubic meters (m^3).

During the operation of all devices, movement in and out of the containment structure was limited to supplying boxes of lamps to the operator and the industrial hygienist collecting the air samples, thus limiting (to the extent practicable) the exchange of air between the containment volume and the outside. In addition, as described previously in Section 2.2, the construction of the containment space itself (e.g., taped and overlapping plastic sheeting) aided in isolating the space and limiting air movement. While the number of air exchanges was not specifically measured, it was estimated using Equation 5.4.

$$N_{AE} = (Q * t) / V \quad \text{Equation 5.4}$$

where: N_{AE} is the estimated number of air exchanges
 Q is the volumetric flow rate of air coming out of the device exhaust
 t is the duration of the area air sampling
 V is the volume of the containment structure

Table 5.8 presents the mean mercury concentrations in the air samples and the estimated mass of mercury released (Hg_R) for each device:

Table 5.8: Mercury Released from DTC Devices (Hg_R)

Device	Flow Rate (ft^3/min)	Time (min)	Number of Air Exchanges	Mean Mercury Concentration (mg/m^3)	Volume (m^3)	Mercury Released (Hg_R)
Manufacturer A	25 ^a	112	1.9	0.0094	40.78	0.75 mg
Manufacturer B	34 ^b	86	2.0	0.010	40.78	0.82 mg
Manufacturer C	42 ^b	100	2.9	0.0095	40.78	1.3 mg

^a Estimate from owner's manual.

^b Measured during operation.

While the reported values for the number of air exchanges are estimates, they do not significantly affect the mass balance because $Hg_R \ll Hg_C$ (refer to Table 5. 9).

Originally, it was also intended to include the wipe sampling results from the interior surfaces of the polyethylene containment structure, to attempt to quantify the contribution of mercury vapor condensation to the overall mass balance. However, this process was impacted by the unexpectedly high ambient concentrations of mercury inside the facilities. Due to these high ambient concentrations, it would not have been possible to effectively differentiate mercury vapors released by the device and condensing on the polyethylene sheeting from vapors already existing in the air and condensing on the sheeting. Furthermore, some of the mercury mass might have been double-counted under such a scenario. Therefore, wipe sampling results were excluded from the Mass Balance Study. Refer to Appendix F for a discussion of the wipe sample results.

5.5 Mass Balance Results

Sections 5.2, 5.3, and 5.4 described the methods used to derive the mass of mercury that was used in the mass balance calculations. Table 5. 9 is a summary of the total mass of mercury contributed by each source.

Table 5. 9: Summary of Mercury Mass Contributions, By Source

Device	Hg _C					Hg _R
	Crushed Lamps	Pre-Filter	HEPA Filter	Carbon Canister(s)	Total	
Manufacturer A	782 mg	NA	2.7 mg	1,013 mg ^a	1797.7 mg	0.75 mg
Manufacturer B	767 mg	12 mg	NA	7.4 mg	786.4 mg	0.82 mg
Manufacturer C	928 mg	47.3 mg	0.029 mg	58 mg	1033.329 mg	1.3 mg

^a Combined recovery by the top and middle carbon canisters on the Manufacturer A device.

Table 5. 10 contains the results of the mercury mass balance calculation for each device, as well as the percentage of mercury accounted for compared to the estimated mass of mercury processed (i.e., the mercury content of the unprocessed whole lamps).

Table 5. 10: Mass Balance Calculation Results

Device	Hg Processed (Hg _T)	Hg Recovered (Hg _C + Hg _R)	% Recovery
Manufacturer A	2,675 mg	1,798 mg	67.3 %
Manufacturer B	2,308 mg	787 mg	34.1 %
Manufacturer C	2,910 mg	1,035 mg	35.6 %

5.6 Mass Balance Discussion

Based on the mass balance results obtained from this study and presented in Table 5. 10, the total mercury mass accounted for ($Hg_C + Hg_R$) was about one third to two thirds less than the estimated input of mercury (Hg_T). Several variables may have contributed to the inability to account for a fairly large percentage of the mercury. Three of the most likely variables that would affect the mass balance are: 1) inaccuracies in the determination of mercury in the crushed lamps; 2) inaccuracies in the determination of mercury in the filter media due to poor recovery during the laboratory analysis; and 3) absorption of mercury on polyethylene (the containment structure) and inside the DTC device. In addition, there is no approved laboratory procedure to estimate the mercury content of whole fluorescent lamps, making this factor another possible cause of the imbalances noted during this study.

5.6.1 Mercury Mass in Crushed Lamps

As indicated by the results summarized in Table 5. 9, a substantial fraction of the mercury produced during the crushing of lamps in the DTC devices accumulates in the crushed lamps. Therefore, this variable has a substantial influence on the mass balance results. It was closely studied to attempt to understand the reason for the disparity between the total mercury mass in the lamps before processing and the mercury mass accounted for after processing.

The proportion of the total mercury mass detected ($Hg_C + Hg_R$) in the crushed lamps was 43 percent for the Manufacturer A device, 97 percent for the Manufacturer B device, and 90 percent for the Manufacturer C device. The lower percentage observed for the Manufacturer A device can be attributed to the relatively larger capture of mercury mass in the more extensive air filtration equipment (HEPA filter and carbon filters) associated with this device. As can be noted from Table 5. 9, the actual mercury mass in the crushed lamps from each of the three devices are similar (having the same orders of magnitude).

The sample results for the crushed lamps for all devices in general may have been biased low, for three reasons.

- The method of collecting the samples of crushed lamps involved digging as deep into the drum as possible to collect the samples. However, due to the high density of the crushed lamps (caused by the unaided compaction of the crushed glass and other debris), the samples could only be collected at a depth of approximately eight inches. The operation of each DTC device causes the drum to vibrate, and this vibration may have caused the phosphor powder fraction of the crushed lamps to stratify vertically within the drum. An analysis of the crushed lamps components indicates that the majority of the mercury will be condensed onto this fine phosphor powder (*refer to Appendix G*), thus causing an unequal distribution of mercury mass with lower concentrations on top. Jang, et

al. (2005)²⁹ and Raposo, et al. (2003)³⁰ provide further information on the distribution of mercury in spent fluorescent lamps. Because of this likely distribution of phosphor powder in the drum, samples collected at a depth of eight inches would likely not be representative of the contents of the drum.

- Some mercury likely volatilized and was released during the collection of the crushed lamps samples from the drum, compositing the samples, and transfer of the material to the sample containers.
- Additional handling and sorting of the composite samples at the laboratory may have resulted in further volatilization of mercury.

Due to a miscommunication between Booz Allen Hamilton and Data Chem, the laboratory initially analyzed only the phosphor powder and glass fines portion of the crushed lamps bulk samples. The results for the mercury concentration in crushed lamps that were obtained in this first analysis were greater than the mercury concentrations in unbroken lamps by an order of magnitude.

When this error was identified, the laboratory was instructed to analyze the remaining crushed lamp sample material (i.e., the broken glass and lamp end caps). The combined results from both analyses were used to estimate mass of mercury in the crushed lamps for the mass balance. Appendix G presents a discussion of the two sets of results.

5.6.2 Mercury Mass in Air Filtration System Elements

An important variable in the mass balance equation is the analytical results for mercury in the various air filtration media associated with the DTC devices. As discussed below, the laboratory-reported concentrations of mercury from the carbon media and the HEPA filters contained significant errors. Because the pre-filters were easily accessible and the amount of material collected in the pre-filters was limited, the pre-filter sampling data are likely to be accurate, and thus, the efforts to identify probable sources of error focused on the HEPA filters and the activated carbon.

Laboratory spike samples were prepared and analyzed, to assess potential matrix interferences from the filter or carbon media, as applicable. Manufacturer A, Manufacturer B, and Manufacturer C were contacted and instructed to submit clean filter media samples to Data Chem. Manufacturer A and Manufacturer C each submitted a HEPA filter and carbon canister, and Manufacturer B submitted its composite filtration cartridge, which consists of a particulate/pre-filter and a carbon canister. The quantity of mercury with which to spike each media was based on the results obtained during prior DTC device tests in this study. Data Chem prepared and analyzed four spike samples and two blank samples per media.

²⁹ Refer to Jang, Min; Hong, Seung Mo; and Park, Jae K. 2005. *Characterization of recovery of mercury from spent fluorescent lamps*. *Waste Management*. 25: 5-14.

³⁰ Refer to Raposo, Cláudio; Windomöller, Cláudio Carvalhinho; and Júnior, Walter Alves Durão. 2003. *Mercury speciation in fluorescent lamps by thermal release analysis*. *Waste Management*. 23: 879-886.

The results for these QA/QC samples are given in Table 5. 11.

Table 5. 11: Spike and Blank Analytical Results for Pollution Control Media

Device	Media	Spiked Concentration	Recovered Concentration	Percent Recovery
Manufacturer A	Carbon (C1)	60 µg/g	67 µg/g	112%
Manufacturer A	Carbon (C2)	60 µg/g	56 µg/g	93%
Manufacturer A	Carbon (C3)	60 µg/g	60 µg/g	100%
Manufacturer A	Carbon (C4)	60 µg/g	100 µg/g	167%
Manufacturer A	Carbon Blank (CB1)	0 µg/g	7.4 µg/g	NA
Manufacturer A	Carbon Blank (CB2)	0 µg/g	20 µg/g	NA
Manufacturer A	HEPA Filter (F1)	2 µg/sample	2.2 µg/sample	110%
Manufacturer A	HEPA Filter (F2)	2 µg/sample	2.1 µg/sample	105%
Manufacturer A	HEPA Filter (F3)	2 µg/sample	2.2 µg/sample	110%
Manufacturer A	HEPA Filter (F4)	2 µg/sample	2.2 µg/sample	110%
Manufacturer A	HEPA Filter Blank (FB1)	0 µg/g	ND	NA
Manufacturer A	HEPA Filter Blank (FB2)	0 µg/g	ND	NA
Manufacturer B	Carbon (C1)	20 µg/g	4.5 µg/g	23%
Manufacturer B	Carbon (C2)	20 µg/g	4.4 µg/g	22%
Manufacturer B	Carbon (C3)	20 µg/g	4.3 µg/g	22%
Manufacturer B	Carbon (C4)	20 µg/g	4.3 µg/g	22%
Manufacturer B	Carbon Blank (CB1)	0 µg/g	ND	NA
Manufacturer B	Carbon Blank (CB2)	0 µg/g	ND	NA
Manufacturer C	Carbon (C1)	6 µg/g	3.4 µg/g	57%
Manufacturer C	Carbon (C2)	6 µg/g	3.6 µg/g	60%
Manufacturer C	Carbon (C3)	6 µg/g	3.6 µg/g	60%
Manufacturer C	Carbon (C4)	6 µg/g	3.6 µg/g	60%
Manufacturer C	Carbon Blank (CB1)	0 µg/g	ND	NA
Manufacturer C	Carbon Blank (CB2)	0 µg/g	ND	NA
Manufacturer C	HEPA Filter (F1)	1 µg/sample	0.67 µg/sample	67%
Manufacturer C	HEPA Filter (F2)	1 µg/sample	0.84 µg/sample	84%
Manufacturer C	HEPA Filter (F3)	1 µg/sample	0.72 µg/sample	72%
Manufacturer C	HEPA Filter (F4)	1 µg/sample	0.76 µg/sample	76%
Manufacturer C	HEPA Filter Blank (FB1)	0 µg/g	ND	NA
Manufacturer C	HEPA Filter Blank (FB2)	0 µg/g	ND	NA

ND - Not detected above the analytical limit of detection.

NA - Not applicable

Differences between the spiked concentration and detected concentration generally reflect potential interferences caused by the pollution control media, as well as

analytical error. As indicated above, the Manufacturer B carbon media, Manufacturer C carbon media, and Manufacturer C HEPA filter produced results with very low recoveries. Thus, portions of the mercury that are not accounted for in the mass balance could have been retained in the pollution control media for these two devices but may not have been detected in the laboratory analysis. The Manufacturer A carbon media spikes generally produced results above 100 percent, which is consistent with the mercury detected in the manufacturer-supplied blanks. The HEPA filter spikes were also slightly above 100 percent in all cases, but are within ± 10 percent of the actual spiked value. No mercury was detected in the HEPA filter blanks.

5.6.3 Mercury Mass Adhering to Surfaces

Difficulties with contamination prevented the use of the wipe samples collected for the mass balance. Bulk samples of the polyethylene used for each containment structure were not collected. Because mercury permeates through and adheres to polyethylene, a significant portion of the mercury not accounted for in the mass balance may have been associated with the containment structure. It is also possible that some amount of mercury adhered to the insides of the DTC devices.

5.6.4 Mercury Mass in Ambient Air

The mass of mercury released during DTC device operation (Hg_R) was calculated based on Equation 5.3, which included the number of air exchanges, the concentration of mercury in the air inside the containment structure, and the volume of the containment structure. The number of air exchanges was not measured during the Study; numbers of air exchanges were calculated for each device based on the speeds of the exhaust fans. However, the errors associated with these numbers are not known, and these errors would affect the result of the Hg_R calculation. Additionally, it is possible that some portion of the mercury released from the DTC devices permeated through the containment structure and, therefore, was not accounted for in the mass balance equation.

5.7 Mass Balance Study Observations

A Mass Balance Study was conducted in order to determine whether the mercury from lamps crushed in the various DTC devices could be accounted for in recognizable mass flows associated with operation of the devices (i.e., crushed lamps, air filtration equipment, and fugitive emissions to the air). The study was unable to establish a concrete relationship between mass input and output, based on the media and waste streams that could be readily sampled during these tests. For all three devices, the estimated input mercury quantities on a mass basis were substantially larger than the measured output quantities. The following factors should be considered in designing any future Mass Balance Study.

- Appropriate sampling procedures for the crushed lamp samples need to be developed. The drum used for sampling the crushed lamps could be retrofitted to allow multiple samples to be collected at various depths within the drum.

- Any steps taken to avoid releases to the air when creating a composite sample and expediting transfer of the sample to the container will likely reduce mercury losses.
- A validated and approved test method for quantifying the mercury in whole unbroken lamps is needed, including an understanding of the relative accuracy and error inherent to such a test.
- An approved test method for quantifying the mercury in the pollution control media (HEPA, carbon, and particle filters) is needed, including an understanding of the relative accuracy and error inherent to such a test.
- The material used to construct the containment structure could have a significant affect on the containment and measurement of mercury. A material better suited to mercury sampling, such as vinyl, should be considered if a containment structure is used.
- Wipe sampling procedures need to be improved and pre and post samples of the material used to construct the containment structure may be necessary.

No scientific methodology was applied to attempt to understand the relative impact of each of the above factors on the results presented here because it was beyond the scope of this Mass Balance Study.

6. LIMITATIONS

After reviewing the data collected during the Study, a number of factors were identified that may have affected the study results:

- Mercury background levels inside the facilities where the tests were performed
- Differences in environmental conditions (i.e., temperature and relative humidity) at each test site resulting in greater or lesser volatilization of mercury
- Cross-contamination from lamps broken during shipment to the processing site
- Contamination from lamps broken during operation.

This section provides a summary of how these factors may have influenced the study results.

6.1 Background Levels of Mercury

The DTC Device Study was conducted at operational lamp recycling facilities that crush large quantities of spent fluorescent lamps. At AERC Ashland and AERC Melbourne, the DTC devices were operated in a separate bay from the primary lamp processing areas. At EPSI Phoenix, due to the configuration of the plant, the tests could not be isolated from the normal plant operations as effectively as at the other sites. The Study was conducted at fluorescent lamp recycling facilities for several reasons:

- These facilities possessed the appropriate permits to process mercury-containing fluorescent lamps.
- These facilities had ample supplies of fluorescent lamps that were provided at no cost to the study team.
- The facilities had the capacity to process and dispose of the drums of crushed lamps, with no shipping, manifesting, or disposal arrangement required of the study team.

The study team made every effort to isolate the study area from normal lamp processing operations. At all three locations, a containment structure of plastic sheeting was constructed around the study area; however, as discussed below, this was only partially effective as a barrier to ambient, background mercury contamination.

At the beginning of testing at each location, two analytical air samples were collected in the immediate vicinity of the study area, to attempt to measure background mercury concentrations inside the lamp recycling facility. The results indicated that each facility had elevated concentrations of mercury in the ambient air. (*Refer to Table 4.1 and Table 4.2 for the background concentration measurements for each facility.*)

The background mercury concentration affected, to some extent, the analytical sample results. Elevated background concentrations would have the potential to

bias any study results and may affect the validity of conclusions drawn from the Study by:

- Elevating the ambient air sampling analytical results and real-time (i.e., Jerome) readings above what they would have been if background conditions were not characterized by elevated levels of mercury; and
- Causing deposition of mercury on the containment area surfaces, which later could have re-volatilized during the tests and created “false positives” or led to exceedances of OSHA or ACGIH standards.

The high background mercury made it more difficult to definitively attribute the mercury measurements to the DTC devices. In retrospect, background sampling was likely inadequate to fully characterize this confounding factor. If future research is conducted in an industrial lamp recycling facility, it will be important that rigorous background sampling be performed, which could include collecting analytical air samples and direct-reading air measurements before, during, and after testing.

6.2 Experimental Conditions

As mentioned in Section 4.4.3, the outside temperatures were 25°F-50°F higher during Phase II of the PVS (performed in June 2003) than during Phase I (performed in February 2003), which could have elevated the indoor temperature during air volume changes (e.g., doors opening). An increase in ambient temperature has been shown to cause an increase in volatilization of mercury, resulting in greater detected concentrations (*see footnote 22 in Section 4.4.3*). The Study was not designed to account for the change in ambient temperature when comparing the results from PVS – Phase I to the results from PVS – Phase II. As a result, it is difficult to determine the extent to which any differences in measured mercury concentrations were directly caused by a decline in device performance. To make such a determination possible, in conducting future research, the environmental conditions of the test should be maintained at constant levels.

6.3 Contamination from Lamps Broken During Shipment

Another source of potential contamination of mercury during the Study was the shipping boxes containing the fluorescent lamps that were received at the lamp recycling facilities. On average, approximately 10 percent of the lamps in each box were observed to be broken during shipment to, and/or pre-handling in, the lamp recycling facility. In order to investigate this hypothesis, box tests were conducted. The box test results were discussed in Section 4.6.

At AERC Melbourne, measurable ambient concentrations of mercury were recorded in the containment structure, while boxes of broken lamps were present and open, and no lamps were being crushed (*refer to Figure 4. 14*). Many of these concentrations exceeded the PEL and/or TLV values. Measurable concentrations, the majority of which were also above the PEL and/or TLV values, were also noted from ambient air sampling during a follow-up box test conducted at AERC Ashland. The study results

suggest that, to minimize operator exposures, boxes of lamps (especially those with significant breakage) should be staged in a separate area from the DTC device and preferably one where: 1) worker contact is minimal (e.g., a locked storage closet); and 2) workers accessing the area have the necessary PPE, respiratory protection. This information is important for all persons working with or around spent lamps, not just DTC device operators.

6.4 Contamination from Lamps Broken During DTC Device Operation

As will be discussed in Chapter 7, lamps occasionally broke while they were being fed into the DTC devices. The mercury released from these lamps directly relates to operator exposure during DTC device operation. The occurrences of lamp breakage were not consistent throughout the Study, so it is difficult to determine the average impact that lamp breakage during device operation had on the results of the Study.

7. DISCUSSION

Purposely breaking large numbers of mercury-containing fluorescent lamps can release substantial amounts of mercury to the air. Containing the released mercury is the central goal in the design and operation of drum top lamp crushing devices. The basic purpose of this Study was to examine how well the tested DTC devices met the design goal of containing mercury (as measured by operator exposure) when in routine use. The Study examined the performance of four devices over a five month period. Over the course of the Study, approximately 5,500 lamps were crushed by each of the three devices used throughout the Study, inside a constructed enclosure over a range of environmental and operational conditions. A considerable amount of data was generated that provides insight into the performance of DTC devices during field applications.

Testing in this Study was performed under low ventilation conditions, within a constructed containment structure. This was done both to measure ambient mercury concentrations during device operation in a controlled environment (i.e., segregated from the ambient background mercury at the lamp recycling facilities) and to evaluate performance under plausible, worst-case operating conditions (such as in an unventilated truck trailer).³¹ Operator exposures would be expected to be lower than found in this Study if a DTC device is operated in a room with higher ventilation rates or if far fewer lamps are crushed over a longer period of time (i.e., 40-80 lamps crushed per day as apposed to 400-800 lamps crushed per hour). The containment structure was only partially effective in isolating the Study operations from the background mercury produced by the lamp recycling activities at the facilities used as testing locations in the Study because mercury is able to permeate through and sorb onto polyethylene, which was the material used to construct the containment (*refer to Chapter 6 for further discussion*). Measurements made before testing and during non-operational periods indicated that elevated background levels, which varied by facility, were present throughout the entire Study.

The following discussion is based on the evaluation of results from the air monitoring and sample data collected during the course of the Study. Observations and experience gained during the operation of these devices provide further important information about the use of DTC devices.

7.1 Summary of Results

Over the course of the Study, a total of 185 analytical air samples were collected during device operation (not including overnight and background air samples). Sixty-five samples (35.1 percent) were below both the ACGIH TLV and the OSHA PEL values. Eighty-four samples (45.4 percent) were equal to or above the TLV but

³¹ *The facilities used to conduct the Study had background mercury levels that were higher than would be expected at a location that was not routinely handling mercury, as discussed in detail in Sections 4.2 and 6.1. Correction of data by subtracting the background levels from the sample results may be an appropriate way to view the data, although doing so would not reduce all the exceedances of the PEL or TLV to below those levels.*

below the PEL value, and thirty-six samples (19.5 percent) were greater than or equal to the PEL value.³²

7.1.1 Exposures during Routine Crushing Operations

Overall, seven operator shoulder samples (i.e., average mercury concentration in the operator breathing zone air) exceeded the PEL value. Three of these samples were collected while testing the Manufacturer B device, one was collected while testing the Manufacturer C device, and three were collected while testing the Manufacturer D device, which was removed from the Study. It is important to note that the shoulder samples were average measurements, taken over the time period required to crush one or two drums of lamps (typically one to three hours). The Jerome analyzer readings, taken inside the containment structure, show the fact that there were a number of excursions above the PEL during routine crushing operations, even when the analytical air samples were not above the PEL. Refer to Figure 4. 3, Figure 4. 6, Figure 4. 8, Figure 4. 10, and Appendix A for graphs of the Jerome analyzer readings.

All three devices that completed the Study, especially the Manufacturer B and Manufacturer C devices, experienced problems in maintaining operator exposures below the ACGIH recommended TLV of 0.025mg/m³ within the containment structure during routine lamp processing. The TLV value is a time-weighted average (TWA) calculated over a normal eight hour work day that is considered protective of worker health and safety.³³ Analytical air samples collected in the operator's breathing zone and Jerome analyzer results show that the concentration of mercury inside the containment structure was above the TLV value the majority of the time.

The Manufacturer A device maintained operator shoulder sample concentrations below the mercury TLV value during four of the five rounds of testing; the Manufacturer A device exceeded the TLV during EFT #1, when the feeding tube was not properly connected to the drum-top assembly (*refer to footnote 23 in Section 4.5.1.1*). The Manufacturer B and Manufacturer C devices exceeded the TLV value in at least one operator shoulder sample during four of the five testing occurrences, even when corrected for background mercury levels. The only test in which all operator shoulder samples for all three devices were below the TLV value was PVS – Phase I at AERC Ashland in February 2003; this may have been, in part, due to the fact that the devices were new, the outside temperature was lower, and only low mercury, Alto® lamps (manufactured by Phillips Lighting) were processed.

Exhaust or feed tube air samples (sometimes both) for all three devices also exceeded the TLV value during portions of the Study. The Manufacturer A device had feed tube and exhaust samples that exceeded the TLV value only during EFT #1, most

³² *This discussion of the number of data that exceeded the TLV and the PEL does not correct for background. There were not enough background data to reasonably estimate the contribution that background mercury could have made to the measured mercury concentrations.*

³³ *The results obtained in the Study were not normalized to an eight hour workday because DTC device use patterns may vary significantly. In some cases only a dozen lamps may be crushed in a single day. In other cases a device may be used to process thousands of lamps from different sources, so the operator may be using the device forty hours a week or more. Therefore, sample results that are greater than the TLV should not necessarily be interpreted to indicate that use of one of the DTC devices included in the Study would result in time-weighted, operator exposure above the TLV.*

likely, because of a missing gasket on the feed tube (*refer to footnote 23 in Section 4.5.1.1*). All exhaust and feed tube samples for the Manufacturer B device were above the TLV value, except those taken during PVS – Phase I. Six of the 10 exhaust and feed tube samples collected for the Manufacturer C device were above the TLV value. The degrees to which temperature and changes in device performance affected these data are topics for future research.

As discussed in Section 3.5.3, the Manufacturer D device performed poorly, allowing the mercury concentrations inside the containment structure to exceed the OSHA PEL value by nearly 9 fold. This device was removed from the test after two rounds of testing due to its poor performance (*refer to Appendix I*).

7.1.2 Exposures during Routine Drum and Filter Changes

When the drum beneath a DTC device is filled with crushed lamps, the DTC device must be secured to a new drum. This operation involves unsealing the DTC device from the drum, lifting it off the drum, and placing it on a new, empty drum. During this operation, the full drum of crushed lamps is open to the air for some period of time during which mercury vapor is released uncontrolled to the air (in this Study, drum changes lasted approximately two to 10 minutes). Because of mercury's volatility under typical indoor conditions, the drum change operation poses the potential for significant mercury release, particularly while the full drum is open to the air (as illustrated by the results below). Minimizing the time during which the full drum is open to the air will help reduce operator exposure to mercury and mercury releases to the environment.

Two types of samples were collected for all three devices during drum changes: drum change samples and ceiling samples.³⁴ All of the DTC devices tested exceeded the PEL value at least once during drum changes. PEL value exceedances during drum changes were frequent for the Manufacturer B and Manufacturer C devices. The drum change samples for the Manufacturer A device exceeded the PEL value in only one of the five tests (EFT #2). The Manufacturer A device features a larger particulate filter and a larger amount of activated carbon than the other two devices. The more substantial pollution control equipment could, at least partially, explain the differences between the results for the Manufacturer A device and the results for the other devices.

7.1.3 Exposures Resulting From DTC Device Malfunction

There were two major types of malfunctions that occurred and caused increased mercury release and operator exposure – improper device assembly and feed tube jamming. The Manufacturer A device was not assembled correctly during EFT #1 (*refer to footnote 23 in Section 4.5.1.1*), which caused average ambient mercury concentrations to exceed the PEL in the sample collected near the feed tube, and to reach 0.074 ug/m³ in one operator shoulder sample. The samples collected for EFT #1 were collected over the course of filling two drums, meaning that the mercury

³⁴ Drum change samples and ceiling samples are described in Section 3.1.

concentrations as measured by analytical air samples were averages of the concentrations in the air throughout the filling of both drums.

The missing seal was replaced for the second drum, so during the second drum, the mercury concentrations inside the containment were most likely lower because the device was assembled correctly. With average mercury concentrations at 74 percent of the PEL value, it is very likely that the mercury concentrations in the operator's breathing zone exceeded the PEL at some point during the filling of the first drum. (There are no Jerome data available for this time period to verify this because the Jerome was in regeneration mode.) These levels were nearly four times the average concentrations measured for this device in the other portions of the Study, showing a higher rate of mercury release as a result of seal failure/improper assembly.

A common malfunction experienced with all the devices was jamming of the feed tube. The Study was not designed to quantify increased ambient mercury concentrations or increased operator exposure caused by this malfunction. When the lamps jammed in the feed tube, debris from inside the DTC device and the drum occasionally blew back towards the operator, indicating that a fraction of the mercury in the lamp that jammed was not being captured by the DTC device.

The high operator exposures experienced during the use of the Manufacturer D device were likely due to poor design and malfunction. As noted in Section 3.5.3 and Appendix I, Manufacturer D sent two different DTC devices of different design for the first two rounds of testing, and the device for the second round of testing was clearly damaged, with a visible crack in the vacuum pump motor housing. However, during Phase I of the PVS, when the device had no visible damage, only "low mercury," Alto® lamps were crushed, and outdoor temperatures were between 28 and 43 degrees Fahrenheit, operation of the Manufacturer D device resulted in ambient mercury concentration nearly 9 times the OSHA PEL value. This highlights the importance of design and optimal operation.

7.1.4 Changes in DTC Performance over Time

The performance validation study was designed to examine the change in performance over time. The Study included five rounds of testing over a 5-month period, and approximately 5,500 lamps were crushed by each device. The data generated by the Study indicate that one device (from Manufacturer A) maintained its ability to contain the mercury released when lamps were crushed over the duration of the Study, while the other two devices that completed the Study declined in performance over this time frame and use. The Study was not designed to determine the reason for the decline in performance by the Manufacturer B and C devices. However, there are several possibilities, including possible saturation of the carbon filter material and wear and tear on DTC device seals. The changes in performance over time documented in the Study may be evidence of potential difficulties in maintaining optimal performance by DTC devices. Careful attention to inspection and maintenance of the devices may make it possible for operators to detect and repair any worn components before their deterioration could result in mercury exposures.

7.1.5 Overnight Tests

Air samples were also collected within the containment structure, near the devices, during non-operational periods, with the DTC devices attached to drums that were full or partially full of crushed lamps. These tests were conducted overnight at all three locations during the EFTS. Per manufacturer instructions, the Manufacturer A device was left running on ventilation mode throughout the course of the tests (that is, the fan/vacuum pump was running, with air being exhausted through the carbon filter, whenever a drum was attached to the device), and the Manufacturer B and Manufacturer C devices were turned off. The results from the overnight samples were inconclusive as to whether or not mercury was released from DTC devices that were attached to drums containing crushed lamps.

7.1.6 U-Tube Test

The Manufacturer B and Manufacturer C devices have attachments that enable them to process U-tubes. A test was conducted to evaluate airborne mercury levels from the two devices while processing U-tubes. The facility was only able to collect a limited number of U-tubes for this test, so each device processed fewer than 90 U-tubes. Seven of the eight U-tube samples were above the TLV value, and two of the operator breathing zone samples (one for each device) equaled or slightly exceeded the PEL value. These levels are generally higher than the levels measured when crushing straight lamps, especially in light of the fact that so few U-tubes were processed by each device. A possible explanation for the high mercury levels is the fact that the U-tube attachments have larger openings than the feed tubes for the straight lamps, which could have allowed some air to flow from inside the device out into the containment structure.

7.1.7 Exposures Resulting from Lamp Breakage

Another source of mercury release associated with use of DTC devices was breakage of lamps either before they were fed into the device, or as they were being fed in. Studies of lamp breakage inside the containment structure via the Box Test indicated that lamps broken during handling may have had an affect on the sample results. Lamps also sometimes broke and shattered while being fed into the DTC. No testing of the resulting mercury release was attempted, because this breakage occurred sporadically and was a random event. However, during the first test of the Manufacturer B device at the EPSI Phoenix facility (EFT #2), the Jerome analyzer readings demonstrate that the ambient mercury concentration increased inside the containment structure when a bulb was broken.

As shown in Figure 4. 8 and Appendix A, Figure 32, the mercury concentration was 0.033 mg/m³ before a lamp was broken and increased to 0.169 mg/m³ four minutes after a lamp was broken. This was an increase of 400 percent in ambient mercury concentrations. These data are further supported by research performed by Aucott, et al., in which it was shown that “between 17 and 40 percent of the mercury in broken low-mercury fluorescent bulbs is released to the air during a two-week period

immediately following breakage, with higher temperatures contributing to higher release rates.”³⁵ The potential for lamp breakage outside the DTC device is inherent to device use. Possible release of and exposure to mercury vapor, as a result of broken lamps, is an important consideration as part of any operations managing fluorescent bulbs.

Because of the multiple potential sources of mercury being released during normal DTC device operations – during drum changes, through the degradation of seals over time (leading to leaks), possible leakage due to improper assembly or malfunction, and the breakage of lamps outside the DTC device, either during handling or feeding lamps into the device – a respirator was always available to the operator during the Study. Either use of a respirator, or continuous air monitoring for mercury with a mercury vapor monitor, such as a Jerome or Lumex, were the only ways to ensure that operator mercury exposures remained below the OSHA PEL and AGCIH TLV throughout the Study.³⁶

7.2 Safety Concerns when Operating DTC Devices

Throughout the DTC Device Study, field observations were made and documented by the study team. These observations provide insight into potential safety issues and mitigation measures that were undertaken during the Study (and could be used by other device operators) to enhance the safety of operating DTC devices.

7.2.1 Operator Safety

As noted above, when lamps were being fed into the DTC devices, they would occasionally break and/or jam in the feed tubes. This was an issue common to all devices. Lamps sometimes broke before they could be fully fed into the devices, causing, in some instances, visible release of phosphor powder, as well as flying shards of glass. The configuration of the feed tubes on several devices exacerbated this problem, where, for example, the operator either had to lower the lamps to waist level or raise them up to shoulder level in order to insert them into the feed tube.

Various articles of personal protective equipment (PPE) were used by the study team during operation of DTC devices to ensure operator safety (*refer to Photograph 7. 1*). These included safety glasses, full-face shields, puncture-resistant (Kevlar®) gloves, hearing protection, and air-purifying, negative pressure respirators (when air monitoring readings were above pre-determined safe levels). Disposable Tyvek® coveralls were also worn by the DTC device operator and assistant, to reduce both skin exposure to the airborne mercury and the possibility of tracking mercury residues out of the testing facility.

³⁵ Aucott, Michael; McLinden, Michael; and Winka, Michael. 2003. *Release of Mercury from Broken Fluorescent Bulbs*. *Journal of Air & Waste Management Association*. 53: 143-151. The lamps used in this investigation were Phillips four-foot Econ-o-watt F40 CW/RS/EW, 0 8E bulbs, which are reported to contain 4.4 mg or 4.7 mg of mercury.

³⁶ The traditional hierarchy of occupational chemical exposure control specifies that engineering controls (*i.e.*, adequate monitoring and ventilation) be used before relying on PPE.



Photograph 7. 1: Clearing Jammed Feed Tube of Manufacturer A Device

Due to the possibility of mercury release from lamp breakage outside the DTC device or leaks from the DTC device, respiratory protection was always available to the operator and assistants throughout the Study and was used most of the time.

7.2.2 Number of Operators

During the Study, two people operated the DTC devices at each location. One person fed the lamps into the device, and the other person supplied the operator with full boxes of lamps, removed the empty lamp boxes, and handed lamps to the machine operator, allowing for efficiency in feeding lamps. While one person could probably operate the DTC device, the study team found it much easier and more efficient to use the two-person team. This was particularly important when it came to changing drums. Having a two person team available allowed drum changes to be performed much more securely and quickly (the Manufacturer B device required a two-person team to change drums, but the other devices did not). The advantages of a two-person team included both help in lifting the DTC off the full drum and positioning it correctly on the empty drum, as well as allowing the full drum to be more quickly covered and sealed.

7.2.3 Location and Ventilation for Lamp Crushing Activities

As discussed in Section 4.2, the background mercury concentrations in the industrial lamp crushing facilities were several orders of magnitude higher than background mercury concentrations that would be expected outside or in a building that is not associated with mercury processing activities, such as a home or an office building. One of the reasons that this Study was conducted at lamp recycling facilities was that these facilities already have safeguards in place to prevent exposure to visitors to the facility and to residents in the surrounding neighborhood.

These safeguards include a separate ventilation system for the offices, which does not cycle the air from the crushing area into the offices, and fume hoods on the industrial lamp crushers that vent fumes through carbon filters. The separate ventilation system protects the office workers from exposure to mercury. The production workers at the facility (i.e., those operating recycling equipment) are

aware of the potential of mercury exposure and have been trained in practices that will prevent mercury release and exposure. Production workers at lamp recycling facilities are required to have OSHA Safety Training. Additionally, material safety data sheets (MSDS) for mercury must be made available to these workers.

7.3 Potential DTC Design Modifications

Drum top lamp crusher design is an evolving field, and many aspects of device design can affect its ability to contain mercury (e.g., see Section 3.5.1). The devices tested in this Study are only the second generation of drum-top lamp crushers and, while they represent a significant improvement over the first generation of such devices, further improvements in design and operation procedures would be beneficial.³⁷ Based on operator observations, the following areas for potential improvements in DTC device design were noted by the study team:

- Development of Leak Detection Systems: As discussed above, DTC devices may develop undetected leaks and release significant amounts of mercury as a result. While a portable mercury vapor monitor can easily detect rising airborne mercury concentrations, these devices are expensive to purchase and operate, ranging from \$15,000- \$22,000. Development of an effective leak detection system, such as a continuously operating pressure monitor, may reduce the need for continuous monitoring of DTC devices in operation to ensure operator safety and compliance with regulatory standards.
- Improvement in Mercury Capture during Drum Change: Drum changes were identified in the Study as the routine activity with the highest potential for operator exposure to mercury concentrations above the PEL. None of the devices tested were capable of maintaining mercury concentrations below the PEL during drum changes, so improvements in device designs to reduce mercury releases during this operation would be very beneficial.
- Chemical Treatment of Released Mercury Vapor: Most of the mercury released from lamps in DTC devices is elemental mercury vapor, which is volatile at room temperatures. Elemental mercury reacts with sulfiding agents very readily and quickly under environmental conditions to form mercuric sulfide. Because mercuric sulfide is a solid (powder) at room temperature, its release to the air should be much easier to control than mercury vapor. Airborne mercury sulfide powder inside a drum would most likely settle into the crushed lamps in the drum or be captured by the pollution control media of DTC devices. Incorporating sulfiding-agent injectors into a device design could potentially reduce mercury release during all activities associated with DTC device use (except lamp breakage outside the device). The study team did not explore this possibility, so we are unable provide any specific design recommendations.

³⁷ Based on a 1994 EPA study, some of the first DTC device designs (not necessarily designs from the manufacturers that participated in this Study) may have used no mercury emissions controls.

- Increase in the Amount of Pollution Control Used in the Device: The Manufacturer A device showed the best performance overall. This device used approximately 87 pounds of activated carbon, which most likely contributed to its good performance. The other devices included much less activated carbon in their air filtration systems (*refer to Table 5. 6 for the specifications of the pollution control media for each device*).

This Study was designed to assess the potential for operator exposure to mercury, while operating the four DTC devices tested. The areas of improvement noted above resulted from observations made by the study team in the course of testing the devices and preparing this report. This list is not meant to be exhaustive.

7.4 Future Areas for Study

There are several areas in which additional study would be beneficial:

- Environmental Impacts of DTC Device Use: DTC devices have the potential to be used in a wide variety of places. It is possible that the use of these devices will decrease the overall release of mercury to the environment by decreasing the uncontrolled disposal of mercury fluorescent lamps (i.e., disposal in a dumpster). Future research to assess the potential impacts of DTC device use could include:
 - How much the use of DTC devices can impact the total amount of mercury being released into the environment;
 - How much mercury is emitted from DTC devices for each lamp crushed or each drum full of lamps crushed;
 - Who (in addition to the operator) may be exposed to mercury releases related to operation of a DTC device;
 - How the emissions from DTC devices compare to the emissions from other mercury emissions sources, including industrial lamp recycling facilities; and
 - Whether significant amounts of mercury collect in areas where DTC devices are stored and operated.
- Mercury Release from DTC Devices during Non-operational Periods: The overnight tests conducted in this Study were inconclusive (*refer to Section 4.7*). Because it is probable that in many cases drums partially filled with lamps will be stored for extended periods of time, more information about the release of mercury from DTC devices which are attached to partially filled drums is needed in order to fully characterize the mercury exposure that could be realized as a result of the use of a DTC device.
- Mass Balance Study: A concrete relationship between mercury input and mercury retention and release was not established for any of the devices in the Mass Balance Study. The following factors should be considered if a future Mass Balance Study is undertaken:
 - Appropriate procedures for representative sampling of the crushed lamps in the drum need to be developed;

- A validated and approved test method for quantifying the mercury in whole unbroken lamps is needed, including the relative accuracy and error inherent in such a test;
 - An approved test method for quantifying the mercury in the pollution control media (HEPA, carbon, and particle filters) is needed, including the relative accuracy and error inherent in such a test;
 - A study design specific to measuring all system inputs and outputs, including the use of a clean-room and the measurement of emissions; and
 - Wipe sampling procedures need to be improved, including pre and post sampling of the material used to construct the containment structure.
- Development of a Standard Test Method(s) for DTC Device Performance: A standard DTC device evaluation protocol that can be used by DTC device manufacturers would ensure that manufacturer performance data are generated in a consistent manner, under known conditions. A true evaluation of crusher performance can be developed only if the volume of the crushing room, the air exchange rate, the lamp crushing rate, the duration of crushing, and all sampling and analytical methods are known and validated. Absent this information, a poorly performing DTC device could be “tested” and shown to perform well with regard to operator exposure because the test was performed using unrealistic ventilation rates or room size or was performed outdoors. Evaluating DTC performance under consistent, known conditions would also allow meaningful comparison of the performance of different lamp crushers. A standardized test method would help ensure the repeatability and accuracy of any tests results .
 - Investigation of Mercury Release through Different Lamp Management Methods: This Study only examines mercury release from fluorescent lamps as a result of the use of DTC devices (as measured by operator exposure). When lamps are handled and recycled as whole lamps, there is the potential for breakage and, therefore, the potential for mercury release, during the storage and shipping of the lamps. Information about the frequency of breakage and the amount of mercury released when whole lamps are stored and then shipped to a recycler is needed in order to compare these different lamp recycling methods. Additionally, more information on releases of mercury resulting from disposal of lamps would provide a useful baseline with which to compare releases due to recycling.
 - Aerosolization of Mercury: Additional study may be appropriate to determine whether aerosol mercury was not detected using the MCE filters because no aerosolization occurred or because any aerosol mercury collected on the filter was vaporized by the sampling vacuum pump.

7.5 Conclusions

The potential use of DTC devices involves a number of trade-offs. Spent mercury lamps contain elemental mercury, some of which is released to the air when lamps are broken. If thrown into a dumpster for disposal at a municipal solid waste landfill, breakage will occur either in the dumpster or at the landfill. In either case, a portion of the mercury contained in the lamps is immediately released to the

environment by volatilization, and the remaining mercury is available for release to the environment, over time, by leaching or in landfill gas.

Recycling of spent lamps represents one of the best ways to control the release of mercury to the environment from landfilling of fluorescent lamps, by keeping mercury out of landfills in the first place. Recycling can be done either on an individual lamp basis (i.e., sending whole, boxed lamps to a recycler), or by using a DTC device at the point where lamps are removed from service. Use of DTC devices has obvious appeal in that the devices reduce lamp volume, allowing several hundred crushed lamps to occupy the space that 40 or 50 whole lamps would occupy, thereby reducing storage and shipping costs. This leads to a reduction in recycling costs on a per-lamp basis. Crushing lamps before shipment also has the advantage of allowing shipping to the recycler in a well-sealed, durable container that is unlikely to release substantial amounts of mercury during shipment, while whole lamps may be broken during shipment and release mercury.

The DTC devices evaluated as part of this Study all released some mercury when used and so have the concern of creating new mercury exposures. The mercury released during DTC device use will inevitably create certain new mercury exposure situations. The DTC device operator and any assistants handling lamps or working directly with the DTC device are the most obvious new exposures. Less direct mercury exposures that could be created by DTC device use include anyone working in or visiting buildings in which DTC devices are used. The only way to eliminate these unnecessary indirect mercury exposures would be to keep the ventilation of the lamp crushing room completely separate from the general building ventilation system as is done at industrial lamp recycling facilities.

The data collected in the course of this Study indicate that none of the DTC devices evaluated completely controlled mercury emissions during lamp processing operations, even with optimal operation. The Study further indicates that maintaining optimal performance consistently over years of DTC device use for the current generation of devices will be challenging. Even generally well designed devices released mercury in routine use, particularly during drum changes. Device malfunctions increased mercury release by a small amount (i.e., when lamps jammed in the feed tube) or by a significant amount (i.e., when the flange gasket was not included in assembly). Use of a poorly designed device could result in mercury exposures nearly an order of magnitude above the OSHA PEL. Fundamental design changes to reduce the reliance on fallible components (such as seals) would be needed to improve the ruggedness of drum-top crushing devices.

Office of Solid Waste and Emergency Response
1200 Pennsylvania Avenue, NW
Washington, DC 20460
EPA530-R-06-002
August 24, 2006

www.epa.gov/epaoswer/hazwaste/id/univwast/drumtop/drum-top.htm

Appendix A

Air and Wipe Sample Results

Table 1: Analytical Air Sample Results

Performance Validation Study – Phase I – Ashland, Virginia – February 24-28, 2003								
Type	Media	Device	Location	Flow Rate (lpm)	Sample time (min)	Volume (liters)	Result (mg/m ³)	Sample #
Background	Hydrar	All	E. bay by center bay door	0.209	278	58.24	0.0047	3705-B-225-04
Background	MCEF	All	E. bay by center bay door	0.209	278	58.24	<0.00017	3705-B-225-03
Background	Hydrar	All	Middle of E. bay	0.212	278	58.94	0.0039	3705-B-225-02
Background	MCEF	All	Middle of E. bay	0.212	278	58.94	<0.00017	3705-B-225-01
Personal	Hydrar	Manufacturer A	Device operation	0.1535	112	17.19	0.012	3705-RA-227-22
Personal	MCEF	Manufacturer A	Device operation	0.1535	112	17.19	<0.00058	3705-RA-227-21
Personal	Hydrar	Manufacturer A	Device operation	0.154	112	17.25	0.011	3705-RA-227-24
Personal	MCEF	Manufacturer A	Device operation	0.154	112	17.25	<0.00058	3705-RA-227-23
Personal	Hydrar	Manufacturer A	Drum change	0.2525	12	3.03	0.02	3705-RA-227-34
Personal	MCEF	Manufacturer A	Drum change	0.2525	12	3.03	<0.0033	3705-RA-227-33
Area	Hydrar	Manufacturer A	By device exhaust	0.1515	112	16.97	0.0028	3705-RA-227-30
Area	MCEF	Manufacturer A	By device exhaust	0.1515	112	16.97	<0.00059	3705-RA-227-29
Area	Hydrar	Manufacturer A	By device exhaust	0.1535	112	17.19	0.011	3705-RA-227-32
Area	MCEF	Manufacturer A	By device exhaust	0.1535	112	17.19	<0.00058	3705-RA-227-31
Area	Hydrar	Manufacturer A	By device feed tube	0.1515	112	16.97	0.013	3705-RA-227-26
Area	MCEF	Manufacturer A	By device feed tube	0.1515	112	16.97	<0.00059	3705-RA-227-25
Area	Hydrar	Manufacturer A	By device feed tube	0.1545	112	17.3	0.011	3705-RA-227-28
Area	MCEF	Manufacturer A	By device feed tube	0.1545	112	17.3	<0.00058	3705-RA-227-27
Personal	Hydrar	Manufacturer B	Device operation	0.153	86	13.16	0.012	3705-DA-228-50
Personal	MCEF	Manufacturer B	Device operation	0.153	86	13.16	<0.00076	3705-DA-228-49
Personal	Hydrar	Manufacturer B	Device operation	0.151	86	12.99	0.013	3705-DA-228-52
Personal	MCEF	Manufacturer B	Device operation	0.151	86	12.99	<0.00077	3705-DA-228-51
Personal	Hydrar	Manufacturer B	Drum change	0.253	13	3.29	0.025	3705-DA-228-62
Personal	MCEF	Manufacturer B	Drum change	0.253	13	3.29	<0.0030	3705-DA-228-61

Performance Validation Study – Phase I – Ashland, Virginia – February 24-28, 2003

Type	Media	Device	Location	Flow Rate (lpm)	Sample time (min)	Volume (liters)	Result (mg/m ³)	Sample #
Area	Hydrar	Manufacturer B	By device exhaust	0.1535	86	13.2	0.012	3705-DA-228-58
Area	MCEF	Manufacturer B	By device exhaust	0.1535	86	13.2	<0.00076	3705-DA-228-57
Area	Hydrar	Manufacturer B	By device exhaust	0.1515	86	13.03	0.012	3705-DA-228-60
Area	MCEF	Manufacturer B	By device exhaust	0.1515	86	13.03	<0.00077	3705-DA-228-59
Area	Hydrar	Manufacturer B	By device feed tube	0.145	86	12.47	0.0039	3705-DA-228-54
Area	MCEF	Manufacturer B	By device feed tube	0.145	86	12.47	<0.00080	3705-DA-228-53
Area	Hydrar	Manufacturer B	By device feed tube	0.1515	86	13.03	0.012	3705-DA-228-56
Area	MCEF	Manufacturer B	By device feed tube	0.1515	86	13.03	<0.00077	3705-DA-228-55
Personal	Hydrar	Manufacturer C	Device operation	0.153	100	15.3	0.012	3705-AA-226-06
Personal	MCEF	Manufacturer C	Device operation	0.153	100	15.3	<0.00065	3705-AA-226-05
Personal	Hydrar	Manufacturer C	Device operation	0.1505	100	15.05	0.015	3705-AA-226-08
Personal	MCEF	Manufacturer C	Device operation	0.1505	100	15.05	<0.00066	3705-AA-226-07
Personal	Hydrar	Manufacturer C	Drum change	0.2545	18	4.58	0.019	3705-AA-226-20
Personal	MCEF	Manufacturer C	Drum change	0.2545	18	4.58	<0.0022	3705-AA-226-19
Personal	Hydrar	Manufacturer C	Filter change	0.2555	12	3.07	0.019	3705-AA-226-18
Personal	MCEF	Manufacturer C	Filter change	0.2555	12	3.07	<0.00033	3705-AA-226-17
Area	Hydrar	Manufacturer C	By device exhaust	0.1209	100	12.09	0.0055	3705-AA-226-10
Area	MCEF	Manufacturer C	By device exhaust	0.1209	100	12.09	<0.00083	3705-AA-226-09
Area	Hydrar	Manufacturer C	By device exhaust	0.15	100	15	0.01	3705-AA-226-12
Area	MCEF	Manufacturer C	By device exhaust	0.15	100	15	<0.00067	3705-AA-226-11
Area	Hydrar	Manufacturer C	By device feed tube	0.125	100	12.56	0.0095	3705-AA-226-14
Area	MCEF	Manufacturer C	By device feed tube	0.125	100	12.56	<0.00080	3705-AA-226-13
Area	Hydrar	Manufacturer C	By device feed tube	0.158	100	15.8	0.013	3705-AA-226-16
Area	MCEF	Manufacturer C	By device feed tube	0.158	100	15.8	<0.00063	3705-AA-226-15
Personal	Hydrar	Manufacturer D	Device operation	0.153	55	8.42	0.04	3705-HA-227-36
Personal	MCEF	Manufacturer D	Device operation	0.153	55	8.42	<0.0012	3705-HA-227-35

Performance Validation Study – Phase I – Ashland, Virginia – February 24-28, 2003								
Type	Media	Device	Location	Flow Rate (lpm)	Sample time (min)	Volume (liters)	Result (mg/m ³)	Sample #
Personal	Hydrar	Manufacturer D	Device operation	0.156	55	8.58	0.13	3705-HA-227-38
Personal	MCEF	Manufacturer D	Device operation	0.156	55	8.58	<0.0012	3705-HA-227-37
Personal	Hydrar	Manufacturer D	Drum change	0.154	6	0.924	0.19	3705-HA-227-48
Personal	MCEF	Manufacturer D	Drum change	0.154	6	0.924	<0.011	3705-HA-227-47
Area	Hydrar	Manufacturer D	By device exhaust	0.1505	55	8.28	0.33	370-5-HA-227-44
Area	MCEF	Manufacturer D	By device exhaust	0.1505	55	8.28	<0.0012	3705-HA-227-43
Area	Hydrar	Manufacturer D	By device exhaust	0.253	55	13.92	0.36	3705-HA-227-46
Area	MCEF	Manufacturer D	By device exhaust	0.253	55	13.92	<0.00072	3705-HA-227-45
Area	Hydrar	Manufacturer D	By device feed tube	0.1515	55	8.33	0.58	3705-HA-227-40
Area	MCEF	Manufacturer D	By device feed tube	0.1515	55	8.33	<0.0013	3705-HA-227-39
Area	Hydrar	Manufacturer D	By device feed tube	0.155	53	8.23	0.64	3705-HA-227-42
Area	MCEF	Manufacturer D	By device feed tube	0.155	53	8.23	<0.0012	3705-HA-227-41

Performance Validation Study – Phase II – Ashland, Virginia – June 9-13, 2003								
Type	Media	Device	Location	Flow Rate (lpm)	Sample time (min)	Volume (liters)	Result (mg/m ³)	Sample #
Personal	Hydrar	Manufacturer A	Device operation (RS)	0.195	64	12.5	0.012	3705-RA-610-33
Personal	MCEF	Manufacturer A	Device operation (RS)	0.195	64	12.5	<0.00080	3705-RA-610-34
Personal	Hydrar	Manufacturer A	Device operation (LS)	0.196	64	12.5	0.013	3705-RA-610-35
Personal	MCEF	Manufacturer A	Device operation (LS)	0.196	64	12.5	<0.00080	3705-RA-610-36
Personal	Hydrar	Manufacturer A	Drum change	0.261	12	3.1	0.031	3705-RA-610-45
Personal	MCEF	Manufacturer A	Drum change	0.261	12	3.1	<0.0032	3705-RA-610-46
Personal	Hydrar	Manufacturer A	Ceiling #1	0.247	4	1	0.067	3705-RA-610-51
Personal	MCEF	Manufacturer A	Ceiling #1	0.247	4	1	<0.010	3705-RA-610-52

Performance Validation Study – Phase II – Ashland, Virginia – June 9-13, 2003

Type	Media	Device	Location	Flow Rate (lpm)	Sample time (min)	Volume (liters)	Result (mg/m ³)	Sample #
Personal	Hydrar	Manufacturer A	Ceiling #2	0.247	4	1	0.042	3705-RA-610-53
Personal	MCEF	Manufacturer A	Ceiling #2	0.247	4	1	<0.010	3705-RA-610-54
Area	Hydrar	Manufacturer A	By device exhaust	0.197	58	11.4	0.015	3705-RA-610-37
Area	MCEF	Manufacturer A	By device exhaust	0.197	58	11.4	<0.00088	3705-RA-610-38
Area	Hydrar	Manufacturer A	By device exhaust	0.198	58	11.5	0.014	3705-RA-610-39
Area	MCEF	Manufacturer A	By device exhaust	0.198	58	11.5	<0.00087	3705-RA0610-40
Area	Hydrar	Manufacturer A	By device feed tube	0.2	58	11.6	0.015	3705-RA-610-41
Area	MCEF	Manufacturer A	By device feed tube	0.2	58	11.6	<0.00086	3705-RA-610-42
Area	Hydrar	Manufacturer A	By device feed tube	0.186	58	10.8	0.013	3705-RA-610-43
Area	MCEF	Manufacturer A	By device feed tube	0.186	58	10.8	<0.00093	3705-RA-610-44
Personal	Hydrar	Manufacturer B	Device operation (RS)	0.2	34	6.8	0.034	3705-DA-611-91
Personal	MCEF	Manufacturer B	Device operation (RS)	0.2	34	6.8	<0.0015	3705-DA-611-92
Personal	Hydrar	Manufacturer B	Device operation (LS)	0.2	34	6.8	0.034	3705-DA-611-93
Personal	MCEF	Manufacturer B	Device operation (LS)	0.2	34	6.8	<0.0015	3705-DA-611-94
Personal	Hydrar	Manufacturer B	Drum change	0.257	12	3.1	0.074	3705-DA-611-103
Personal	MCEF	Manufacturer B	Drum change	0.257	12	3.1	<0.0032	3705-DA-611-104
Personal	Hydrar	Manufacturer B	Ceiling #1	0.26	4	1	0.094	3705-DA-611-105
Personal	MCEF	Manufacturer B	Ceiling #1	0.26	4	1	<0.010	3705-DA-611-106
Personal	Hydrar	Manufacturer B	Ceiling #2	0.26	4	1	0.11	3705-DA-611-107
Personal	MCEF	Manufacturer B	Ceiling #2	0.26	4	1	<0.010	3705-DA-611-108
Area	Hydrar	Manufacturer B	By device exhaust	0.212	34	7.2	0.026	3705-DA-611-95
Area	MCEF	Manufacturer B	By device exhaust	0.212	34	7.2	<0.0014	3705-DA-611-96
Area	Hydrar	Manufacturer B	By device exhaust	0.198	34	6.7	0.034	3705-DA-611-97
Area	MCEF	Manufacturer B	By device exhaust	0.198	34	6.7	<0.0015	3705-DA-611-98
Area	Hydrar	Manufacturer B	By device feed tube	0.202	34	6.9	0.033	3705-DA-611-99
Area	MCEF	Manufacturer B	By device feed tube	0.202	34	6.9	<0.0014	3705-DA-611-100

Performance Validation Study – Phase II – Ashland, Virginia – June 9-13, 2003

Type	Media	Device	Location	Flow Rate (lpm)	Sample time (min)	Volume (liters)	Result (mg/m ³)	Sample #
Area	Hydrar	Manufacturer B	By device feed tube	0.2	34	6.8	0.034	3705-DA-611-101
Area	MCEF	Manufacturer B	By device feed tube	0.2	34	6.8	<0.0015	3705-DA-611-102
Personal	Hydrar	Manufacturer C	Device operation (LS)	0.203	37	7.5	0.039	3705-AA-612-147
Personal	MCEF	Manufacturer C	Device operation (LS)	0.203	37	7.5	<0.0013	3705-AA-612-148
Personal	Hydrar	Manufacturer C	Device operation (RS)	0.199	37	7.4	0.018	3705-AA-612-145
Personal	MCEF	Manufacturer C	Device operation (RS)	0.199	37	7.4	<0.0013	3507-AA-612-146
Personal	Hydrar	Manufacturer C	Filter change	0.255	12	3.1	0.039	3705-AA-612-157
Personal	MCEF	Manufacturer C	Filter change	0.255	12	3.1	<0.0032	3705-AA-612-158
Personal	Hydrar	Manufacturer C	Drum change	0.255	14	3.6	0.072	3705-AA-612-159
Personal	MCEF	Manufacturer C	Drum change	0.255	14	3.6	<0.0028	3705-AA-612-160
Personal	Hydrar	Manufacturer C	Ceiling #1	0.254	4	1	0.1	3705-AA-612-161
Personal	MCEF	Manufacturer C	Ceiling #1	0.254	4	1	<0.010	3705-AA-612-162
Personal	Hydrar	Manufacturer C	Ceiling #2	0.254	4	1	0.21	3705-AA-612-163
Personal	MCEF	Manufacturer C	Ceiling #2	0.254	4	1	<0.010	3705-AA-612-164
Area	Hydrar	Manufacturer C	By device exhaust	0.2	37	7.4	0.039	3705-AA-612-149
Area	MCEF	Manufacturer C	By device exhaust	0.2	37	7.4	<0.0013	3705-AA-612-150
Area	Hydrar	Manufacturer C	By device exhaust	0.206	37	7.6	0.042	3705-AA-612-151
Area	MCEF	Manufacturer C	By device exhaust	0.206	37	7.6	<0.0013	3705-AA-612-152
Area	Hydrar	Manufacturer C	By device feed tube	0.209	37	7.7	0.042	3705-AA-612-153
Area	MCEF	Manufacturer C	By device feed tube	0.209	37	7.7	<0.0013	3705-AA-612-154
Area	Hydrar	Manufacturer C	By device feed tube	0.203	37	7.5	0.039	3705-AA-612-155
Area	MCEF	Manufacturer C	By device feed tube	0.203	37	7.5	<0.0013	3705-AA-612-156

Extended Field Test #1 – Phoenix, Arizona – March 24-28, 2003

Type	Media	Device	Location	Flow Rate (lpm)	Sample time (min)	Volume (liters)	Result (mg/m ³)	Sample #
Background	Hydrar	All	E. of containment in warehouse	0.1365	205	27.98	0.0059	3705-B-324-03
Background	MCEF	All	E. of containment in warehouse	0.1365	205	27.98	<0.00036	3705-B-324-04
Background	Hydrar	All	N. of containment in warehouse	0.155	205	31.78	0.014	3705-B-324-01
Background	MCEF	All	N. of containment in warehouse	0.155	205	31.78	<0.00031	3705-B-324-02
Personal	Hydrar	Manufacturer A	Device operation - 2 drums	0.1635	162	26.49	0.074	3705-RA-324-05
Personal	MCEF	Manufacturer A	Device operation - 2 drums	0.1635	162	26.49	0.00053	3705-RA-324-06
Personal	Hydrar	Manufacturer A	Device operation - 2 drums	0.1505	162	24.38	0.043	3705-RA-324-07
Personal	MCEF	Manufacturer A	Device operation - 2 drums	0.1505	162	24.38	<0.00041	3705-RA-324-08
Personal	Hydrar	Manufacturer A	2nd drum change	0.257	22	5.65	0.075	3705-RA-324-13
Personal	MCEF	Manufacturer A	2nd drum change	0.257	22	5.65	<0.0018	3705-RA-324-14
Area	Hydrar	Manufacturer A	By device exhaust	0.156	162	25.27	0.045	3705-RA-324-09
Area	MCEF	Manufacturer A	By device exhaust	0.156	162	25.27	<0.00040	3705-RA-324-10
Area	Hydrar	Manufacturer A	By device feed tube	0.1765	162	28.59	0.11	3705-RA-324-11
Area	MCEF	Manufacturer A	By device feed tube	0.1765	162	28.59	0.0022	3705-RA-324-12
Overnight	Hydrar	Manufacturer A	By device exhaust	0.163	418	68.13	0.086	3705-RA-324-15
Overnight	MCEF	Manufacturer A	By device exhaust	0.163	418	68.13	<0.00015	3705-RA-324-16
Overnight	Hydrar	Manufacturer A	By device feed tube	0.1515	438	66.36	0.021	3705-RA-324-17
Overnight	MCEF	Manufacturer A	By device feed tube	0.1515	438	66.36	<0.00015	3705-RA-324-18
Personal	Hydrar	Manufacturer B	Device operation - 2 drums	0.23	125	28.75	0.084	3705-DA-325-19
Personal	MCEF	Manufacturer B	Device operation - 2 drums	0.23	125	28.75	0.00059	3705-DA-325-20
Personal	Hydrar	Manufacturer B	Device operation - 2 drums	0.1355	125	16.94	0.016	3705-DA-325-21
Personal	MCEF	Manufacturer B	Device operation - 2 drums	0.1355	125	16.94	<0.00059	3705-DA-325-22
Personal	Hydrar	Manufacturer B	1st drum change	0.2115	12	2.54	0.13	3705-DA-325-27
Personal	MCEF	Manufacturer B	1st drum change	0.2115	12	2.54	<0.0039	3705-DA-325-28
Personal	Hydrar	Manufacturer B	2nd drum change	0.2275	13	2.96	0.078	3705-DA-325-33
Personal	MCEF	Manufacturer B	2nd drum change	0.2275	13	2.96	<0.0034	3705-DA-325-34

Extended Field Test #1 – Phoenix, Arizona – March 24-28, 2003

Type	Media	Device	Location	Flow Rate (lpm)	Sample time (min)	Volume (liters)	Result (mg/m ³)	Sample #
Area	Hydrar	Manufacturer B	By device exhaust	0.136	125	17	0.035	3705-DA-325-23
Area	MCEF	Manufacturer B	By device exhaust	0.136	125	17	<0.00059	3705-DA-325-24
Area	Hydrar	Manufacturer B	By device feed tube	0.1995	125	24.94	0.07	3705-DA-325-25
Area	MCEF	Manufacturer B	By device feed tube	0.1995	125	24.94	<0.00040	3705-DA-325-26
Overnight	Hydrar	Manufacturer B	By device exhaust	0.1218	516	62.85	0.027	3705-DA-325-29
Overnight	MCEF	Manufacturer B	By device exhaust	0.1218	516	62.85	<0.00016	3705-DA-325-30
Overnight	Hydrar	Manufacturer B	By device feed tube	0.1345	516	69.4	0.026	3705-DA-325-31
Overnight	MCEF	Manufacturer B	By device feed tube	0.1345	516	69.4	<0.00014	3705-DA-325-32
Personal	Hydrar	Manufacturer C	Device operation - 2 drums	0.1515	196	29.69	0.03	3705-AA-327-43
Personal	MCEF	Manufacturer C	Device operation - 2 drums	0.1515	196	29.69	<0.00034	3705-AA-327-44
Personal	Hydrar	Manufacturer C	Device operation - 2 drums	0.162	196	31.75	0.074	3705-AA-327-45
Personal	MCEF	Manufacturer C	Device operation - 2 drums	0.162	196	31.75	<0.00031	3705-AA-327-46
Personal	Hydrar	Manufacturer C	1st filter change	0.2455	22	5.4	0.076	3705-AA-327-51
Personal	MCEF	Manufacturer C	1st filter change	0.2455	22	5.4	<0.0018	3705-AA-327-52
Personal	Hydrar	Manufacturer C	1st drum change	0.2425	14	3.4	0.16	3705-AA-327-53
Personal	MCEF	Manufacturer C	1st drum change	0.2425	14	3.4	<0.0029	3705-AA-327-54
Personal	Hydrar	Manufacturer C	3rd filter change	0.2545	12	3.05	0.021	3705-AA-327-59
Personal	MCEF	Manufacturer C	3rd filter change	0.2454	12	3.05	<0.0033	3705-AA-327-60
Area	Hydrar	Manufacturer C	By device exhaust	0.149	196	29.2	0.014	3705-AA-327-47
Area	MCEF	Manufacturer C	By device exhaust	0.149	196	29.2	<0.00034	3705-AA-327-48
Area	Hydrar	Manufacturer C	By device feed tube	0.1395	196	27.34	0.071	3705-AA-327-49
Area	MCEF	Manufacturer C	By device feed tube	0.1395	196	27.34	<0.00037	3705-AA-327-50
Overnight	Hydrar	Manufacturer C	By device exhaust	0.1	776	77.6	0.0095	3705-AA-327-55
Overnight	MCEF	Manufacturer C	By device exhaust	0.1	776	77.6	<0.00013	3705-AA-327-56
Overnight	Hydrar	Manufacturer C	By device feed tube	0.1012	776	78.53	0.014	3705-AA-327-57
Overnight	MCEF	Manufacturer C	By device feed tube	0.1012	776	78.53	<0.00013	3705-AA-327-58

Extended Field Test #1 – Phoenix, Arizona – March 24-28, 2003

Type	Media	Device	Location	Flow Rate (lpm)	Sample time (min)	Volume (liters)	Result (mg/m ³)	Sample #
Personal	Hydrar	Manufacturer D	Device operation - 2 drums	0.189	21	3.97	0.13	3705-HA-326-35
Personal	MCEF	Manufacturer D	Device operation - 2 drums	0.189	21	3.97	<0.0025	3705-HA-326-36
Personal	Hydrar	Manufacturer D	Device operation - 2 drums	0.1485	21	3.12	0.11	3705-HA-326-37
Personal	MCEF	Manufacturer D	Device operation - 2 drums	0.1485	21	3.12	<0.0032	3705-HA-326-38
Area	Hydrar	Manufacturer D	By device exhaust	0.1555	186	28.92	0.065	3705-HA-326-39
Area	MCEF	Manufacturer D	By device exhaust	0.1555	186	28.92	<0.00035	3705-HA-326-40
Area	Hydrar	Manufacturer D	By device feed tube	0.1605	186	29.85	0.022	3705-HA-326-41
Area	MCEF	Manufacturer D	By device feed tube	0.1605	186	29.85	<0.00034	3705-HA-326-42

Extended Field Test #2 – Melbourne, Florida – April 28 - May 2, 2003

Type	Media	Device	Location	Flow Rate (lpm)	Sample time (min)	Volume (liters)	Result (mg/m ³)	Sample #
Background	Hydrar	All	18 ft N. of dock door	0.2175	298	64.8	0.012	3705-B-429-03
Background	MCEF	All	18 ft N. of dock door	0.2175	298	64.8	<0.00015	3705-B-429-04
Background	Hydrar	All	24 ft. E. of dock door	0.20525	298	61.16	0.016	3705-B-429-01
Background	MCEF	All	24 ft. E. of dock door	0.20525	298	61.16	<0.00016	3705-B-429-02
Personal	Hydrar	Manufacturer A	Device operation (LS) - 2 drums	0.154	142	21.87	0.018	3705-RA-51-61
Personal	MCEF	Manufacturer A	Device operation (LS) - 2 drums	0.154	142	21.87	<0.00046	3705-RA-51-62
Personal	Hydrar	Manufacturer A	Device operation (RS) - 1st drum	0.1515	79	11.97	0.026	3705-RA-51-65
Personal	MCEF	Manufacturer A	Device operation (RS) - 1st drum	0.1515	79	11.97	<0.00083	3705-RA-51-66
Personal	Hydrar	Manufacturer A	Device operation (LS) - 1st drum	0.1495	79	11.81	0.024	3705-RA-51-63
Personal	MCEF	Manufacturer A	Device operation (LS) - 1st drum	0.1495	79	11.81	<0.00085	3705-RA-51-64
Personal	Hydrar	Manufacturer A	Device operation (RS) - 2nd drum	0.15	63	9.45	0.016	3705-RA-51-81
Personal	MCEF	Manufacturer A	Device operation (RS) - 2nd drum	0.15	63	9.45	<0.0011	3705-RA-51-82

Extended Field Test #2 – Melbourne, Florida – April 28 - May 2, 2003

Type	Media	Device	Location	Flow Rate (lpm)	Sample time (min)	Volume (liters)	Result (mg/m ³)	Sample #
Personal	Hydrar	Manufacturer A	Device operation (LS) - 2nd drum	0.148	63	9.32	0.017	3705-RA-51-79
Personal	MCEF	Manufacturer A	Device operation (LS) - 2nd drum	0.148	63	9.32	<0.0011	3705-RA-51-80
Personal	Hydrar	Manufacturer A	1st drum change	0.256	12	3.07	0.075	3705-RA-51-71
Personal	MCEF	Manufacturer A	1st drum change	0.256	12	3.07	<0.0033	3705-RA-51-72
Personal	Hydrar	Manufacturer A	2nd drum change	0.2485	12	2.98	0.081	3705-RA-52-43
Personal	MCEF	Manufacturer A	2nd drum change	0.2485	12	2.98	<0.0034	3705-RA-52-44
Personal	Hydrar	Manufacturer A	Ceiling #1 - 1st drum change	0.253	4	1.01	0.17	3705-RA-51-75
Personal	MCEF	Manufacturer A	Ceiling #1 - 1st drum change	0.253	4	1.01	<0.0099	3705-RA-51-76
Personal	Hydrar	Manufacturer A	Ceiling #2 - 1st drum change	0.253	4	1.01	0.11	3705-RA-51-77
Personal	MCEF	Manufacturer A	Ceiling #2 - 1st drum change	0.253	4	1.01	<0.0099	3705-RA-51-78
Area	Hydrar	Manufacturer A	By device exhaust	0.1565	142	22.22	0.018	3705-RA-51-67
Area	MCEF	Manufacturer A	By device exhaust	0.1565	142	22.22	<0.00045	3705-RA-51-68
Area	Hydrar	Manufacturer A	By device feed tube	0.1555	142	22.08	0.0063	3705-RA-51-69
Area	MCEF	Manufacturer A	By device feed tube	0.1555	142	22.08	<0.00045	3705-RA-51-70
Overnight	Hydrar	Manufacturer A	By device exhaust	0.154	874	134.6	0.013	3705-RA-51-83
Overnight	MCEF	Manufacturer A	By device exhaust	0.154	874	134.6	<0.00007	3705-RA-51-84
Overnight	Hydrar	Manufacturer A	By device feed tube	0.154	874	134.6	0.013	3705-RA-51-85
Overnight	MCEF	Manufacturer A	By device feed tube	0.154	874	134.6	<0.00007	3705-RA-51-86
Overnight	Hydrar	Manufacturer A	Outside containment	0.1575	874	137.66	0.017	3705-RA-51-87
Overnight	MCEF	Manufacturer A	Outside containment	0.1575	874	137.66	<0.00007	3705-RA-51-88
Personal	Hydrar	Manufacturer B	Device operation (RS) - 2 drums ¹	0.15833	163	25.81	0.14	3705-DA-429-05
Personal	MCEF	Manufacturer B	Device operation (RS) - 2 drums ¹	0.15833	163	25.81	0.00066	3705-DA-429-06
Personal	Hydrar	Manufacturer B	Device operation (LS) - 2 drums ¹	0.14867	163	24.23	0.12	3705-DA-429-07
Personal	MCEF	Manufacturer B	Device operation (LS) - 2 drums ¹	0.14867	163	24.23	<0.00041	3705-DA-429-08
Personal	Hydrar	Manufacturer B	1st drum change	0.2535	12	3.04	0.015	3705-DA-429-13
Personal	MCEF	Manufacturer B	1st drum change	0.2535	12	3.04	<0.0033	3705-DA-429-14

Extended Field Test #2 – Melbourne, Florida – April 28 - May 2, 2003

Type	Media	Device	Location	Flow Rate (ppm)	Sample time (min)	Volume (liters)	Result (mg/m ³)	Sample #
Personal	Hydrar	Manufacturer B	2nd drum change	1 0.254	20	5.08	0.041	3705-DA-429-15
Personal	MCEF	Manufacturer B	2nd drum change	1 0.254	20	5.08	<0.0020	3705-DA-429-16
Personal	Hydrar	Manufacturer B	Ceiling #1 - 2nd drum change	1 0.2535	4	1.01	0.23	3705-DA-429-23
Personal	MCEF	Manufacturer B	Ceiling #1 - 2nd drum change	1 0.2535	4	1.01	<0.0099	3705-DA-429-24
Personal	Hydrar	Manufacturer B	Ceiling #2 - 2nd drum change	1 0.2535	4	1.01	0.64	3705-DA-429-25
Personal	MCEF	Manufacturer B	Ceiling #2 - 2nd drum change	1 0.2535	4	1.01	<0.0099	3705-DA-429-26
Area	Hydrar	Manufacturer B	By device exhaust	1 0.153	163	24.94	0.13	3705-DA-429-09
Area	MCEF	Manufacturer B	By device exhaust	1 0.153	163	24.94	0.00072	3705-DA-429-10
Area	Hydrar	Manufacturer B	By device feed tube	1 0.154	163	25.1	0.27	3705-DA-429-11
Area	MCEF	Manufacturer B	By device feed tube	1 0.154	163	25.1	0.0019	3705-DA-429-12
Overnight	Hydrar	Manufacturer B	By device exhaust	1 0.147	714	104.96	0.035	3705-DA-429-17
Overnight	MCEF	Manufacturer B	By device exhaust	1 0.147	714	104.96	<0.00009	3705-DA-429-18
Overnight	Hydrar	Manufacturer B	By device feed tube	1 0.149	714	106.39	0.036	3705-DA-429-19
Overnight	MCEF	Manufacturer B	By device feed tube	1 0.149	714	106.39	<0.00009	3705-DA-429-20
Overnight	Hydrar	Manufacturer B	Outside containment	1 0.153	714	109.24	0.021	3705-DA-429-21
Overnight	MCEF	Manufacturer B	Outside containment	1 0.153	714	109.24	<0.00009	3705-DA-429-22
Personal	Hydrar	Manufacturer B	Device operation (RS) - 1 drum	2 0.1535	56	8.6	0.088	3705-DA-52-91
Personal	MCEF	Manufacturer B	Device operation (RS) - 1 drum	2 0.1535	56	8.6	<0.0012	3705-DA-52-92
Personal	Hydrar	Manufacturer B	Device operation (LS) - 1 drum	2 0.1535	56	8.6	0.094	3705-DA-52-89
Personal	MCEF	Manufacturer B	Device operation (LS) - 1 drum	2 0.1535	56	8.6	<0.0012	3705-DA-52-90
Area	Hydrar	Manufacturer B	By device exhaust	2 0.1525	57	8.69	0.076	3705-DA-52-93
Area	MCEF	Manufacturer B	By device exhaust	2 0.1525	57	8.69	<0.0012	3705-DA-52-94
Area	Hydrar	Manufacturer B	By device feed tube	2 0.152	57	8.66	0.09	3705-DA-52-95
Area	MCEF	Manufacturer B	By device feed tube	2 0.152	57	8.66	<0.0012	3705-DA-52-96
Personal	Hydrar	Manufacturer B	3rd drum change	2 0.256	12	3.07	0.2	3705-DA-52-97
Personal	MCEF	Manufacturer B	3rd drum change	2 0.256	12	3.07	<0.0033	3705-DA-52-98

Extended Field Test #2 – Melbourne, Florida – April 28 - May 2, 2003

Type	Media	Device	Location	Flow Rate (lpm)	Sample time (min)	Volume (liters)	Result (mg/m ³)	Sample #
Personal	Hydrar	Manufacturer C	Device operation (LS) - 2 drums	0.154	145	22.33	0.063	3705-AA-430-27
Personal	MCEF	Manufacturer C	Device operation (LS) - 2 drums	0.154	145	22.33	<0.00045	3705-AA-430-28
Personal	Hydrar	Manufacturer C	Device operation (RS) - 1st drum	0.1545	81	12.51	0.0047	3705-AA-430-29
Personal	MCEF	Manufacturer C	Device operation (RS) - 1st drum	0.1545	81	12.51	<0.00080	3705-AA-430-30
Personal	Hydrar	Manufacturer C	Device operation (LS) - 1st drum	0.153	81	12.39	0.07	3705-AA-430-31
Personal	MCEF	Manufacturer C	Device operation (LS) - 1st drum	0.153	81	12.39	<0.00081	3705-AA-430-32
Personal	Hydrar	Manufacturer C	Device operation (RS) - 2nd drum	0.1555	67	10.42	0.034	3705-AA-430-55
Personal	MCEF	Manufacturer C	Device operation (RS) - 2nd drum	0.1555	67	10.42	<0.00096	3705-AA-430-56
Personal	Hydrar	Manufacturer C	Device operation (LS) - 2nd drum	0.1505	67	10.08	0.052	3705-AA-430-57
Personal	MCEF	Manufacturer C	Device operation (LS) - 2nd drum	0.1505	67	10.08	<0.00099	3705-AA-430-58
Personal	Hydrar	Manufacturer C	1st filter change	0.2485	12	2.98	0.064	3705-AA-430-37
Personal	MCEF	Manufacturer C	1st filter change	0.2485	12	2.98	<0.0034	3705-AA-430-38
Personal	Hydrar	Manufacturer C	1st drum change	0.2485	17	4.22	0.11	3705-AA-430-39
Personal	MCEF	Manufacturer C	1st drum change	0.2485	17	4.22	<0.0024	3705-AA-430-40
Personal	Hydrar	Manufacturer C	3rd filter change	0.2485	12	2.98	0.06	3705-AA-430-41
Personal	MCEF	Manufacturer C	3rd filter change	0.2485	12	2.98	<0.0034	3705-AA-430-42
Personal	Hydrar	Manufacturer C	2nd drum change	0.2555	12	3.07	0.036	3705-AA-430-59
Personal	MCEF	Manufacturer C	2nd drum change	0.2555	12	3.07	<0.0033	3705-AA-430-60
Personal	Hydrar	Manufacturer C	Ceiling #1 - 1st drum change	0.2475	4	0.99	0.12	3705-AA-430-45
Personal	MCEF	Manufacturer C	Ceiling #1 - 1st drum change	0.2475	4	0.99	<0.010	3705-AA-430-46
Personal	Hydrar	Manufacturer C	Ceiling #2 - 1st drum change	0.2475	4	0.99	0.26	3705-AA-430-47
Personal	MCEF	Manufacturer C	Ceiling #2 - 1st drum change	0.2475	4	0.99	<0.010	3705-AA-430-48
Area	Hydrar	Manufacturer C	By device exhaust	0.154	148	22.79	0.048	3705-AA-430-33
Area	MCEF	Manufacturer C	By device exhaust	0.154	148	22.79	<0.00044	3705-AA-430-34
Area	Hydrar	Manufacturer C	By device feed tube	0.154	148	22.79	0.048	3705-AA-430-35
Area	MCEF	Manufacturer C	By device feed tube	0.154	148	22.79	<0.00044	3705-AA-430-36

Extended Field Test #2 – Melbourne, Florida – April 28 - May 2, 2003

Type	Media	Device	Location	Flow Rate (lpm)	Sample time (min)	Volume (liters)	Result (mg/m ³)	Sample #
Overnight	Hydrar	Manufacturer C	By device exhaust	0.152	991	150.63	0.019	3705-AA-430-49
Overnight	MCEF	Manufacturer C	By device exhaust	0.152	991	150.63	<0.00007	3705-AA-430-50
Overnight	Hydrar	Manufacturer C	By device feed tube	0.1505	991	149.15	0.021	3705-AA-430-51
Overnight	MCEF	Manufacturer C	By device feed tube	0.1505	991	149.15	<0.00007	3705-AA-430-52
Overnight	Hydrar	Manufacturer C	Outside containment	0.1555	991	154.1	0.016	3705-AA-430-53
Overnight	MCEF	Manufacturer C	Outside containment	0.1555	991	154.1	<0.00006	3705-AA-430-54

Extended Field Test #3 – Ashland, Virginia – June 9-13, 2003

Type	Media	Device	Location	Flow Rate (lpm)	Sample time (min)	Volume (liters)	Result (mg/m ³)	Sample #
Background	Hydrar	All	E. bay near door to W. bay	0.205	264	54.1	0.0086	3705-BA-69-03
Background	MCEF	All	E. bay near door to W. bay	0.205	264	54.1	<0.00018	3705-BA-69-04
Background	Hydrar	All	Middle of E. bay	0.221	264	58.3	0.013	3705-BA-69-01
Background	MCEF	All	Middle of E. bay	0.221	264	58.3	<0.00017	3705-BA-69-02
Personal	Hydrar	AERC	AERC personnel sample	0.202	89	18	0.089	3705-FA-611-113
Personal	MCEF	AERC	AERC personnel sample	0.202	89	18	0.0023	3705-FA-611-114
Personal	Hydrar	AERC	AERC personnel sample	0.202	89	18	0.073	3705-FA-611-115
Personal	MCEF	AERC	AERC personnel sample	0.202	89	18	0.0023	3705-FA-611-116
Personal	Hydrar	Manufacturer A	Device operation (LS) - 2 drums	0.195	129	25.2	0.0093	3705-RA-610-05
Personal	MCEF	Manufacturer A	Device operation (LS) - 2 drums	0.195	129	25.2	<0.00040	3705-RA-610-06
Personal	Hydrar	Manufacturer A	Device operation (RS) - 1st drum	0.202	67	13.5	0.011	3705-RA-610-09
Personal	MCEF	Manufacturer A	Device operation (RS) - 1st drum	0.202	67	13.5	<0.00074	3705-RA-610-10
Personal	Hydrar	Manufacturer A	Device operation (LS) - 1st drum	0.2	67	13.4	0.0062	3705-RA-610-07
Personal	MCEF	Manufacturer A	Device operation (LS) - 1st drum	0.2	67	13.4	<0.00075	3705-RA-610-08
Personal	Hydrar	Manufacturer A	Device operation (RS) - 2nd drum	0.198	62	12.3	0.015	3705-RA-610-25
Personal	MCEF	Manufacturer A	Device operation (RS) - 2nd drum	0.198	62	12.3	<0.00081	3705-RA-610-26

Extended Field Test #3 – Ashland, Virginia – June 9-13,2003

Type	Media	Device	Location	Flow Rate (lpm)	Sample time (min)	Volume (liters)	Result (mg/m ³)	Sample #
Personal	Hydrar	Manufacturer A	Device operation (LS) - 2nd drum	0.198	62	12.3	0.015	3705-RA-610-23
Personal	MCEF	Manufacturer A	Device operation (LS) - 2nd drum	0.198	62	12.3	<0.00081	3705-RA-610-24
Personal	Hydrar	Manufacturer A	1st drum change	0.259	12	3.1	0.013	3705-RA-610-15
Personal	MCEF	Manufacturer A	1st drum change	0.259	12	3.1	<0.0032	3705-RA-610-16
Personal	Hydrar	Manufacturer A	2nd drum change	0.259	12	3.1	0.025	3705-RA-610-17
Personal	MCEF	Manufacturer A	2nd drum change	0.259	12	3.1	<0.0032	3705-RA-610-18
Personal	Hydrar	Manufacturer A	Ceiling #1 - 1st drum change	0.251	4	1	0.05	3705-RA-610-19
Personal	MCEF	Manufacturer A	Ceiling #1 - 1st drum change	0.251	4	1	<0.010	3705-RA-610-20
Personal	Hydrar	Manufacturer A	Ceiling #2 - 1st drum change	0.251	4	1	0.047	3705-RA-610-21
Personal	MCEF	Manufacturer A	Ceiling #2 - 1st drum change	0.251	4	1	<0.010	3705-RA-610-22
Area	Hydrar	Manufacturer A	By device exhaust	0.201	145	29.1	0.01	3705-RA-610-11
Area	MCEF	Manufacturer A	By device exhaust	0.201	145	29.1	<0.00034	3705-RA-610-12
Area	Hydrar	Manufacturer A	By device feed tube	0.201	145	29.1	0.011	3705-RA-610-13
Area	MCEF	Manufacturer A	By device feed tube	0.201	145	29.1	<0.00034	3705-RA-610-14
Overnight	Hydrar	Manufacturer A	By device exhaust	0.155	360	55.8	0.0066	3705-RA-610-27
Overnight	MCEF	Manufacturer A	By device exhaust	0.155	360	55.8	<0.00018	3705-RA-610-28
Overnight	Hydrar	Manufacturer A	By device feed tube	0.152	360	54.7	0.012	3705-RA-610-29
Overnight	MCEF	Manufacturer A	By device feed tube	0.152	360	54.7	<0.00018	3705-RA-610-30
Overnight	Hydrar	Manufacturer A	Outside containment	0.156	360	56.2	0.017	3705-RA-610-31
Overnight	MCEF	Manufacturer A	Outside containment	0.156	360	56.2	<0.00018	3705-RA-610-32
Personal	Hydrar	Manufacturer B	Device operation (LS) - 2 drums	0.198	97	19.2	0.064	3705-DA-611-55
Personal	MCEF	Manufacturer B	Device operation (LS) - 2 drums	0.198	97	19.2	<0.00052	3705-DA-611-56
Personal	Hydrar	Manufacturer B	Device operation (RS) - 1st drum	0.2	59	11.8	0.076	3705-DA-611-59
Personal	MCEF	Manufacturer B	Device operation (RS) - 1st drum	0.2	59	11.8	<0.00085	3705-DA-611-60
Personal	Hydrar	Manufacturer B	Device operation (LS) - 1st drum	0.198	59	11.7	0.058	3705-DA-611-57
Personal	MCEF	Manufacturer B	Device operation (LS) - 1st drum	0.198	59	11.7	<0.00085	3705-DA-611-58

Extended Field Test #3 – Ashland, Virginia – June 9-13,2003

Type	Media	Device	Location	Flow Rate (lpm)	Sample time (min)	Volume (liters)	Result (mg/m ³)	Sample #
Personal	Hydrar	Manufacturer B	Device operation (RS) - 2nd drum	0.204	27	5.5	0.11	3705-DA-611-75
Personal	MCEF	Manufacturer B	Device operation (RS) - 2nd drum	0.204	27	5.5	<0.0018	3705-DA-611-76
Personal	Hydrar	Manufacturer B	Device operation (LS) - 2nd drum	0.202	38	7.7	0.081	3705-DA-611-73
Personal	MCEF	Manufacturer B	Device operation (LS) - 2nd drum	0.202	38	7.7	<0.0013	3705-DA-611-74
Personal	Hydrar	Manufacturer B	1st drum change	0.26	20	5.2	0.2	3705-DA-611-65
Personal	MCEF	Manufacturer B	1st drum change	0.26	20	5.2	<0.0019	3705-DA-611-66
Personal	Hydrar	Manufacturer B	2nd drum change	0.26	12	3.1	0.065	3705-DA-611-67
Personal	MCEF	Manufacturer B	2nd drum change	0.26	12	3.1	<0.0032	3705-DA-611-68
Personal	Hydrar	Manufacturer B	Ceiling #1 - 1st drum change	0.255	4	1	0.1	3705-DA-611-69
Personal	MCEF	Manufacturer B	Ceiling #1 - 1st drum change	0.255	4	1	<0.010	3705-DA-611-70
Personal	Hydrar	Manufacturer B	Ceiling #2 - 1st drum change	0.255	4	1	0.19	3705-DA-611-71
Personal	MCEF	Manufacturer B	Ceiling #2 - 1st drum change	0.255	4	1	<0.010	3705-DA-611-72
Area	Hydrar	Manufacturer B	By device exhaust	0.203	99	20.1	0.074	3705-DA-611-61
Area	MCEF	Manufacturer B	By device exhaust	0.203	99	20.1	<0.00050	3705-DA-611-62
Area	Hydrar	Manufacturer B	By device feed tube	0.21	99	20.8	0.047	3705-DA-611-63
Area	MCEF	Manufacturer B	By device feed tube	0.21	99	20.8	<0.00048	3705-DA-611-64
Overnight	Hydrar	Manufacturer B	By device exhaust	0.157	802	125.9	0.00052	3705-DA-611-77
Overnight	MCEF	Manufacturer B	By device exhaust	0.157	802	125.9	<0.00008	3705-DA-611-78
Overnight	Hydrar	Manufacturer B	By device feed tube	0.154	802	123.5	0.049	3705-DA-611-79
Overnight	MCEF	Manufacturer B	By device feed tube	0.154	802	123.5	<0.00008	3705-DA-611-80
Overnight	Hydrar	Manufacturer B	Outside containment	0.141	802	113.1	0.00052	3705-DA-611-81
Overnight	MCEF	Manufacturer B	Outside containment	0.141	802	113.1	<0.00009	3705-DA-611-82
Personal	Hydrar	Manufacturer C	Device operation (LS) - 2 drums	0.202	131	26.5	0.029	3705-AA-612-117
Personal	MCEF	Manufacturer C	Device operation (LS) - 2 drums	0.202	131	26.5	<0.00038	3705-AA-612-118
Personal	Hydrar	Manufacturer C	Device operation (RS) - 1st drum	0.211	79	16.7	0.053	3705-AA-612-121
Personal	MCEF	Manufacturer C	Device operation (RS) - 1st drum	0.211	79	16.7	<0.00060	3705-AA-612-122

Extended Field Test #3 – Ashland, Virginia – June 9-13, 2003

Type	Media	Device	Location	Flow Rate (lpm)	Sample time (min)	Volume (liters)	Result (mg/m ³)	Sample #
Personal	Hydrar	Manufacturer C	Device operation (LS) - 1st drum	0.2	79	15.8	0.049	3705-AA-612-119
Personal	MCEF	Manufacturer C	Device operation (LS) - 1st drum	0.2	79	15.8	<0.00063	3705-AA-612-120
Personal	Hydrar	Manufacturer C	Device operation (RS) - 2nd drum	0.212	52	11	0.039	3705-AA-612-137
Personal	MCEF	Manufacturer C	Device operation (RS) - 2nd drum	0.212	52	11	<0.00091	3705-AA-612-138
Personal	Hydrar	Manufacturer C	Device operation (LS) - 2nd drum	0.198	52	10.3	0.039	3705-AA-612-135
Personal	MCEF	Manufacturer C	Device operation (LS) - 2nd drum	0.198	52	10.3	<0.00097	3705-AA-612-136
Personal	Hydrar	Manufacturer C	1st filter change	0.255	12	3.1	0.055	3705-AA-612-127
Personal	MCEF	Manufacturer C	1st filter change	0.255	12	3.1	<0.0032	3705-AA-612-128
Personal	Hydrar	Manufacturer C	1st drum change	0.255	12	3.1	0.15	3705-AA-612-129
Personal	MCEF	Manufacturer C	1st drum change	0.255	12	3.1	<0.0032	3705-AA-612-130
Personal	Hydrar	Manufacturer C	3rd filter change	0.255	12	3.1	0.17	3705-AA-612-165
Personal	MCEF	Manufacturer C	3rd filter change	0.255	12	3.1	<0.0032	3705-AA-612-166
Personal	Hydrar	Manufacturer C	2nd drum change	0.255	13	3.3	0.094	3705-AA-612-167
Personal	MCEF	Manufacturer C	2nd drum change	0.255	13	3.3	<0.0030	3705-AA-612-168
Personal	Hydrar	Manufacturer C	Ceiling #1 - 1st drum change	0.26	4	1	0.19	3705-AA-612-131
Personal	MCEF	Manufacturer C	Ceiling #1 - 1st drum change	0.26	4	1	<0.010	3705-AA-612-132
Personal	Hydrar	Manufacturer C	Ceiling #2 - 1st drum change	0.26	4	1	0.22	3705-AA-612-133
Personal	MCEF	Manufacturer C	Ceiling #2 - 1st drum change	0.26	4	1	<0.010	3705-AA-612-134
Area	Hydrar	Manufacturer C	By device exhaust	0.2	132	26.4	0.041	3705-AA-612-123
Area	MCEF	Manufacturer C	By device exhaust	0.2	132	26.4	<0.00038	3705-AA-612-124
Area	Hydrar	Manufacturer C	By device feed tube	0.201	132	26.5	0.00075	3705-AA-612-125
Area	MCEF	Manufacturer C	By device feed tube	0.201	132	26.5	<0.00038	3705-AA-612-126
Overnight	Hydrar	Manufacturer C	By device exhaust	0.144	821	118.2	0.057	3705-AA-612-139
Overnight	MCEF	Manufacturer C	By device exhaust	0.144	821	118.2	<0.00008	3705-AA-612-140
Overnight	Hydrar	Manufacturer C	By device feed tube	0.157	821	128.9	0.058	3705-AA-612-141
Overnight	MCEF	Manufacturer C	By device feed tube	0.157	821	128.9	<0.00008	3705-AA-612-142

Extended Field Test #3 – Ashland, Virginia – June 9-13,2003

Type	Media	Device	Location	Flow Rate (lpm)	Sample time (min)	Volume (liters)	Result (mg/m ³)	Sample #
Overnight	Hydrar	Manufacturer C	Outside containment	0.15	821	123.1	0.044	3705-AA-612-143
Overnight	MCEF	Manufacturer C	Outside containment	0.15	821	123.1	<0.00008	3705-AA-612-144

Box Test – Ashland, Virginia

Box test	Hydrar	Manufacturer A	E. side of containment	0.199	64	12.7	0.018	3705-TA-610-47
Box test	MCEF	Manufacturer A	E. side of containment	0.199	64	12.7	<0.00079	3705-TA-610-48
Box test	Hydrar	Manufacturer A	W. side of containment	0.203	64	13	0.1	3705-TA-610-49
Box test	MCEF	Manufacturer A	W. side of containment	0.203	64	13	<0.00077	3705-TA-610-50
Box test	Hydrar	Manufacturer B	E. side of containment	0.201	36	7.2	0.12	3705-TA-611-109
Box test	MCEF	Manufacturer B	E. side of containment	0.201	36	7.2	<0.0014	3705-TA-611-110
Box test	Hydrar	Manufacturer B	W. side of containment	0.199	36	7.2	0.12	3705-TA-611-111
Box test	MCEF	Manufacturer B	W. side of containment	0.199	36	7.2	<0.0014	3705-TA-611-112
Box test	Hydrar	Manufacturer C	E. side of containment	0.201	45	9	0.05	3705-TA-612-167
Box test	MCEF	Manufacturer C	E. side of containment	0.201	45	9	<0.0011	3705-TA-612-168
Box test	Hydrar	Manufacturer C	W. side of containment	0.201	45	9	0.014	3705-TA-612-169
Box test	MCEF	Manufacturer C	W. side of containment	0.201	45	9	<0.0010	3705-TA-612-170

“U” Tube Test – Ashland, Virginia

Personal	Hydrar	Manufacturer B	"U" tubes - device operation (LS)	0.2	12	2.4	0.1	3705-DA-611-83
Personal	MCEF	Manufacturer B	"U" tubes - device operation (LS)	0.2	12	2.4	<0.0042	3705-DA-611-84
Personal	Hydrar	Manufacturer B	"U" tubes - device operation (RS)	0.197	12	2.4	0.018	3705-DA-611-85
Personal	MCEF	Manufacturer B	"U" tubes - device operation (RS)	0.197	12	2.4	<0.0042	3705-DA-611-86
Area	Hydrar	Manufacturer B	"U" tubes - by device exhaust	0.198	12	2.4	0.083	3705-DA-611-87
Area	MCEF	Manufacturer B	"U" tubes - by device exhaust	0.198	12	2.4	<0.0042	3705-DA-611-88
Area	Hydrar	Manufacturer B	"U" tubes - by device feed tube	0.205	12	2.5	0.092	3705-DA-611-89
Area	MCEF	Manufacturer B	"U" tubes - by device feed tube	0.205	12	2.5	<0.0040	3705-DA-611-90
Personal	Hydrar	Manufacturer C	"U" tubes - device operation (LS)	0.209	14	2.9	0.11	3705-AA-612-171
Personal	MCEF	Manufacturer C	"U" tubes - device operation (LS)	0.209	14	2.9	<0.0034	3705-AA-612-172

Extended Field Test #3 – Ashland, Virginia – June 9-13,2003

Type	Media	Device	Location	Flow Rate (lpm)	Sample time (min)	Volume (liters)	Result (mg/m ³)	Sample #
Personal	Hydrar	Manufacturer C	"U" tubes - device operation (RS)	0.207	14	2.9	0.026	3705-AA-612-173
Personal	MCEF	Manufacturer C	"U" tubes - device operation (RS)	0.207	14	2.9	<0.0034	3705-AA-612-174
Area	Hydrar	Manufacturer C	"U" tubes - by device exhaust	0.205	14	2.8	0.046	3705-AA-612-175
Area	MCEF	Manufacturer C	"U" tubes - by device exhaust	0.205	14	2.8	<0.0036	3705-AA-612-176
Area	Hydrar	Manufacturer C	"U" tubes - by device feed tube	0.201	14	2.8	0.05	3705-AA-612-177
Area	MCEF	Manufacturer C	"U" tubes - by device feed tube	0.201	14	2.8	<0.0036	3705-AA-612-178

Table 2: Wipe Sample Results

Performance Validation Study – Phase I – Ashland, Virginia – February 24-28, 2003						
Device	Date	Sample Location	Pre-Wipe #1	Post-Wipe #1	Pre-Wipe #2	Post-Wipe #2
Blank	2/27/2003	Blank	<0.01	<0.01	<0.01	<0.01
Blank	2/27/2003	Blank	<0.01	<0.01	<0.01	<0.01
Manufacturer A	2/27/2003	Floor-2 ft from device	0.36	0.14	0.16	0.19
Manufacturer A	2/27/2003	Floor-5 ft from device	0.21	0.11	0.18	0.15
Manufacturer A	2/27/2003	Ceiling	0.49	0.071	0.16	0.049
Manufacturer A	2/27/2003	East wall of containment	0.026	0.033	0.014	0.024
Manufacturer A	2/27/2003	West wall of containment	0.11	0.032	0.071	0.013
Manufacturer A	2/27/2003	Exterior drum surface-side	0.059	0.12	0.017	0.046
Manufacturer A	2/27/2003	DTC device	0.4	0.2	0.32	0.17
Manufacturer A	2/27/2003	DTC device feed tube exterior	0.48	0.053	0.055	0.062
Manufacturer A	2/27/2003	Floor at device exhaust	0.14	0.14	0.048	0.11
Blank	2/28/2003	Blank	<0.01	<0.01	<0.01	<0.01
Blank	2/28/2003	Blank	<0.01	<0.01	<0.01	<0.01
Manufacturer B	2/28/2003	Floor-2 ft from device	0.065	0.054	0.064	0.13
Manufacturer B	2/28/2003	Floor-5 ft from device	0.14	0.074	0.12	0.067
Manufacturer B	2/28/2003	Ceiling	0.053	0.2	0.045	0.097
Manufacturer B	2/28/2003	East wall of containment	0.017	0.02	0.029	<0.01
Manufacturer B	2/28/2003	West wall of containment	0.044	0.015	0.015	0.015
Manufacturer B	2/28/2003	Exterior drum surface-side	0.17	0.073	0.038	0.053
Manufacturer B	2/28/2003	DTC device	0.017	0.18	0.019	1.2
Manufacturer B	2/28/2003	DTC device feed tube exterior	<0.01	0.33	<0.01	0.64
Manufacturer B	2/28/2003	Floor at device exhaust	0.049	0.27	0.048	0.12
Blank	2/26/2003	Blank	<0.01	<0.01	<0.01	<0.01
Blank	2/26/2003	Blank	<0.01	<0.01	<0.01	<0.01
Manufacturer C	2/26/2003	Floor-2 ft from device	0.13	3.1	0.43	0.33
Manufacturer C	2/26/2003	Floor-5 ft from device	0.11	0.62	0.11	0.15
Manufacturer C	2/26/2003	Ceiling	0.71	0.27	0.2	0.15
Manufacturer C	2/26/2003	East wall of containment	<0.01	0.12	0.02	0.024
Manufacturer C	2/26/2003	West wall of containment	<0.01	0.034	<0.01	0.021
Manufacturer C	2/26/2003	Exterior drum surface-side	0.067	0.027	0.051	0.044
Manufacturer C	2/26/2003	DTC device	0.041	0.27	0.037	0.93
Manufacturer C	2/26/2003	DTC device feed tube exterior	0.02	0.052	0.017	0.047
Manufacturer C	2/26/2003	Floor at device exhaust	0.12	0.45	0.072	0.48
Manufacturer D	2/27/2003	Floor-2 ft from device	0.088	0.06	0.076	0.041
Manufacturer D	2/27/2003	Floor-5 ft from device	0.053	0.063	0.088	0.072

Performance Validation Study – Phase I – Ashland, Virginia – February 24-28, 2003						
Device	Date	Sample Location	Pre-Wipe #1	Post-Wipe #1	Pre-Wipe #2	Post-Wipe #2
Manufacturer D	2/27/2003	Ceiling	0.63	0.1	0.25	0.082
Manufacturer D	2/27/2003	East wall of containment	0.39	0.019	0.41	0.015
Manufacturer D	2/27/2003	West wall of containment	0.11	<0.01	0.028	0.017
Manufacturer D	2/27/2003	Exterior drum surface-side	0.31	0.052	0.4	0.037
Manufacturer D	2/27/2003	DTC device	0.067	0.067	0.049	0.051
Manufacturer D	2/27/2003	DTC device feed tube exterior	0.069	0.027	0.039	0.029
Manufacturer D	2/27/2003	Floor at device exhaust	0.27	0.097	0.31	0.085

Performance Validation Study – Phase II – Ashland, Virginia – June 9-13, 2003				
Device	Date	Sample Location	Pre-Wipe	Post-Wipe
Manufacturer A	6/10/2003	Floor-2 ft from device	0.22	0.98
Manufacturer A	6/10/2003	Floor-5 ft from device	0.093	0.47
Manufacturer A	6/10/2003	Ceiling	0.011	0.029
Manufacturer A	6/10/2003	East wall of containment	0.019	0.026
Manufacturer A	6/10/2003	West wall of containment	0.012	0.026
Manufacturer A	6/10/2003	Exterior drum surface-side	0.052	0.024
Manufacturer A	6/10/2003	DTC device	1.7	1.1
Manufacturer A	6/10/2003	DTC device feed tube exterior	0.39	0.36
Manufacturer A	6/10/2003	Floor at device exhaust	0.45	0.37
Manufacturer B	6/11/2003	Floor-2 ft from device	0.49	0.41
Manufacturer B	6/11/2003	Floor-5 ft from device	0.17	0.31
Manufacturer B	6/11/2003	Ceiling	0.081	0.16
Manufacturer B	6/11/2003	East wall of containment	0.039	0.068
Manufacturer B	6/11/2003	West wall of containment	0.048	0.073
Manufacturer B	6/11/2003	Exterior drum surface-side	0.31	0.043
Manufacturer B	6/11/2003	DTC device	0.98	0.45
Manufacturer B	6/11/2003	DTC device feed tube exterior	0.49	0.24
Manufacturer B	6/11/2003	Floor at device exhaust	0.54	0.22
Manufacturer C	6/12/2003	Floor-2 ft from device	0.13	0.17
Manufacturer C	6/12/2003	Floor-5 ft from device	0.19	0.22
Manufacturer C	6/12/2003	Ceiling	0.046	0.019
Manufacturer C	6/12/2003	East wall of containment	0.016	0.023
Manufacturer C	6/12/2003	West wall of containment	0.024	0.022
Manufacturer C	6/12/2003	Exterior drum surface-side	0.57	0.31
Manufacturer C	6/12/2003	DTC device	0.98	0.43
Manufacturer C	6/12/2003	DTC device feed tube exterior	0.25	0.17
Manufacturer C	6/12/2003	Floor at device exhaust	0.069	0.41

Extended Field Test #1 – Phoenix, Arizona – March 24-28, 2003				
Device	Date	Sample Location	Pre Wipe	Post Wipe
Background	3/24/2003	Ground in front of containment	1.4	
Background	3/24/2003	Ground in front of containment	0.69	
Blank	3/24/2003	Blank	<0.01	
Blank	3/24/2003	Blank	<0.01	
Manufacturer A	3/24/2003	Floor-2 ft from device	0.22	0.41
Manufacturer A	3/24/2003	Floor-5 ft from device	0.034	1.3
Manufacturer A	3/24/2003	Ceiling	<0.01	0.81
Manufacturer A	3/24/2003	East wall of containment	0.011	0.11
Manufacturer A	3/24/2003	West wall of containment	0.053	0.058
Manufacturer A	3/24/2003	Exterior drum surface-side	0.037	0.22
Manufacturer A	3/24/2003	DTC device	0.94	0.53
Manufacturer A	3/24/2003	DTC device feed tube exterior	0.16	0.17
Manufacturer A	3/24/2003	Floor at device exhaust	0.26	5
Blank	3/25/2003	Blank	<0.01	
Blank	3/25/2003	Blank	<0.01	
Manufacturer B	3/25/2003	Floor-2 ft from device	0.73	0.44
Manufacturer B	3/25/2003	Floor-5 ft from device	0.43	1.6
Manufacturer B	3/25/2003	Ceiling	0.18	0.51
Manufacturer B	3/25/2003	East wall of containment	0.21	0.8
Manufacturer B	3/25/2003	West wall of containment	0.088	0.11
Manufacturer B	3/25/2003	Exterior drum surface-side	0.14	0.05
Manufacturer B	3/25/2003	DTC device	0.8	0.61
Manufacturer B	3/25/2003	DTC device feed tube exterior	0.091	0.48
Manufacturer B	3/25/2003	Floor at device exhaust	0.17	0.45
Blank	3/27/2003	Blank	<0.01	
Blank	3/27/2003	Blank	<0.01	
Manufacturer C	3/27/2003	Floor-2 ft from device	0.17	1.3
Manufacturer C	3/27/2003	Floor-5 ft from device	0.042	0.17
Manufacturer C	3/27/2003	Ceiling	0.071	0.14
Manufacturer C	3/27/2003	East wall of containment	0.019	2.7
Manufacturer C	3/27/2003	West wall of containment	0.032	1
Manufacturer C	3/27/2003	Exterior drum surface-side	0.065	0.36
Manufacturer C	3/27/2003	DTC device	0.067	0.85
Manufacturer C	3/27/2003	DTC device feed tube exterior	0.11	0.23
Manufacturer C	3/27/2003	Floor at device exhaust	0.083	2.6

Extended Field Test #1 – Phoenix, Arizona – March 24-28, 2003				
Device	Date	Sample Location	Pre Wipe	Post Wipe
Blank	3/26/2003	Blank	<0.01	
Blank	3/26/2003	Blank	0.018	
Manufacturer D	3/26/2003	Floor-2 ft from device	0.28	3.1
Manufacturer D	3/26/2003	Floor-5 ft from device	0.18	0.23
Manufacturer D	3/26/2003	Ceiling	0.034	0.038
Manufacturer D	3/26/2003	East wall of containment	5.3	4.5
Manufacturer D	3/26/2003	West wall of containment	0.96	0.4
Manufacturer D	3/26/2003	Exterior drum surface-side	1.1	0.88
Manufacturer D	3/26/2003	DTC device	2.1	1.2
Manufacturer D	3/26/2003	DTC device feed tube exterior	1.3	0.56
Manufacturer D	3/26/2003	Floor at device exhaust	0.33	4.5

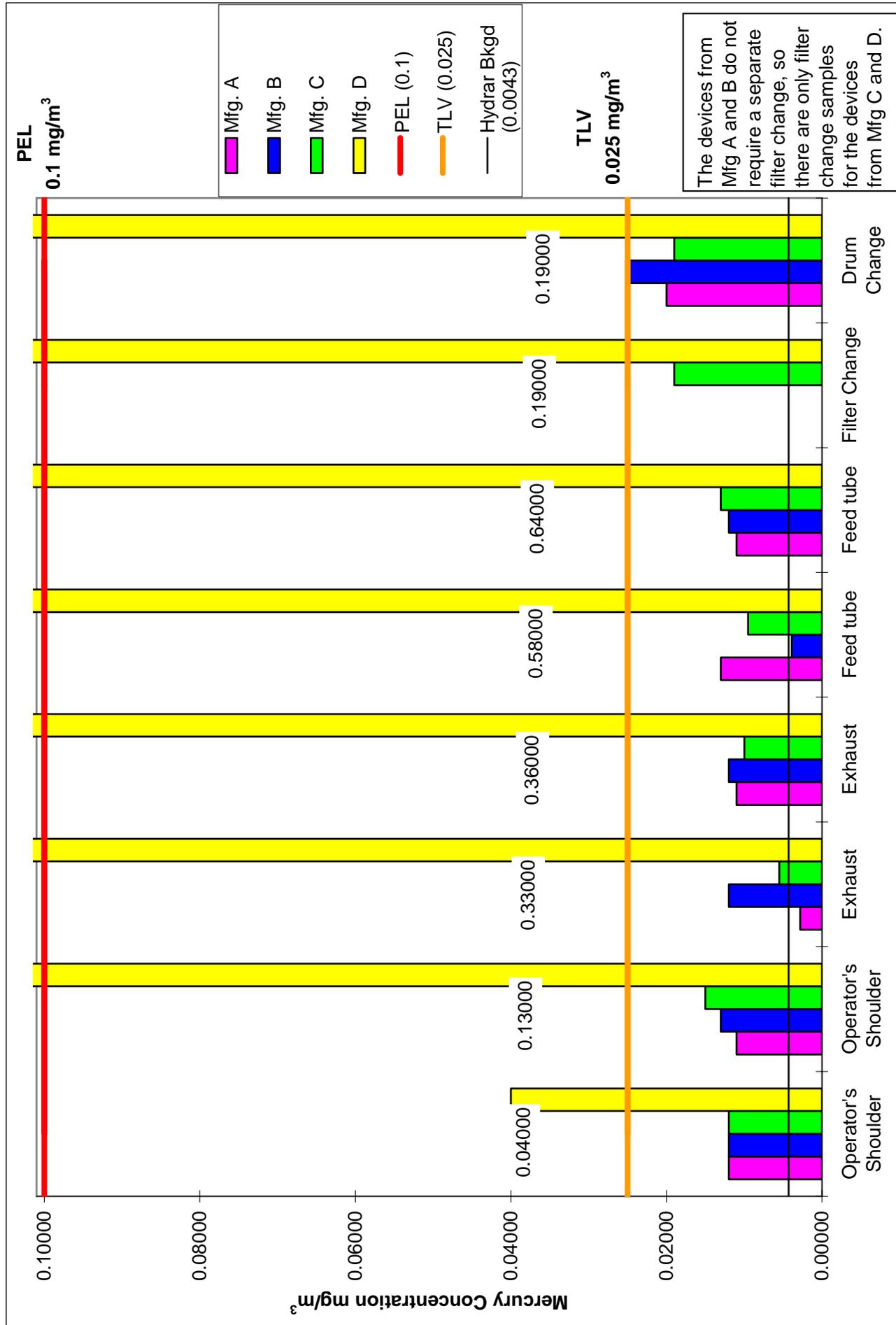
Extended Field Test #2 – Melbourne, Florida – April 28 - May 2, 2003				
Device	Date	Sample Location	Pre-Wipe	Post-Wipe
Blank	5/1/2003	Blank	<0.01	
Blank	5/1/2003	Blank	<0.01	
Manufacturer A	5/1/2003	Floor-2 ft from device	0.095	0.61
Manufacturer A	5/1/2003	Floor-5 ft from device	0.083	0.46
Manufacturer A	5/1/2003	Ceiling	0.036	0.1
Manufacturer A	5/1/2003	East wall of containment	0.015	0.14
Manufacturer A	5/1/2003	West wall of containment	0.019	0.052
Manufacturer A	5/1/2003	Exterior drum surface-side	0.036	0.18
Manufacturer A	5/1/2003	DTC device	0.54	1.3
Manufacturer A	5/1/2003	DTC device feed tube exterior	0.2	0.2
Manufacturer A	5/1/2003	Floor at device exhaust	0.1	3.6
Manufacturer A	5/2/2003	Next day: Floor-2 ft from device		0.86
Manufacturer A	5/2/2003	Next day: E. wall of containment		0.078
Blank	4/29/2003	Blank	<0.01	
Blank	4/29/2003	Blank	<0.01	
Manufacturer B	4/29/2003	Floor-2 ft from device	0.67	17
Manufacturer B	4/29/2003	Floor-5 ft from device	0.46	6
Manufacturer B	4/29/2003	Ceiling	0.057	0.39
Manufacturer B	4/29/2003	East wall of containment	0.074	0.28
Manufacturer B	4/29/2003	West wall of containment	0.035	0.17
Manufacturer B	4/29/2003	Exterior drum surface-side	0.13	0.12
Manufacturer B	4/29/2003	DTC device	0.3	2.2

Extended Field Test #2 – Melbourne, Florida – April 28 - May 2, 2003				
Device	Date	Sample Location	Pre-Wipe	Post-Wipe
Manufacturer B	4/29/2003	DTC device feed tube exterior	0.63	0.63
Manufacturer B	4/29/2003	Floor at device exhaust	0.1	11
Manufacturer B	4/29/2003	Inside drum before crushing	0.024	
Manufacturer B	4/30/2003	Next day: Floor-2 ft from device		17.00
Manufacturer B	4/30/2003	Next day: E. wall of containment		0.550
Blank	4/30/2003	Blank	<0.01	
Blank	4/30/2003	Blank	0.017	
Manufacturer C	4/30/2003	Floor-2 ft from device	0.21	0.16
Manufacturer C	4/30/2003	Floor-5 ft from device	0.17	0.18
Manufacturer C	4/30/2003	Ceiling	0.11	0.1
Manufacturer C	4/30/2003	East wall of containment	0.11	0.02
Manufacturer C	4/30/2003	West wall of containment	0.086	0.022
Manufacturer C	4/30/2003	Exterior drum surface-side	0.11	0.046
Manufacturer C	4/30/2003	DTC device	0.25	0.24
Manufacturer C	4/30/2003	DTC device feed tube exterior	0.18	0.15
Manufacturer C	4/30/2003	Floor at device exhaust	0.08	0.49
Manufacturer C	5/1/2003	Next day: Floor-2 ft from device		0.650
Manufacturer C	5/1/2003	Next day: E. wall of containment		0.026

Extended Field Test #3 – Ashland, Virginia – June 9-13,2003				
Device	Date	Sample Location	Pre-Wipe	Post-Wipe
Blank	6/10/2003	Blank	<0.01	
Blank	6/10/2003	Blank	<0.01	
Manufacturer A	6/10/2003	Floor-2 ft from device	0.055	1.6
Manufacturer A	6/10/2003	Floor-5 ft from device	0.21	1.4
Manufacturer A	6/10/2003	Ceiling	0.025	0.19
Manufacturer A	6/10/2003	East wall of containment	<0.01	0.21
Manufacturer A	6/10/2003	West wall of containment	0.1	0.11
Manufacturer A	6/10/2003	Exterior drum surface-side	0.73	0.13
Manufacturer A	6/10/2003	DTC device	0.5	1.1
Manufacturer A	6/10/2003	DTC device feed tube exterior	0.061	0.32
Manufacturer A	6/10/2003	Floor at device exhaust	0.12	1.7
Manufacturer A	6/11/2003	Next day: Floor-2 ft from device		1.00
Manufacturer A	6/11/2003	Next day: E. wall of containment		0.022
Operator	6/10/2003	Tad's Hands	1.8	
Operator	6/10/2003	Steve's Hands	1.9	

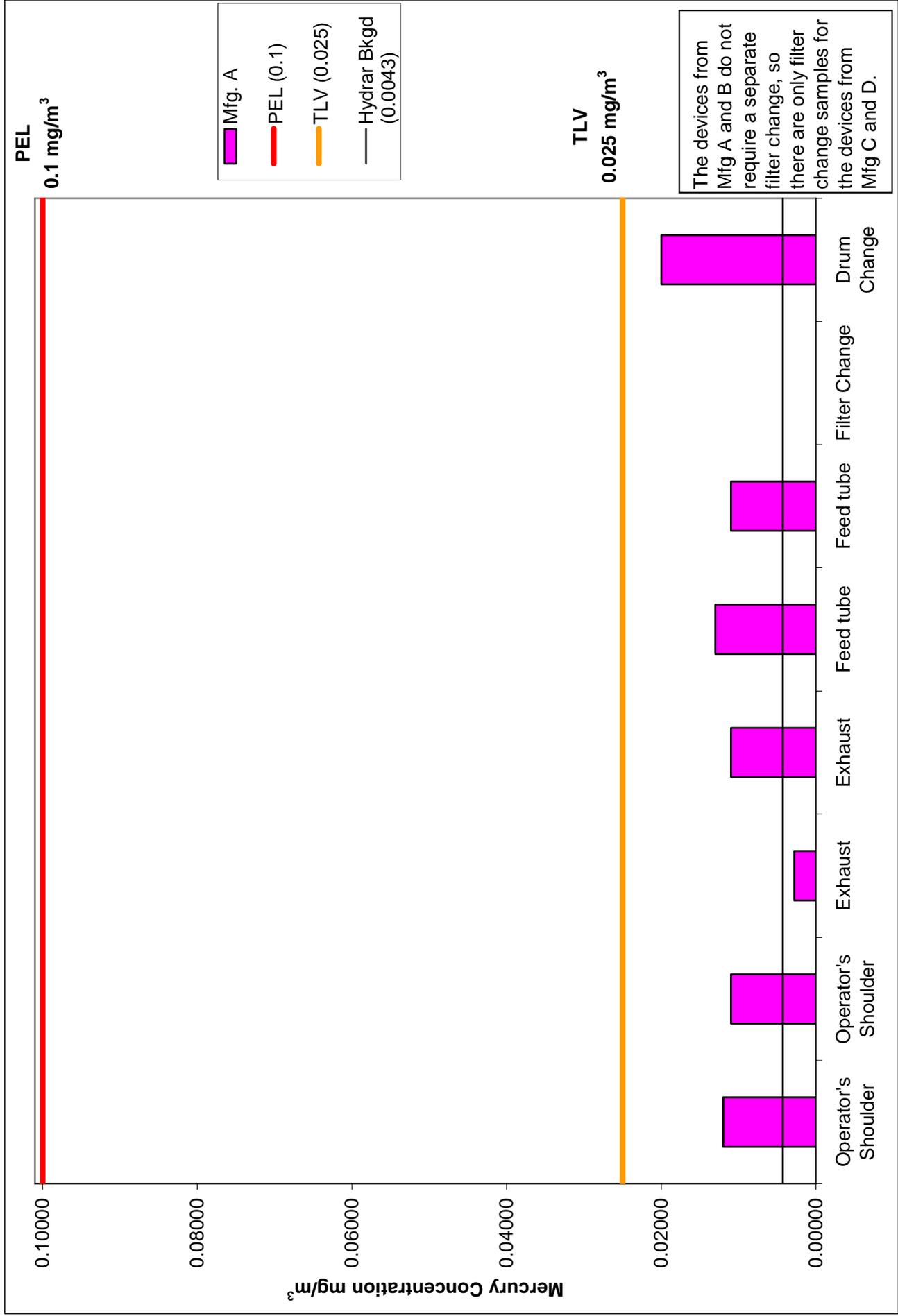
Extended Field Test #3 – Ashland, Virginia – June 9-13,2003				
Device	Date	Sample Location	Pre-Wipe	Post-Wipe
Operator	6/10/2003	Tad's Face	0.055	
Operator	6/10/2003	Steve's Face	0.53	
Blank	6/11/2003	Blank	<0.01	
Blank	6/11/2003	Blank	<0.01	
Manufacturer B	6/11/2003	Floor-2 ft from device	0.14	1.1
Manufacturer B	6/11/2003	Floor-5 ft from device	0.048	0.79
Manufacturer B	6/11/2003	Ceiling	0.031	0.099
Manufacturer B	6/11/2003	East wall of containment	0.035	0.072
Manufacturer B	6/11/2003	West wall of containment	0.024	0.055
Manufacturer B	6/11/2003	Exterior drum surface-side	0.14	0.058
Manufacturer B	6/11/2003	DTC device	0.23	3.8
Manufacturer B	6/11/2003	DTC device feed tube exterior	0.22	0.8
Manufacturer B	6/11/2003	Floor at device exhaust	0.17	1.5
Manufacturer B	6/12/2003	Next day: Floor-2 ft from device		0.230
Manufacturer B	6/12/2003	Next day: E. wall of containment		0.065
Blank	6/12/2003	Blank	<0.01	
Blank	6/12/2003	Blank	0.012	
Manufacturer C	6/12/2003	Floor-2 ft from device	0.051	1.1
Manufacturer C	6/12/2003	Floor-5 ft from device	0.059	0.12
Manufacturer C	6/12/2003	Ceiling	0.061	0.44
Manufacturer C	6/12/2003	East wall of containment	0.02	0.097
Manufacturer C	6/12/2003	West wall of containment	0.034	0.092
Manufacturer C	6/12/2003	Exterior drum surface-side	0.2	0.12
Manufacturer C	6/12/2003	DTC device	1.7	1.8
Manufacturer C	6/12/2003	DTC device feed tube exterior	0.096	0.36
Manufacturer C	6/12/2003	Floor at device exhaust	0.22	2.8
Manufacturer C	6/13/2003	Next day: Floor-2 ft from device		0.830
Manufacturer C	6/13/2003	Next day: E. wall of containment		0.017
Blank	6/13/2003	Blank	<0.01	
Blank	6/13/2003	Blank	<0.01	

Figure 1: Performance Validation Study – Phase I Analytical Air Results
All Devices – Ashland, Virginia – February 24-28, 2003



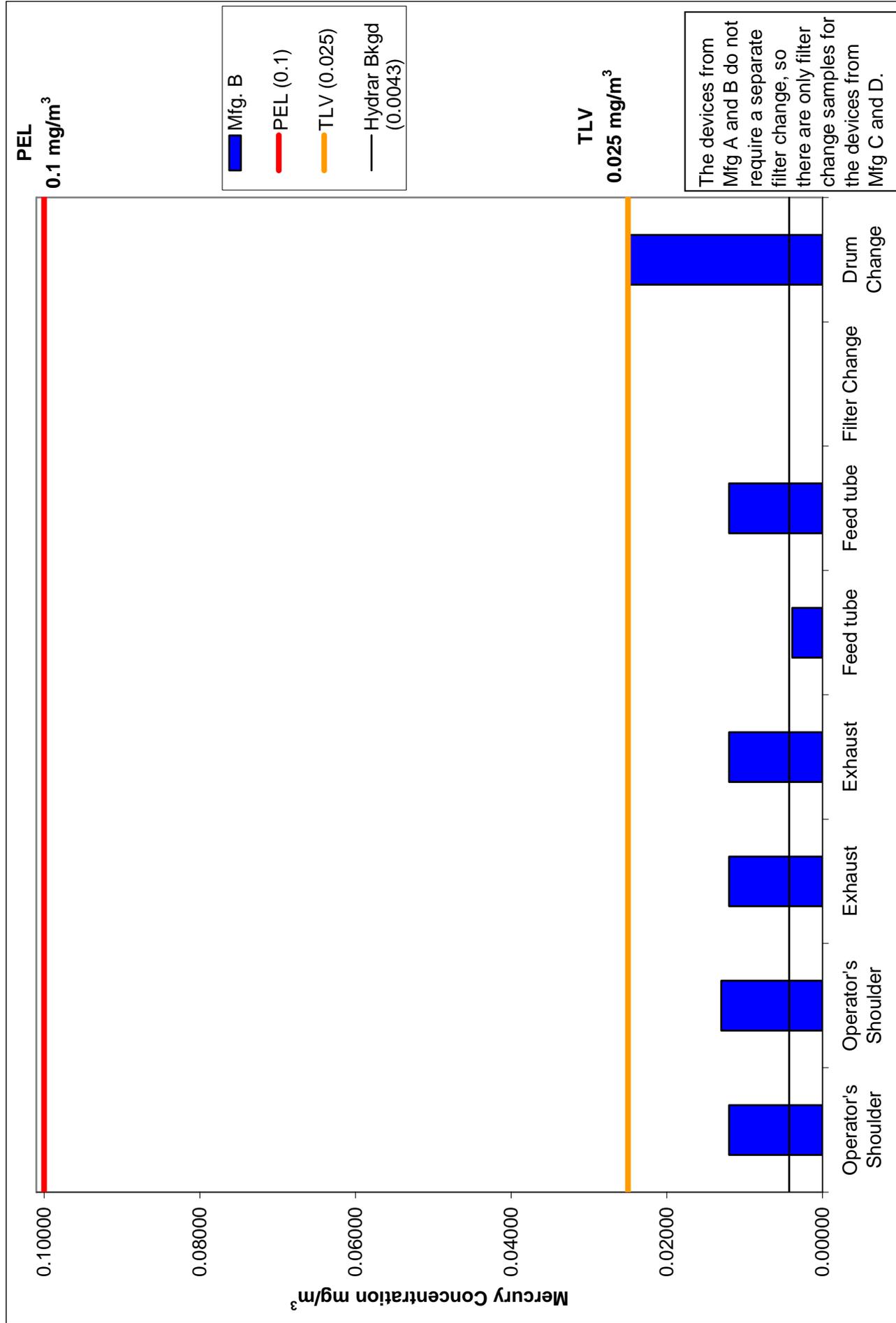
The TLV is included on the graph as a point of reference. The results shown on this graph do not represent eight-hour, time-weighted averages.

**Figure 2: Performance Validation Study – Phase I Analytical Air Results
 Manufacturer A – Ashland, Virginia – February 24-28, 2003**



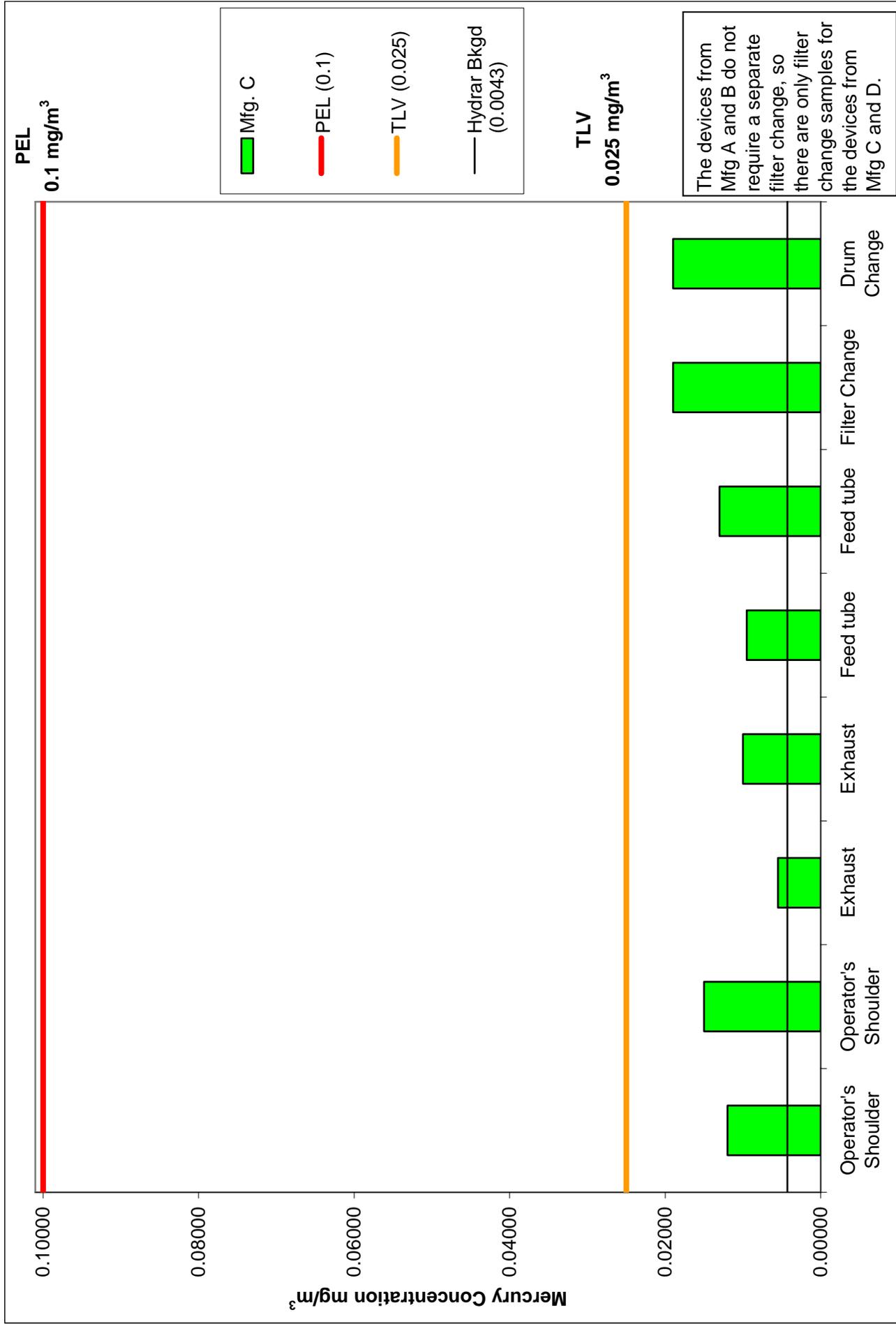
The TLV is included on the graph as a point of reference. The results shown on this graph do not represent eight-hour, time-weighted averages.

**Figure 3: Performance Validation Study – Phase I Analytical Air Results
 Manufacturer B – Ashland, Virginia – February 24-28, 2003**



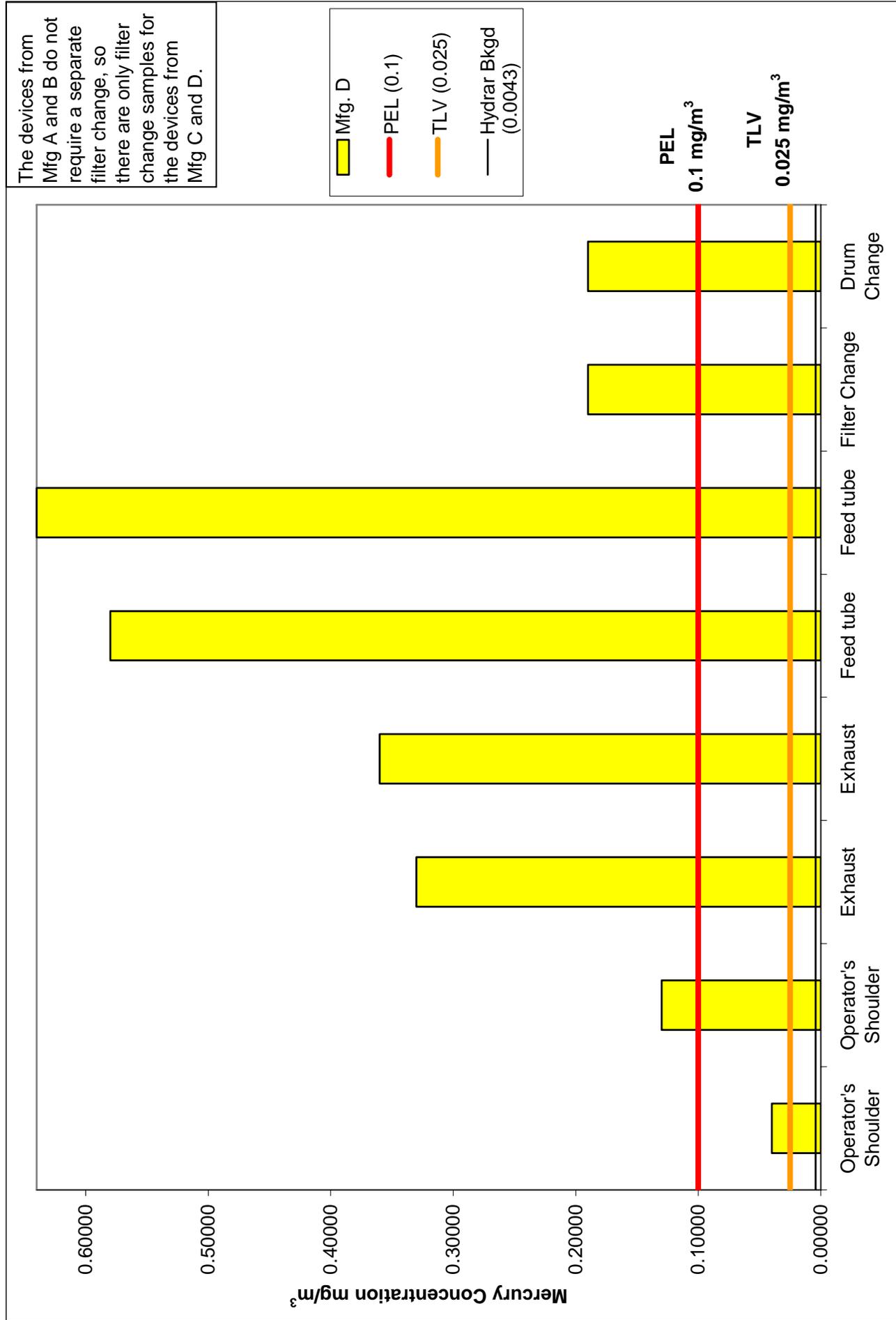
The TLV is included on the graph as a point of reference. The results shown on this graph do not represent eight-hour, time-weighted averages.

**Figure 4: Performance Validation Study – Phase I Analytical Air Results
 Manufacturer C – Ashland, Virginia – February 24-28, 2003**



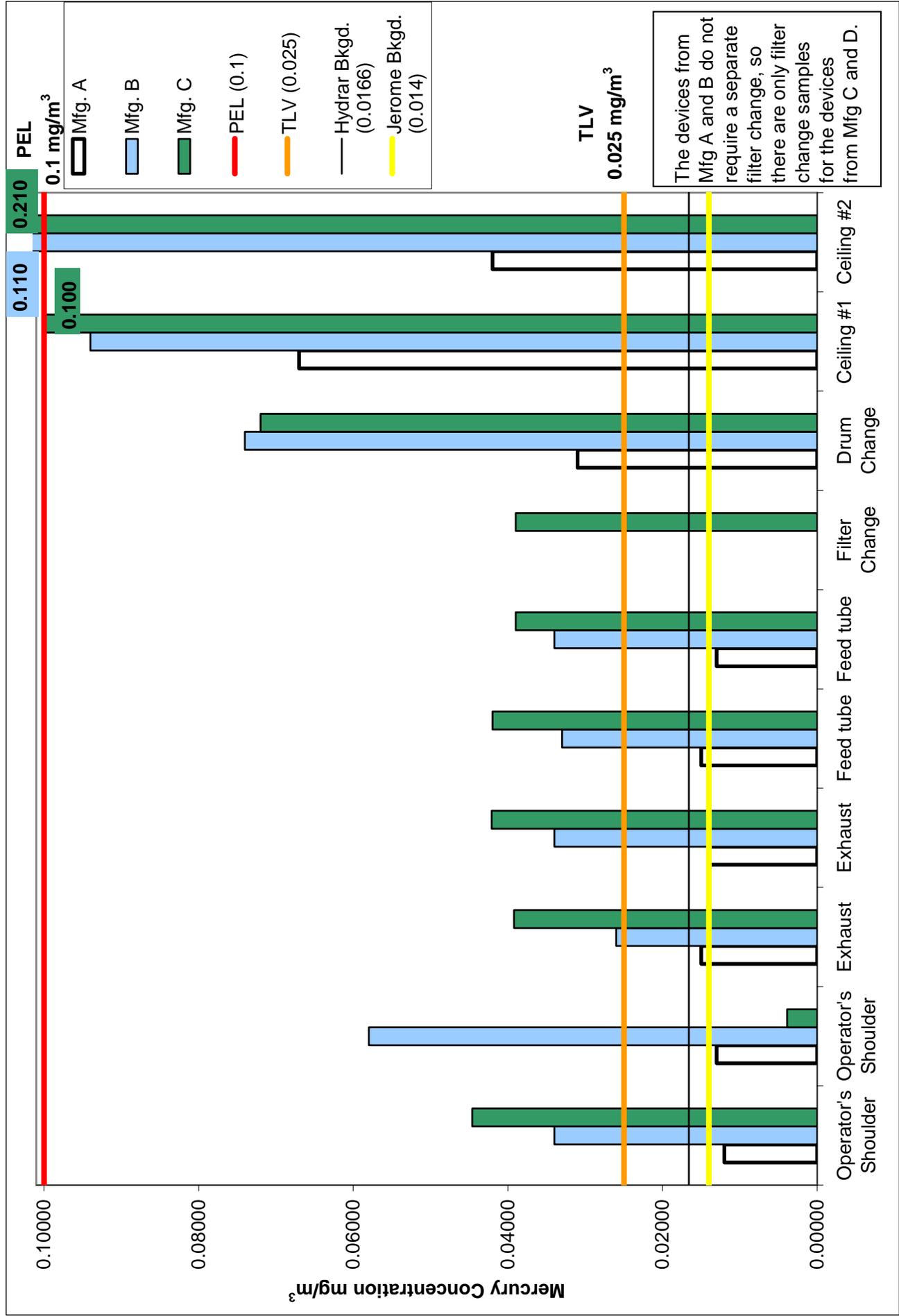
The TLV is included on the graph as a point of reference. The results shown on this graph do not represent eight-hour, time-weighted averages.

**Figure 5: Performance Validation Study – Phase I Analytical Air Results
 Manufacturer D – Ashland, Virginia – February 24-28, 2003**



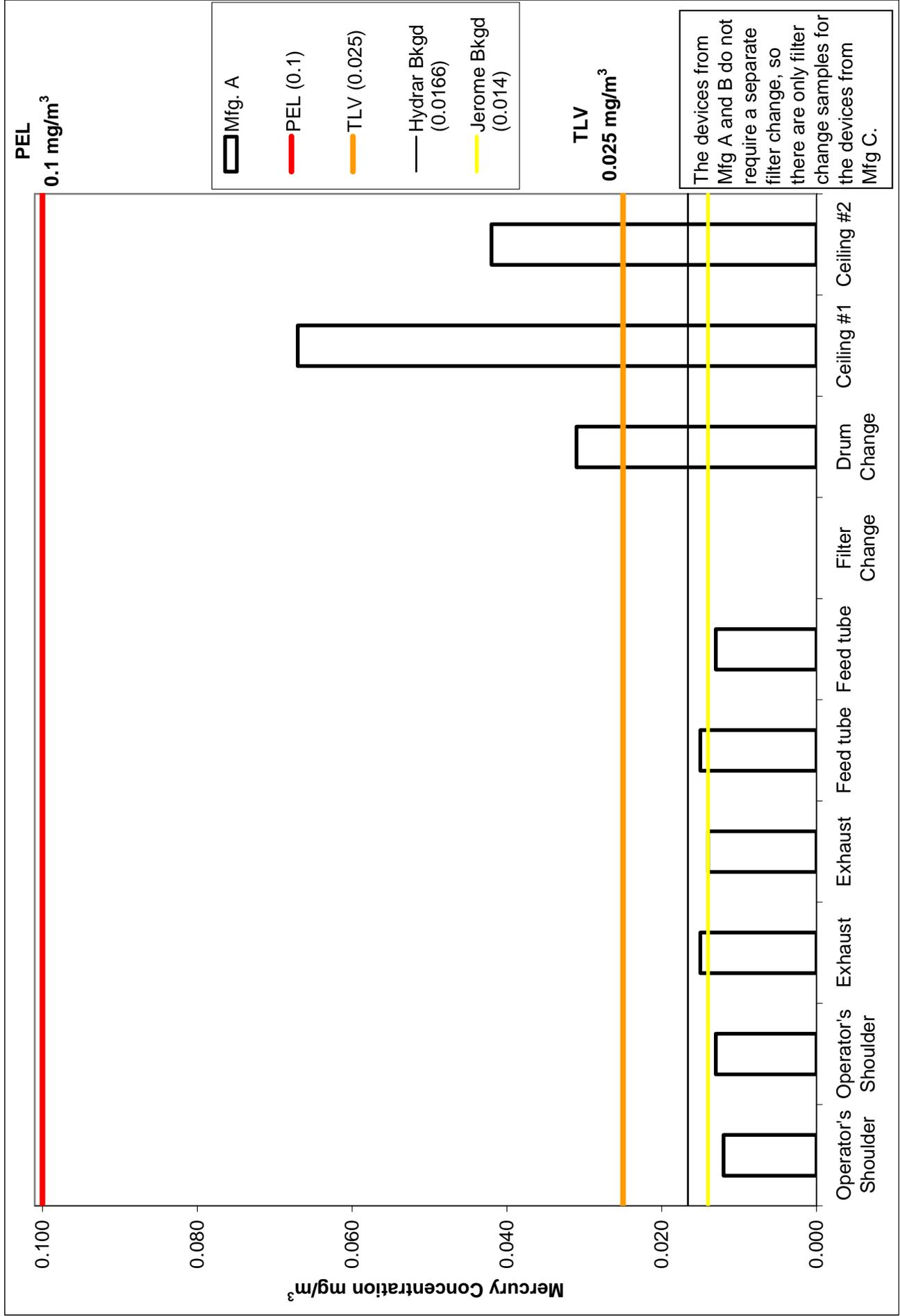
The TLV is included on the graph as a point of reference. The results shown on this graph do not represent eight-hour, time-weighted averages.

**Figure 6: Performance Validation Study – Phase II Analytical Air Results
All Devices – Ashland, Virginia – June 9-13, 2003**



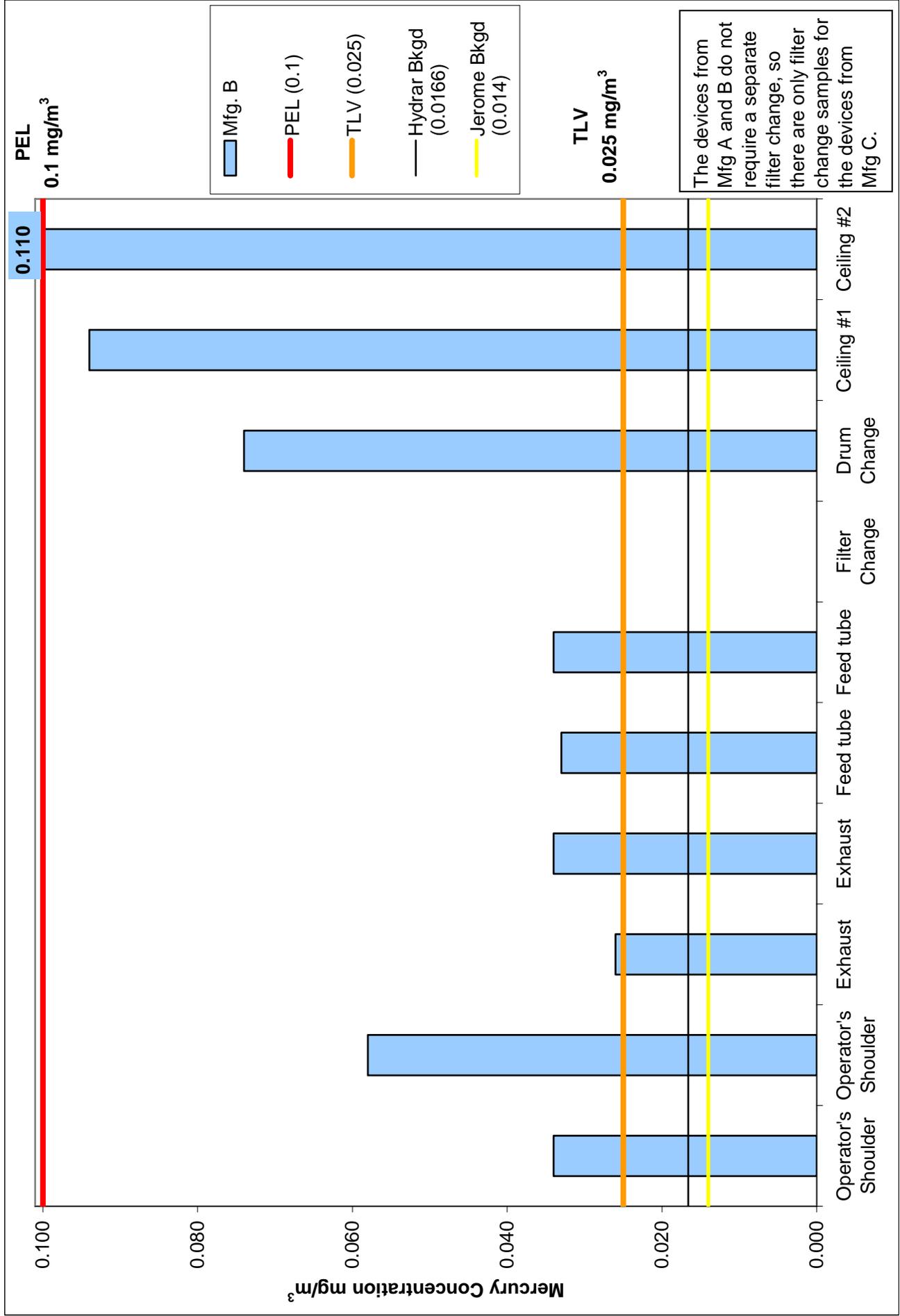
The TLV is included on the graph as a point of reference. The results shown on this graph do not represent eight-hour, time-weighted averages.

**Figure 7: Performance Validation Study – Phase II Analytical Air Results
 Manufacturer A – Ashland, Virginia – June 9-13, 2003**



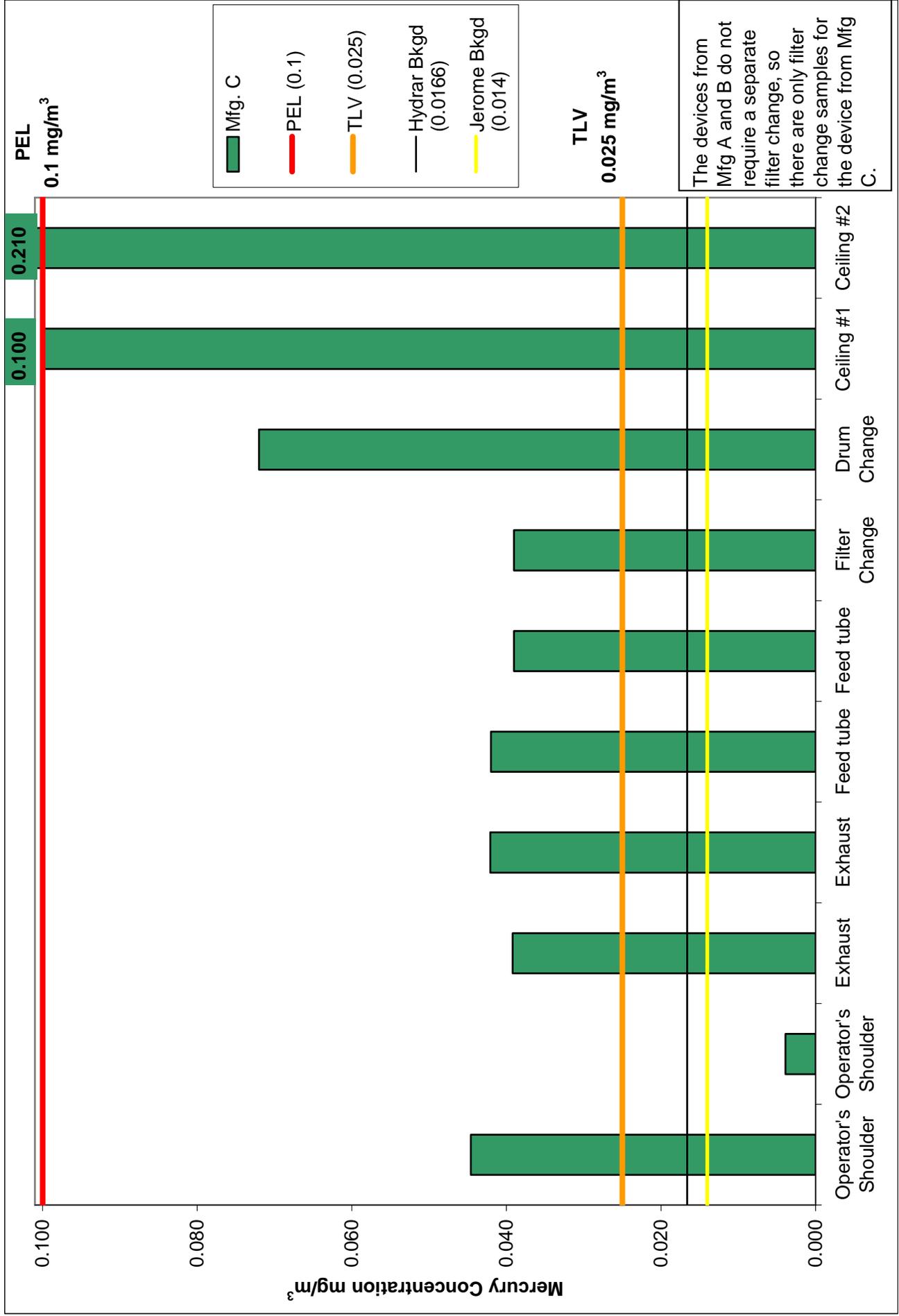
The TLV is included on the graph as a point of reference. The results shown on this graph do not represent eight-hour, time-weighted averages.

**Figure 8: Performance Validation Study – Phase II Analytical Air Results
 Manufacturer B – Ashland, Virginia – June 9-13, 2003**



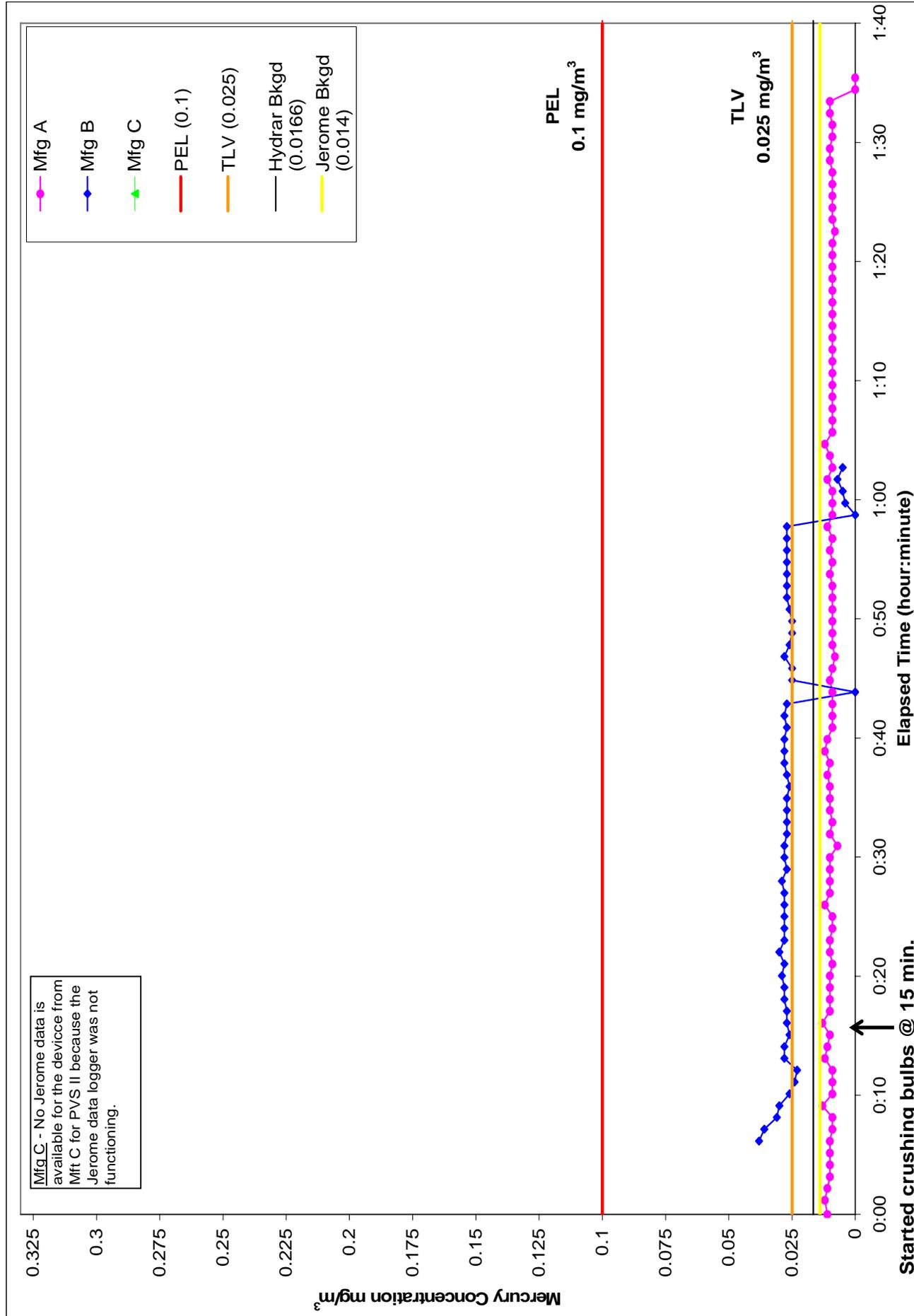
The TLV is included on the graph as a point of reference. The results shown on this graph do not represent eight-hour, time-weighted averages.

**Figure 9: Performance Validation Study – Phase II Analytical Air Results
 Manufacturer C – Ashland, Virginia – June 9-13, 2003**



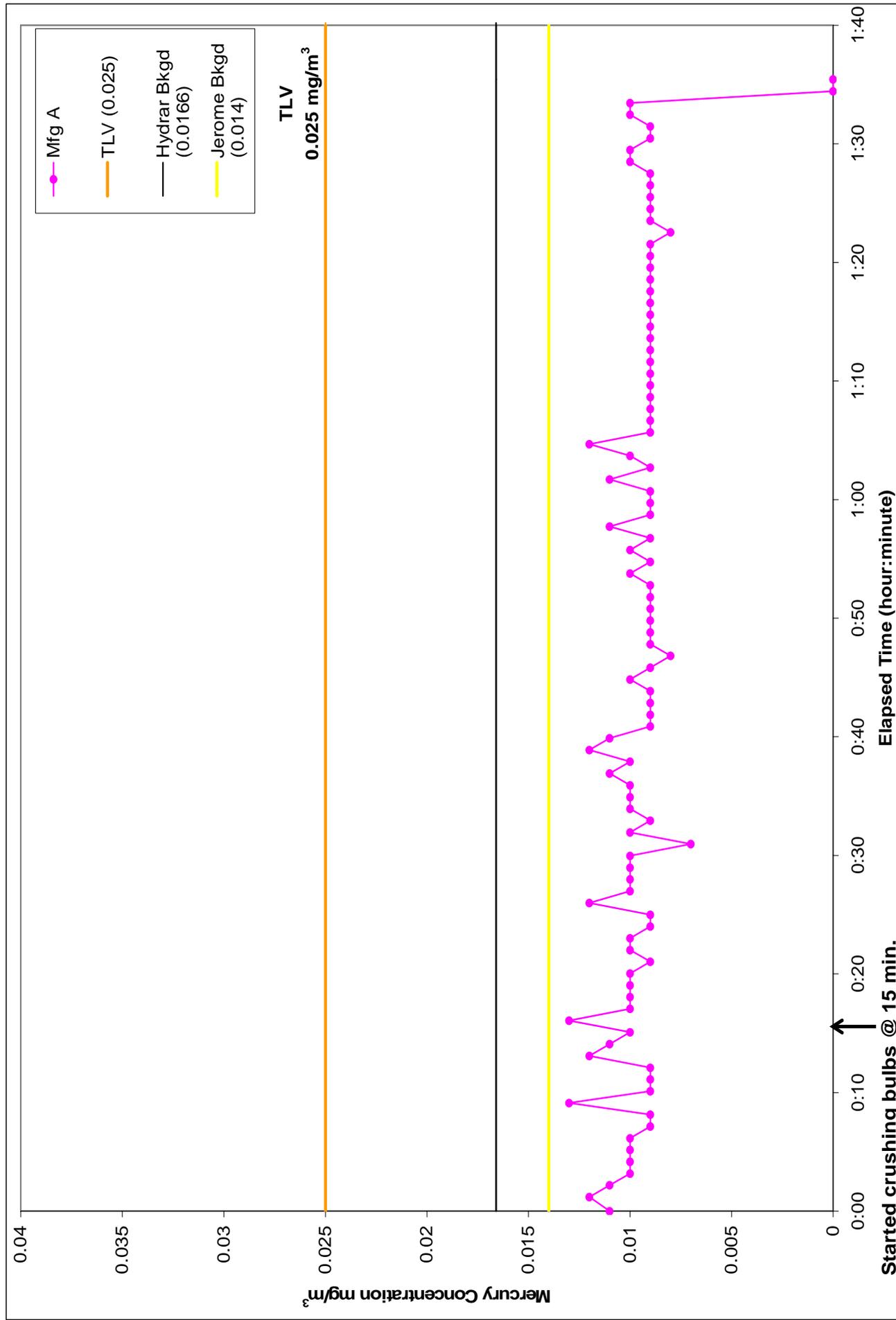
The TLV is included on the graph as a point of reference. The results shown on this graph do not represent eight-hour, time-weighted averages.

**Figure 10: Performance Validation Study – Phase II Jerome Results
All Devices – Ashland, Virginia – June 9-13, 2003**



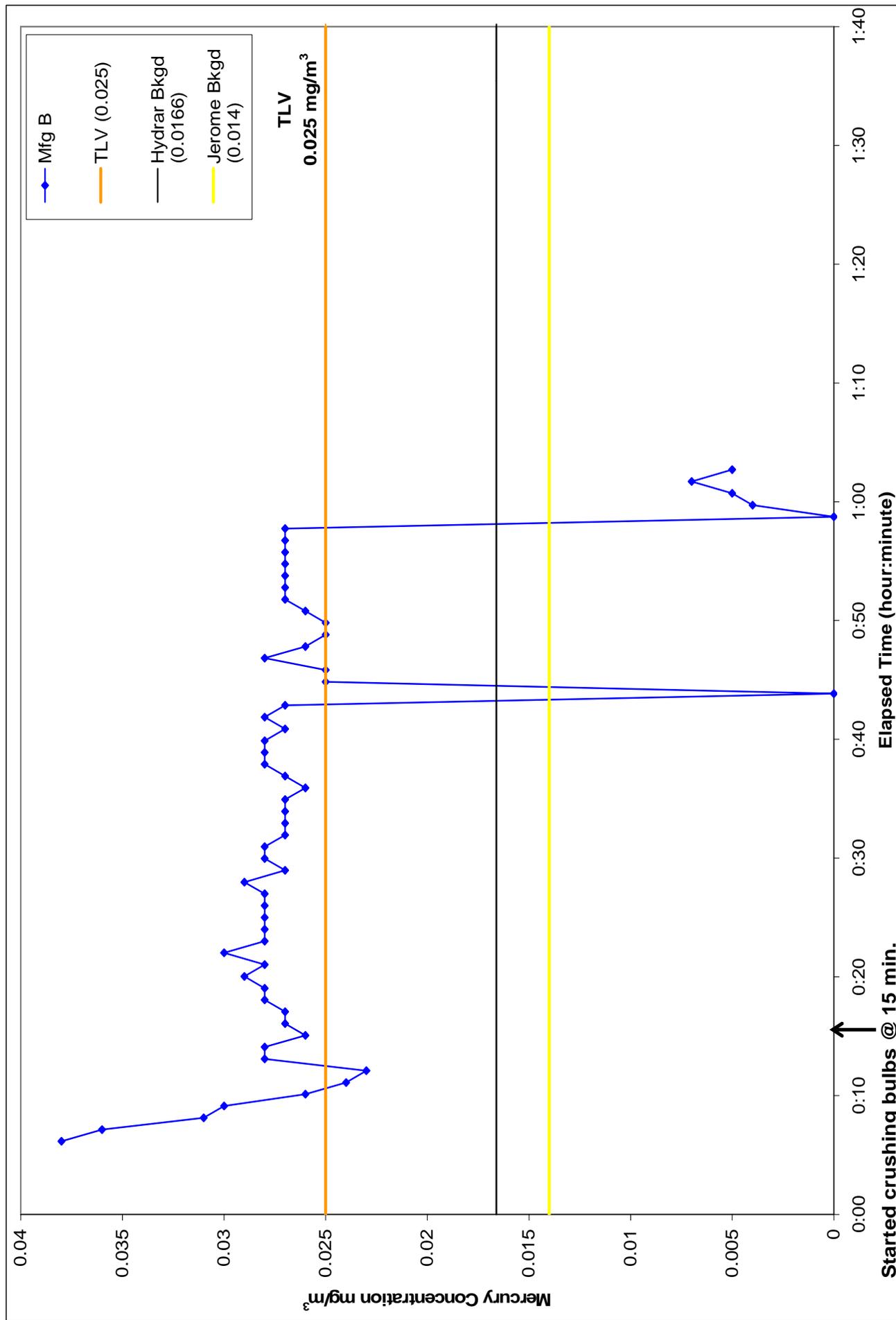
The TLV is included on the graph as a point of reference. The results shown on this graph do not represent eight-hour, time-weighted averages.

**Figure 11: Performance Validation Study – Phase II Jerome Results
 Manufacturer A – Ashland, Virginia – June 9-13, 2003**



The TLV is included on the graph as a point of reference. The results shown on this graph do not represent eight-hour, time-weighted averages.

**Figure 12: Performance Validation Study – Phase II Jerome Results
 Manufacturer B – Ashland, Virginia – June 9-13, 2003**



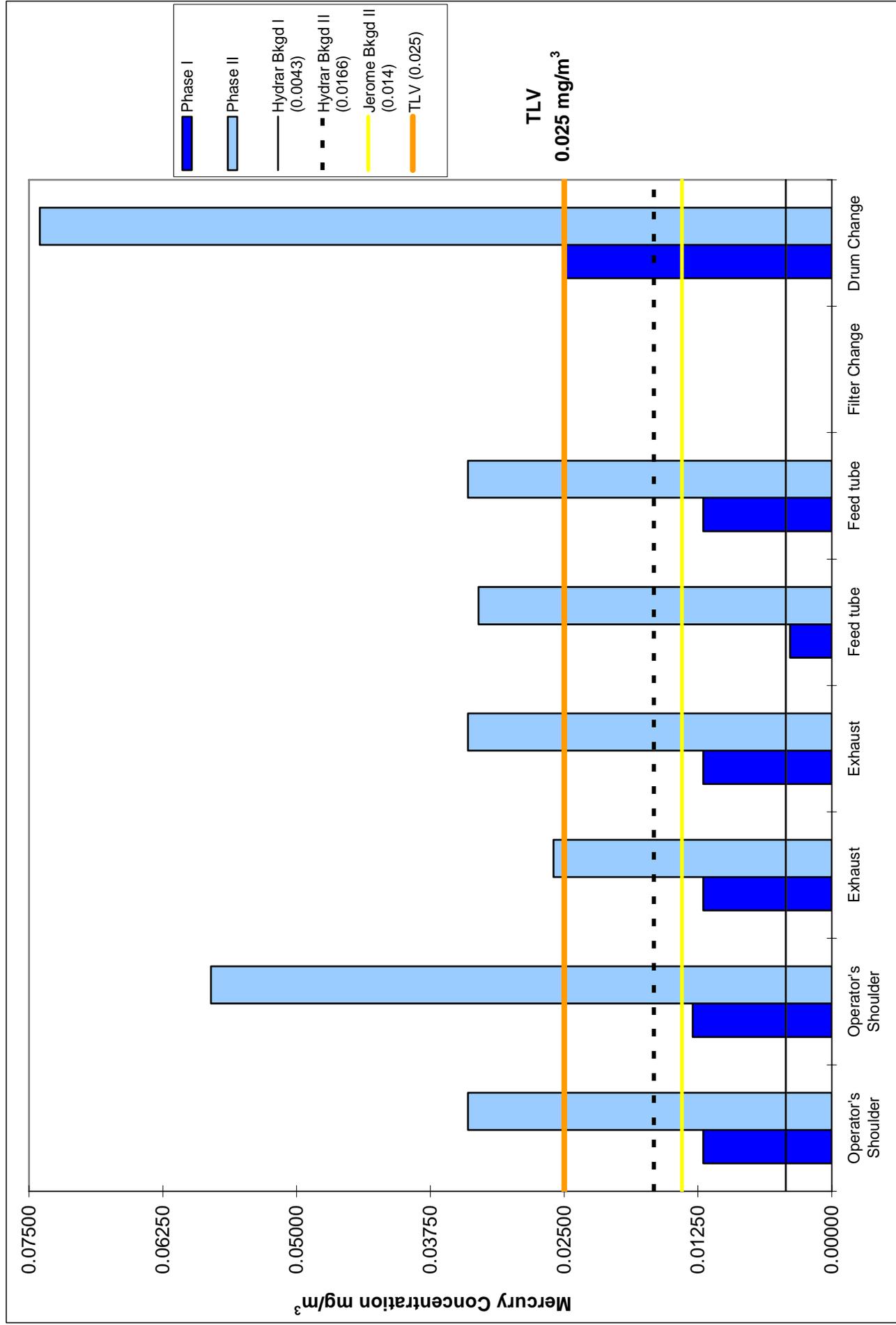
The TLV is included on the graph as a point of reference. The results shown on this graph do not represent eight-hour, time-weighted averages.

**Figure 13: Performance Validation Study – Phase I and Phase II Analytical Air Results
Manufacturer A Device**



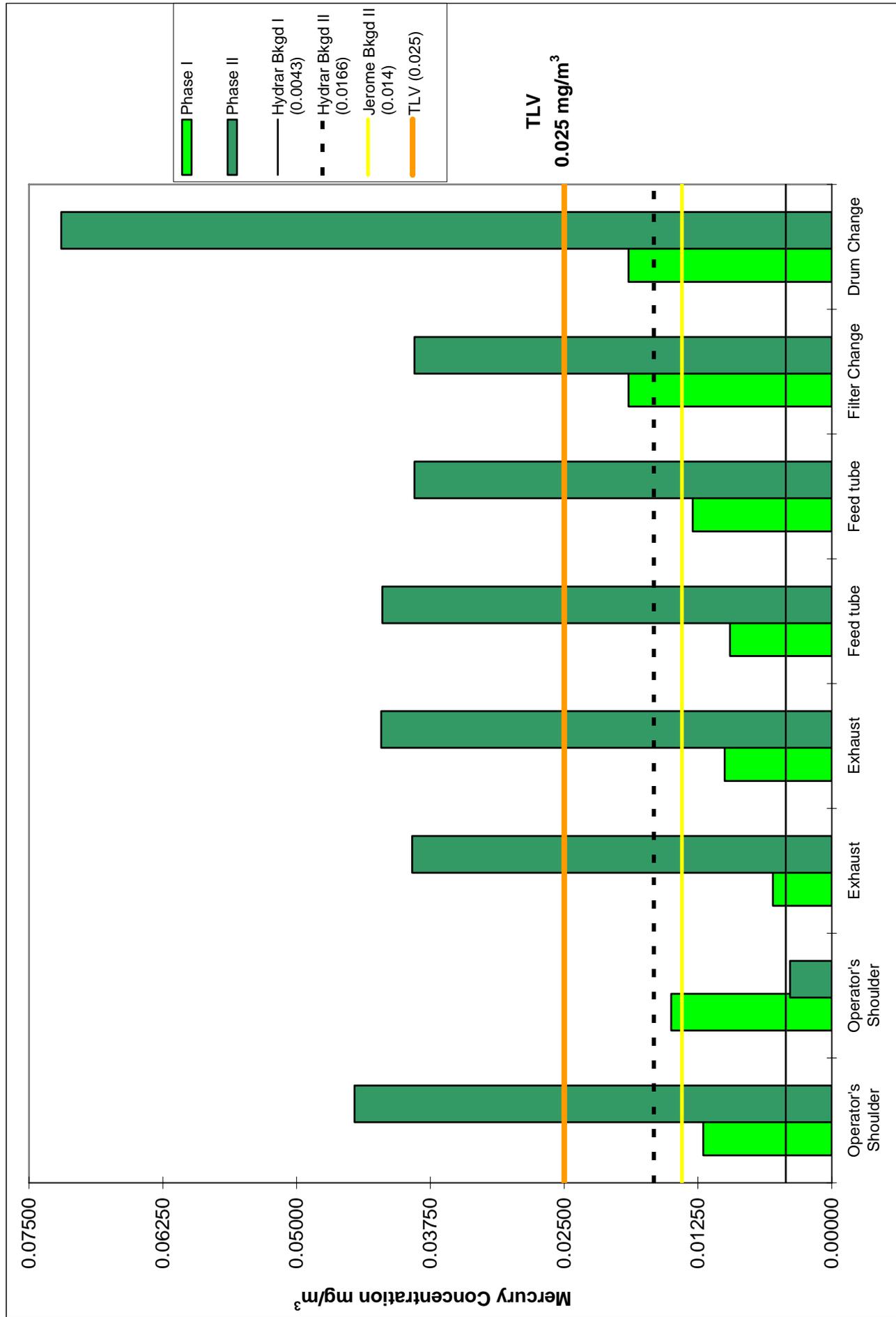
The TLV is included on the graph as a point of reference. The results shown on this graph do not represent eight-hour, time-weighted averages.

**Figure 14: Performance Validation Study – Phase I and Phase II Analytical Air Results
Manufacturer B Device**



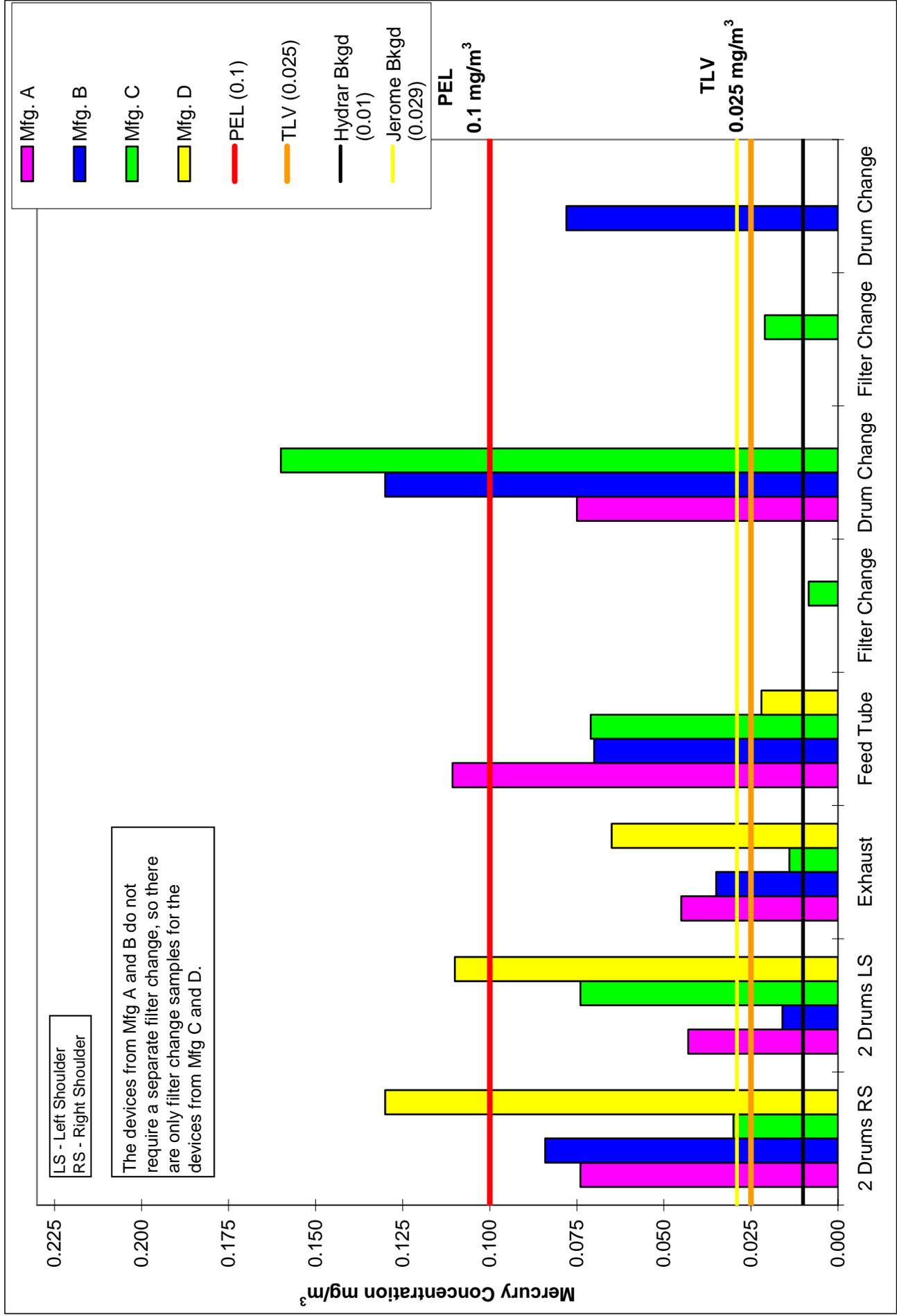
The TLV is included on the graph as a point of reference. The results shown on this graph do not represent eight-hour, time-weighted averages.

**Figure 15: Performance Validation Study – Phase I and Phase II Analytical Air Results
Manufacturer C Device**



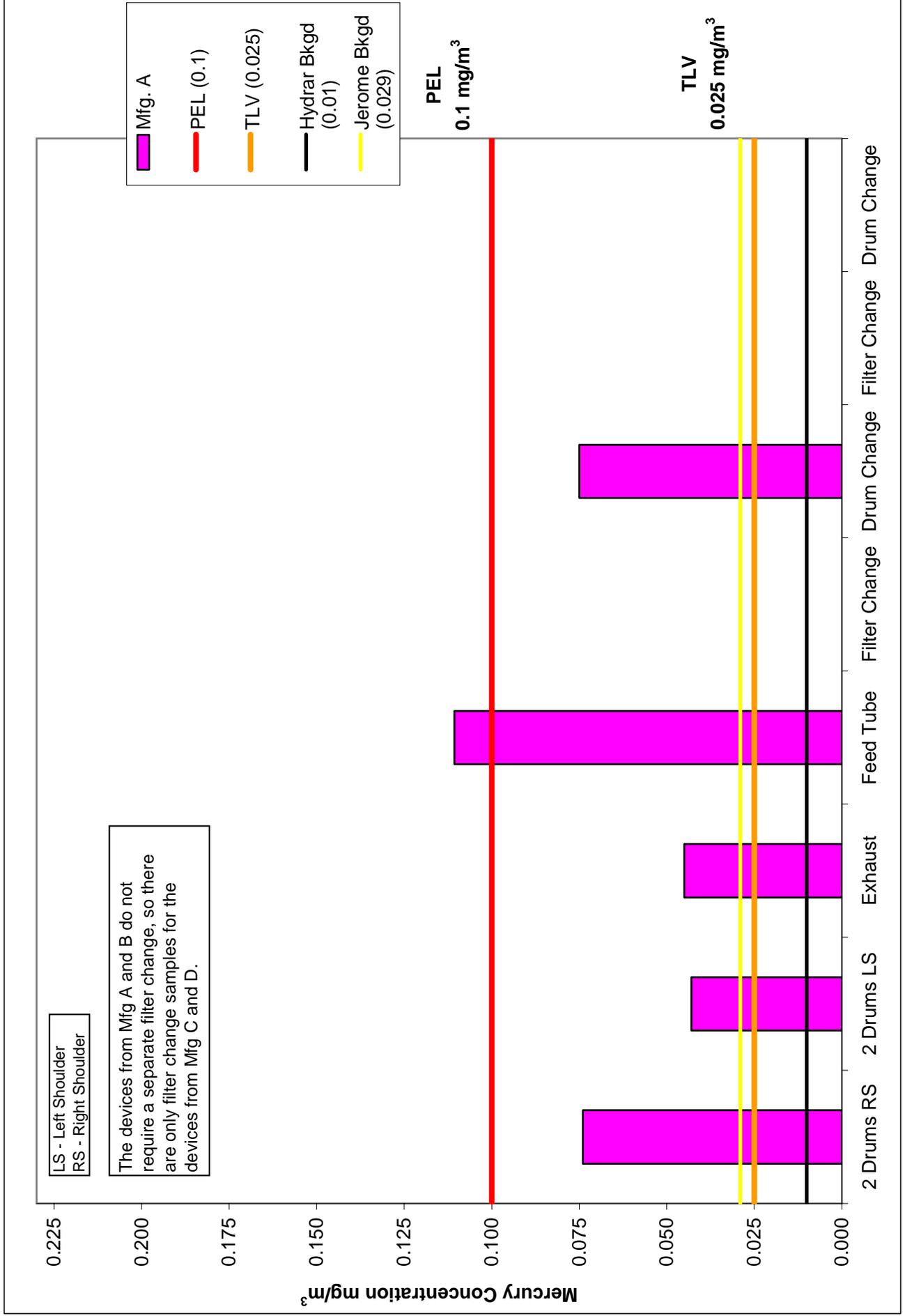
The TLV is included on the graph as a point of reference. The results shown on this graph do not represent eight-hour, time-weighted averages.

**Figure 16: Extended Field Test #1 Analytical Air Results
All Devices – Phoenix, Arizona – March 24-28, 2003**



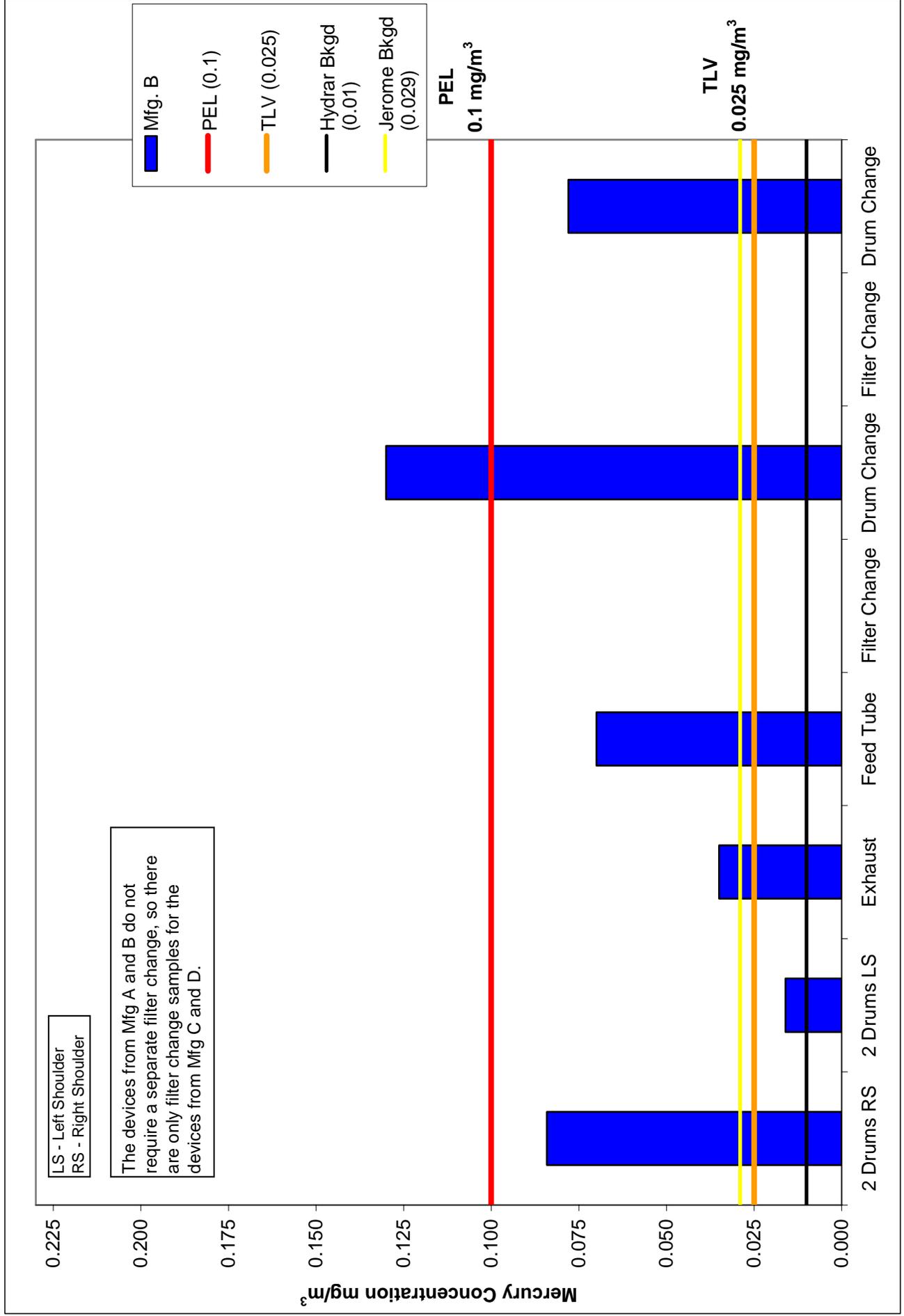
The TLV is included on the graph as a point of reference. The results shown on this graph do not represent eight-hour, time-weighted averages.

**Figure 17: Extended Field Test #1 Analytical Air Results
 Manufacturer A – Phoenix, Arizona – March 24-28, 2003**



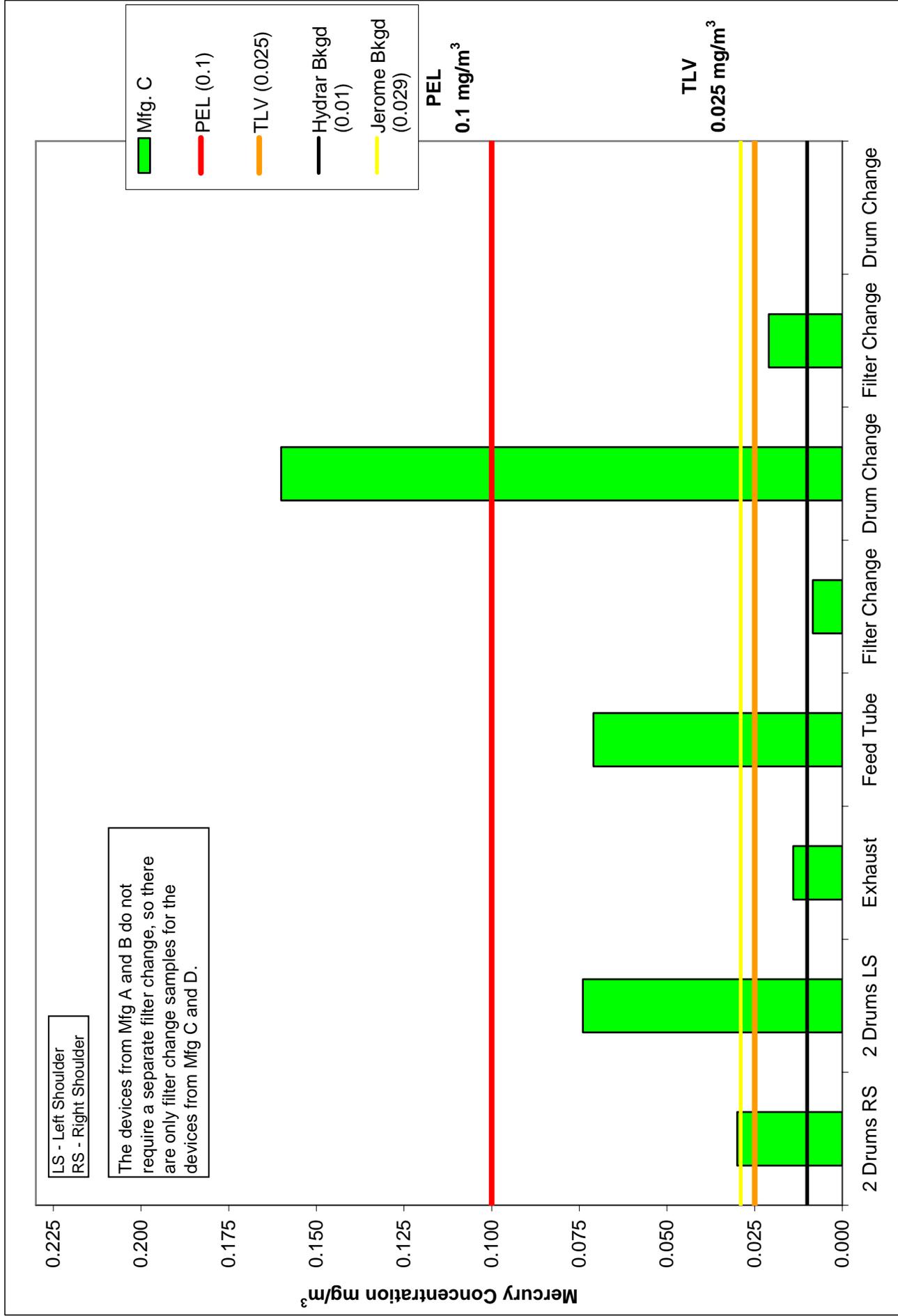
The TLV is included on the graph as a point of reference. The results shown on this graph do not represent eight-hour, time-weighted averages.

**Figure 18: Extended Field Test #1 Analytical Air Results
 Manufacturer B – Phoenix, Arizona – March 24-28, 2003**



The TLV is included on the graph as a point of reference. The results shown on this graph do not represent eight-hour, time-weighted averages.

**Figure 19: Extended Field Test #1 Analytical Air Results
 Manufacturer C – Phoenix, Arizona – March 24-28, 2003**

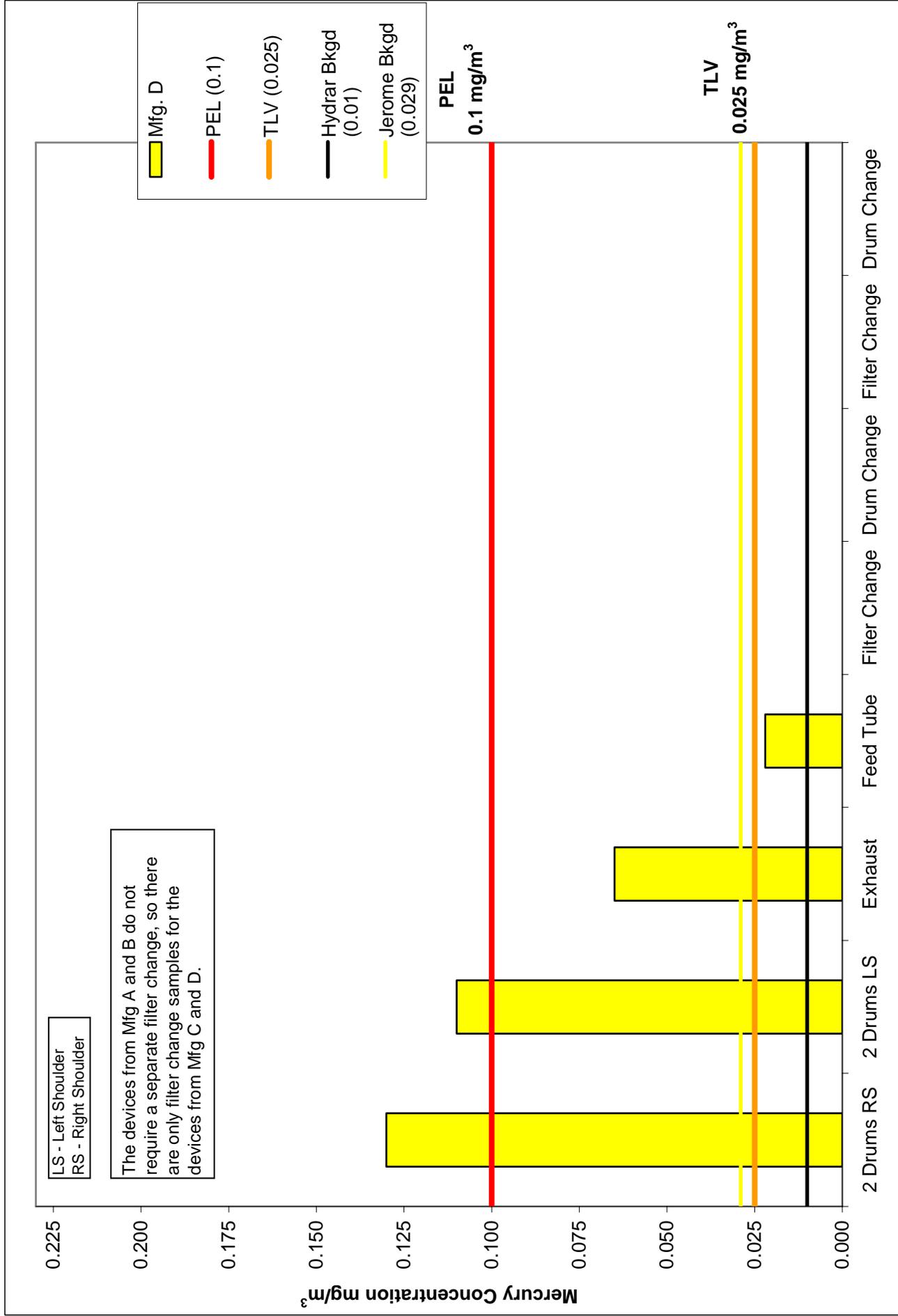


LS - Left Shoulder
 RS - Right Shoulder

The devices from Mfg A and B do not require a separate filter change, so there are only filter change samples for the devices from Mfg C and D.

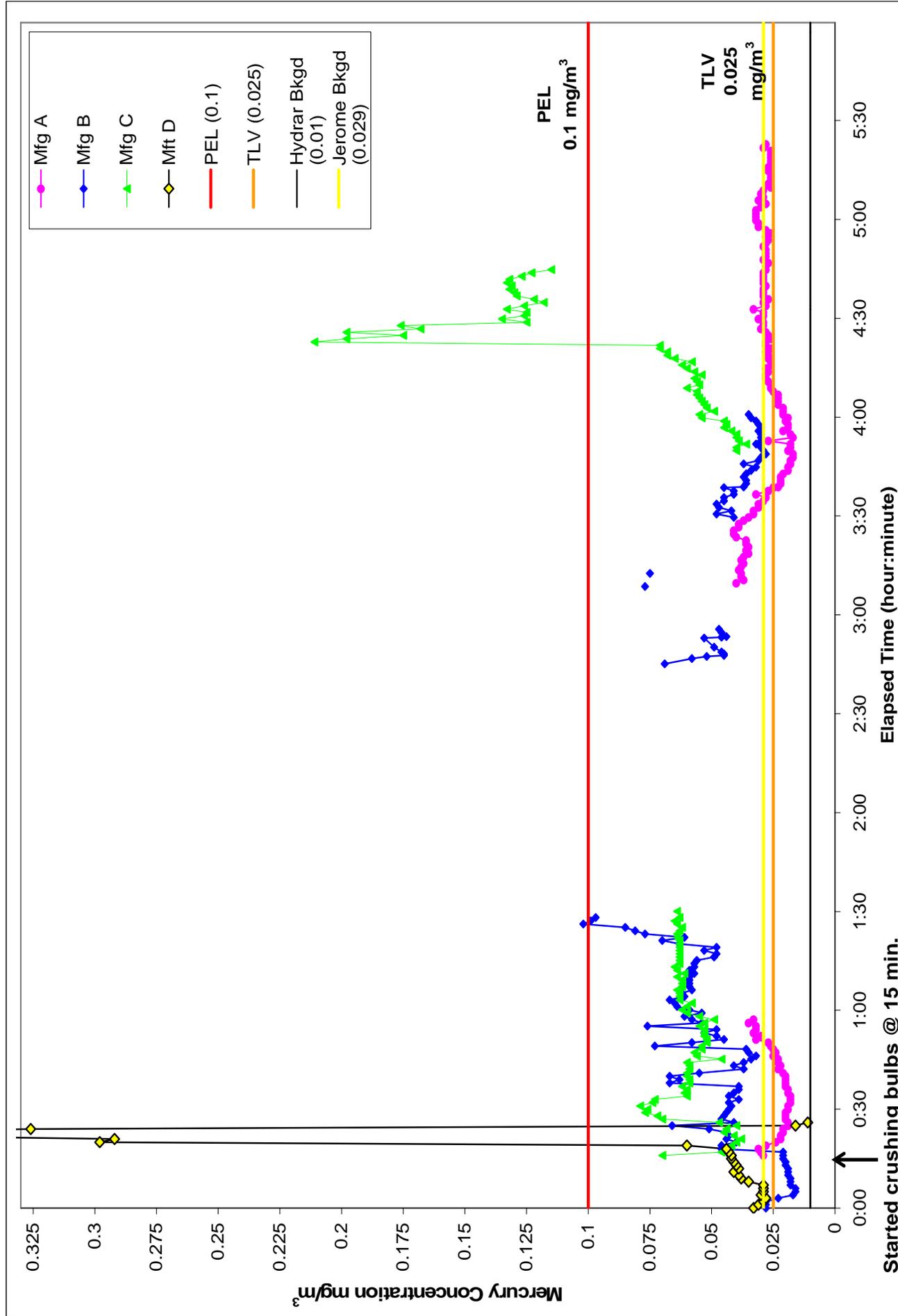
The TLV is included on the graph as a point of reference. The results shown on this graph do not represent eight-hour, time-weighted averages.

**Figure 20: Extended Field Test #1 Analytical Air Results
 Manufacturer D – Phoenix, Arizona – March 24-28, 2003**



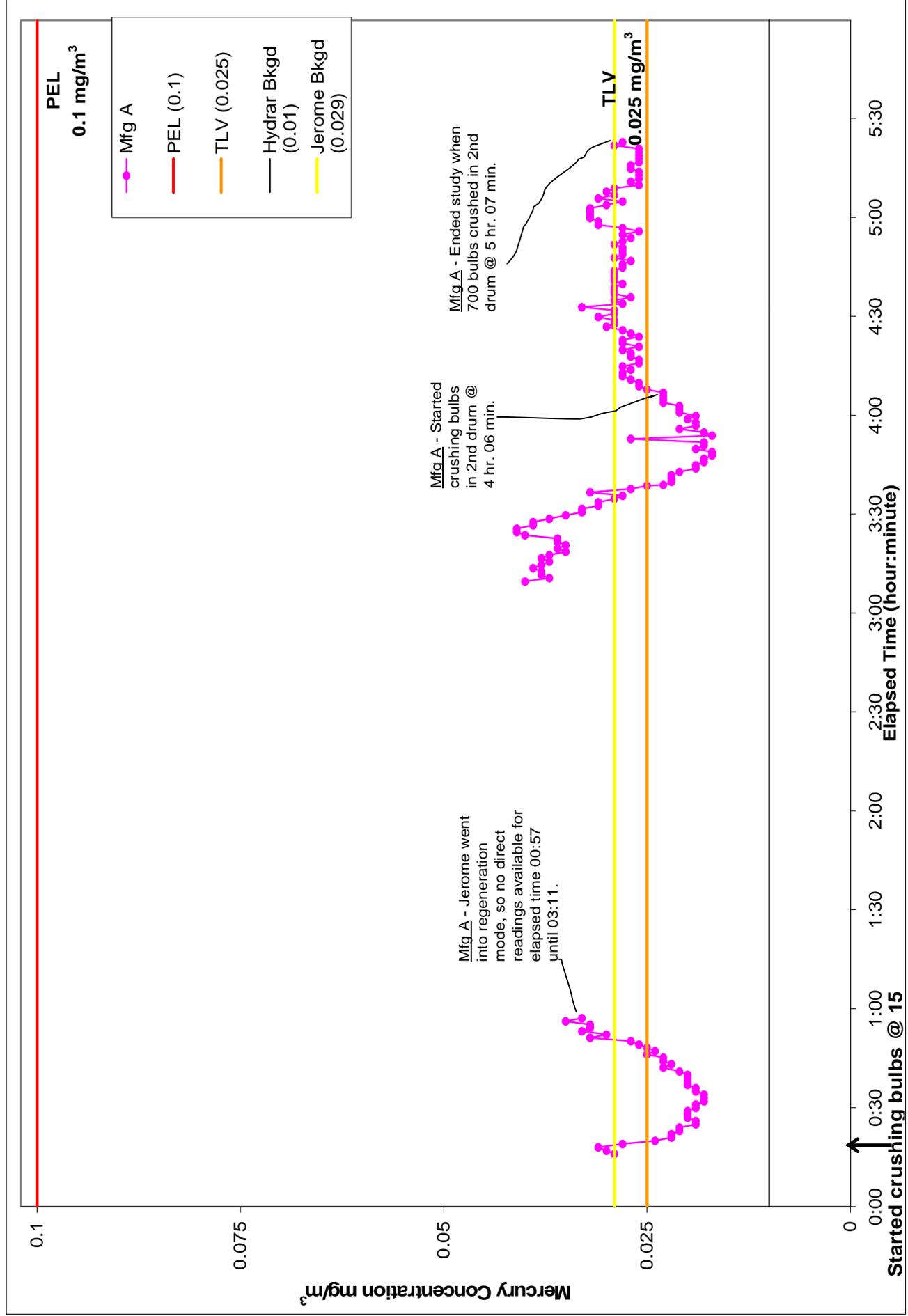
The TLV is included on the graph as a point of reference. The results shown on this graph do not represent eight-hour, time-weighted averages.

**Figure 21: Extended Field Test #1 Jerome Results
All Devices – Phoenix, Arizona – March 24-28, 2003**



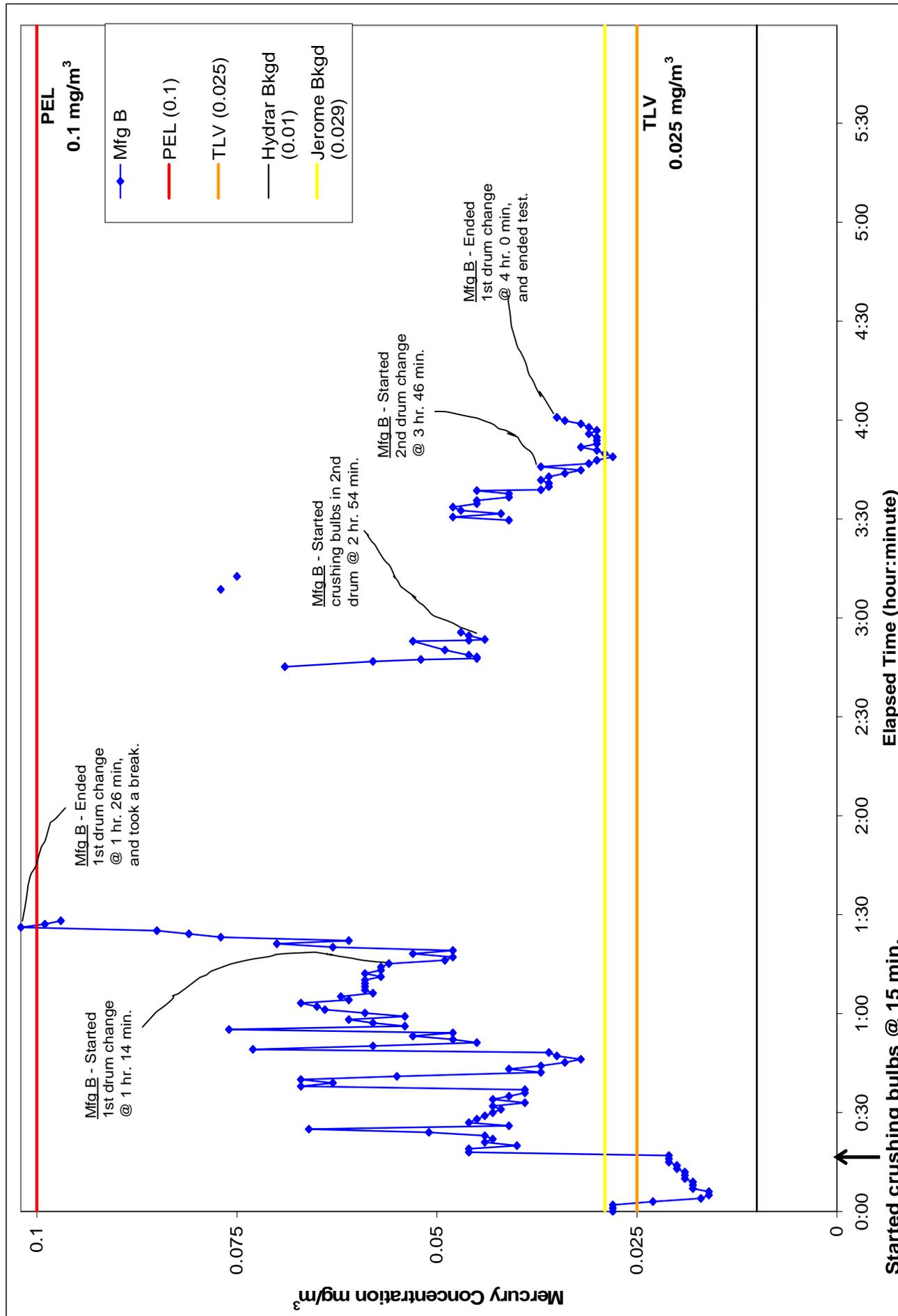
The TLV is included on the graph as a point of reference. The results shown on this graph do not represent eight-hour, time-weighted averages.

**Figure 22: Extended Field Test #1 Jerome Results
Manufacturer A – Phoenix, Arizona – March 24-28, 2003**



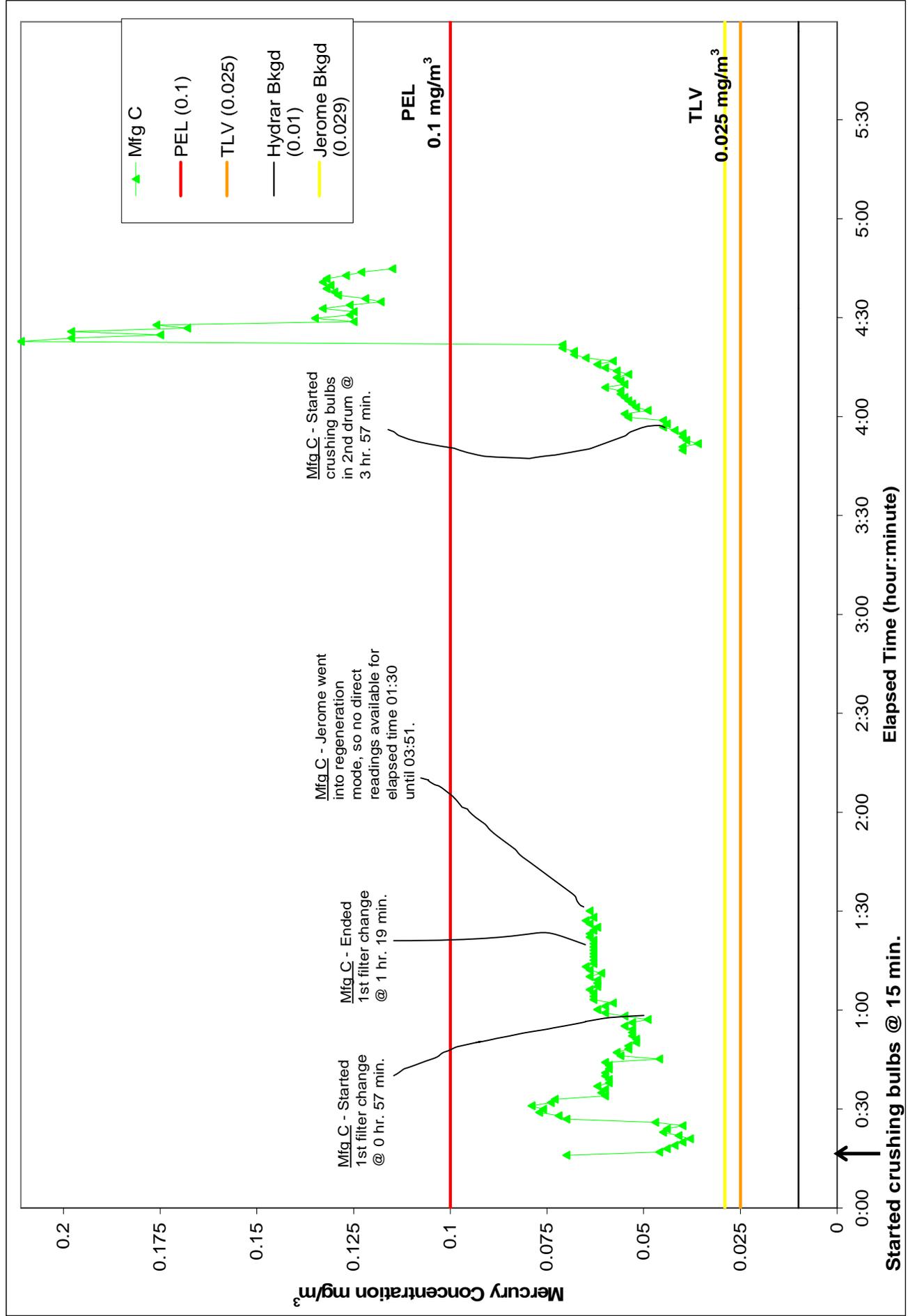
The TLV is included on the graph as a point of reference. The results shown on this graph do not represent eight-hour, time-weighted averages.

**Figure 23: Extended Field Test #1 Jerome Results
Manufacturer B – Phoenix, Arizona – March 24-28, 2003**



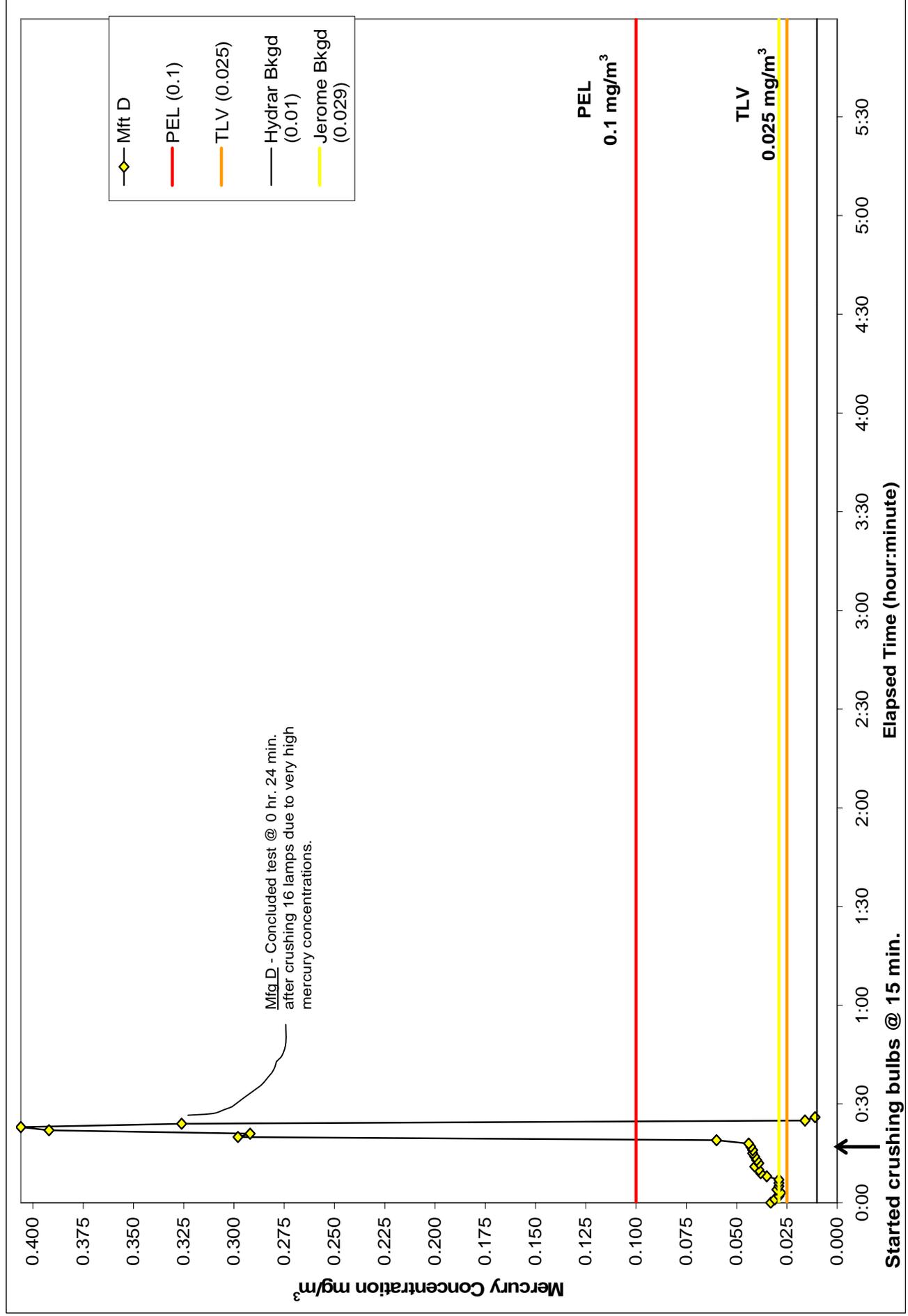
The TLV is included on the graph as a point of reference. The results shown on this graph do not represent eight-hour, time-weighted averages.

**Figure 24: Extended Field Test #1 Jerome Results
Manufacturer C – Phoenix, Arizona – March 24-28, 2003**



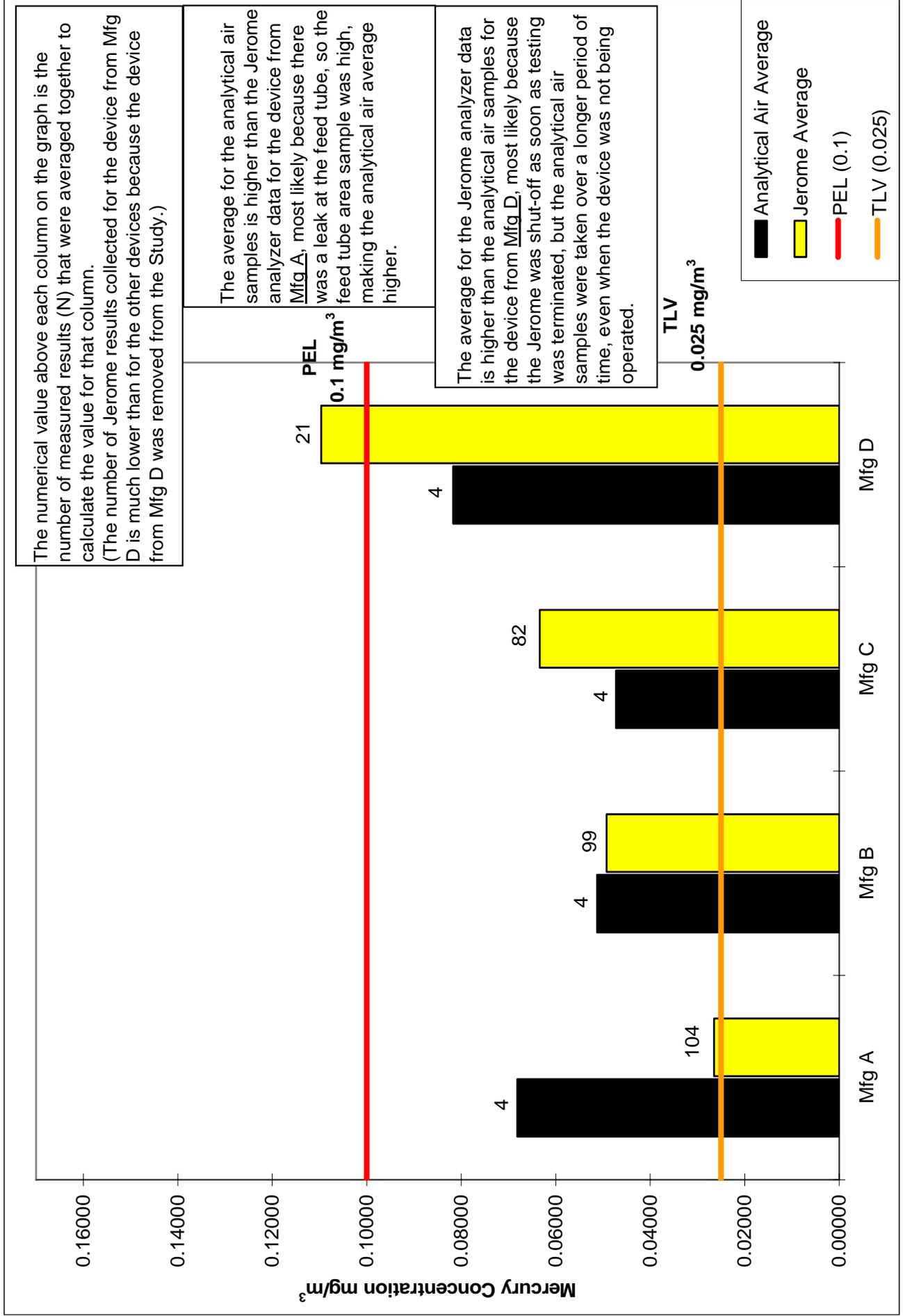
The TLV is included on the graph as a point of reference. The results shown on this graph do not represent eight-hour, time-weighted averages.

**Figure 25: Extended Field Test #1 Jerome Results
Manufacturer D – Phoenix, Arizona – March 24-28, 2003**



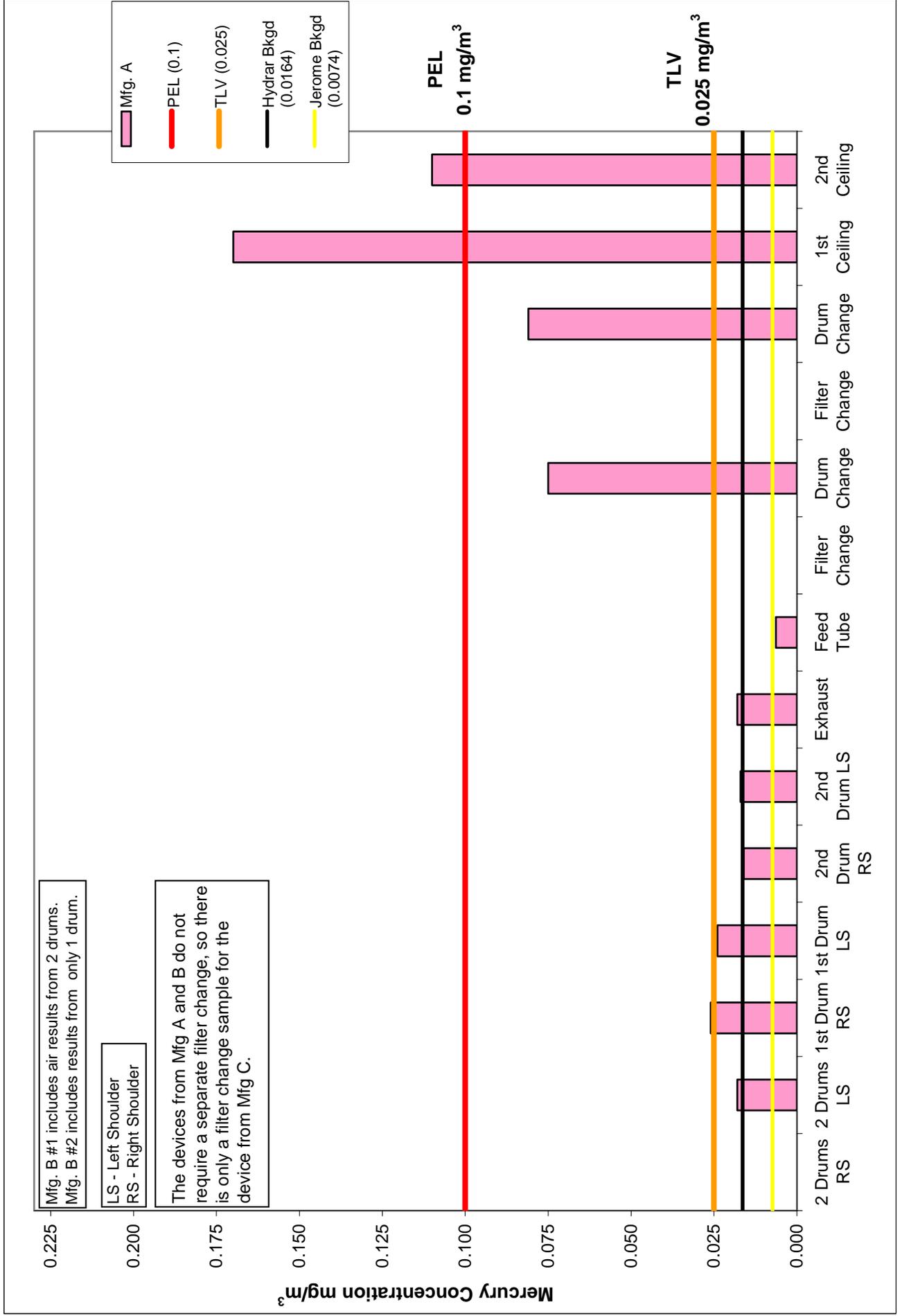
The TLV is included on the graph as a point of reference. The results shown on this graph do not represent eight-hour, time-weighted averages.

**Figure 26: Extended Field Test #1 – Comparison of Analytical Air and Jerome Results
All Devices – Phoenix, Arizona – March 24-28, 2003**



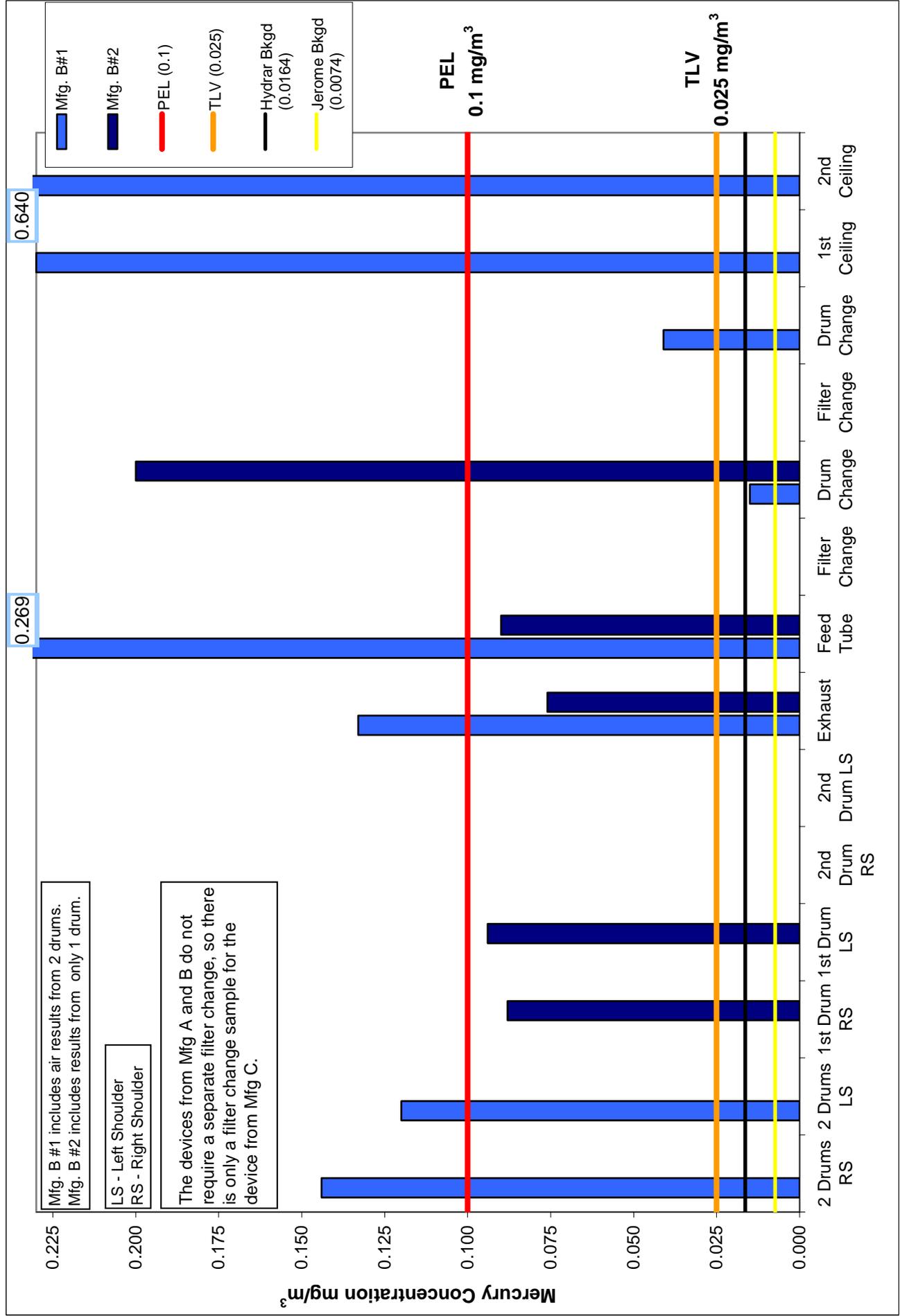
The TLV is included on the graph as a point of reference. The results shown on this graph do not represent eight-hour, time-weighted averages.

**Figure 28: Extended Field Test #2 Analytical Air Results
 Manufacturer A – Melbourne, Florida – April 28-May 2, 2003**



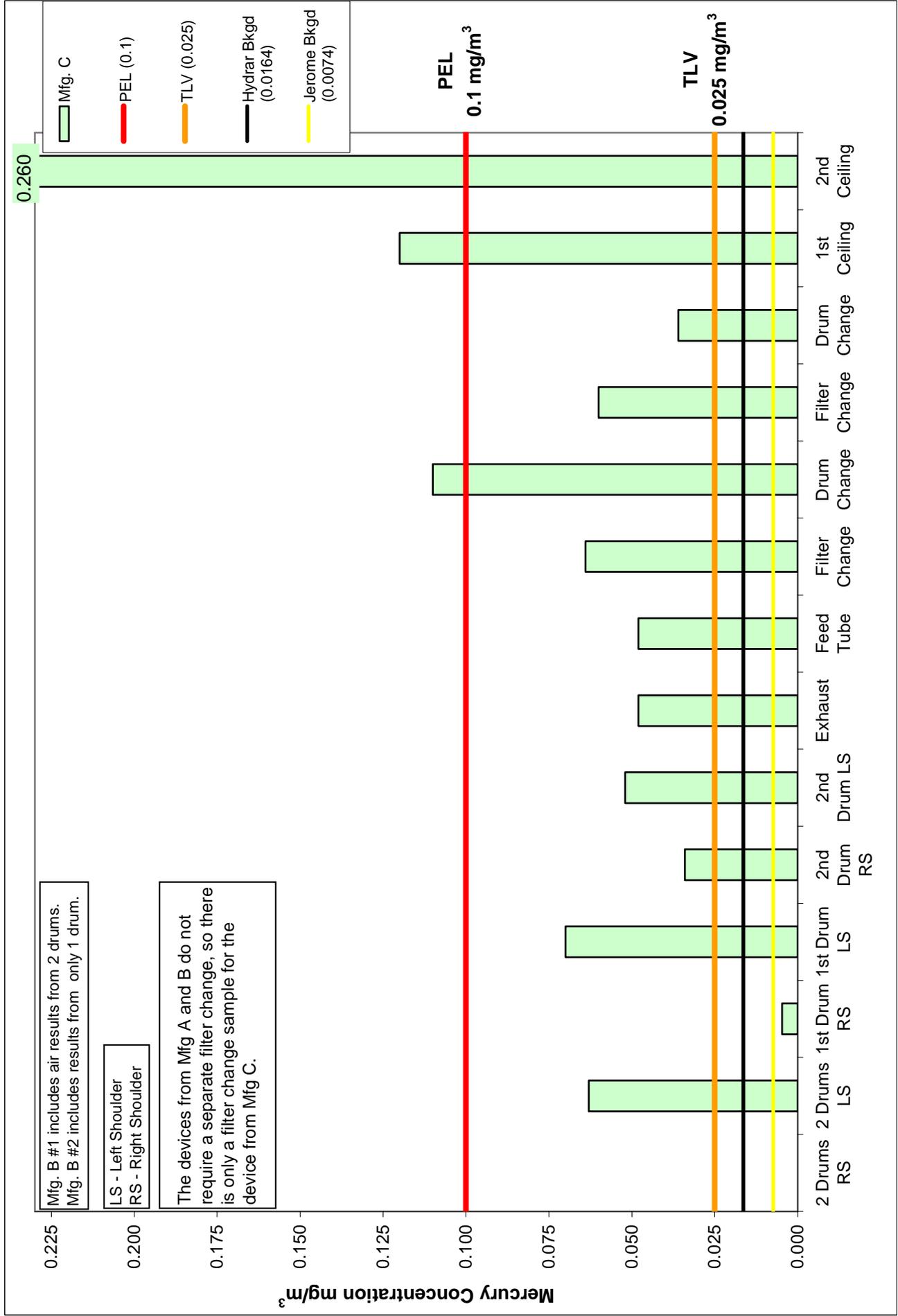
The TLV is included on the graph as a point of reference. The results shown on this graph do not represent eight-hour, time-weighted averages.

**Figure 29: Extended Field Test #2 Analytical Air Results
 Manufacturer B – Melbourne, Florida – April 28-May 2, 2003**



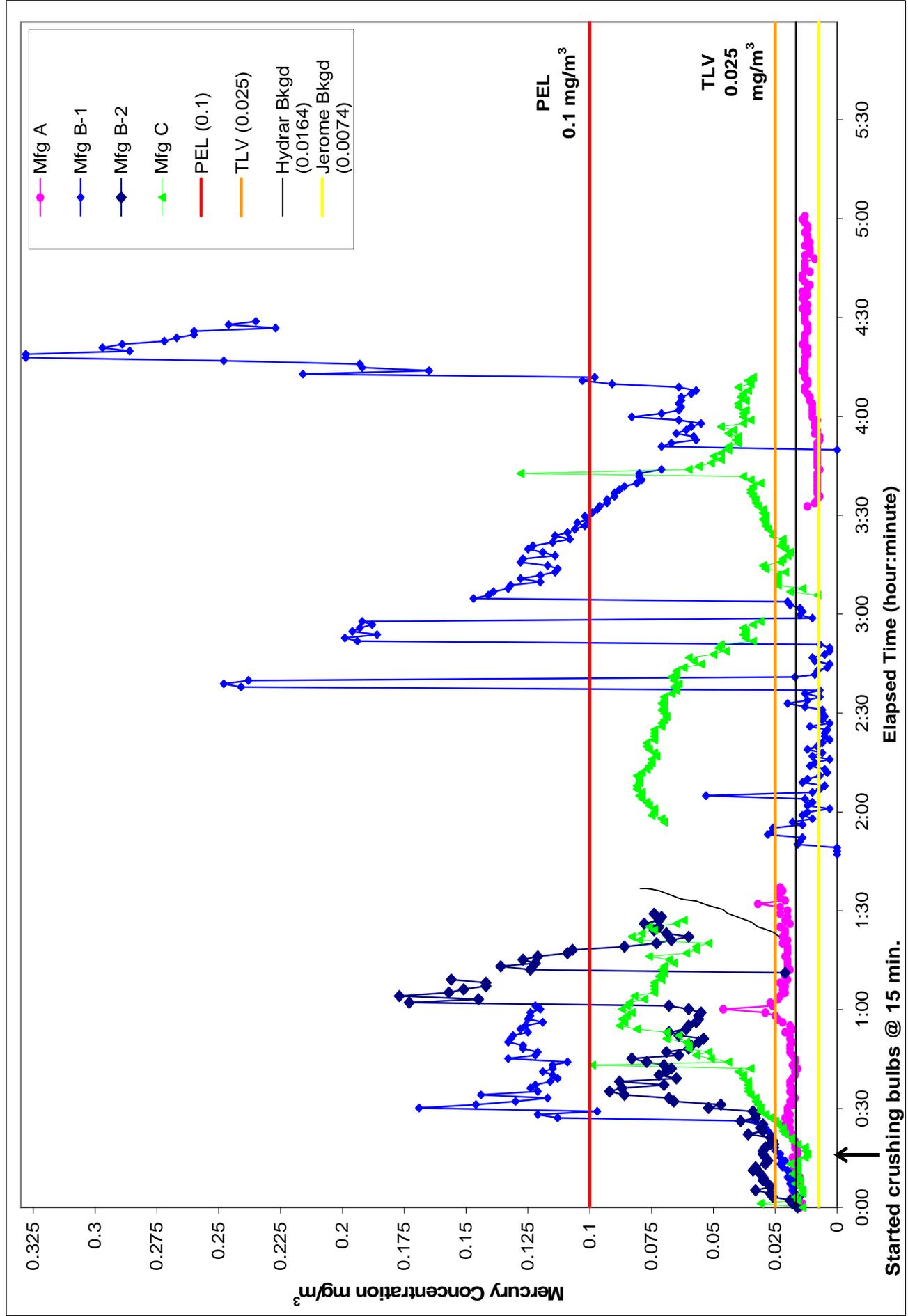
The TLV is included on the graph as a point of reference. The results shown on this graph do not represent eight-hour, time-weighted averages.

**Figure 30: Extended Field Test #2 Analytical Air Results
 Manufacturer C – Melbourne, Florida – April 28-May 2, 2003**



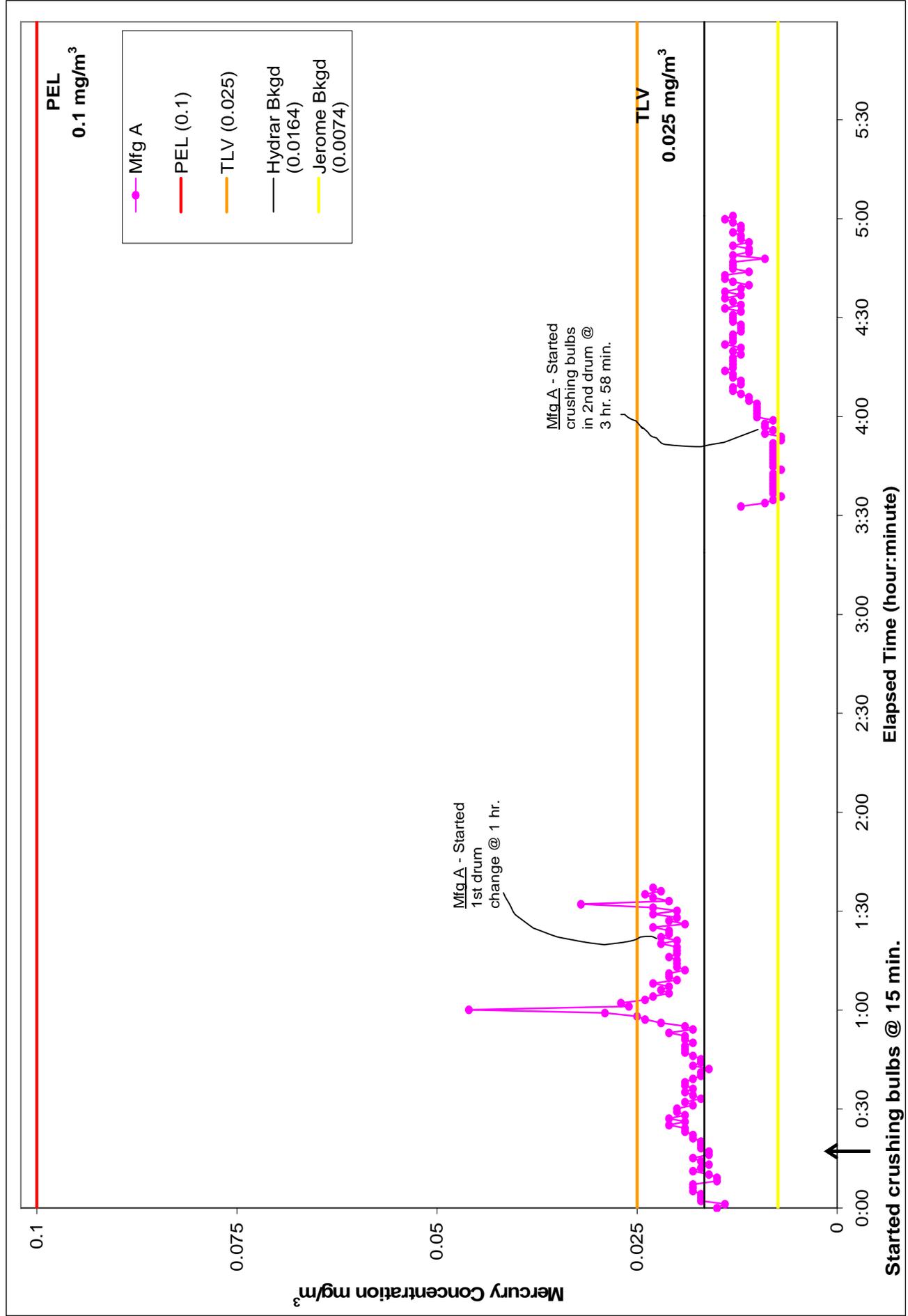
The TLV is included on the graph as a point of reference. The results shown on this graph do not represent eight-hour, time-weighted averages.

**Figure 31: Extended Field Test #2 Jerome Results
All Devices – Melbourne, Florida – April 28-May 2, 2003**



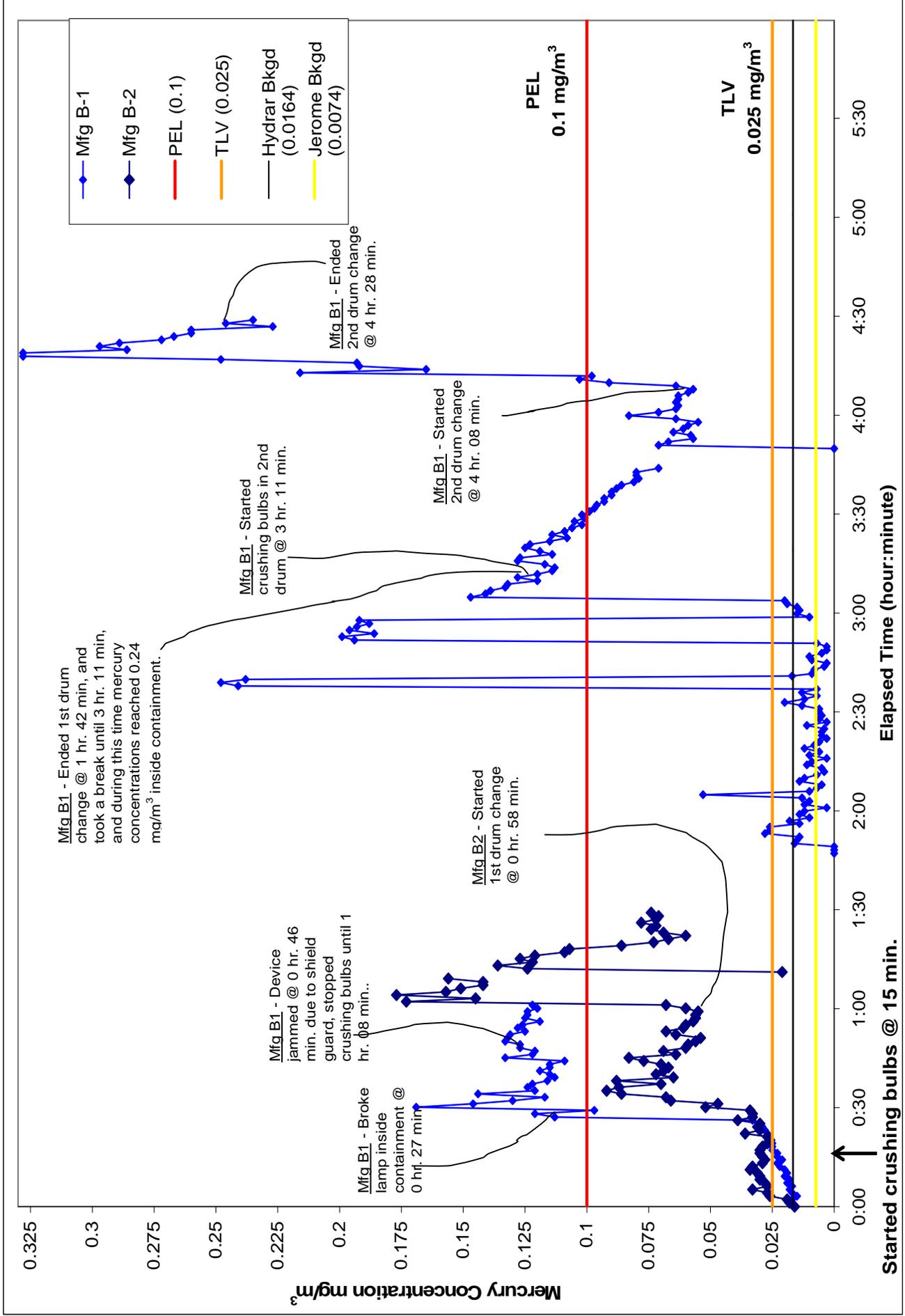
The TLV is included on the graph as a point of reference. The results shown on this graph do not represent eight-hour, time-weighted averages.

**Figure 32: Extended Field Test #2 Jerome Results
 Manufacturer A – Melbourne, Florida – April 28-May 2, 2003**



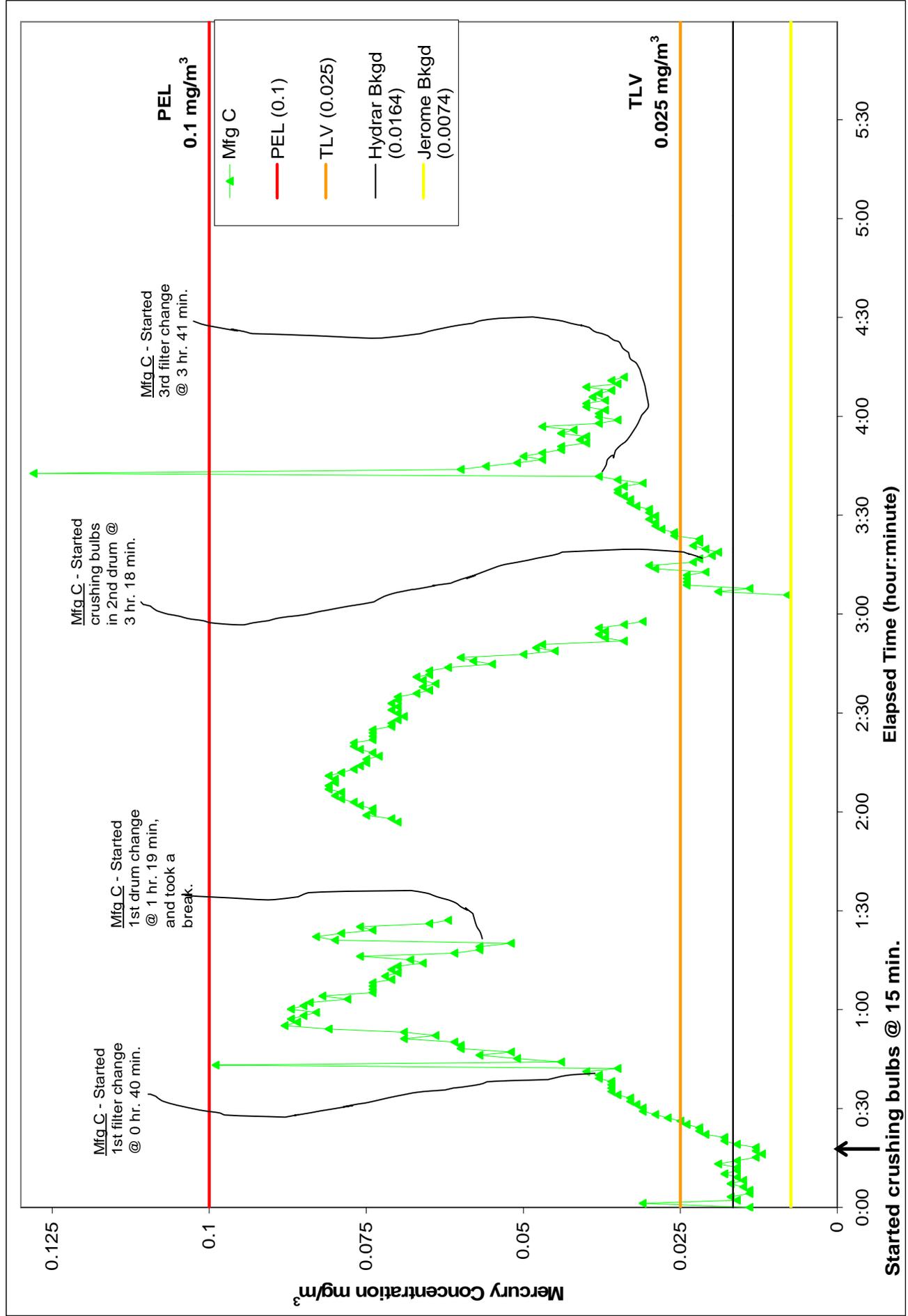
The TLV is included on the graph as a point of reference. The results shown on this graph do not represent eight-hour, time-weighted averages.

**Figure 33: Extended Field Test #2 Jerome Results
 Manufacturer B – Melbourne, Florida – April 28-May 2, 2003**



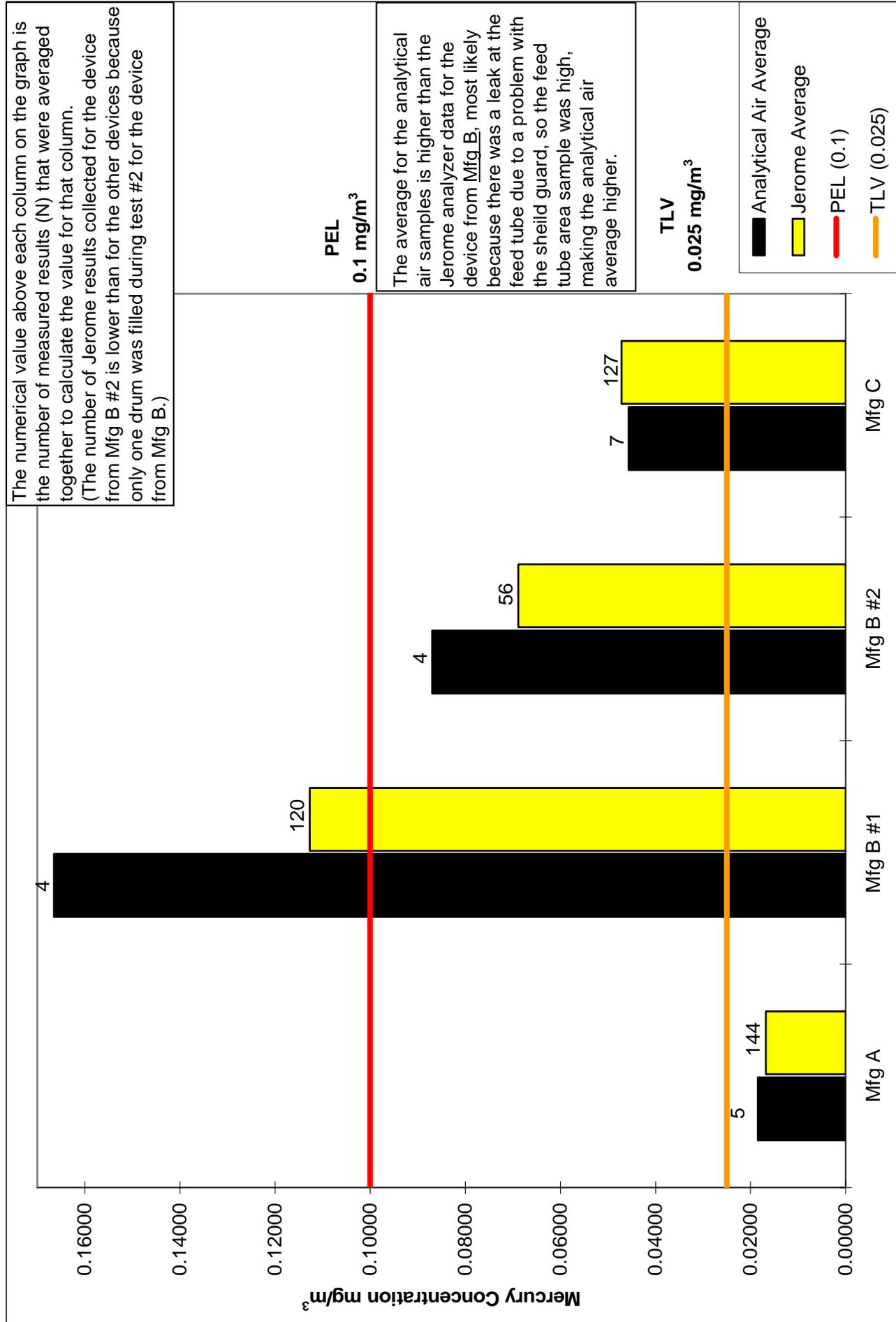
The TLV is included on the graph as a point of reference. The results shown on this graph do not represent eight-hour, time-weighted averages.

**Figure 34: Extended Field Test #2 Jerome Results
 Manufacturer C – Melbourne, Florida – April 28-May 2, 2003**



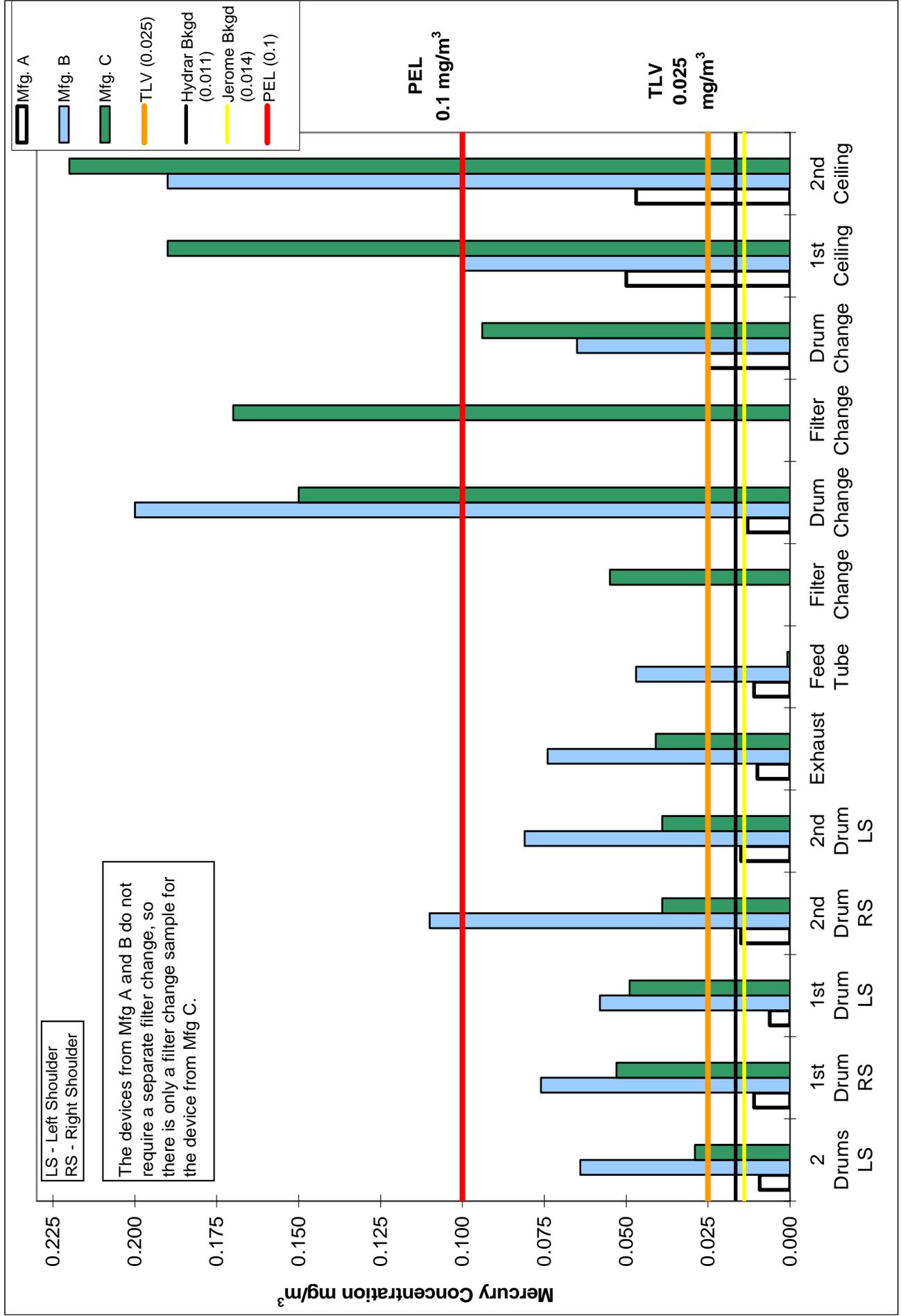
The TLV is included on the graph as a point of reference. The results shown on this graph do not represent eight-hour, time-weighted averages.

**Figure 35: Extended Field Test #2 – Comparison of Analytical Air and Jerome Results
All Devices – Melbourne, Florida – April 28-May 2, 2003**



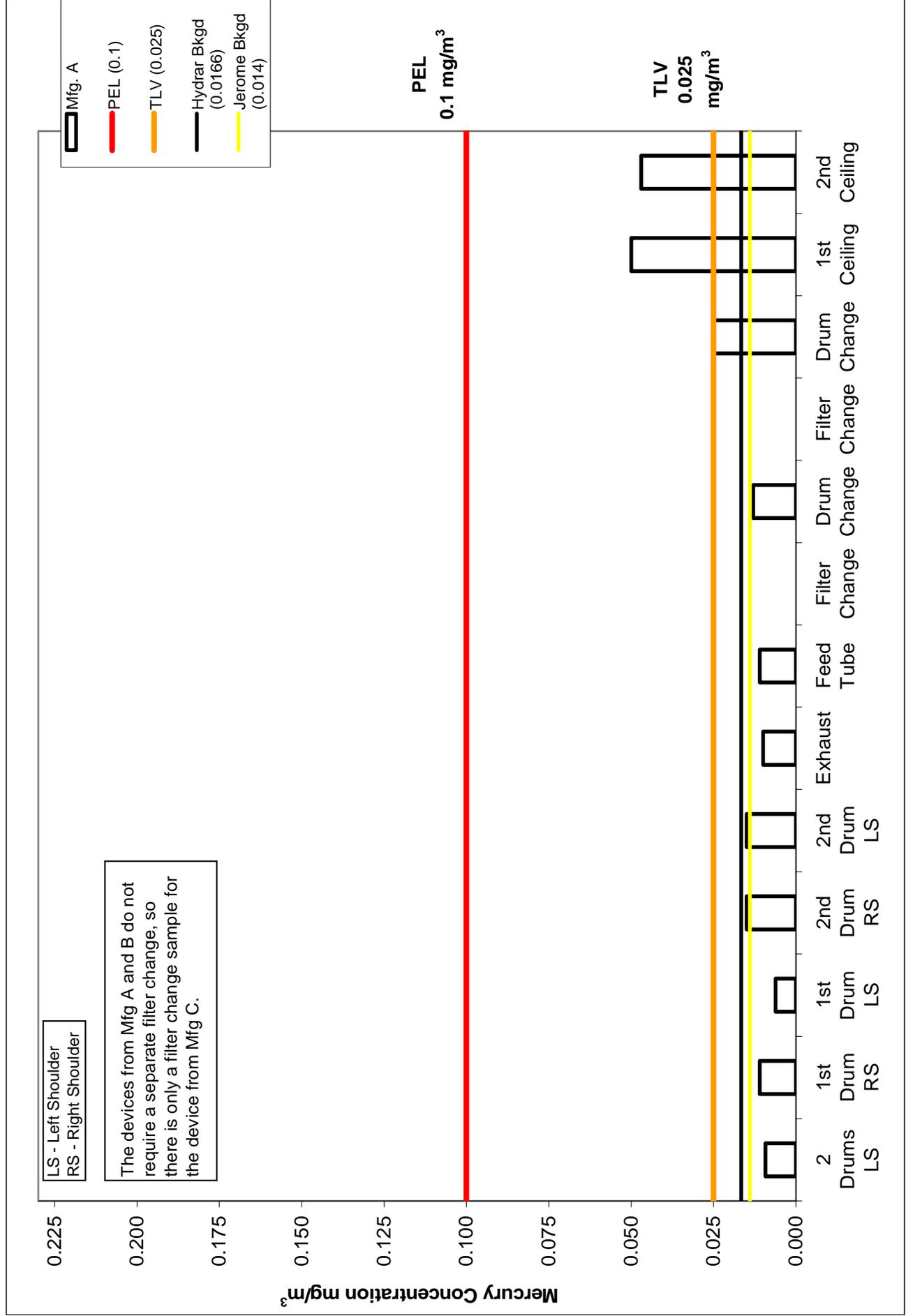
The TLV is included on the graph as a point of reference. The results shown on this graph do not represent eight-hour, time-weighted averages.

**Figure 36: Extended Field Test #3 Analytical Air Results
All Devices – Ashland, Virginia – June 9-13, 2003**



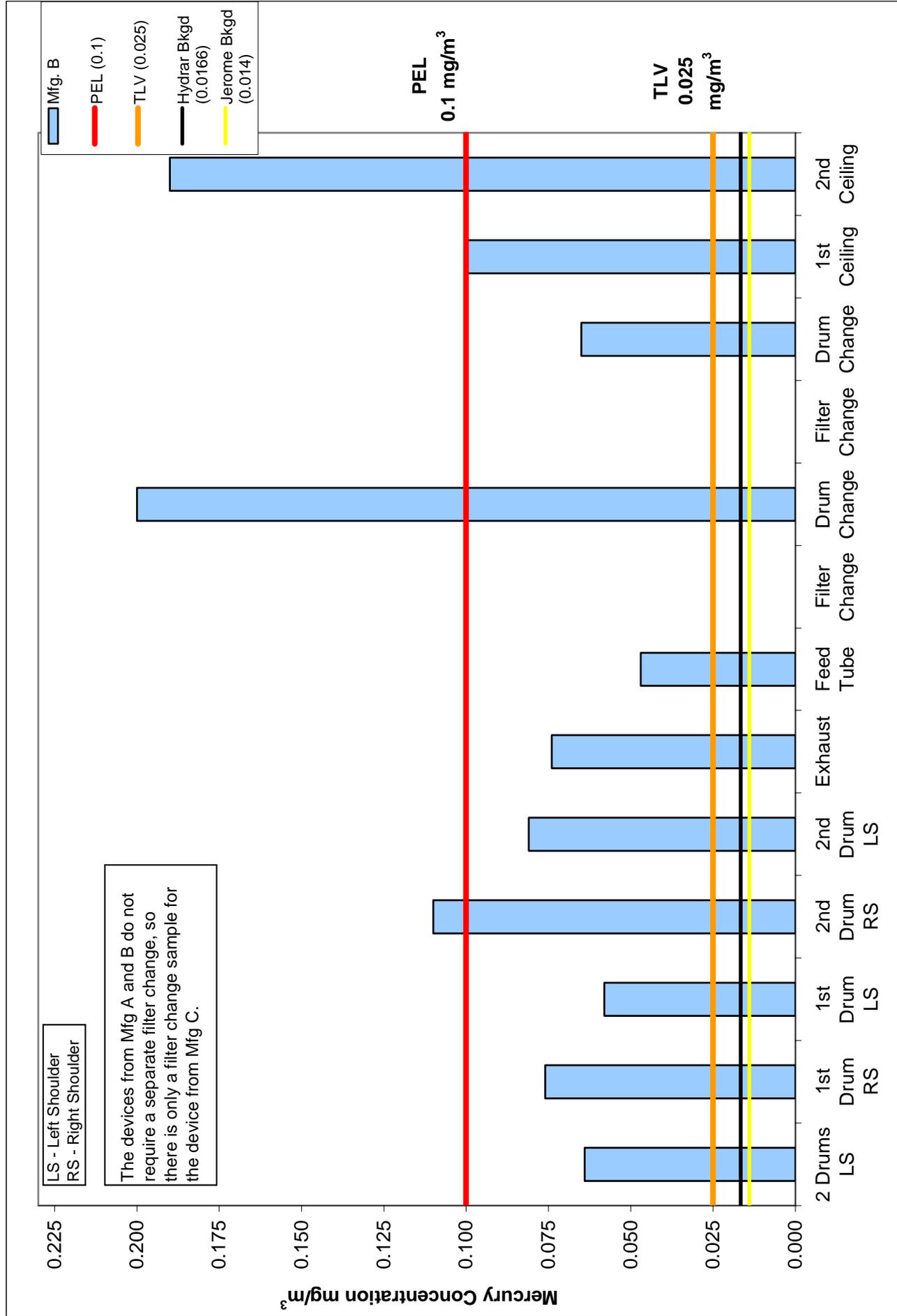
The TLV is included on the graph as a point of reference. The results shown on this graph do not represent eight-hour, time-weighted averages.

**Figure 37: Extended Field Test #3 Analytical Air Results
 Manufacturer A – Ashland, Virginia – June 9-13, 2003**



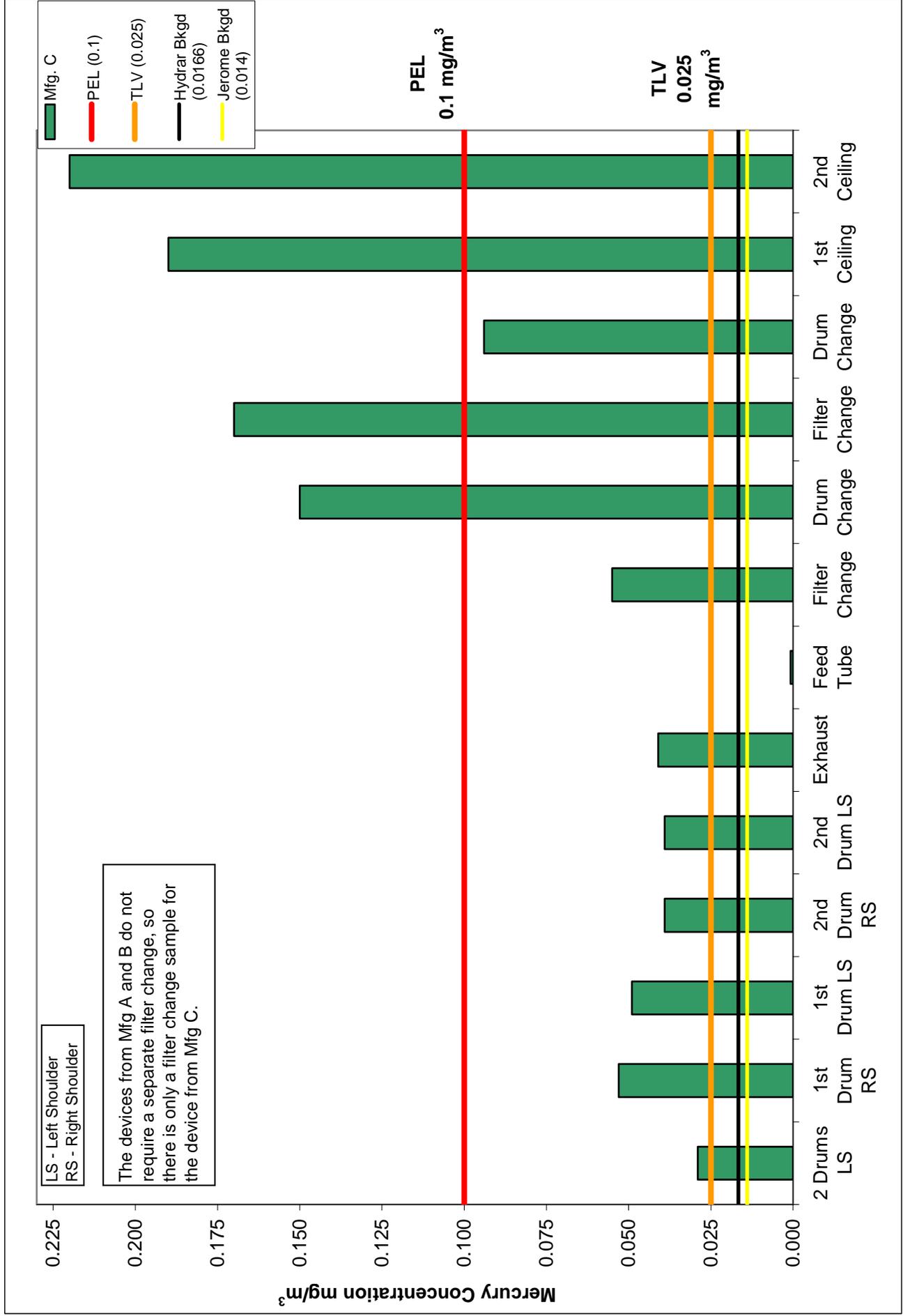
The TLV is included on the graph as a point of reference. The results shown on this graph do not represent eight-hour, time-weighted averages.

**Figure 38: Extended Field Test #3 Analytical Air Results
 Manufacturer B – Ashland, Virginia – June 9-13, 2003**



The TLV is included on the graph as a point of reference. The results shown on this graph do not represent eight-hour, time-weighted averages.

**Figure 39: Extended Field Test #3 Analytical Air Results
 Manufacturer C – Ashland, Virginia – June 9-13, 2003**

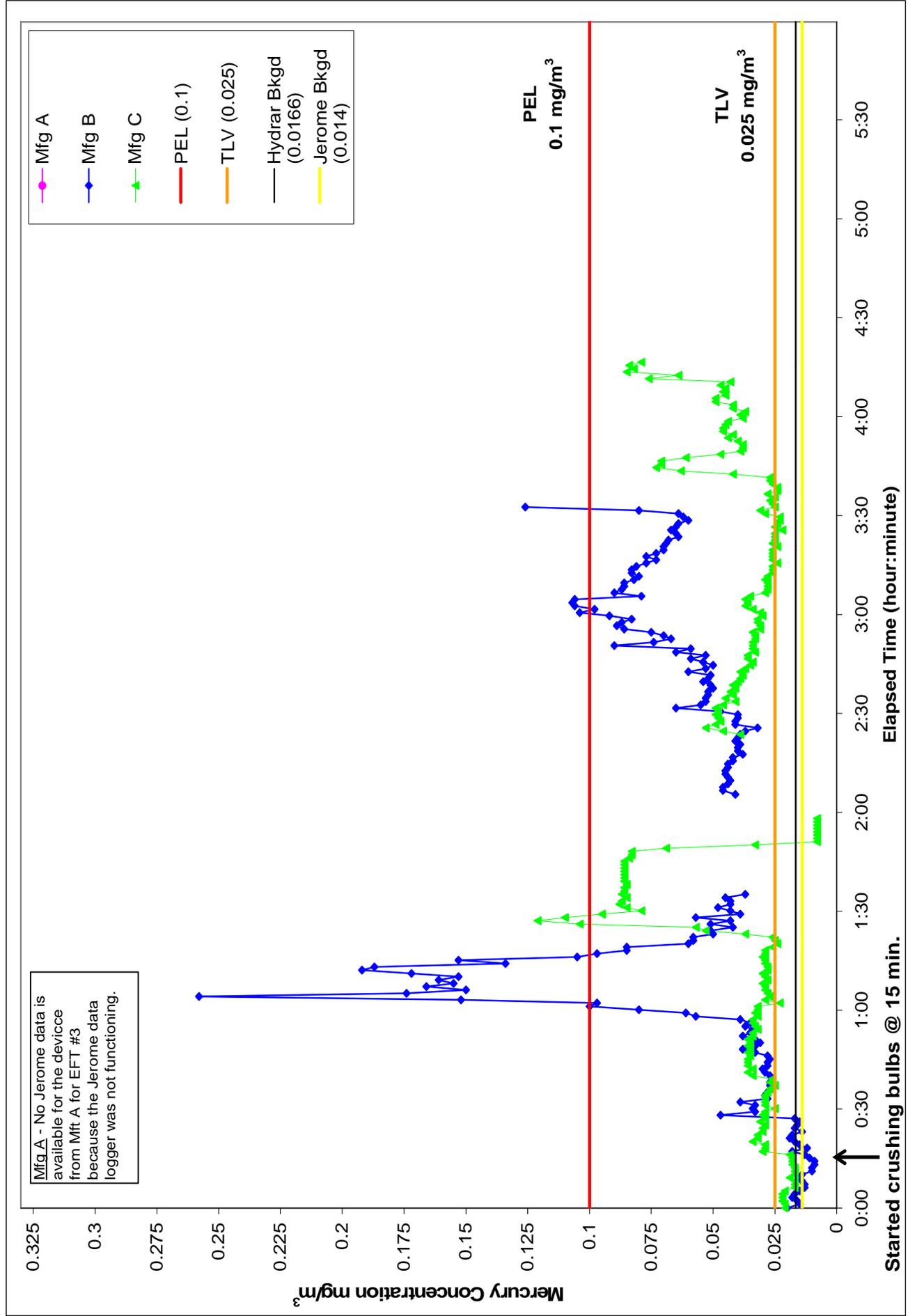


LS - Left Shoulder
 RS - Right Shoulder

The devices from Mfg A and B do not require a separate filter change, so there is only a filter change sample for the device from Mfg C.

The TLV is included on the graph as a point of reference. The results shown on this graph do not represent eight-hour, time-weighted averages.

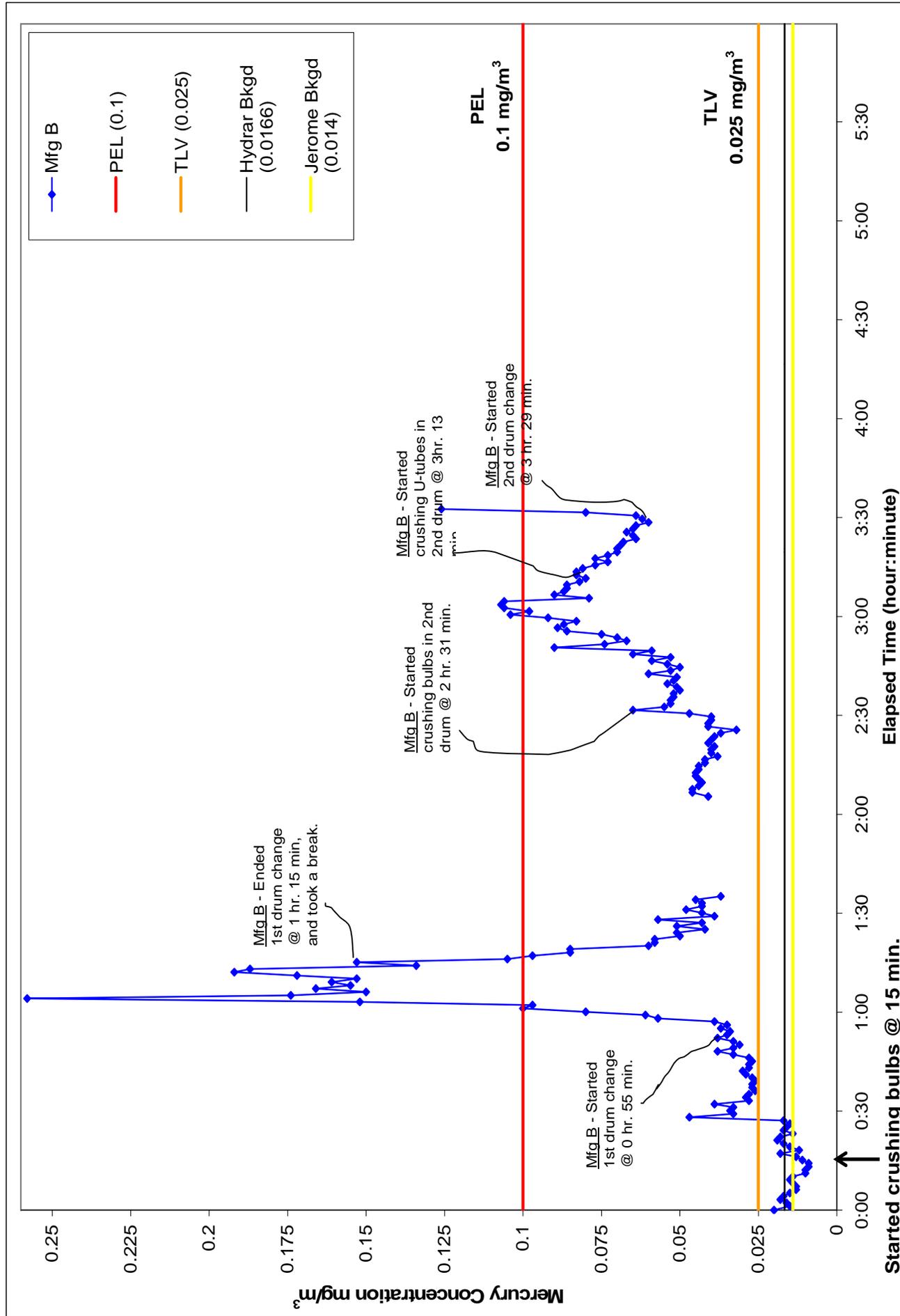
**Figure 40: Extended Field Test #3 Jerome Results
All Devices – Ashland, Virginia – June 9-13, 2003**



Mfg A - No Jerome data is available for the device from Mft A for EFT #3 because the Jerome data logger was not functioning.

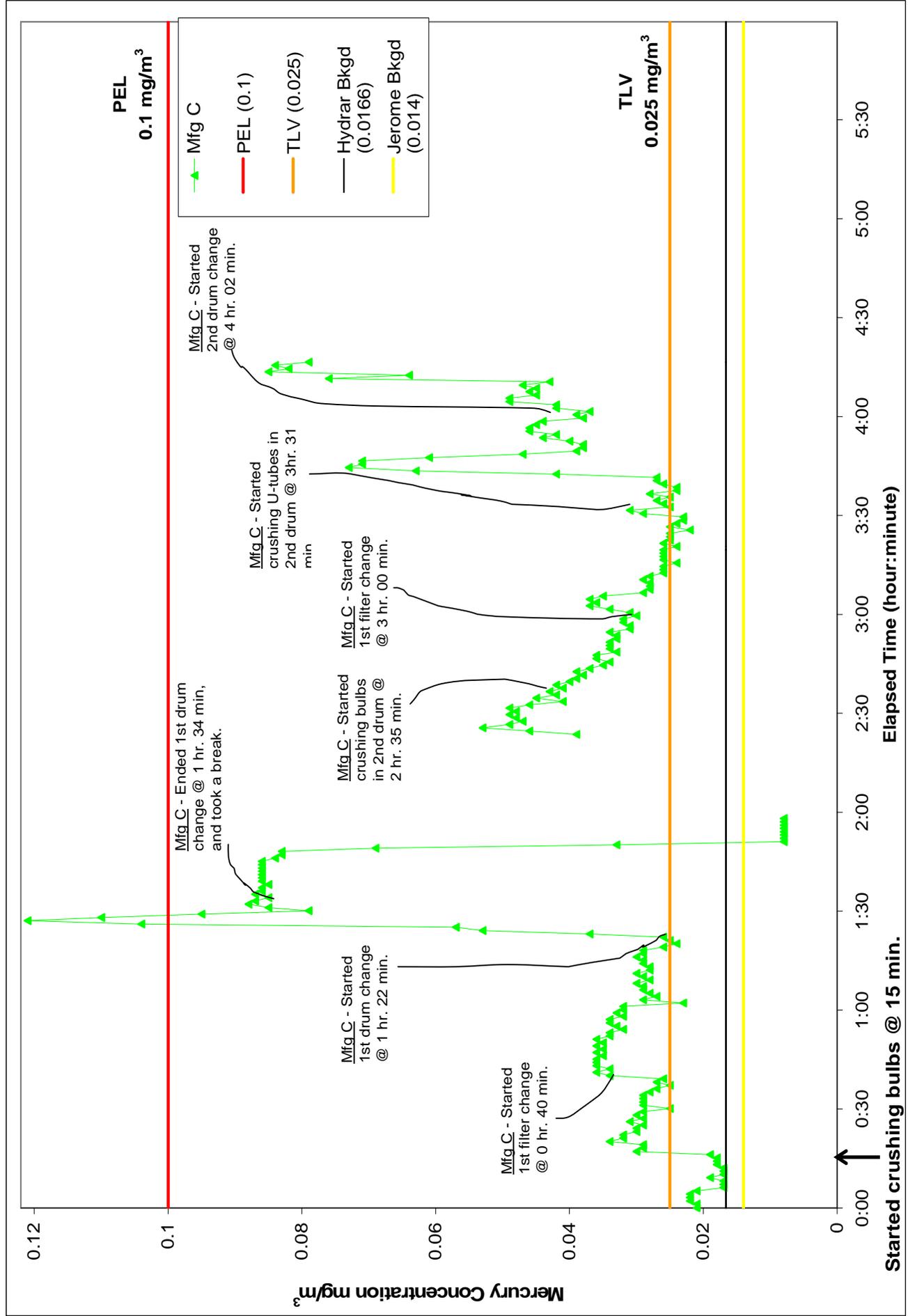
The TLV is included on the graph as a point of reference. The results shown on this graph do not represent eight-hour, time-weighted averages.

**Figure 41: Extended Field Test #3 Jerome Results
 Manufacturer B – Ashland, Virginia – June 9-13, 2003**



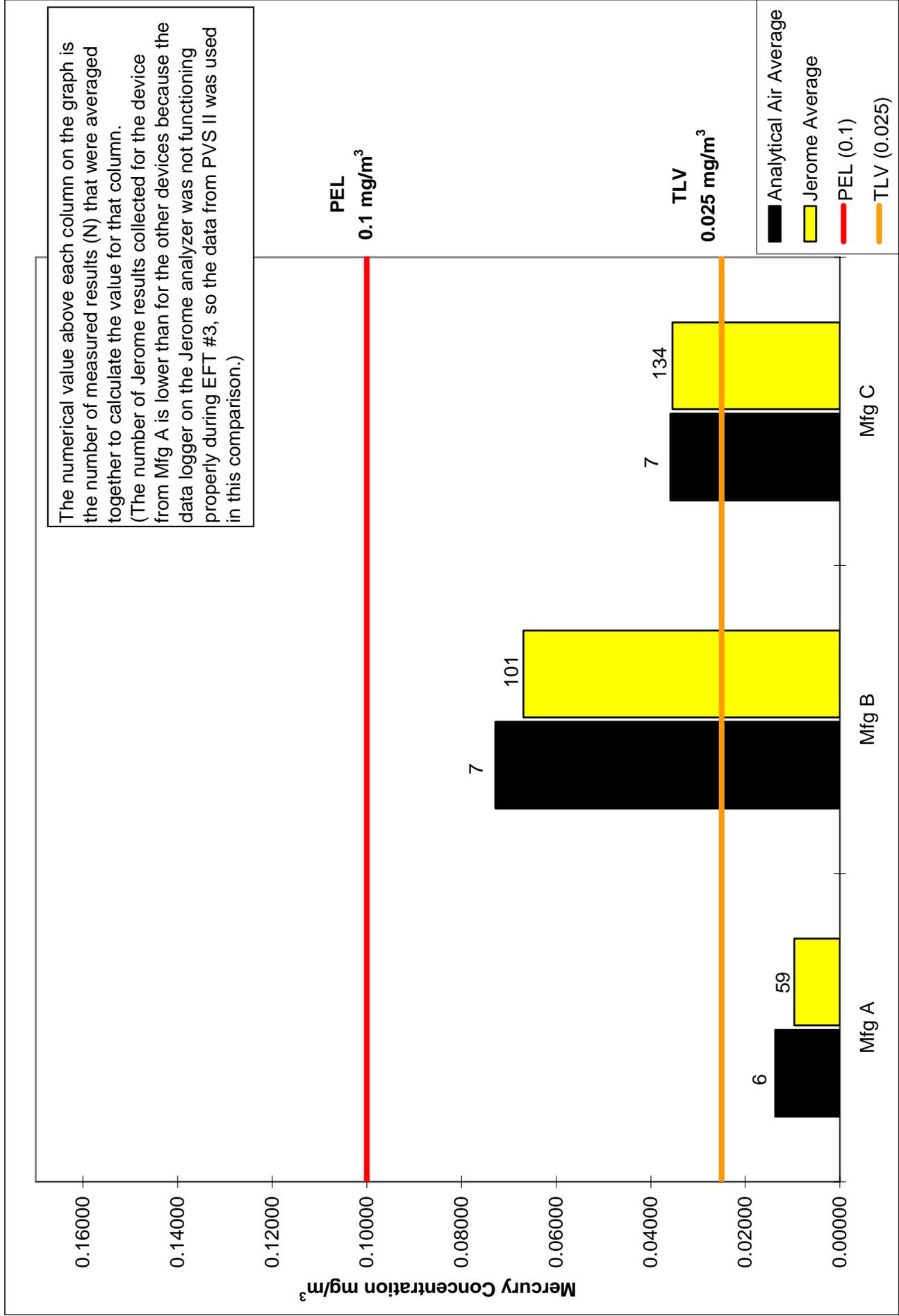
The TLV is included on the graph as a point of reference. The results shown on this graph do not represent eight-hour, time-weighted averages.

**Figure 42: Extended Field Test #3 Jerome Results
 Manufacturer C – Ashland, Virginia – June 9-13, 2003**



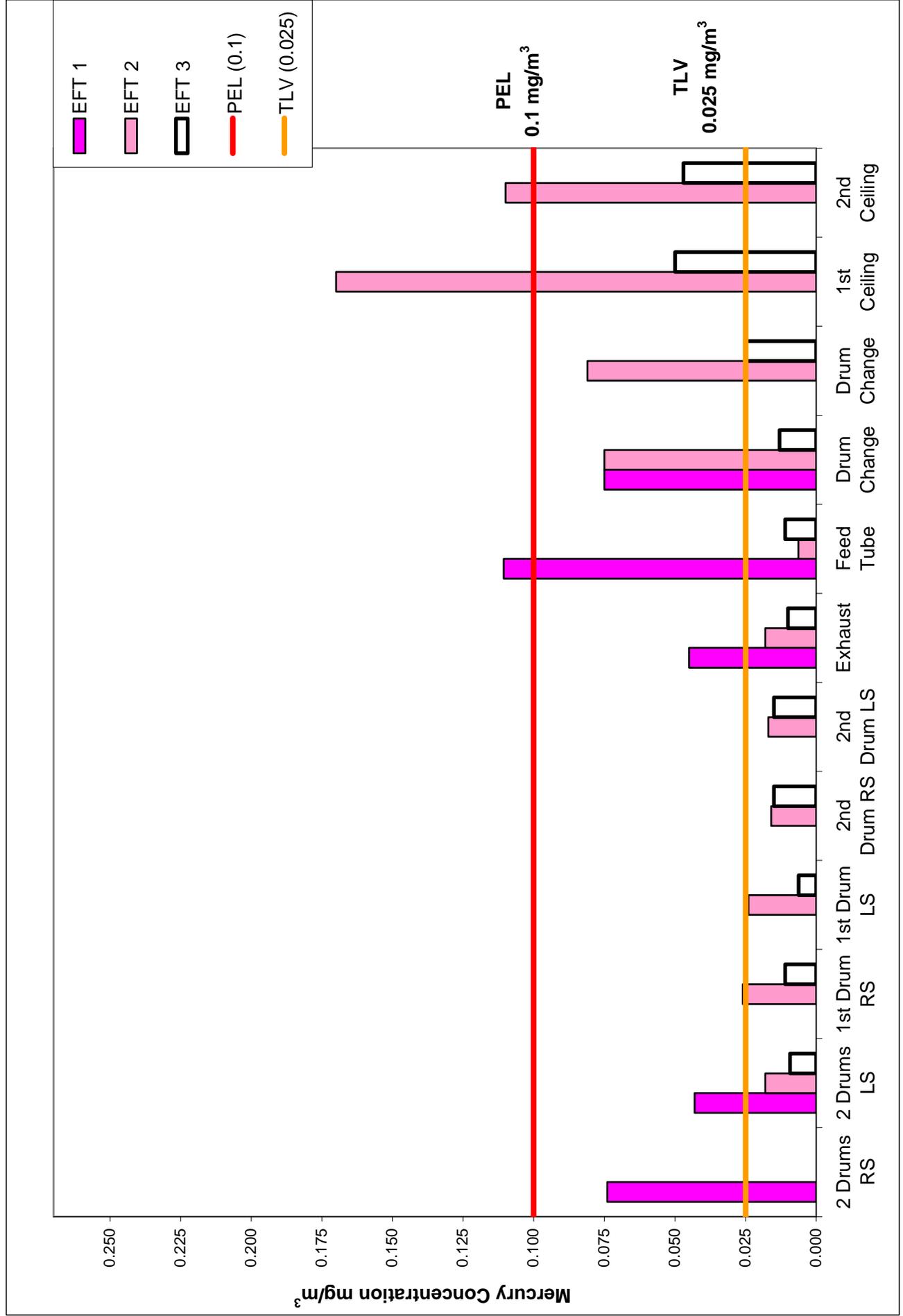
The TLV is included on the graph as a point of reference. The results shown on this graph do not represent eight-hour, time-weighted averages.

**Figure 43: Extended Field Test #3 – Comparison of Analytical Air and Jerome Results
All Devices – Ashland, Virginia – June 9-13, 2003**



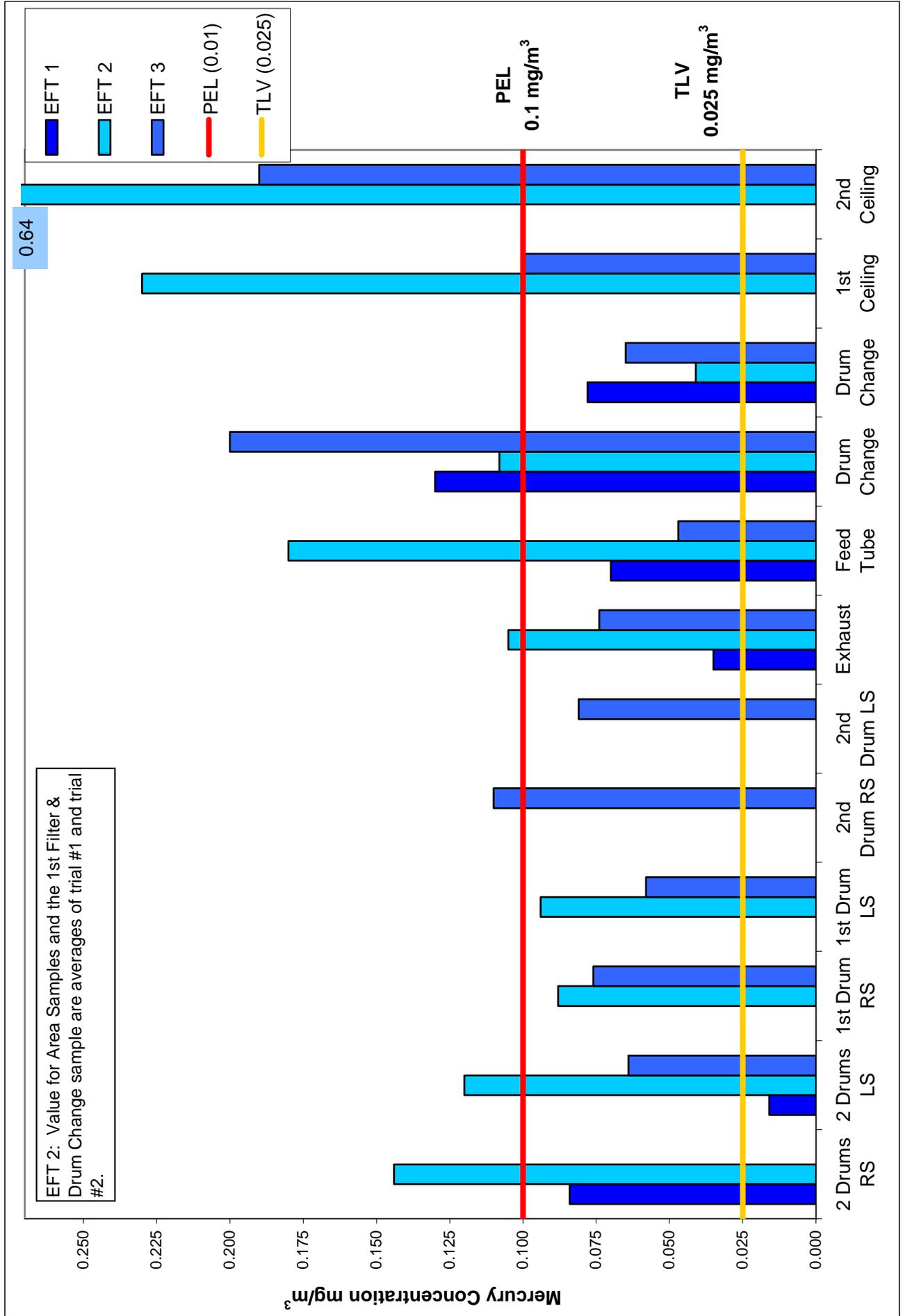
The TLV is included on the graph as a point of reference. The results shown on this graph do not represent eight-hour, time-weighted averages.

**Figure 44: Analytical Air Results – Manufacturer A
Extended Field Test Study**



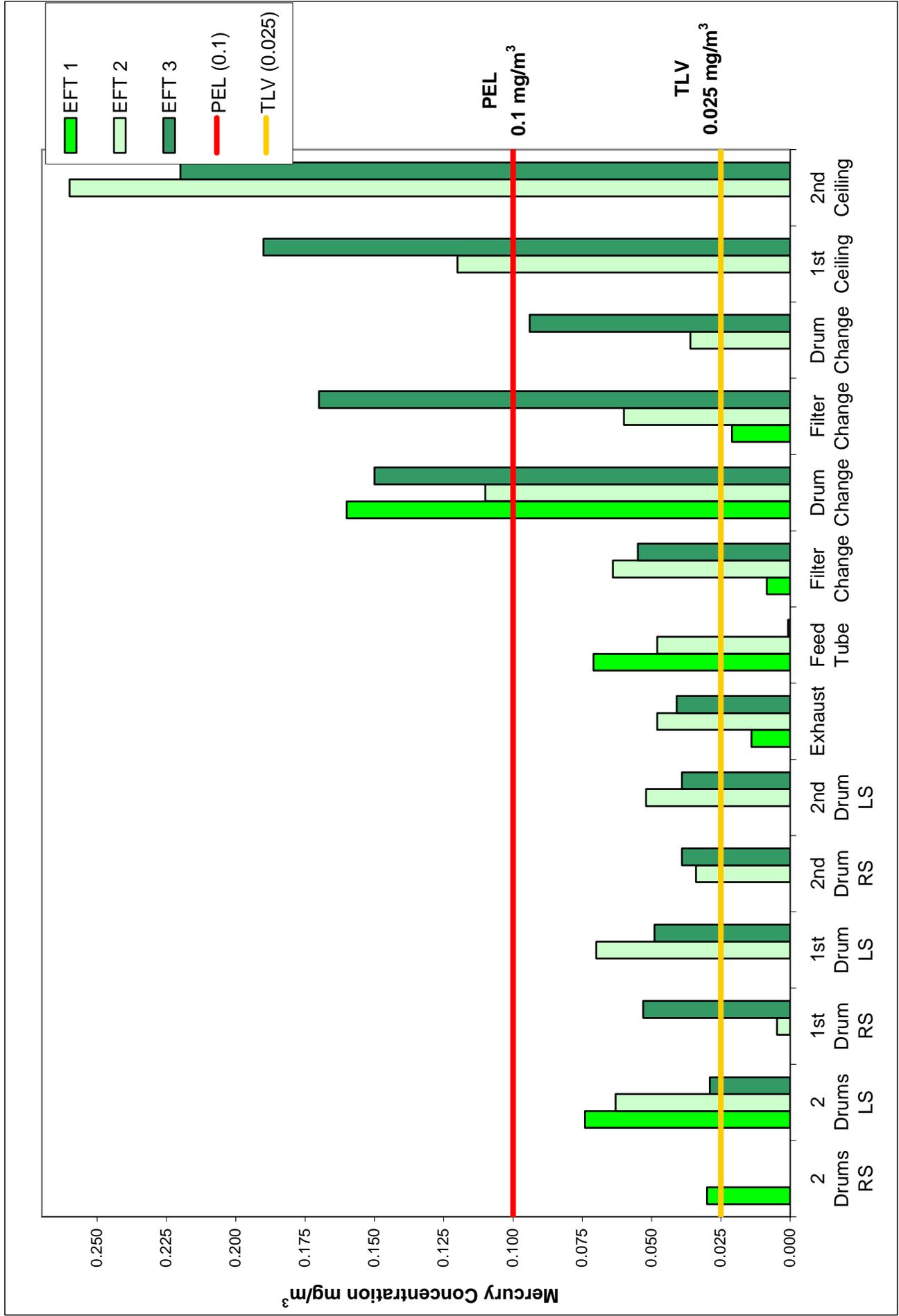
The TLV is included on the graph as a point of reference. The results shown on this graph do not represent eight-hour, time-weighted averages.

**Figure 45: Analytical Air Results – Manufacturer B
Extended Field Test Study**



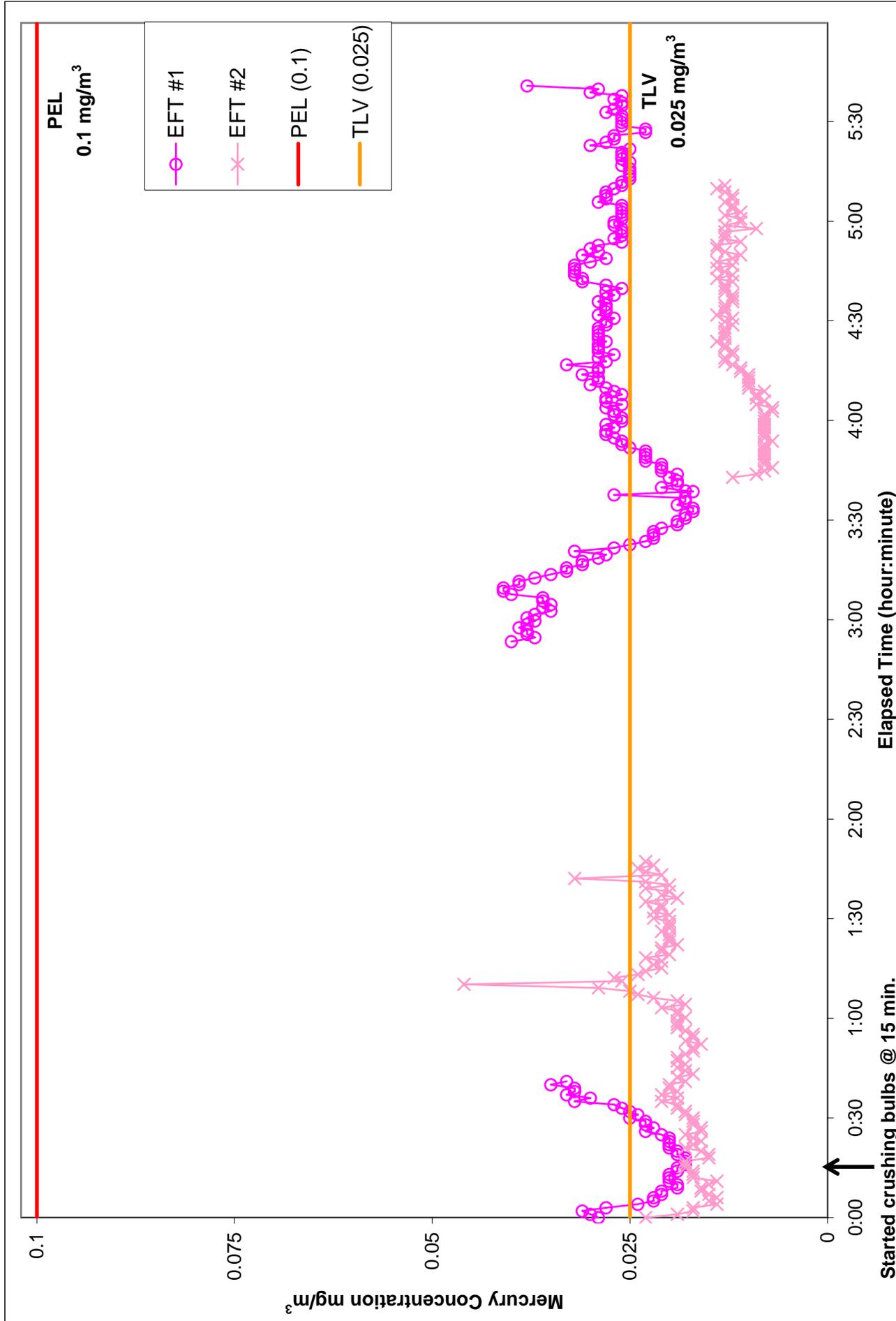
The TLV is included on the graph as a point of reference. The results shown on this graph do not represent eight-hour, time-weighted averages.

**Figure 46: Analytical Air Results – Manufacturer C
Extended Field Test Study**



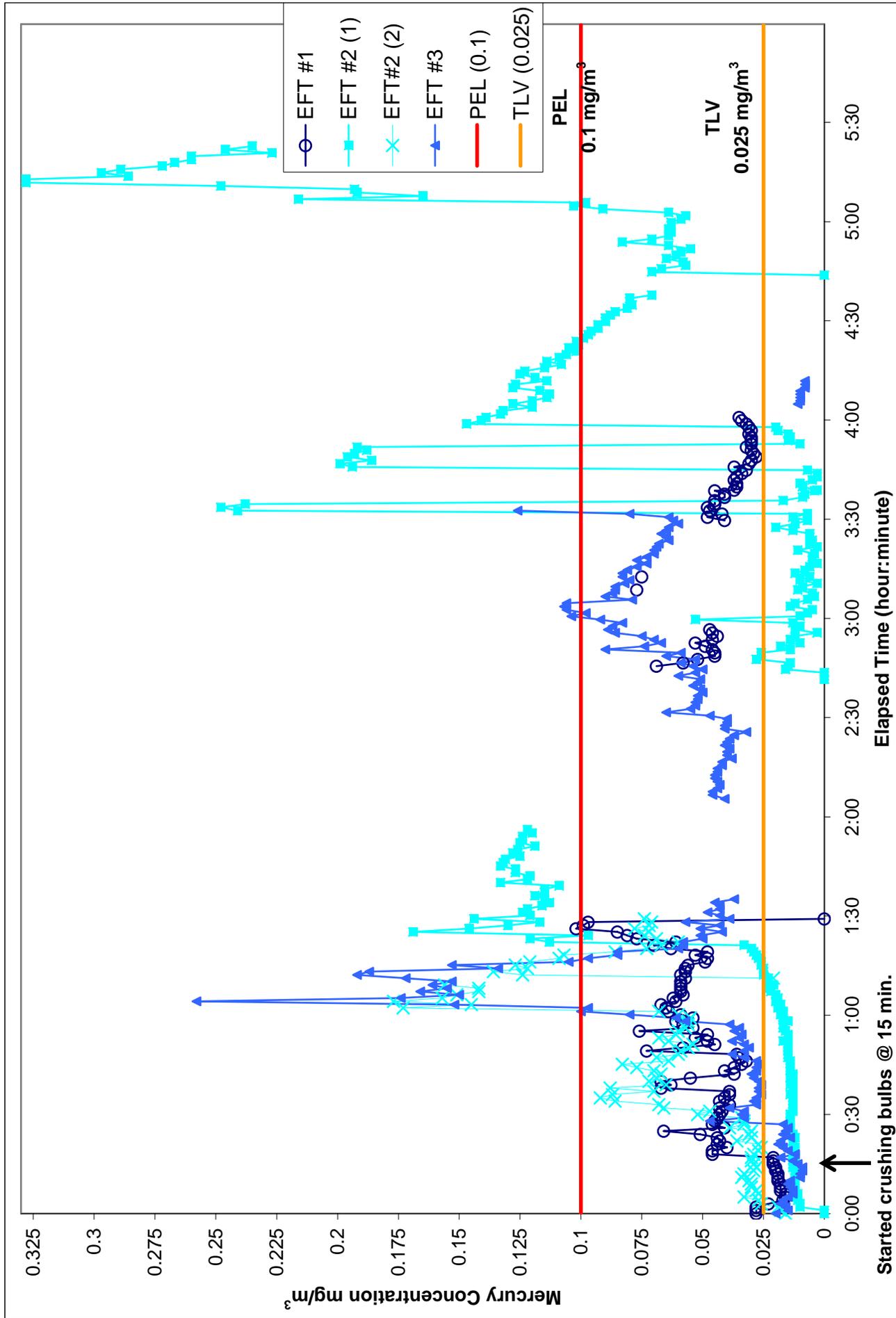
The TLV is included on the graph as a point of reference. The results shown on this graph do not represent eight-hour, time-weighted averages.

**Figure 47: Jerome Results – Manufacturer A
Extended Field Test Study**



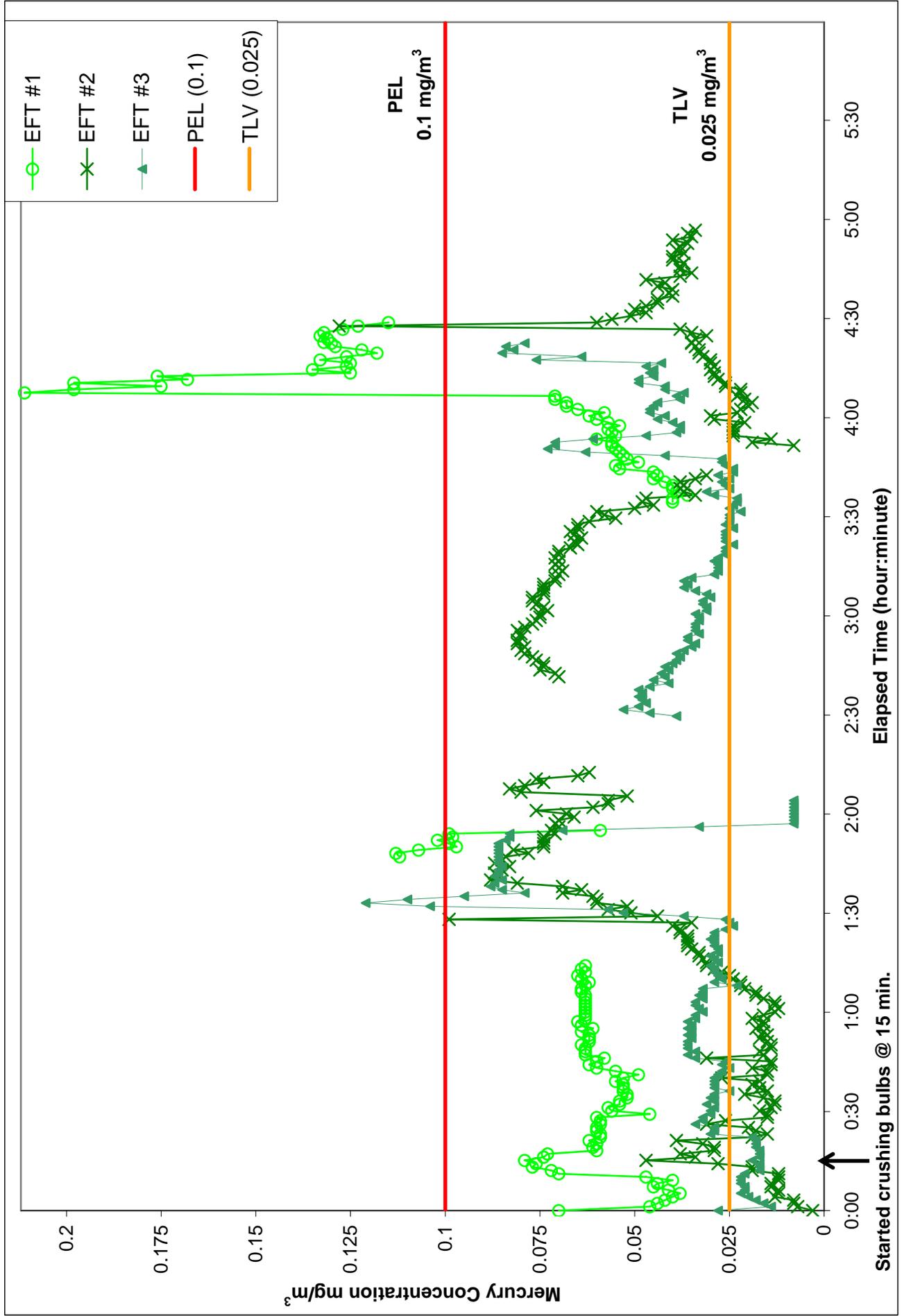
The TLV is included on the graph as a point of reference. The results shown on this graph do not represent eight-hour, time-weighted averages.

**Figure 48: Jerome Results – Manufacturer B
Extended Field Test Study**



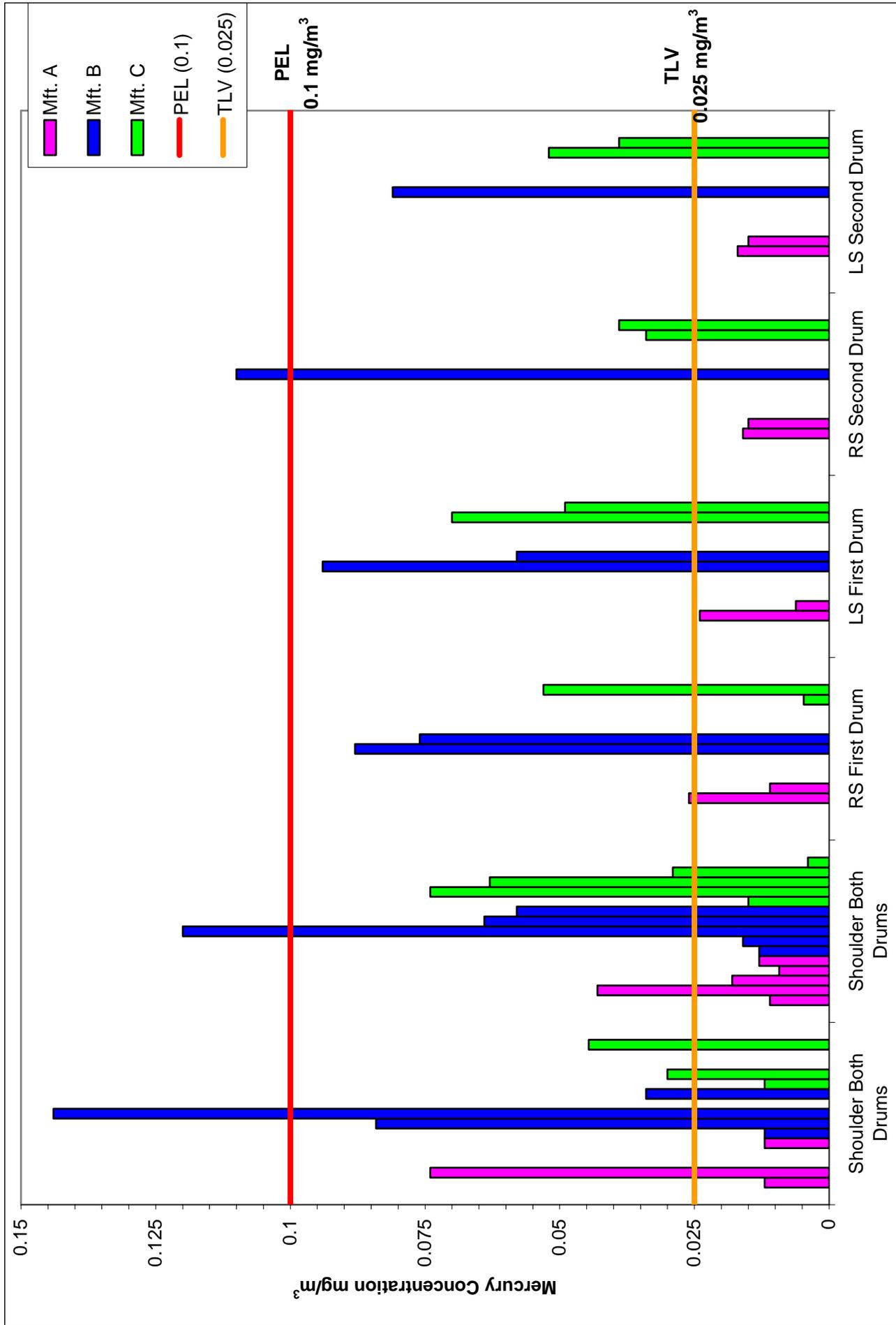
The TLV is included on the graph as a point of reference. The results shown on this graph do not represent eight-hour, time-weighted averages.

**Figure 49: Jerome Results – Manufacturer C
Extended Field Test Study**



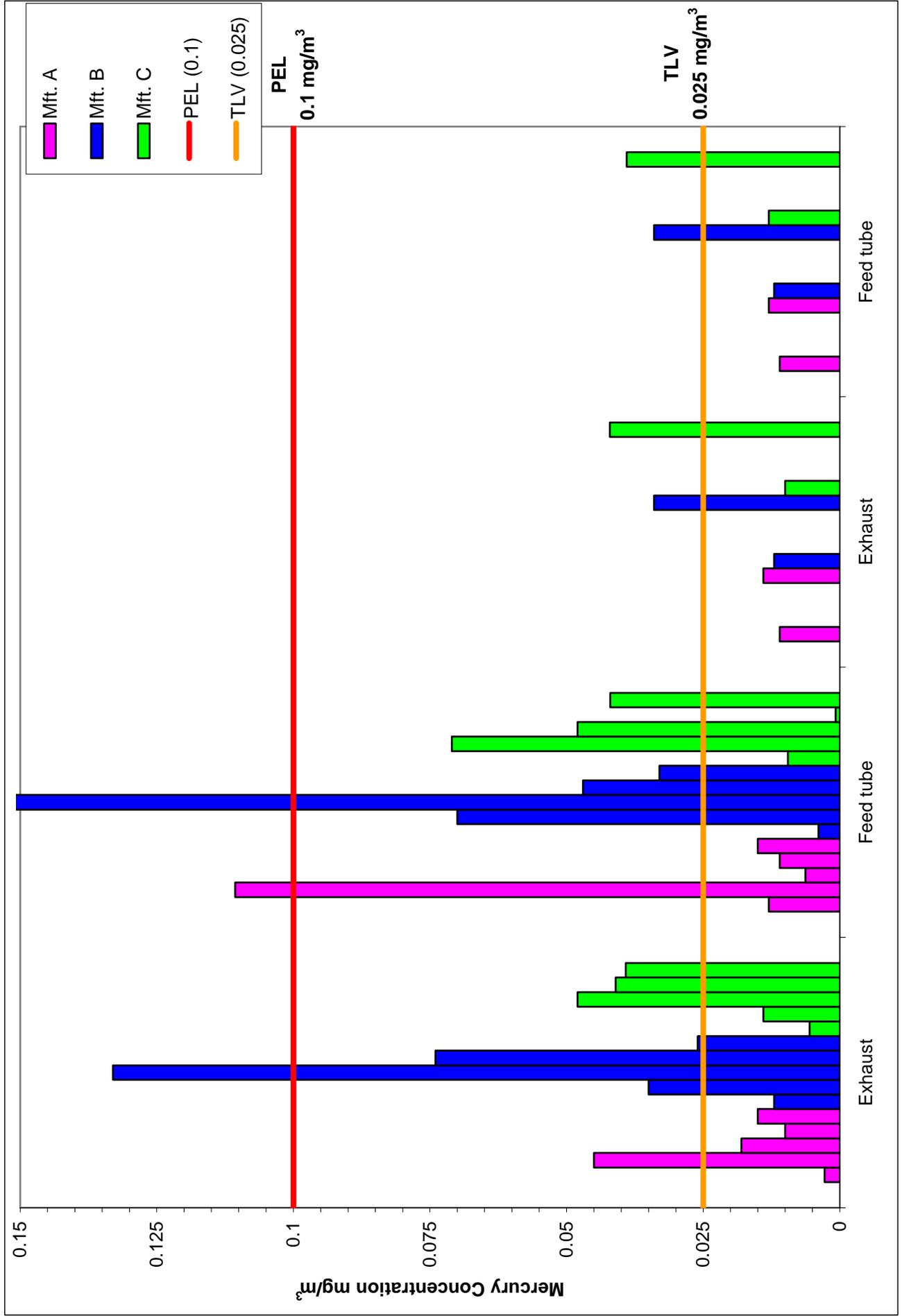
The TLV is included on the graph as a point of reference. The results shown on this graph do not represent eight-hour, time-weighted averages.

**Figure 50: Analytical Air Results – Operator Shoulder Samples
All Devices – All Locations**



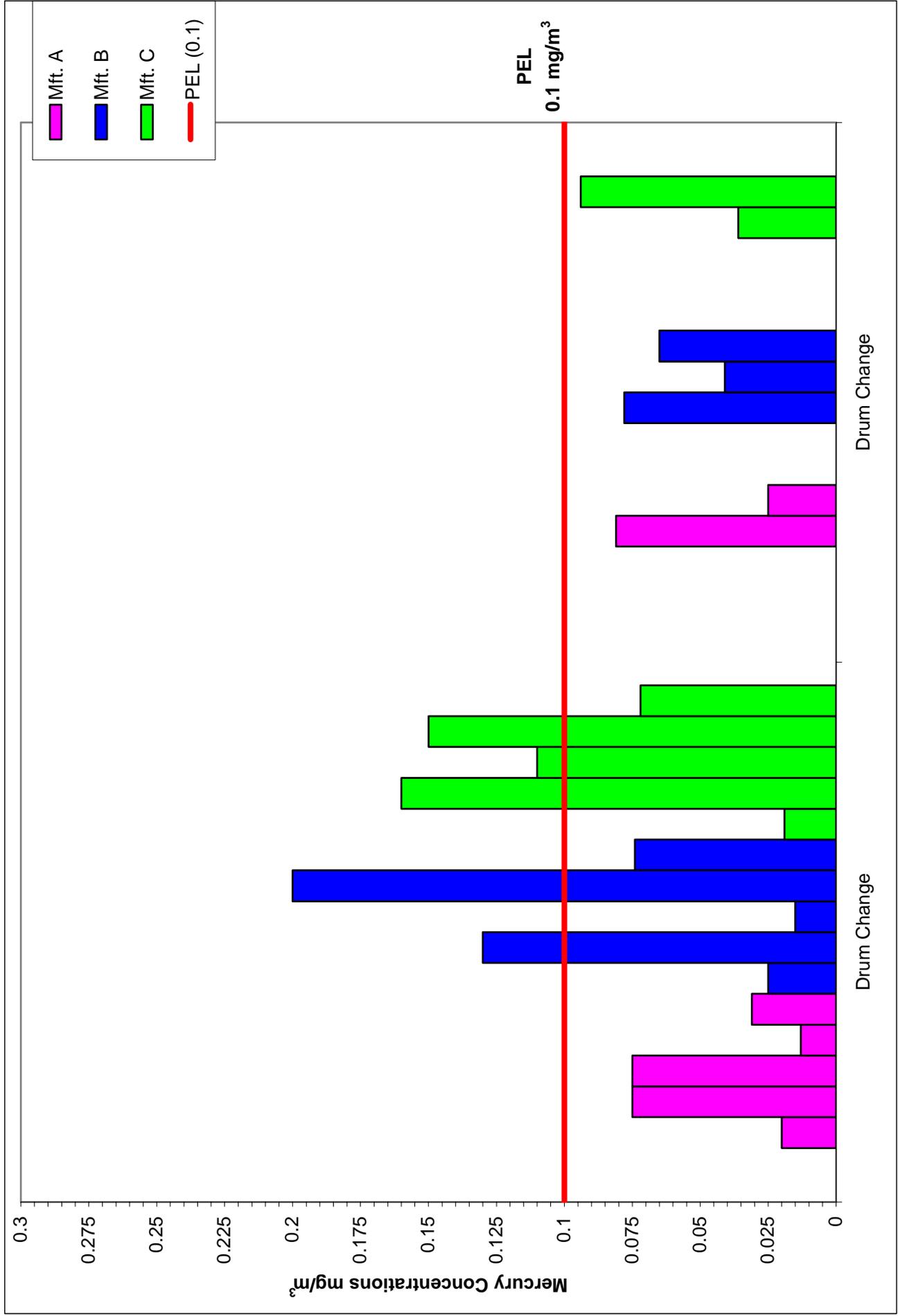
The TLV is included on the graph as a point of reference. The results shown on this graph do not represent eight-hour, time-weighted averages.

**Figure 51: Analytical Air Results – Area Samples
All Devices – All Locations**



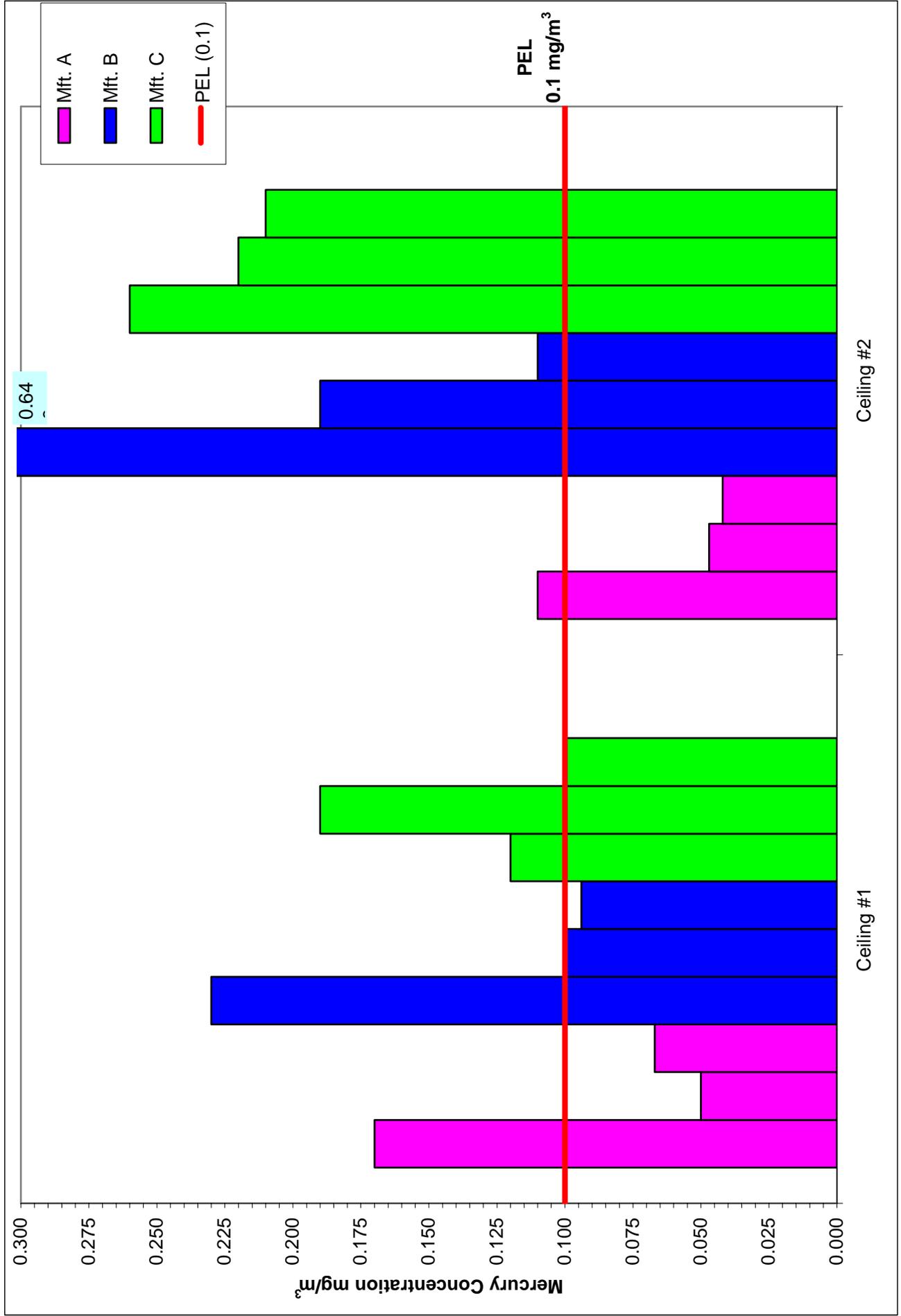
The TLV is included on the graph as a point of reference. The results shown on this graph do not represent eight-hour, time-weighted averages.

**Figure 52: Analytical Air Results – Drum Change Samples
All Devices – All Locations**



The TLV is included on the graph as a point of reference. The results shown on this graph do not represent eight-hour, time-weighted averages.

**Figure 53: Analytical Air Results – Ceiling Samples
All Devices – All Locations**



The TLV is included on the graph as a point of reference. The results shown on this graph do not represent eight-hour, time-weighted averages.

Appendix B
Air Sampling Data Forms

Sample Shipping Information

Samples were placed in an oversized, sturdy box with packing material to fill voids and protect the samples during shipping. The sampling personnel then signed the chain-of-custody forms, and placed them in the box with the samples. Samples were shipped via Federal Express to the laboratory.

AIR SAMPLING DATA FORM

Client FEA Date 2/25/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description BACKGROUND

Work Location EAST MIDDLE OF BAY

Respirators/PPE _____

Controls _____

Sample # 3705-AG-2/25-01 Pump # 13027 Media MCEP + HYDROCAR
3705-SE-2/25-02 Hydro 0.212 278 min 58.94 L
Calibration: Pre 201 cc/min Post _____ Time: On 1306 Off 1307 Volume 58.94 L

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS: Pelota 1 & 2

Industrial Hygienist: _____ Reviewed By: _____

5299 DTC Blvd., Suite 840
Greenwood Village, Colorado 80111
303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 2/25/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description BACKGROUNDS

Work Location EAST BAY AT DOOR TO WEST BAY

Respirators/PPE _____

Controls _____

Sample # 3705-B6-2/25-03 Pump # 11249 Media LCRF
3705-B6-2/25-04 HYDRAR

Calibration: Pre 208 Post 211 Time: On 1306 Off 1314 Volume 53.24 L
209-5 278

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>fta</u>	<u>0.1 mg/m³</u>		

COMMENTS: PHOTO 1

Industrial Hygienist:

Reviewed By:

AIR SAMPLING DATA FORM

Client EPA Date 2/26/03 Job Code _____

Employee TAD RADEWSKI SSN # _____ Job Title _____

Work Description FEEDING TIL & TUBES INTO AIRCYCLE BUBBLES
TRAP DEVICE

Work Location E. BAY MIDDLE INSIDE CONTAINMENT

Respirators/PPE GLOVES PEL SAFETY GLASSES TYVEK COVERALLS

Controls _____

Sample # 3705-BA-2/26/03 Pump # 3496 Media MCFE
3705-AA-2/26-06 HYDRAN

Calibration: Pre 153 Post 151 Time: On 1320 Off 100 Volume 10.2 l

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>H</u>	<u>2.1 mg/m³</u>	<u>HVE = 0.012 mg/m³</u>	<u>0.0035 mg/m³</u>
		<u>MEE = ND</u>	

COMMENTS: ~~180 MINUTE 2 HRS~~
140 MINUTE 2 HR 20 MIN 100 MIN
(2.33 NL)(0.012 mg/L) / 5 HRS 0.0035

Industrial Hygienist:

Reviewed By:

AIR SAMPLING DATA FORM

Client PPA Date 2/26/03 Job Code _____

Employee TAD RADEWSKI SSN # _____ Job Title _____

Work Description FEEDING TIZ TUBES INTO AIRCYCLE BULBATER
DTC DEVICE

Work Location E. BAY MIDDLE INSIDE CONTAINMENT

Respirators/PPE GLOVES SAFETY GLASSES TYNEK COVERALLS

Controls _____

Sample # 3705-A/A-2/26-07 Amp # 12704 Media MCEFF
3705-A/A-2/26-08 H7PPEP

Calibration: 1505 0.1505 Time: 7:10
Pre 151 100 ml Post 150 100 ml On 1320 off 5:00 Volume 10.05 L

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>	<u>AMD 0.015 mg/m³</u>	<u>0.0044 mg/m³</u>
		<u>MGE N/D</u>	

COMMENTS: 140 min 2 HR 30 min 100 min
(2.33 HRS X 0.015) / 8 = 0.0044

Industrial Hygienist: _____

Reviewed By: _____

AIR SAMPLING DATA FORM

Client EPA Date 7/26/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description AIRCYCLE BULB KASPER

Work Location ON FLD ID DTC DEVICE EXHAUST

Respirators/PPE _____

Controls _____

Sample # 3705-A/A-2/26-09 Pump # 13661 Media NICEF

3705-A/A-2/26-10 Calibration: _____ Time: _____

Pre 151 Post 120.9 On 1320 Off _____ Volume 12.79 L

Substance	OSHA PEL	Concentration	8 Hour TWA
-----------	----------	---------------	------------

<u>H₂</u>	<u>0.1 mg/m³</u>	<u>H₂ 0.0055</u>	<u>0.0111 mg/m³</u>
----------------------	-----------------------------	-----------------------------	--------------------------------

		<u>NICE UD</u>	
--	--	----------------	--

COMMENTS:

1 hr 140 min = 2 hrs 20 min 100 min

(233 Pa)(0.0055) / 8 hr = 0.0016

Industrial Hygienist: _____

Reviewed By: _____

AIR SAMPLING DATA FORM

Client EPA Date 2/26/05 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description AIRCYCLE BULB EXHAUSTWork Location ON FLR @ DTC DEVICE EXHAUST

Respirators/PPE _____

Controls _____

Sample # 3705-A/A-2/26-11 Pump # 11330 Media MCEP
3705-A/A-2/26-12 #VDRBKCalibration: Pre 150 Post 150 Time: On 1320 Off 100 Volume _____
150 100

Substance OSHA PEL Concentration 8 Hour TWA

H 0.1 mg/m³ HYD 0.010 mg/m³ 0.0029 mg/m³MCEP ND

COMMENTS:

140 min = 2 hrs 20 min 100 min

$$(2.33)(0.010)/8 = 0.0029$$

Industrial Hygienist: _____

Reviewed By: _____

BOOZ-ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 2/26/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description MCEEF FLOW METER

Work Location BY DTC DEVICE FEED TUBE

Respirators/PPE _____

Controls _____

Sample # 3705-1A-2/26-03 ¹³ 11308 Media MCEEF
3705-1A-2/26-03 ¹⁴ 11308 Media HYDRAR

Calibration: Pre 300 158 Post 12555 Time: On 1320 Off 10V Volume 2.5 L.

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>H₂</u>	<u>0.1 mg/m³</u>	<u>1/40 = 0.0025</u>	<u>0.0027 mg/m³</u>
		<u>MCE = ND</u>	

COMMENTS: 140 min x 2.5 L/min 20 min (excl. min)
(2.35)(0.0025)/8 = 0.0027

Industrial Hygienist: _____ Reviewed By: _____

BOOZ-ALLEN & HAMILTON

5299 DTC Blvd., Suite 840
Greenwood Village, Colorado 80111
303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPP Date 2/26/23 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description ~~BOOZ~~ AIRCYCE BLDG ENTER

Work Location BY DTC DEVICE FKED TUBE

Respirators/PPE _____

Controls _____

Sample # 3705-A/A-2/26-15 Pump # 1320 Media MDF 15
3705-A/A-2/26-16

Calibration: Pre 1.58 - 0.1 min Post 1.58 Time: On 1320 Off 104 Volume 15.0 L

Substance	OSHA PEL	Concentration	8 Hour TWA
Hg	0.1 mg/m ³	MMD 0.013	0.0038 mg/m ³
		MDE = MTD	

COMMENTS: MDE = MTD
(2.33 x 0.613) / 30 = 0.0038

Industrial Hygienist: _____

Reviewed By: _____

AIR SAMPLING DATA FORM

Client EPA Date 2/26/03 Job Code _____

Employee TAD RADZINSKI SSN # _____ Job Title _____

Work Description FIL AIRFLOW BULB FATER

PRE FILTER CHANGE @ 50% DRUM CAPACITY

Work Location _____

Respirators/PPE GLOVES SAFETY GLASSES TYNEK COVERALLS

Controls _____

Sample # 3705-A/A-2/26-17 Pump # 11334 Media MCEP

3705-A/A-2/26-18 HYDRAK

Calibration: Time: _____

Pre 257 Post 255.5 On 21401 off 1473 Volume 5.01 L

257 255.5 254 12 ml/min

Substance OSHA PEL Concentration 8 Hour TWA

Hyd 0.1 mg/m³ HYD C 0.9

MCEP = ND

COMMENTS: 12 min

Industrial Hygienist: _____

Reviewed By: _____

AIR SAMPLING DATA FORM

Client EPA Date 2/26/03 Job Code _____

Employee Tad Radzinski SSN # _____ Job Title _____

Work Description Air Cycle Bulb Enter
Pre Filter change @ 100% Drum Capacity

Work Location _____

Respirators/PPE Gloves Safety Glasses Tyvek Coveralls

Controls _____

Sample # 3705-R/A-2/26-1A Pump # 11334 Media MCEF

3705-R/A-2/26-20

Calibration: Pre 254.5 Post 252.0 Time: On 1442 Off 5:10 Volume 4.58 l.

254.5

18

Substance OSHA PEL Concentration 8 Hour TWA

Hy 0.1 mg/m³ HYD = 0.009

MCE = ND

COMMENTS: 18 min

Industrial Hygienist:

Reviewed By:

AIR SAMPLING DATA FORM

Client EPA Date 2/27/03 Job Code _____

Employee Tad Radzinski SSN # _____ Job Title _____

Work Description Feeding in 12 tubes into ~~Air~~ ^{Resource Technology Incorporated} ~~5010~~ ~~8400~~
DTC Device

Work Location E. Bay Middle Inside Containment

Respirators/PPE Gloves Safety Glasses Tyvek Coveralls

Controls _____

Sample # 3705-R-A-2/27-21 Pump # 11308 Media MCEP
3705-R-A-2/27-22 11308 1F YOKAW

Calibration: Pre 154 cc/min Post 153.5 cc/min Time: On 8:30 Off 10:26 Volume 1.111
153.5 113 112

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m3</u>		

COMMENTS: 113 ml

Industrial Hygienist: _____

Reviewed By: _____

BOOZ-ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 2/27/03 Job Code _____

Employee Tad Radzinski SSN # _____ Job Title _____

Work Description Feeding T12 Tubes into ~~Avecycle~~ ^{Resource Technology, Inc.} ~~filter~~ ^{but, cat.} DTC Device

Work Location E. Bay middle Inside Containment

Respirators/PPE Gloves Safety Glasses Tyvek Coveralls

Controls _____

3705-14-A-2/27-27

Sample # 3705-R-A-2/27-27 Pump # 13027 Media # 11CEP

1-HDRAR

Calibration:

Pre 153 Post 154 Time: On 8:30 Off 10:23 Volume 7.25 L.

113 112

Substance OSHA PEL Concentration 8 Hour TWA

H₂ 0.1 mg/m³

COMMENTS: 113 ppm

Industrial Hygienist:

Reviewed By:

ROOZ-ALLEN & HAMILTON

5299 DTC Blvd., Suite 349

Greenwood Village, Colorado 80111

303.694.4159 FAX: 303.694.7367

AIR SAMPLING DATA FORM

Client: EPA Date: 2/27/93 Job Code: _____

Employee: _____ SSN #: _____ Job Title: _____

Work Description: How much dust in the kitchen

Work Location: by DTT. Home used time

Respiratory PPE: _____

Controls: _____

Sample # 1 Date 2/27/93 Time 12:00 Method 1/2 liter

Calibration: Pre 1515 Post _____ Time: On _____ Off _____ Volume 1/2 L

Substance: 1/2 OSHA PEL: _____ Concentration: _____ R. F. C. TWA: _____

COMMENTS: 1/2 liter

Technician Signature: _____ Received By: _____

AIR SAMPLING DATA FORM

Client EPA Date 2/27/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description ~~Area~~ Resource Technology Inc.

Work Location By DTC Device Feed Time

Respirators/PPE _____

Controls _____

Sample # 3705-R-A-2/27-27
3705-R-A-2/27-28 Pump # 1249 Media MCEC HYDRAK

Calibration: Pre 153 - 4 min Post 154 3 min Time: On 3 Off 10:23 Volume 182 L
154.5 112

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS: 112 min

Industrial Hygienist: _____ Reviewed By: _____

AIR SAMPLING DATA FORM

Client EPA Date 2/27/03 Job Code _____
Employee _____ SSN # _____ Job Title _____
Work Description Resource Technology, Inc.
Work Location On floor at DTC Device Exhaust
Respirators/PPE _____
Controls _____

Sample # 3703-R-A-277-29 Pump # 1366 Media 100% HYDRAL

Calibration: Pre 15.2 Post 15.5 Time: On 8:51 Off 10:02 Volume 12.97 L

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>	<u>102</u>	

COMMENTS: 112

Industrial Hygienist:

Reviewed By:

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 2/27/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description Resource Technology, Inc.

Work Location 8th floor @ DTC Device Exhaust

Respirators/PPE _____

Controls _____

Sample # 3705-R-A-7(27-31) 3705-R-A-2(27-32) Pump # 13673 Media MF-1
Hi-Dur AC

Calibration: Pre 1535 Post 154 Time: On 11:01 Off 11:03 Volume 2.1 L

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>H₂</u>	<u>0.1 mg/m³</u>		

COMMENTS: 112 ppm

Industrial Hygienist:

Reviewed By:

BOOZ-ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 2/27/03 Job Code _____
Employee Tad Radmski SSN # _____ Job Title _____
Work Description Resource Technology, Inc.
Filter change at 100% drum capacity.
Work Location _____
Respirators/PPE Gloves Safety Glasses Tyvek Coveralls
Controls _____

Sample # 3105-R-H-2/27-33 Pump # 11330 Media 1ALFT
3105-R-H-2/27-34 HEP/PAK

Calibration: Pre 4.52 cc/min Post 253 - 1.00 cc Time: On 10:11 OFF 10:29 Volume 3.03 L
2525 12

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>H₂</u>	<u>0.2 mg/m</u>		

COMMENTS: 12 min

Industrial Hygienist:

Reviewed By:

AIR SAMPLING DATA FORM

Client EPA Date 2/27/03 Job Code _____

Employee Jad SSN # _____ Job Title _____

Work Description Hazardous Materials Specialist, Inc.

Work Location _____

Respirators/PPE _____

Controls _____

310 G-H-A-2/27-35

Sample # 4705 H-A 2/27-35 Pump # 11308 Media MCEP HYDRAR

Calibration: Pre 153 cc/min Post 153 cc/min Time: On 1516 Off 1611 Volume 3.42 L.
153 55

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS: 55 min

Industrial Hygienist:

Reviewed By:

AIR SAMPLING DATA FORM

Client: EPA Date: 2/27/83 Job: CRN
Employee: JAD SSN: _____ Job Title: _____
Work Description: Hydrocarbons, methane, by volume
Work Location: _____
Sampling Method: _____
Comments: _____

Sample # 185 H-A 2/27-83 Date: 2/27/83 Time: 1:50 p.m. Media: HYDRAR

Dilution: Flow: 15.5 L/min Cost: 152¹ /min Time: _____ Off: _____ Volume: 2.1
156 55

Distance: _____ (ft) (m) Concentration: _____ B. Temp: _____
114 0.1 mg/m³

Comments: See notes

Responsible Analyst: _____ Inspected By: _____

BOOZ-ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 2/27/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description Hazardous Materials Specialist

Work Location Feed tube

Respirators/PPE _____

Controls _____

Sample # 325-11-A-2/27-40 Pump # 12708 Media MCF HYDRAR
325-11-A-2/27-39

Calibration: Pre 15 lcc/min Post 15.2 lcc/min Time: On _____ Off _____ Volume 5.45 l
151.5 55

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS: 55 min

Industrial Hygienist: _____

Reviewed By: _____

AIR SAMPLING DATA FORM

Client EPA Date 2/27/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description Hazardous Materials Specialist

Work Location Feed tube

Respirators/PPE _____

Controls _____

Sample # 3705-H-A-2/27-41 Pump # 11249 Media MCEP
3705-H-A-2/27-42

Calibration: Pre 154 cc/min Post 156 cc/min Time: On 1516 Off 1611 Volume 5.15
55 55 (53)

Substance Hg OSHA PEL 0.1 mg/m³ Concentration _____ 8 Hour TWA _____

COMMENTS: 55 min

Industrial Hygienist: _____

Reviewed By: _____

AIR SAMPLING DATA FORM

Client EPA Date 2/27/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description Hazardous Materials Specialist, Inc

Work Location Exhaust

Respirators/PPE _____

Controls _____

3705-H-A-2/27-43

Sample # 3705-H-A-2/27-44 Pump # 13661 Media MCEP HYDEAR

Calibration: Pre 151 OE/m³ Post 150 cc/min Time: On 55 off _____ Volume 3.0 liters
150.5 55

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS: 55 min

Industrial Hygienist:

Reviewed By:

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840
Greenwood Village, Colorado 80111
303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 2/27/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description Hazardous Materials Specialist, Inc.

Work Location Exhaust

Respirators/PPE _____

Controls _____

3705-H-A-2/27-45

Sample # 3705-H-A-2/27-4b Pump # 11330 Media MUEF HYDRAR

Calibration:

Pre 253 cc/min Post 253 cc/min Time: On 10:16 off 10:11 Volume 5.22

Substance _____ OSHA PEL _____ Concentration _____ 8 Hour TWA _____

Hg 0.1 mg/m³

COMMENTS: 55 min

Industrial Hygienist: _____

Reviewed By: _____

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 2/28/03 Job Code _____

Employee Tad Ratzinski SSN # _____ Job Title _____

Work Description Feeding cubes into ~~sample~~ Dextrek DTC Device

Work Location E Bay Middle Inside Containment

Respirators/PPE Gloves safety glasses goggles Overall

Controls _____

5702-D-A-3/28-50

Sample # 3703-A-2/28 Pump # 11332 Media MCEP

HYDRAR

Calibration: Pre 149.1 min Post 152.6 min Time: On _____ Off 1132 Volume 15.16 L

153

86

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>114</u>	<u>2.5 mg/m</u>		

COMMENTS: 86 min

Industrial Hygienist: _____

Reviewed By: _____

AIR SAMPLING DATA FORM

Client EPA Date 2/28/03 Job Code _____
 Employee Tad Radzinski SSN # _____ Job Title _____
 Work Description Feeding tubes into Acetone DTC Device
 Work Location E Bay middle Inside Container
 Respirators/PPE Gloves Safety Glasses Tyvek coveralls
 Controls _____

Sample # 1 5705-D-A-2/28-01 Pump # 11249 Media MCFE
-52 14121

Calibration: Pre 151 2:00 Post 151 10:00 Time: 10:00
 On 10:00 OFF 11:30 Volume 12.99 L
151 76 80

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS: 76 min

Industrial Hygienist:

Reviewed By:

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 2/28/05 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description locate DTC device

Work Location By DTC device feed tube

Respirators/PPE _____

Controls _____

Sample # 3705-D-4 2/28-5B
-54 Pump # 15496 Media MS2-F
730R11

Calibration: Pre 145 Post 138cc/min Timer: On 1:32 Off 1:32 Volume 12.470

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS: 5/6 min

Industrial Hygienist:

Reviewed By:

BOOZ-ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4154 FX, 303.694.7367

DATE SAMPLED: 10/11/88

Client: IBM Date: 10/25/88 Job Code: _____

Employee: 2024 I Job Title: _____

Work Description: Remove oil - device

Work Location: Shop 2 - device feed line

Respirators/TPE: _____

Controls: _____

Sample # 1 12 2:54 10/25

Calibration: 15.2 1132 13.096

Signature: _____

Comments: See notes

Industrial Hygienist:

Date: (month) 1988

5299 DTC Blvd., Suite 840
Greenwood Village, Colorado 80111
303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 2/28/03 Job Code _____

Employee _____ SSN # 13673 Job Title _____

Work Description Detrinite DTC Device

Work Location On floor next to DTC Device Exhaust

Respirators/PPE _____

Controls _____

Sample # 3705-D-A-2/28-57 Amp # 13673 Media MICEF

Calibration: Pre 153.5 Post 154 cc/min Time: On 10:26 Off 11:32 Volume 13,20 L

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS: See memo

Industrial Hygienist: _____ Reviewed By: _____

AIR SAMPLING DATA FORM

Client EPA Date 2/29/03 Job Code _____
Employee _____ SSN # _____ Job Title _____
Work Description Decontaminate DTC device
Work Location on flow @ DTC device exhaust
Respirators/PPE _____
Controls _____

Sample # 3103 D-A-2/28 01 Pump # 12704 Media MDEF

Calibration: Pre 151.5 Post 152 cc/min Time: On 11:32 Off 11:32 Volume 13.03 L
HYDRITE

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>tg</u>	<u>3.1 mg/m³</u>		

COMMENTS: SLC max

Industrial Hygienist:

Reviewed By:

BOOZ-ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 2/28/83 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description Dextroite DTC Denive

Filter Drum Change when ~~stop~~ Drum Full

Work Location _____

Respirators/PPE Gloves Safety Glasses Tuxedo Overall

Controls _____

1050 H-2/49-61

Sample # 102 Pump # 1930 Media MILFF

MVPEK

Calibration: Pre 253 Post 254 cc/min On 119 Off 132 Volume 3.29 L

Substance CO OSHA PEL 0.1 mg/m³ Concentration _____ 8 Hour TWA _____

COMMENTS: 15 min

Industrial Hygienist: _____

Reviewed By: _____

Appendix B
Air Sampling Data Forms

Sample Shipping Information

Samples were placed in an oversized, sturdy box with packing material to fill voids and protect the samples during shipping. The sampling personnel then signed the chain-of-custody forms, and placed them in the box with the samples. Samples were shipped via Federal Express to the laboratory.

AIR SAMPLING DATA FORM

Client EPA Date 2/28/03 Job Code _____

Employee _____ SSN # ~~13673~~ Job Title _____

Work Description Dextroic DTC Device

Work Location on floor next to DTC Device Exhaust

Respirators/PPE _____

Controls _____

Sample # 3705-D-A-2/28-57
-58 Pump # 13673 Media MCEF

Calibration: Pre 153 cc/min Post 154 cc/min Time: On 1006 OFF 1132 Volume 13.20 L
153.5 86

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS: See memo

Industrial Hygienist: _____ Reviewed By: _____

AIR SAMPLING DATA FORM

Client: EPA Date: 2/28/03 Job Code: _____

Employee: _____ SSN #: _____ Job Title: _____

Work Description: Dextrite DTC Device

Work Location: On floor @ DTC device exhaust

Respirators/PPE: _____

Controls: _____

Sample # 3705-D-A-2/28-59 Pump # 12709 Media MCEF

Calibration: Pre 151 Post 152 cc/min Time: HYDRATE
On 1000 Off 1132 Volume 13.03 L
151.5 86

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS: Sl. min

Industrial Hygienist: _____ Reviewed By: _____

BOOZ-ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 2/28/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description Dextre DTC Denise

Filter drum change when ~~off~~ Drum Full

Work Location _____

Respirators/PPE Gloves Safety Glasses Tyvek Overall

Controls _____

1705-A-2/28-61

Sample # -62 Pump # 1830 Media M LFF

HYDRAR

Calibration: Pre 252 Post 254 Time: On 1119 Off 1132 Volume 3.29 L

253

Substance OSHA PEL Concentration 8 Hour TWA

Hg

0.1 mg/m³

COMMENTS: 13 min

Industrial Hygienist: _____

Reviewed By: _____

AIR SAMPLING DATA FORM

Client EPA Date 3/24/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description Background

Work Location North of containment in Warehouse on top of

Air Cycle Bulb & crushed Boxed crate

Respirators/PPE _____

Controls _____

Sample # 3705-B-3/24/03 ^{tube} Pump # 13684 Media Hydrex

Calibration: ⁻⁰² Filter Time: _____
Pre 162 cc/min Post 148 cc/min On 7.58 Off 11:23 Volume 31.78 L
~~155~~ 155 205

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>H₂</u>	<u>0.1 mg/m³</u>		

COMMENTS: 205 min

Industrial Hygienist: _____

Reviewed By: _____

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 3/24/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description Background

East of containment warehouse

Work Location on top of boxes of bulbs

Respirators/PPE _____

Controls _____

Sample # 3705-B-3/24-03 Pump # 800 885 Media Hydax
-04 MUEF

Calibration: Pre 151cc/min Post 122cc/min Time: On 7:57 Off 11:23 Volume 27.98L
136.5 205

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS: 208 min

Industrial Hygienist: _____

Reviewed By: _____

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840
Greenwood Village, Colorado 80111
303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client	<u>EPA</u>	Date	<u>3/27/03</u>	Job Code	
Employee	<u>Tad</u>	SSN #		Job Title	
Work Description	<u>Personal RTI</u>				
Work Location					
Respirators/PPE	<u>Respirator, tyvek, safety goggles</u>				
Controls	<u>Jerome</u>				
<hr/>					
Sample #	<u>3705-R-A-3/24-05</u>	Pump #	<u>14959</u>	Media	<u>MCEF Hydrax</u>
Calibration:		Time:			
Pre	<u>16 lcc/min</u>	Post	<u>16 lcc/min</u>	Off	<u>12:26</u>
	<u>163.5</u>	#1	<u>10:45</u>		<u>26.49L</u>
		#2	<u>2:56</u>		
			<u>162</u>		
			<u>3:37</u>		
Substance	OSHA PEL	Concentration	8 Hour TWA		
<u>Hg</u>	<u>0.1 mg/m³</u>				
COMMENTS:	<u>175 min</u>				
Industrial Hygienist:	Reviewed By:				

AIR SAMPLING DATA FORM

Client EPA Date 3/24/03 Job Code _____

Employee Tad SSN # _____ Job Title _____

Work Description Personal

Work Location _____

Respirators/PPE Respirator, tyvek, safety goggles

Controls Jerome

Sample # 3705-R-A3/24-07 Pump # 2018 Media Hydrav MCEF
-08

Calibration: Pre 152 cc/min Post 149 cc/min Time: On# 10:45 Off 12:26 Volume 24.38L
150.5 #2 2.36 3.37

Substance Hg OSHA PEL 0.1 mg/m³ Concentration 162 8 Hour TWA

COMMENTS: *15 min.

Industrial Hygienist:

Reviewed By:

AIR SAMPLING DATA FORM

Client EPA Date 3/24/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description Inside containment

Work Location Area sample on fiber drum next to exhaust
-elevated

Respirators/PPE Respirators, tyvek, safety goggles

Controls Jeime

Sample # 3705-R-A-3/24-03 Pump # 12713 Media MCEF
Hydrex

Calibration: Pre 152 cc/min Post 160 cc/min Time: On# 10:45 Off 12:26 Volume 25.27L
156 #2 2:36 3:37

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>	<u>112</u>	

COMMENTS: 17 min.

Industrial Hygienist:

Reviewed By:

AIR SAMPLING DATA FORM

Client EPA Date 3/24/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description Inside containment

Area sample on fiber drum next to inlet feed tube

Work Location _____

Respirators/PPE Respirator, tyvek, safety goggles

Controls None

Sample # 3705-RA-3/24-11 Pump # 13658 Media MCEP Hydrar
-112

Calibration: Pre 148cc/min Post 205cc/min Time: On 10:45 Off 12:26 Volume 28.59L
174-5 #2 2:36 3:37

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>	<u>162</u>	

COMMENTS: 175 min

Industrial Hygienist:

Reviewed By:

AIR SAMPLING DATA FORM

Client EPA Date 3/24/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description Filter change #1 and #2 (see notes below)

Work Location left red cap on for first filter change - soaked some media for filter change #2. only included time for 2nd filter change in total volume.

Respirators/PPE _____

Controls _____

Sample # 3705 R-A-3/24/03 Pump # 11302 Media McEF Hyd

Calibration: Pre 248cc/min Post 266cc/min Time: On #2 7:50am OFF 8:12pm Volume 5.65L

257 on 3/24/03 12:12 pm 12:28 pm (left red cap on) - did not include in L

13 9214 on 3/25/03 22

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS: 22 min.

Industrial Hygienist:

Reviewed By:

LEN & HAMILTON
1000 E. 10th Ave., Suite 840
Denver, Colorado 80111
4.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

EPA

Date 3/24/03

Job Code

SSN #

Job Title

Description

Overnight m containment - RTJ
Exhaust

Work Location

Respirators/PPE

Controls

Sample # 3705-R-A-3/24-15 Pump # ~~12705~~ 11252
-16 Media Hydran
MCEF

Calibration: 169 cc/min Time: 4:27pm
Pre ~~157~~ cc/min Post ~~163~~ On ~~4:07pm~~ Off 11:35pm Volume 68.13 L
157 163 428 (418)

Substance	OSHA PEL	Concentration	8 Hour TWA
Hg	0.1 mg/m ³		

COMMENTS: 428 min.

Industrial Hygienist:

Reviewed By:

AIR SAMPLING DATA FORM

Client EPA Date 3/24/13 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description Overnight in Containment - RTI
field tube

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3705-R-A-3/24-17 Pump # 11179 Media Hydrar
-18 MCEF

Calibration: Pre 157 cc/min Post 146 cc/min Time: On 4:07pm Off 11:35pm Volume 66.36 L
151.5 448 438

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>H₂</u>	<u>0.1 mg/m³</u>		

COMMENTS: 448 min.

Industrial Hygienist: _____

Reviewed By: _____

AIR SAMPLING DATA FORM

Client EPA Date 3/25/03 Job Code _____

Employee Tad SSN # _____ Job Title _____

Work Description Personal - Dextrite

Work Location _____

Respirators/PPE Respirator, tyvek, safety goggles

Controls Jerome

Sample # 3705-D-A-3/25-19 ^{tube} Pump # 12713 Media Hydrar
- 20-ft. line MCEP

Calibration: Pre 159 cc/min Post 301 cc/min Time: On 9:46 OFF 10:56 Volume 28.75L
230 12:29 1:24

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>	<u>125</u>	

COMMENTS: 125 min

Industrial Hygienist: _____

Reviewed By: _____

AIR SAMPLING DATA FORM

Client EPA Date 3/25/83 Job Code _____

Employee Jad SSN # _____ Job Title _____

Work Description Personal - Dextrite

Work Location _____

Respirators/PPE Respirator, tyvek, safety goggles

Controls Jerome

Sample # 3705-D-A-5/25-21 Rep # 13684 Media Hydrar
-22 MCEF

Calibration: Pre 142 cc/min Post 129 cc/min Time: On 9:46 Off 10:56 Volume 16.94L
135.5 12.29 .25 1:24

Substance Hg OSHA PEL 0.1 mg/m³ Concentration _____ 8 Hour TWA _____

Comments: 135 min

Industrial Hygienist: _____

Reviewed By: _____

AIR SAMPLING DATA FORM

Client EDA Date 3/25/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description Inside containment - hextrite

area sample on fiber drum next to exhaust

Work Location -elevated

Respirators/PPE _____

Controls Jerome

Sample # 3705-D-A-3/25-23 Pump # ~~800485~~ 3715 800885 Media Hydran
-24 MCEF

Calibration: 152 120cc/min Time: _____
Pre ~~152~~ 152 cc/min Post 9:46 On 9:46 Off 10:56 Volume 17.0 L
~~152~~ 12:29 1:24

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>		<u>125</u> <u>0.1 mg/m³</u>	

COMMENTS: 125 min

Industrial Hygienist: _____

Reviewed By: _____

AIR SAMPLING DATA FORM

Client EPA Date 3/25/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description Inside containment - Dextrose
area sample on fiber drum next to inlet feed tube

Work Location _____

Respirators/PPE _____

Controls Jerome

Sample # 3705-D-A-3/25-25 Pump # 2018 Media Hydrav
-26 MCEF

Calibration: Pre 156 cc/min Post 243 cc/min Time: On 9:46 Off 10:56 Volume 24.94 L
149.5 12:29 125 1:24

Substance Hg OSHA PEL 0.1 mg/m³ Concentration _____ 8 Hour TWA _____

COMMENTS: 125 min

Industrial Hygienist: _____

Reviewed By: _____

AIR SAMPLING DATA FORM

Client EPA Date 3/25/03 Job Code _____Employee Tad SSN # _____ Job Title _____Work Description ~~First Pump~~ change - Dextrite

Work Location _____

Respirators/PPE Respirator, tyvek, safety gogglesControls JeromeSample # 3705-D-A3/25-27 Pump # 14959 Media Hydra
-28 MCEFCalibration: Pre 253 cc/min Post 170 cc/min Time: On 10:44 Off 10:56 Volume 2.54 L
211.5 12

Substance OSHA PEL Concentration 8 Hour TWA

Hg 0.1 mg/m³ _____COMMENTS: 12 min.

Industrial Hygienist: _____

Reviewed By: _____

BOOZ-ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 3/25/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description Overnight in containment Dextroite

Work Location Exhaust

Respirators/PPE _____

Controls _____

Sample # 3705-D-A-3/25-29 Pump # 2018 Media Hydrex

Calibration: Pre 153 cc/min Post 76.8 ⁻³⁰ 90.6 Time: On 1:34pm OFF 10:10pm MCFE 02.852 Volume 39.71 L

Substance Hg OSHA PEL 0.1 mg/m³ Concentration 516 8 Hour TWA _____

COMMENTS: 576 min

Industrial Hygienist: _____

Reviewed By: _____

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 3/25/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description Overnight in containment - Dextate

Work Location seed tube

Respirators/PPE _____

Controls _____

Sample # 3705-0A-3/25-31 Pump # 3715 Media Hydrar

Calibration: Pre 143 cc/min Post 126 cc/min Time: On 1:34 pm OFF 10:10 pm Volume 69.40 L
134.5 516

Substance OSHA PEL Concentration 8 Hour TWA

Hg 0.1 mg/m³

COMMENTS: 576 min

Industrial Hygienist:

Reviewed By:

AIR SAMPLING DATA FORM

Client EPA Date 3/25/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description Second Drum Change, Nextlife

Work Location (^{Area 0} Performed on 3/26/03 - after overnight maintenance)

Respirator/PPE Respirator, tyvek, safety goggles

Controls _____

Sample # 7705 O.P. 3/25/03 Pump # 11202 Media Hydrex
-34 MCP

Calibration: Pre 2.55 sec/min Post 2.00 sec/min Time: On 101 bpm Off 0.29 sec Volume 2.96 L
2275 13

Substance	OSHA PEL	Concentration	# Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS: 13 min

Industrial Hygienist:

Reviewed By:

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 3/26/03 Job Code _____

Employee Tad SSN # _____ Job Title _____

Work Description Personnel - HMs

Work Location _____

Respirators/PPE Respirator, tyvek, gloves, safety goggles

Controls Jeopardy

Sample # 3705-H-A-3/26-35 ^{tube} Pump # 2517 Media Hydrar
-36 filter MCEF

Calibration: Pre 187cc/min Post 191cc/min Time: On 8:13 OFF 8:34 Volume 3.97 L
189 21

Substance H₂ OSHA PEL 0.1 mg/m³ Concentration _____ 8 Hour TWA _____

COMMENTS: 21 min.

Industrial Hygienist: _____

Reviewed By: _____

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840
Greenwood Village, Colorado 80111
303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 3/26/03 Job Code _____

Employee Tad SSN # _____ Job Title _____

Work Description Personal - HMS

Work Location _____

Respirators/PPE Respirator, tyvek, gloves, goggles

Controls Temp

Sample # 3705-HA-3/26-32 ^{tube} Pump # 3714 Media Hydrax
- 38 filter MCEF

Calibration: Pre 147 cc/min Post 150 cc/min Time: On 8:13 Off 8:34 Volume 3.12 L
148.5 21

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS: 21 min

Industrial Hygienist: _____

Reviewed By: _____

AIR SAMPLING DATA FORM

Client EIP Date 3/26/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description HMS Inside containment - on fibre drum near exhaust

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3705-HA-246-39 Resp # 2018 Media Hydrex MCFE
-40

Calibration: Pre 150 cc/min Post 153 cc/min Time: On 8:13 Off 11:19 Volume 28.92 L
1555 186

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS: 186 min

Industrial Hygienist: _____

Reviewed by: _____

AIR SAMPLING DATA FORM

Client: EPA Date: 3/26/03 Job Code: _____

Employee: _____ SSN #: _____ Job Title: _____

Work Description: HMS
Inside containment - on fiber drum near a lex
tube

Work Location: _____

Respirators/PPE: _____

Controls: _____

Sample # 3705-H-A 3/26-41 Pump # 3715 Media Hydrox
-42 MCFCalibration: Pre 141 cc/min Post 160 cc/min Time 5:13 off 11:19 Volume 29.85 L
1205 1800

Substance: _____ OSHA PEL: _____ Concentration: _____ 8 Hour TWA: _____

Hy 0.1 mg/m³ _____ _____COMMENTS: 144 min

Industrial Hygienist: _____ Reviewed By: _____

AIR SAMPLING DATA FORM

Client EPA Date 3/27/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description Personal - Air cycle

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3705-A-A-3/27-43 ^{tube} Pump # 80885 Media Hydrav
-44-Filter MCEP

Calibration: Pre 158cc/min Post 151.5 Time: On 10:21 Off 10:42 Volume 29.69L
1310 1503
1650 1752

Substance Hg OSHA PEL 0.1 mg/m³ Concentration 196 8 Hour TWA

COMMENTS:

186 min.

Industrial Hygienist:

Reviewed By:

AIR SAMPLING DATA FORM

Client EPA Date 3/27/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description Personal - Air Cycle

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3705-A-A-3/27-45 Pump # 2517 Media Hydrav
-46 MCEFCalibration: Pre 162 cc/min Post 162 cc/min Time: On 1021 Off 1042 Volume 31.75L
1:02 1310 1503Substance Hg OSHA PEL 0.1 mg/m³ Concentration 1752 8 Hour TWA 196COMMENTS: 162 min

Industrial Hygienist: _____

Reviewed By: _____

AIR SAMPLING DATA FORM

Client EPA Date 3/27/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description Av Cycle - Inside containment - on filter
down near exhaust

Work Location _____

Respirators/PPE _____

Controls _____

Sample # ~~3705 A-A-07/11~~ Pump # 3714 Media Hydrav
MCEF
2705-A-A-3/27-47

Calibration: Pre 155 cc/min Post 143 cc/min Time: On 10:21 Off 10:42 Volume 29,20 L
149 1310 1503

Substance H₂ OSHA PEL 0.1 mg/m³ Concentration 196 8 Hour TWA

COMMENTS: 146 min

Industrial Hygienist: _____

Reviewed By: _____

AIR SAMPLING DATA FORM

Client EPA Date 3/27/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description Av Cycle - Inside containment - on fiber dam
near inlet feed tube

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3705-A-A-3/27-49 Pump # 14959 Media Hydram
-50 MCEFCalibration: Pre 147 cc/min Post 132 cc/min Time: On 1021 Off 1042 Volume 27,34 L
139.5 1310 1503Substance Hg OSHA PEL 0.1 mg/m³ Concentration 196 8 Hour TWACOMMENTS: 18 1/2 min

Industrial Hygienist: _____

Reviewed By: _____

AIR SAMPLING DATA FORM

Client EPA Date 3/27/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description Filter / Pump change #1 Aircycle
Drum #1

Work Location _____

Respirators/PPE Respirators, Tyvek, goggles, gloves

Controls Jerome

Sample # 3705-AA-3/27-51 Pump # 2018 Media Hydax
-52 MCEP 5.401

Calibration: Pre 251 c/min Post 240 c/min Time: On 1350 off 1412 Volume 48.12 L
245-5 22

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS: 22 min.

Industrial Hygienist: _____

Reviewed By: _____

AIR SAMPLING DATA FORM

Client: EPA Date 3/27/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description Fi Her / Drum Change # 2 Arcycle
Drum # 1

Work Location _____

Respirators/PPE Respirators, Tyvek, Goggles, Gloves

Controls Jerome

Sample # 3705-A-A-3/27-53 Pump # 3715 Media Hydram
54 MCEF

Calibration: Pre 243 cc/min Post 242 cc/min Time: On 1449 Off 1503 Volume 3.90 L
242.5 14

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS: 14 min

Industrial Hygienist: _____

Reviewed By: _____

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840
Greenwood Village, Colorado 80111
303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 3/27/03 Job Code _____
Employee _____ SSN # _____ Job Title _____
Work Description Aircycle - overnight in containment
Let samples run throughout night. ↓ airflow
Work Location because could not get in facility to turn
off in middle of night
Respirators/PPE _____
Controls Exhaust

Sample # 3705-AA-3/27-55 Pump # 2018 Media Hydax
56 MCEP
Calibration: Time: 3/27/03
Pre 105 cc/min Post 95 cc/min On 7:24 pm Off 8:20 am on 3/28/03 Volume 77.6 L
1.0 776

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>H₂</u>	<u>0.1 mg/m³</u>		

COMMENTS: Nil min
↓

Industrial Hygienist: _____ Reviewed By: _____

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 3/27/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description air cycle - overnight in containment

let samples run throughout night. ↓

Work Location air flow, because could not get in facility to
turn off in middle of night.

Respirators/PPE _____

Controls feed tube

Sample # 3705-A-A-3/27-57 Pump # 8715 Media Hydrov
-58 MCEF

Calibration: Pre 166 cc/min Post 101.2 Time: on 3/27/03
96.4 cc/min On 7:24 Off 8:20 am Volume 78.53 L
77c

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS: 714 min

Industrial Hygienist:

Reviewed By:

AIR SAMPLING DATA FORM

Client EPA Date 3/27/03 Job Code _____
Employee _____ SSN # _____ Job Title _____
Work Description Filter Change #3 - Air Cycle
Drum #2
Work Location _____
Respirators/PPE _____
Controls _____

Sample # 3205-A-A-3/27-59 Pump # 2018 Media Hydrex
-60 MCEE

Calibration: Pre 248 cc/m Post 261 cc/m Time: On 1749 Off 1801 Volume 3.05 L
254.5 12

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS: 12 min

Industrial Hygienist: _____ Reviewed By: _____

Appendix B
Air Sampling Data Forms

Sample Shipping Information

Samples were placed in an oversized, sturdy box with packing material to fill voids and protect the samples during shipping. The sampling personnel then signed the chain-of-custody forms, and placed them in the box with the samples. Samples were shipped via Federal Express to the laboratory.

AIR SAMPLING DATA FORM

Client EPA Date 4/29/07 Job Code _____

Employee _____ SSN # ~~12708~~ Job Title 3705

Work Description Background - East Bay 24 feet east of dock door^{man}

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3705-B-4/29-01 Pump # 12708 Media Hydraz
.02 MCEP

Calibration: Pre 207.5 α /_{min} Post 203 cc/min Time: On 9:41 a.m. Off 2:39 p.m. Volume 61.16 L
205.25 298

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS: Photo #6 on my camera is of the background sample
Photo #7 is man dock door
Photo #8 - other background
298 minutes

Industrial Hygienist: _____

Reviewed By: _____

AIR SAMPLING DATA FORM

Client EPA Date 4/29/03 Job Code _____

Employee _____ SSN # _____ Job Title 3705

Work Description Background
East Bay 18ft North of ^{Max} Dock door

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3705-B-4/29-04 Pump # 13657 Media Hydram
MCEP

Calibration: Pre 206 cc/min Post 229 cc/min Time: On 9:41 am Off 2:39 pm Volume 64.8 L
217.5 298

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS: 298 minutes

Industrial Hygienist: _____ Reviewed By: _____

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840
Greenwood Village, Colorado 80111
303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 4/29/03 Job Code _____

Employee Tad Radzinski SSN # _____ Job Title _____

Work Description Feeding Tubes into Dextrose DTC Device

East Bay Inside Containment

Work Location Right shoulder / chest area

Respirators/PPE _____

Controls _____

Sample # 3705-D-A-4/29-05 Pump # 13682 Media Hydrar

-06

3:07 4:33 6:00

MCEF

Calibration:

Pre 156 cc/min

Post 158 cc/min

Time: 113

On 161 cc/min Off _____

7:20

Volume 25.81 L

158.3?

Substance OSHA PEL Concentration 8 Hour TWA

Hg 0.1 mg/m³

COMMENTS:

163 minutes

Industrial Hygienist: _____

Reviewed By: _____

AIR SAMPLING DATA FORM

Client EPA Date 4/29/03 Job Code _____

Employee Tad Radzinski SSN # _____ Job Title _____

Work Description Feeding tubes into Dextite DTC Device
East Bay Inside Containment

Work Location Left + Shoulder/chest area

Respirators/PPE _____

Controls _____

Sample # 3705-D-A-4/29-07 Pump # 13914 Media # Hydvar

Calibration: Pre 150 cc/min Post 148 cc/min Time: 3:07 4:33
On 148 cc/min Off _____ Volume 24.23 L

1867 #3

Substance OSHA PEL Concentration 8 Hour TWA

Hg 0.1 mg/m³

COMMENTS: 163 min.

Industrial Hygienist: _____

Reviewed By: _____

AIR SAMPLING DATA FORM

Client EPA Date 4/29/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description Dextrite DTC Device

Inside Containment - on fiber drum near exhaust

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3705-D-A-4/29-09 Pump # 12671 Media Hydrav

-10

#3 154 cc/min 163 minutes

MCEF

Calibration: 1
Pre 151 cc/min

Post 154 cc/min

Time: 3:07 4:33 6:09 7:20
On Off

Volume 24.94L
~~74.82L~~

153

Substance OSHA PEL Concentration 8 Hour TWA

Hg 0.1 mg/m³

COMMENTS: 163 min

Industrial Hygienist: _____

Reviewed By: _____

AIR SAMPLING DATA FORM

Client EPA Date 4/29/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description Dextrite DTC Device

Inside containment - on fiber drum near inlet

Work Location feed + 1 be

Respirators/PPE _____

Controls _____

Sample # 3705-D-A-4/29-11 Pump # 13673 Media Hydran

-12 # 156 163 MCEF

Calibration: 152 cc/min Pre 154 cc/min Post
Time: On Off Volume 25.10 L

154

Substance OSHA PEL Concentration 8 Hour TWA

Hg 0.1 mg/m³

COMMENTS: 163 m ~ UTC

Industrial Hygienist:

Reviewed By:

AIR SAMPLING DATA FORM

Client EPA Date 4/27/07 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description Dioxin DTC Device

drum change @ 168 bulbs used 347

Work Location _____ 311

698

Respirators/PPE _____

Controls _____

Sample # 3745.0-2-409-15 Prep # 1308 Media Hydrom

Calibration: Pre 252 cc/min Post 259 cc/min Time: On 4:23 Off 4:35 Volume 3.1 L

253.5

Substance _____ OSHA PEL _____ Concentration _____ 8 Hour TWA _____

Hg _____ 0.1 mg/m³ _____

COMMENTS: 12 min

Industrial Hygienist: _____

Reviewed By: _____

AIR SAMPLING DATA FORM

Client EPA Date 4/29/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description Dextrik DTC Device
Drum-change 1 @ 609 bulb,

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3705-D-A-4/29-15 Pump # 11249 Media Hyd wv
-16 MCEF

Calibration: 258 Time: 7:00pm
Pre 150 cc/min Post 259 cc/min On 250 Off 7:20pm Volume 5.08
254

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1mg/m³</u>		

COMMENTS: 20 min

Industrial Hygienist:

Reviewed By:

AIR SAMPLING DATA FORM

Client EPA Date 4/29/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description Dextrite DTC Device

Work Location Overnight - inside containment on
fiber drum near exhaust

Respirators/PPE _____

Controls _____

Sample # 3705-D-A-4/29-17 Pump # 13914 Media Hydrex
-18

Calibration: Pre 148 Post 146 cc/min Time: On 20:18 Off 8:12 Volume 104.96 L
147

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS: 714 minutes

Industrial Hygienist: _____

Reviewed By: _____

AIR SAMPLING DATA FORM

Client EPA Date 4/29/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description Dixtite DTC Devic

Work Location Overnight +/- inside containment in
fiber down near inlet feed tube

Respirators/PPE _____

Controls _____

Sample # 3705-D-A-4/29-19 Pump # 12705 Media Hydrex
-20 MCEP

Calibration: Time: 714 minutes
Pre 153 Post 149 cc/min On 2018 Off 8:12 Volume 106.39L

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1mg/m³</u>		

COMMENTS: 714 min

Industrial Hygienist:

Reviewed By:

AIR SAMPLING DATA FORM

Client EPA Date 4/29/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description Dextre DTC Device
overnight + - 0 outside containment

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3705-D-A-4/29-21 Pump # 13657 Media Hydrex
-22 mCEF

Calibration: Pre 154 Post 153 Time: On 2018 Off 8:12 Volume 109.24L

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1mg/m³</u>		

COMMENTS: 714 min

Industrial Hygienist:

Reviewed By:

AIR SAMPLING DATA FORM

Client EPA Date 4/29/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description Ceiling - 4 minute sample - (#1)

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3705-D-4-4/29-23 Pump # 11308 Media Hyd. or MCFF
-29

Calibration: Pre 251 cc/min Post 256 cc/min Time: On 7:03pm Off 7:07pm Volume 1.01 L
253.5

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>H₂</u>	<u>0.6 mg/m³</u>		

COMMENTS: 4 min

Industrial Hygienist: _____

Reviewed By: _____

AIR SAMPLING DATA FORM

Client: EPA Date: 4/24/97 Job Code: _____

Employee: _____ SSN: _____ Job Title: _____

Work Description: Colony 4 minute samples HD

Work Location: _____

Respirators/PPE: _____

Controls: _____

Sample # 3705-D-11-4/24-25 Pump # 11308 Media Hydram
26 INCEP

Calibration: 251 cc/min Part 56 cc/min Time: On 7:08 Off 7:12 Volume 1.016
2535

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hyg</u>	<u>Colony/m³</u>		

Comments: 4 min

Industrial Hygienist: _____

Reviewed By: _____

AIR SAMPLING DATA FORM

Client EPA Date 4/30/03 Job Code _____

Employee Tad Radzinski SSN # _____ Job Title _____

Work Description Air cycle

Feeding tubes into Air Cycle Device

Work Location East Bay Inside Containment

Left + shoulder - ^{chest}entire 2 drums (1st + 2nd drums)

Respirators/PPE _____

Controls _____

Sample # 3705-A-A-4/30-27 Pump # 12671 Media Hydrox
28 MCEF

Calibration: Time: 11:15 12:36 2:18 3:22
Pre 155 cc/min Post 153 cc/min On _____ Off _____ Volume 22.33L
154

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS: 145 min

Industrial Hygienist: _____

Reviewed By: _____

AIR SAMPLING DATA FORM

Client EPA Date 4/30/03 Job Code _____

Employee Tad Raczinski SSN # _____ Job Title _____

Work Description QWCycle

Work Location Feeding tubes into Air Cycle Device

East Bay Inside Containment
Right shoulder / ^{chest area} Sampling for first drum

Respirators/PPE _____

Controls _____

Sample # 3705-A-A-4/30-29 Pump # 11249 Media Hydram

Calibration: Pre 15.6 u/min Post 15.3 u/min Time: 15 81 15 min
On 11:31 OFF 12:36 Volume 12.51 L
154.5 22.40 L

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS: 81 min

Industrial Hygienist: _____

Reviewed By: _____

AIR SAMPLING DATA FORM

Client EPA Date 4/30/03 Job Code _____

Employee Tad Radzinski SSN # _____ Job Title _____

Work Description Air Cycle

Work Location Feeding tubes into Air Cycle Device

East Bay Inside Containment
Left Right shoulder/chest area for air removed drum

Respirators/PPE _____

Controls _____

Sample # 3705-A-A-4/30 Pump # 31 13657 Media Hydrex
 Calibration: -32 Time: 15 min MCFR 12.39L
 Pre 156 cfm Post 150 cfm On 11 OEE 11 Volume 27.19L
155

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Ag</u>	<u>0.1 mg/m³</u>		

COMMENTS: SA m/n

Industrial Hygienist:

Reviewed By:

AIR SAMPLING DATA FORM

Client EPA Date 4/30/03 Job Code _____

Employee Tad Budzinski SSN # _____ Job Title _____

Work Description Air Cycle

Inside Containment - on fiber drum near exhaust

Work Location _____

Respiratory/PPE _____

Controls _____

Sample # 3105-A-A-4/30-33 Resp # 11308 Media Hydraw

-34 148 min MCEF

Calibration: Pre 155 cc/min Post 153 cc/min Time: On 11:15 Off 12:56 Volume 22.79 L
154 2:18 3:25

Substance: OSHA PEL Concentration 8 Hour TWA

Hg 0.1 mg/m³

COMMENTS: 148 min

Industrial Hygienist:

Reviewed By:

AIR SAMPLING DATA FORM

Client EPA Date 4/30/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description Air CycleInside Containment - on fiber drum near feedWork Location inlet tube

Respirators/PPE _____

Controls _____

Sample # 5705-A-A-4/30 35 Pump # 11152 Media Hydrus-36 MCE IICalibration: Pre 155 cc/min Post 152 cc/min Tinet On 11:15 Off 2:15 148 min Off 12:30 3:25 Volume 27.796154

Substance _____ OSHA PEL _____ Concentration _____ 8 Hour TWA _____

H₂ 0.1 mg/m³ _____Comments: 148 min

Industrial Hygienist: _____

Reviewed By: _____

AIR SAMPLING DATA FORM

Client EPA Date 4/30/03 Job Code _____

Employee Ted SSN # _____ Job Title _____

Work Description Air Cycle
Filter change #1

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3705-AA-4/30-37 Pump # 13682 Media Hydrex
-38 MCEF

Calibration: Pre 250 cc/min Post 247 cc/min Time: On 11:40 Off 11:52 Volume 2,98 L
248 S

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS: 12 min

Industrial Hygienist: _____

Reviewed By: _____

AIR SAMPLING DATA FORM

Client EPA Date 4/30/03 Job Code _____

Employee Tad SSN # _____ Job Title _____

Work Description Arc Yole

Filter Change #2; Drum Change #1

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3705-A-A-4/30-39 Pump # 13682 Media Hydras MCEP
-40

Calibration: Pre 250 cc/min Post 247 cc/min Time: 17 min
On 12:19 Off 12:36 Volume 4.22 L

248.5

Substance OSHA PEL Concentration 8 Hour TWA

Hg 0.1 mg/m³

COMMENTS: 17 min

Industrial Hygienist: _____

Reviewed By: _____

AIR SAMPLING DATA FORM

Client EPA Date 4/30/03 Job Code _____

Employee Tad SSN # _____ Job Title _____

Work Description Air Cycle
Filter Change #3

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3705-A-A4/30-41 Pump # 13682 Media Hydrex

Calibration: Pre 250 cc/min Post 247 cc/min Time: 12 min
On 2:41 OFF 2:53 Volume 2.98L
248.5

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS: 12 min

Industrial Hygienist:

Reviewed By:

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date ^{performed on} 5/2/03 Job Code _____

Employee Tad SSN # _____ Job Title _____

Work Description RFI drum change #2

Work Location _____

Respirators/PPE _____

Controls _____

(on accident used same labels for Air Cycle machine)

should be 3705 - A - 512-73-79

Sample # 3705 - A - A 4/30 - 43 Pump # 11308 Media Hydrex mCEF

- 44

Calibration: Pre ~~251~~ Post 2470 cal Time: On 8:19 Off 8:31 Volume 3.5 L

250 cc/min 2485 2.98

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS: 12 min

Industrial Hygienist: _____ Reviewed By: _____

AIR SAMPLING DATA FORM

Client CPA Date 4/30/03 Job Code _____

Employee Tad SSN # _____ Job Title _____

Work Description Ceiling #1 Air Cycle

4 minute samples

Work Location done at filter change #1

Respirators/PPE _____

Controls _____

Sample # 3705A-A-4/30-45 Pump # 13673 Media Hydrom

-46 4 min MCE F

Calibration: Pre 249 cc/min Post 246 cc/min Time: On 12:19 OFF 12:23 Volume 0.99L

247.5

Substance	OSHA PEL	Concentration	8 Hour TWA
-----------	----------	---------------	------------

<u>H₂</u>	<u>0.1 mg/m³</u>		
----------------------	-----------------------------	--	--

COMMENTS: 4 min

Industrial Hygienist: _____

Reviewed By: _____

AIR SAMPLING DATA FORM

Client EPA Date 4/30/03 Job Code _____

Employee Ted SSN # _____ Job Title _____

Work Description Ceiling #2 Arcycle

4 minute sample

Work Location done at filter change #2
after ceiling #1

Respirators/PPE _____

Controls _____

Sample # 305-A-A-4/30-47 Pump # 13673 Media Hydrax

Calibration: -48 Time: 4 minutes
Pre 249 cc/min Post 246 cc/min On 12:25 OFF 12:29 Volume 0.99L
747-5

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS: 4 min

Industrial Hygienist:

Reviewed By:

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 4/30/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description Air Cycle - DTC Device

Work Location Overnight - inside containment dr

Fiber down near exhaust

Respirators/PPE _____

Controls _____

Sample # 3705-A-A-4/30-49 Pump # 12708 Media Hydrex

Calibration: Pre 152cc/min Post 152cc/min Time: On 4:26pm Off 8:57am Volume 150,63 L
-50
next day 991 min¹⁵
152
991

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1mg/m³</u>		

COMMENTS: 991 min

Industrial Hygienist: _____ Reviewed By: _____

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840
Greenwood Village, Colorado 80111
303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 4/30/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description Air Cycle Service

Work Location Overnight - inside containment on
Fiber drum near inlet feed tube

Respirators/PPE _____

Controls _____

Sample # 3705-AA-4/30-5 Pump # 13914 Media Hydrom

Calibration: Pre 151 cc/min Post 150 cc/min Time: next day 99 minutes MCEP
150.5 On 4:26 pm Off 8:51 am Volume 149.15 L

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS: 991

Industrial Hygienist: _____ Reviewed By: _____

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 4/30/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description Air Cycle device

overnight - outside containment

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3705-AA-4/30-53 Pump # 13673 Media Hydrar

-54

MCEF

Calibration:

Pre 157 cc/min Post 154 cc/min

155.5

Time: 991 min. max + day

On 4:26 pm Off 8:57 am

Volume 154.10 L

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS: 991 min

Industrial Hygienist:

Reviewed By:

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA TADP Date 4/30/03 Job Code _____

Employee Tad Radzinski SSN # _____ Job Title _____

Work Description Air Cycle

Feeding tubes into Air Cycle Device

Work Location East Bay Inside Containment

Right shoulder / chest area

Respirators/PPE for (second drum) ~~to~~

Controls _____

Sample # 3705-A-A-4/30-55 Pump # 11249 Media Hydrex

-56 MCEF

Calibration: Pre 153 cc/min Post 158 cc/min Time: On 2:18 off 3:25 Volume 10.42 L

155.5

Substance OSHA PEL Concentration 8 Hour TWA

Hg 0.1 mg/m³

COMMENTS: 67 min

Industrial Hygienist:

Reviewed By:

AIR SAMPLING DATA FORM

Client GPA Date 4/30/03 Job Code _____
Employee Tad Radzinski SSN # _____ Job Title _____
Work Description Air Cycle
Feeding tubes into Air Cycle Device
Work Location East Bay, Inside Containment
Left shoulder/chest area
Respirators/PPE for second drum ★
Controls _____

Sample # 3705-A-A-4/30-57 Pump # _____ Media Hydra
-58 MCEF
Calibration: 67 min
Pre 150 cc/min Post 151 cc/min On 2:18 OFF 3:25 Volume 10,08 L
150.5

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS: 67 min

Industrial Hygienist:

Reviewed By:

AIR SAMPLING DATA FORM

Client EPA Date 4/31/09 Job Code _____

Employee ted SSN # _____ Job Title _____

Work Description Fitt Drum Change #2 + Filter change #4

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3705-4/31 ^{A-A-4/31-59} Pump # 11308 Media Hydraw
-60 mCEF

Calibration: Pre 255 cc/min Post 256 cc/min Time: On 9:09:21 Off 9:33 Volume 3.07 L
255.5

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS: 12 min

Industrial Hygienist: _____

Reviewed By: _____

AIR SAMPLING DATA FORM

Client EPA Date 5/1/03 Job Code _____
Employee Tad Radzinski SSN # _____ Job Title _____
Work Description RTI
Feeding tubes into RTI device
Work Location East Bay Inside Containment
Left + Shoulder / chest area
Respirators/PPE Entire 1st + 2nd draw
Controls _____

Sample # 3705-A-A-^{5/1}~~42~~-61 Pump # 13073 Media Hydrar
-62 MCEF
Calibration: Time: 12:08 - 1:27 | 3:50 - 4:53
Pre 154 cc/min Post 154 cc/min On _____ Off _____ Volume 21.87 L
154

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>H₂</u>	<u>0.1 mg/m³</u>		

COMMENTS: 142 mV

Industrial Hygienist:

Reviewed By:

AIR SAMPLING DATA FORM

Client EPA Date 5/1/03 Job Code _____

Employee Jed Radzinski SSN # _____ Job Title _____

Work Description RTI

Work Location Feeding tubes into RTI device

Last leg inside containment
LEFT shoulder/chest area for (1st drum) *

Respirators/PPE _____

Controls _____

Sample # 3705-R-17-5/1-03 Pump # 13914 Media Hydrex

-44 79 min MCEF

Calibration: Pre 150 cc/min Post 149 cc/min Time: On 12:03 OFF 1:27 Volume 11.81 L

149.5

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS: 79 min

Industrial Hygienist: _____

Reviewed By: _____

AIR SAMPLING DATA FORM

Client EPA Date 5/1/03 Job Code _____

Employee Tad Radzinski SSN # _____ Job Title _____

Work Description RT 1

Work Location Feeding tubes into RT 1 Denie

East Bay Inside Containment

Right shoulder / chest area sampling for 1st drum

Respirators/PPE _____

Controls _____

Sample # 3705-K-A-5/1/03⁶⁵ Pump # 12708 Media Hydrom
-66 mCEF

Calibration: Pre 152 c/ppm Post 151 c/ppm Time: 79 min
151.5 On 12:08 Off 1:27 Volume 11,97L

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hy</u>	<u>0.1 mg/m³</u>		

COMMENTS: 79 min

Industrial Hygienist: _____

Reviewed By: _____

AIR SAMPLING DATA FORM

Client EPA Date 5/1/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description RTI

Work Location Inside containment - on fiber drum near exhaust

Respirators/PPE _____

Controls _____

Sample # 3705-R-A-5/1-67 Pump # 12671 Media Hydrex

Calibration: Pre 157 cc/min Post 156.5 cc/min Time: On 1200-1:27 Off 3:50-4:53 Volume 22.22 L

OSHA PEL 0.1 mg/lm?

Substance Ag Concentration _____ 8 Hour TWA _____

Comments: 192 min

Industrial Hygienist: _____ Reviewed By: _____

AIR SAMPLING DATA FORM

Client GPA Date 5/1/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description RTIWork Location Inside containment - on fiber down near feed inlet tube

Respirators/PPE _____

Controls _____

Sample # 3702-R.A-5/1-69ump # 11249 Media HydroCalibration: -7% Time: 1.27 4.53 3.50
Pre 156 cc/min Post 155 cc/min On 17 Off _____ Volume 22.06 L155.5

Substance _____ OSHA PEL _____ Concentration _____ 8 Hour TWA _____

Hg0.1mg/m³COMMENTS: 142 min

Industrial Hygienist: _____

Reviewed By: _____

AIR SAMPLING DATA FORM

Client EPA Date 5/1/03 Job Code _____

Employee Tad SSN # _____ Job Title _____

Work Description ATI
drum change #1

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3705 R-A.5/1-71 Pump # 11300 Media Hydrol
-72 MCEF

Calibration: Pre 256 cc/min Post 256 cc/min Time: On 1:15 Off 1:27 Volume 3.07 L
256

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS: 12 min

Industrial Hygienist: _____ Reviewed By: _____

AIR SAMPLING DATA FORM

Client EPA Date 5/1/03 Job Code _____

Employee Tad SSN # _____ Job Title _____

Work Description Ceiling #1 KTI

4 minute samples

Work Location done at drum change for 1st drum

Respirators/PPE _____

Controls _____

Sample # 3705-R-A-5/1-75 Pump # 13682 Media Hydrex

-76

MCEF

Calibration:

Pre 253 Post 253 Time: On 1:15 Off 1:19 Volume 1.01 L

Substance OSHA PEL Concentration 8 Hour TWA

Hg 0.1mg/m³

COMMENTS: 4 min

Industrial Hygienist:

Reviewed By:

AIR SAMPLING DATA FORM

Client GPA Date 5/1/03 Job Code _____

Employee TAD SSN # _____ Job Title _____

Work Description ceiling #2 RTI

4 minute sample

Work Location above a + down change for 1st down

Respirators/PPE _____

Controls _____

Sample # 3705-R-Asis/1-71 13682 Media Hydrox

Calibration: Pre 256cc/min Post 256cc/min Time: On 1:20 Off 1:24 Volume 1.01 L

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1mg/m³</u>		

COMMENTS: 4 min

Industrial Hygienist: _____ Analyzed By: _____

AIR SAMPLING DATA FORM

Client EPA Date 5/1/03 Job Code _____
Employee Tad Radzinski SSN # _____ Job Title _____
Work Description RTZ
Feeding tubes
Work Location East Bay Inside Containment
Left Shoulder / chest area for 2nd down ★
Respirators/PPE _____
Controls _____

Sample # 3705-RA-5/1-79 Pump # 13914 Media Hydrav
-80 63 mm MCEA

Calibration: Pre 149 cc/min Post 147 cc/min Time: On 3:50 Off 4:53 Volume 9.32 L
148

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS: 63 mm

Industrial Hygienist: _____ Reviewed By: _____

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 5/1/03 Job Code _____

Employee Tad Radzinski SSN # _____ Job Title _____

Work Description RTI

Work Location Feeding Area

East Bay Inside Containment

Right shoulder/chest area for 2nd down *

Respirators/PPE _____

Controls _____

Sample # 3705-R-A-5/1-81 Pump # 12708 Media Hydra

-82

MCEP

Calibration: Pre 151 cc/min Post 149 cc/min Time: On 3:50 off 4:53 Volume 9.45 L

150

Substance	OSHA PEL	Concentration	8 Hour TWA

COMMENTS: 63 min

Industrial Hygienist: _____

Reviewed By: _____

AIR SAMPLING DATA FORM

Client EPA Date 5/1/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description RTI

Work Location overnight - inside containment dr
fiber drum near exhaust

Respirators/PPE _____

Controls _____

Sample # 3705-R-A-511-83 Pump # 13657 Media Hydra
-84 MCEF

Calibration: Pre 155 cc/min Post 153 cc/min Time: 874 min
154 On 5:33pm 5/1/03 Off 8:07am 5/2/03 Volume 134.6 L

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS: 874 min

Industrial Hygienist: _____

Reviewed By: _____

AIR SAMPLING DATA FORM

Client: EPA Date: 5/1/03 Job Code: _____

Employee: _____ SSN #: _____ Job Title: _____

Work Description: RTI

Work Location: overnight - inside containment on

filter down near inlet feed tube

Respirators/PPE: _____

Controls: _____

Sample #: 3705-R-A-5/1-03 Pump #: 1115.2 Media: Hydrex

Calibration: -86 Time: 874 m.u.
Pre: 156 cc/min Post: 152 cc/min On: 5:33 pm Off: 8:01 am Volume: 134.60

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS: 474 m.u.

Industrial Hygienist: _____

Reviewed By: _____

AIR SAMPLING DATA FORM

Client EPA Date 5/1/03 Job Code _____
Employee _____ SSN # _____ Job Title _____
Work Description RTI
overnight - outside containment
Work Location _____
Respirators/PPE _____
Controls _____

Sample # 3705-R-A-5/1-87 Pump # IP-112019 Media Hydraw
-88 IP-452
Calibration: Pre 150cc/min Post 160cc/min Time: On 5:33pm Off 8:07am Volume 137.66 L
155cc/min 9157.5 5/1/03 5/2/03

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1mg/m³</u>		

COMMENTS: 874 m.w

Industrial Hygienist: _____ Reviewed By: _____

AIR SAMPLING DATA FORM

Client EPA Date 5/2/07 Job Code _____

Employee Tad SSN # _____ Job Title _____

Work Description Tad - Left Shoulder - Draw #1

Work Location Dextrite
only 1 draw for this test

Respiratory/PPE _____

Controls _____

Sample # 3205-0-0-5/2-89 Rep # 13657 Media Hydra
-90 MSFP

Calibration: Pre 1536/min Post 1546/min Time: 56 min.
1535 Off 9:07 Volume 8.60 L

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.100/m³</u>		

Comments: Skipped

Industrial Hygienist: _____ Reviewed By: _____

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client GPA Date 5/2/03 Job Code _____

Employee Tad SSN # _____ Job Title _____

Work Description Right shoulder Drum #1

Dextrite

Work Location only 1 drum filled for this test

Respirators/PPE _____

Controls _____

Sample # 3705-D-A-5/2-91 Pump # 11249 Media Hydran

-92

MCFE

Calibration:

Pre 154 cc/min Post 153 cc/min Time: On 9:07 Off 10:03 Volume 8.60 L

153.5

Substance OSHA PEL Concentration 8 Hour TWA

Hg 0.1 mg/m³

COMMENTS: 56 min

Industrial Hygienist:

Reviewed By:

AIR SAMPLING DATA FORM

Client EPA Date 5/2/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description Dextrite - only 1 drum filled

Inside containment on fiber drum near

Work Location exhaust

Respirators/PPE _____

Controls _____

Sample # 3705-D-A-5/2-93 Pump # 11152 Media MCEP
-94

Calibration: Pre 151cc/min Post 154cc/min Time: on 9:07 off 10:04 Volume 8.69L
152.5

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1mg/m³</u>		

COMMENTS: 57 min

Industrial Hygienist: _____

Reviewed By: _____

BOOZ-ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 5/2/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description Dextite - only fill one drum

Work Location Inside containment on fiber drum near inlet feed tube

Respirators/PPE _____

Controls _____

Sample # 3705-DA-5/2-95 Pump # 12708 Media Hydro
-96 mCF

Calibration: Pre 153 cc/min Post 151 cc/min Time: On 9:07 Off 10:09 Volume 8.66L
152

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS: 57 min

Industrial Hygienist: _____

Reviewed By: _____

BOOZ-ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client GPA Date 5/2/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description Dextrite

Drum change for 1 drum filled

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3705-D-A-5/2-97 Pump # 11308 Media Hydraw
-98 MCEF

Calibration: Pre 25 bcc/min Post 25 bcc/min Time: On 9:50 Off 10:02 Volume 3.07 L

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS: 12 min

Industrial Hygienist: _____

Reviewed By: _____

Appendix B

Air Sampling Data Forms

Sample Shipping Information

Samples were placed in an oversized, sturdy box with packing material to fill voids and protect the samples during shipping. The sampling personnel then signed the chain-of-custody forms, and placed them in the box with the samples. Samples were shipped via Federal Express to the laboratory.

AIR SAMPLING DATA FORM

Client EPA Date 6/9/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description Background Samples taken at AEC Facility in
Ashland Virginia

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3105-BA-6/9-01 Pump # 13681 Media Hydra

Calibration: 221 l/min -02 Time: 204 min MCEE

Pre 207 cal/mn Post 236 On 4:19 pm Off 9:03 pm Volume 58.3 l

221.5

Substance	OSHA PEL	Concentration	8 Hour TWA
-----------	----------	---------------	------------

COMMENTS:

Industrial Hygienist:

Reviewed By:

JZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840
Greenwood Village, Colorado 80111
303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client CEA Date 6/9/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description background samples taken at AEEC Facility in
Ashland Virginia

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3705-B-A-6/9-03 Pump # R 2015 Media Hydrus

Calibration: 205 l/min Time: 264 mi MCEF

Pre 204 cc/min Post 207 cc/min On 4:19 pm Off 9:03 pm Volume 54.1 L

Substance	OSHA PEL	Concentration	8 Hour TWA

COMMENTS:

Industrial Hygienist: _____

Reviewed By: _____

BOOZ-ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 6/10/03 Job Code _____

Employee Tad Radzinski SSN # _____ Job Title _____

Work Description RTI Denie

entire 2 drums - LEFT SHOULDER

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3705-RA-6/10-05 Pump # 11249 Media Hydran

Calibration: .195 L/min Time: 9:55-11:02 ^{LT}
Pre 195 cc/min Post 196 cc/min On 12:11-1:13 ^{OFF} Volume 25.2 L

129 min

Substance	OSHA PEL	Concentration	8 Hour TWA
-----------	----------	---------------	------------

<u>Hy</u>	<u>0.1 mg/m³</u>		
-----------	-----------------------------	--	--

COMMENTS:

Industrial Hygienist:

Reviewed By:

BOOZ-ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 6/10/09 Job Code _____

Employee Tad Redzinski SSN # _____ Job Title _____

Work Description RTI Denize

Feeding bulbs in drum #1 ONLY -

Work Location LEFT SHOULDER

Respirators/PPE _____

Controls _____

Sample # 3705-R-A-6/0-07 Pump # 11152 Media Hydra

Calibration: 200 cfm - 08 Time: 9:55-11:02 CFM MDF

Pre 201 cfm/min Post 200 cfm/min On Off Volume 13.4

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS:

Industrial Hygienist: _____ Reviewed By: _____

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 6/10/03 Job Code _____

Employee Tad Radzinski SSN # _____ Job Title _____

Work Description RTI Device

Feeding bulbs in drum #1 ONLY

Work Location RIGHT SHOULDER

Respirators/PPE _____

Controls _____

Sample # 3705-R-A-6/10-09 Pump # 112711 Media Hydram

Calibration: 0.202 $\frac{cc}{min}$ Time: 9:55-10:02 CFM
Pre 203 $\frac{cc}{min}$ Post 202 $\frac{cc}{min}$ On _____ Off _____ Volume 13.5L

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hy</u>	<u>0.1 mg/m^3</u>		

COMMENTS:

Industrial Hygienist:

Reviewed By:

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 6/10/05 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description RTI Device

Work Location Inside containment while feeding bulbs - near Exhaust

Respirators/PPE _____

Controls _____

Sample # 3705-R-A-6/10-11 Pump # 12654 Media Hydrav

Calibration: 0.201 μ m⁻¹² Time: 9:39-11:02 83
Pre 202 cc/min Post 201 cc/min On 12:11-1:13 Off 62 min Volume 29.1 l

45

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS:

Industrial Hygienist:

Reviewed By:

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 6/10/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description RTI Device

Work Location Inside Containment while feeding bulbs near inlet feed tube

Respirators/PPE _____

Controls _____

Sample # 3705-2-A-6/10-13 Pump # 13681 Media Hydrus

Calibration: 0.201 Time: 9:39-11:02 SB MCEP

Pre 200 cc/min Post 202 cc/min On 12:11-1:13 Off 62 Volume 29.1

145

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS: _____

Industrial Hygienist:

Reviewed By:

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 6/16/03 Job Code _____

Employee Tad Redmski SSN # _____ Job Title _____

Work Description On Tad's shoulder while performing Drum change #1

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3705-R-A-610-15 Pump # R2015 Media Hydram

Calibration: 0.259 Lpm Time: 10:50-11:02 12min
Pre 260 cc/min Post 259 cc/min On _____ Off _____ Volume 3.1 L

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS: _____

Industrial Hygienist:

Reviewed By:

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 6/10/03 Job Code _____

Employee Tad Radzinski SSN # _____ Job Title _____

Work Description on Tad's shoulder while performing Drum Change # 2

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3705-R-A.4/10-17 Pump # R2015 Media Hydran

-18 MCEF

Calibration: 0.259 lpm Time: 1:01 - 1:13 12 min

Pre 260 cc/min Post 259 cc/min On _____ Off _____ Volume 3.12

Substance OSHA PEL Concentration 8 Hour TWA

Hg 0.1 mg/m³ _____

COMMENTS: _____

Industrial Hygienist: _____

Reviewed By: _____

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 6/10/03 Job Code _____
Employee Tad Radeinski SSN # _____ Job Title _____
Work Description on tad's shoulder during drum #1 change
ceiling sample #1
Work Location _____
Respirators/PPE _____
Controls _____

Sample # 3705-R-A-6/10-19 Pump # 12708 Media Hydram
MCEF
Calibration: 0.251 ⁻²⁰ Time: 10:50-10:54 4 min
Pre 252 cc/min Post 250 cc/min On _____ Off _____ Volume 1.02

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS:

Industrial Hygienist: _____ Reviewed By: _____

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840
Greenwood Village, Colorado 80111
303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client QPA Date 6/10/03 Job Code _____

Employee Tad Rademski SSN # _____ Job Title _____

Work Description on Tad's shoulder during down #2 change ceiling sample #2

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3705-R-A-6/10-21 Pump # 12708 Media Hydrom

Calibration: 0.251 ⁻²² lpm Time: 10:55-10:59 4min
Pre 252 ccf/m Post 250 ccf/m On _____ Off _____ Volume 1.08

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>H₂</u>	<u>0.1 mg/m³</u>	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____

COMMENTS:

Industrial Hygienist: _____ Reviewed By: _____

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date _____ Job Code _____

Employee Tads SSN # _____ Job Title _____

Work Description On Tads LEFT Shoulder
Drum #2 Whisper Ultra

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3705-R-A-6/10-23 Pump # 11308 Media Hydra

Calibration: 0.198 ⁵²⁴ lpm Time: 12:11-13 62 km
Pre 198 cc/min Post 199 cc/min On _____ Off _____ Volume 12.32

Substance	OSHA PEL	Concentration	8 Hour TWA

COMMENTS:

Industrial Hygienist:

Reviewed By:

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 6/10/03 Job Code _____

Employee Tad Radzinski SSN # _____ Job Title _____

Work Description On Tad's ~~shoulder during drum~~ Tad's
RIGHT shoulder Drum #2

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3705-R-A-6/10-25 Pump # R 2992 Media Hydrex
-26 mCEF

Calibration: 0.198 liter Time: 12:11-1:13 62 ml
Pre 200 cc/min Post 197 cc/min On _____ Off _____ Volume 12.3 l

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____

COMMENTS:

Industrial Hygienist: _____ Reviewed By: _____

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA

Date 6/10/03

Job Code _____

Employee _____

SSN # _____

Job Title _____

Work Description Overnight samples - inside containment
the Near Exhaust

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3705-R-A-6/10-27 Pump # _____

11254

Media Hydram

MCEP

Calibration: 0.155 lpm

Pre 155 c/min

Post 155 c/min

Time: 6:11 pm - 12:11 pm

On _____

Off 360

Volume 55.80

Substance

OSHA PEL

Concentration

8 Hour TWA

Hg

0.1 mg/m³

COMMENTS:

Industrial Hygienist: _____

Reviewed By: _____

BOOZ ALLEN & HAMILTON

12

5299 DTC Blvd., Suite 840
Greenwood Village, Colorado 80111
303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date _____ Job Code _____
Employee _____ SSN # _____ Job Title _____
Work Description Overnight samples - inside containment near feed table
Work Location _____
Respirators/PPE _____
Controls _____

Sample # 3705-R-A-6/10-29 Pump # ~~13911~~ 13681 Media Hydrex
Calibration: 0.152 ³⁰ lp Time: 6:11pm-12:11pm MCET
Pre ~~150 cfm~~ Post 153 cfm On _____ Off 36 Volume 54.7 l
151 cfm

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>H₂</u>	<u>0.1 mg/m³</u>		

COMMENTS:

Industrial Hygienist:

Reviewed By:

BOOZ-ALLEN & HAMILTON

5299 DTC Blvd., Suite 840
Greenwood Village, Colorado 80111
303.694.4159 FX. 303.694.7367

7

AIR SAMPLING DATA FORM

Client: GPA Date _____ Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description: overnight samples - outside containment

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3705-R-13-6/10-31 Pump # 12708 Media Hydrar MCEP

Calibration: 0.156 ⁻³² cfm Time: 6:11 pm - 12:11 pm
Pre 157 cfm Post 156 cfm On _____ Off 300 W Volume 56.2 l

Substance	OSHA PEL	Concentration	8 Hour TWA

COMMENTS:

Industrial Hygienist: _____

Reviewed By: _____

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840
Greenwood Village, Colorado 80111
303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 6/10/03 Job Code _____

Employee Tad Radzinski SSN # _____ Job Title _____

Work Description Personal Sampling during maintenance - RTI Equip

Work Location Right Shoulder Compressor

Respirators/PPE _____

Controls _____

Sample # 3705-R-A-6/10-33 Pump # 11249 Media Hydram

Calibration: 0.195 ⁻³⁴ Open Time: 1:16-2:20 4 min MCEF

Pre 196 column Post: 196 On _____ Off _____ Volume 12.5L

Substance OSHA PEL Concentration 8 Hour TWA

Hg 0.1 mg/m³ _____

COMMENTS: _____

Industrial Hygienist:

Reviewed By:

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 6/10/03 Job Code _____

Employee Tad Radzinski SSN # _____ Job Title _____

Work Description Personal Sampling during one drum - RTI - equip.
Left shoulder Comparison _____

Work Location _____ phase II _____

Respirators/PPE _____

Controls _____

Sample # 3705 R-A-6/10-35 Pump # R. 2992 Media Hydram

Calibration: 0.196 ^{-3h} Apr Time: 1:16-2:20
Pre 197 cc/min Post 195 On _____ Off 64 min Volume 12.50

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>H₂</u>	<u>0.1 mg/m³</u>		

COMMENTS:

Industrial Hygienist: _____

Reviewed By: _____

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 6/10/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description ATE equip comparison phase II - filling 1 drum
Inside Containment - Exhaust

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3705-R-A-6/10-37 Pump # 11308 Media Hydram

Calibration: 0.197 ⁻³⁸ Open Time: 4:14-5:12 58min MCFF
Pre 199 cd/min Post 196 On _____ Off _____ Volume 11.40

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hy</u>	<u>0.1 mg/m³</u>		

COMMENTS: _____

Industrial Hygienist:

Reviewed By:

BOOZ-ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client GIA Date 6/10/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description RII Equipment Comparison Phase II - filling Idm
Inside Containment - Exhaust

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3705-R-A-6/10-39 PUMP # 12664 Media Hydra
mCEF

Calibration: 0.198 ⁻⁴⁰ Open Time: 4:14 - 5:12
Pre 20 lcc/min Post 196 On _____ OFF 58 min Volume 11.5 L

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1mg/m³</u>		

COMMENTS:

Industrial Hygienist:

Reviewed By:

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EIA Date 6/10/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description RTI - Equipment Comparison Phase II - Alling Idema
Inside Containment @ feed tube

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3705-R-A-6/10-41 Pump # ~~13681~~ 13681 Media Hydrom

Calibration: 0.200 ⁴² rpm Time: 13681 4:14 - 5:12 mCEF
Pre ~~302~~ 202 cc/min Post 198 On _____ Off 58 min Volume 11.6 L

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS: _____

Industrial Hygienist:

Reviewed By:

BOOZ-ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client GPA Date 6/10/03 Job Code _____
Employee _____ SSN # _____ Job Title _____
Work Description RTI Equip. Comparison Phase II - filling one drum
Inside container + @ feel like
Work Location _____
Respirators/PPE _____
Controls _____

Sample # 3705-R-A-4/10-43 Pump # 112711 Media Hg drum
Calibration: 0.1862pm-168 Time: 4:14-5:12 MCEF
Pre 204 cc/min Post 204 cc/min On _____ OFF 58 min Volume 10.8 l

Substance	cc/min	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>		<u>0.1 mg/m³</u>		

COMMENTS:

Industrial Hygienist:

Reviewed By:

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 6/10/03 Job Code _____

Employee Tad Radzinski SSN # _____ Job Title _____

Work Description personal sampling - RTI equip. comparison phase during drum change

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3705-R-A-410-45 Pump # R2015 Media Hydrom

Calibration: 0.261 lpm Time: 7:56 - 8:08 M L E F
Pre 263 cc/min Post 260 cc/min On _____ Off 12 min Volume 3.1 l

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>H₂</u>	<u>0.1 mg/m³</u>		

COMMENTS:

Industrial Hygienist:

Reviewed By:

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 6/10/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description Box Test

Taken after finished filling 2 drums for RTI.

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3705-T-A-6/10-47 Pump # 11152 Media Hydra

MCEF

Calibration: 0.199 Lpm Time: 1:16 2:20

Pre 200 cc/min Post 199 cc/min On _____ Off 64 min Volume 12.7 L

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hy</u>	<u>0.1 mg/m³</u>		

COMMENTS:

Industrial Hygienist:

Reviewed By:

BOOZ-ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EIA Date 6/10/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description Box Test

Taken after finished filling 2 drums for RTI

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3705-T-A-6/10-49 Pump # 112711 Media Hy drum

Calibration: 0:203 Time: 1:16-2:20
Pre 202 cc/min Post 204 cc/min On Off 64 min Volume 13.0 l

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS:

Industrial Hygienist:

Reviewed By:

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client GFA Date 6/10/03 Job Code _____

Employee Tad R. Dobson SSN # _____ Job Title _____

Work Description RTI - Equip. Comparison Phase II - Filling area above
Ceiling Sample #1

Work Location _____
4 min. Sample

Inspirators/PPE _____

Controls _____

Sample # 3705-LA-6/10-51 Pump # 11177 Media Hydrac
MCE F

Calibration: 0.2470 52 Time: 7:56 - 8:00
Flow 249 c/min off 4 min Volume 1.0 l
246

Substance	OSHA PEL	Concentration	8 HOUR TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

Comments: _____

Industrial Hygienist:

Reviewed By:

BOOZ-ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client GFA Date 6/10/03 Job Code _____

Employee Tad Radzinski SSN # _____ Job Title _____

Work Description RTF - Equip Comparison Phase II - Filling media
Ceiling sample #2

Work Location _____
4mm sample

Respirators/PPE _____

Controls _____

Sample # 3705-R-A-6/10-53 Pump # 11177 Media Hydrac
in CEF

Calibration: 0.247 54 Time: 8:01 - 8:05
Pre 246 cc/min Post 248 cc/min On _____ Off 4m Volume 1.02

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1mg/m³</u>		

COMMENTS:

Industrial Hygienist:

Reviewed By:

Appendix B
Air Sampling Data Forms

Sample Shipping Information

Samples were placed in an oversized, sturdy box with packing material to fill voids and protect the samples during shipping. The sampling personnel then signed the chain-of-custody forms, and placed them in the box with the samples. Samples were shipped via Federal Express to the laboratory.

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 6/11/03 Job Code _____
Employee Tad SSN # _____ Job Title _____
Work Description Dextric device
entire 2 arms - LEFT shoulder
Work Location _____
Respirators/PPE _____
Controls _____

Sample # 3105-D-A-611-55 Pump # 11249 Media Hydrom
-56 mCEF
Calibration: 0.198 Open Time: 10:20 - 11:25 59
Pre 198 cc/min Post 198 cc/min On 12:41 - Off 1:19 38 Volume 19.28
97

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS:

Industrial Hygienist: _____ Reviewed By: _____

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 6/11/03 Job Code _____

Employee Tad SSN # _____ Job Title _____

Work Description Dextrite Device

1st drum - LEFT Shoulder

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3705-D-A-6/11-57 Pump # 11308 Media Hydra

Calibration: 0.198 Open Time: 10:20 - 11:25 -59
Pre 200 cc/min Post 196 cc/min On 12:44 OFF 1:19 38 mCEF Volume 11.72
19.22

Substance	OSHA PEL	Concentration	8 Hour TWA
-----------	----------	---------------	------------

<u>Hg</u>	<u>0.1 mg/m³</u>		
-----------	-----------------------------	--	--

COMMENTS: _____

Industrial Hygienist: _____

Reviewed By: _____

BOOZ-ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 6/11/03 Job Code _____

Employee Tad SSN # _____ Job Title _____

Work Description Dextrok Device

1st Drum RIGHT Shoulder

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3705-D-A-6/11-59 Pump # 12664 Media Hydro

Calibration: 0.200 ⁻⁶⁰ Open Time: 10:20-11:25 59 MCF
Pre 202 cal Post 199 cal On 12:41 Off 59 Volume 11.8 L
19.8 L

Substance OSHA PEL Concentration 8 Hour TWA

Hy 0.1 mg/m³ _____

COMMENTS:

Industrial Hygienist:

Reviewed By:

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840
Greenwood Village, Colorado 80111
303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 6/11/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description Dextrite Dense

Work Location Inside Containment - near Exhaust on Road

Work Location fiber drum.

Respirators/PPE _____

Controls _____

Sample # 3705-D-A-6/11-61 Pump # R 2992 Media Hydrex

Calibration: 0.203 Lpm Time: 10:20 - 11:27 61
Pre 203 cc/min Post 203 cc/min On 12:41 Off 1:19 38 MCEF
Volume 20.12

99

Substance OSHA PEL Concentration 8 Hour TWA

Hg 0.1 mg/m³ _____

COMMENTS:

Industrial Hygienist:

Reviewed By:

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840
Greenwood Village, Colorado 80111
303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 6/11/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description Poxite Device

Work Location Inside containment - near inlet feed tube on

round fiber drum

Respirators/PPE _____

Controls _____

Sample # 3705-D-A-6/11-63 Pump # 112711 Media Hydrox

Calibration: 0.210 ⁻⁶⁴ Open Time: 10:26 - 11:27 61
Pre 209 cc/min Post 211 cc/min On 12:41 - 01:19 38 Volume 20.8 l
99

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS:

Industrial Hygienist: _____ Reviewed By: _____

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client GIA Date 6/11/05 Job Code _____

Employee Tad SSN # _____ Job Title _____

Work Description Dextrite Penice

Drum change # 2, 1

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3705-D-A-6/11-65 Pump # R 2015 Media Hydro.

Calibration: -66 Time: ' _____
Pre 260 cc/min Post 260 cc/min On 11:05 Off 11:25 Volume 5.28

20

Substance	OSHA PEL	Concentration	8 Hour TWA
-----------	----------	---------------	------------

<u>Hg</u>	<u>0.1 mg/m³</u>		
-----------	-----------------------------	--	--

COMMENTS: _____

Industrial Hygienist: _____

Reviewed By: _____

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 6/11/03 Job Code _____
Employee Tad SSN # _____ Job Title _____
Work Description Dextrok Penite
Drum change #2
Work Location _____
Respirators/PPE _____
Controls _____

Sample # 3705-DA-6/11-67 Pump # R 2015 Media Hydro
-68 MCEF
Calibration: 0.2000 ppm Time: _____
Pre 260 cal/min Post 261 cal/min On 1:39 Off 1:51 Volume 3.12
12 min

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS:

Industrial Hygienist: _____ Reviewed By: _____

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EIA Date 6/11/03 Job Code _____

Employee TAD SSN # _____ Job Title _____

Work Description Dextite Device

Work Location ceiling sample - taken at drum change #1

4 min. sample

Respirators/PPE _____

Controls _____

Sample # 3705-D-A-6/11-69 Pump # 11177 Media Hydra
MUEF

Calibration: 0.255 ⁻⁷⁰ lpm Time: _____
Pre 254 cc/min Post 257 cc/min On 11:05 Off 11:45 Volume 1.00
4

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS:

Industrial Hygienist: _____

Reviewed By: _____

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client CAA Date 6/11/03 Job Code _____

Employee Tad SSN # _____ Job Title _____

Work Description Dextite device

ceiling sample - taken at drum change #1

Work Location _____

4 min. sample

Respirators/PPE _____

Controls _____

Sample # 3705-DA-6/11-7 Pump # 11177 Media Hydrex MCEF

Calibration: 0.255-72 Time: _____
Pre 254cc/min Post 257cc/min On 11:11 OFF 11:15 Volume 1.02

4

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1mg/m³</u>		

COMMENTS: _____

Industrial Hygienist:

Reviewed By:

BOOZ-ALLEN & HAMILTON

5299 DTC Blvd., Suite 840
Greenwood Village, Colorado 80111
303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 6/11/03 Job Code _____

Employee Tal SSN # _____ Job Title _____

Work Description Pesticide Decont

Work Location 2nd Drum LEFT Shoulder

Respirators/PPE _____

Controls _____

Sample # 3705-D-A-6/11-73 Pump # 13681 Media Hydrex

Calibration: 0.202 ⁻⁷⁴ cpm Time: _____
Pre 202 cc/min Post 202 cc/min On 12:41 Off 1:19 Volume 7.7 l
38

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS:

Industrial Hygienist: _____

Reviewed By: _____

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 6/11/03 Job Code _____

Employee TJD SSN # _____ Job Title _____

Work Description Dextite Device

2nd Draw RIGHT Shoulder

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3705-D-A-6/11-75 Pump # 11152 Media Hydra
13914

Calibration: 0.204 76 Time: _____
Pre 206 cc/min Post 206 cc/min On 12:52 Off 1:19 Volume 5.52
202 27

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1mg/m³</u>		

COMMENTS:

Industrial Hygienist: _____ Reviewed By: _____

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 6/11/09 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description Dextrolle device
Overnight air sampler placed near exhaust

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3705-D-A-6/11-77 Pump # 11254 Media Hydram

Calibration: 0.157 ⁻⁷⁸ Post 136 cc/min Time: 5:53 On 7:15 Off 802 min Volume 125.90

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>H₂</u>	<u>0.1 mg/m³</u>		

COMMENTS: _____

Industrial Hygienist:

Reviewed By:

BOOZ-ALLEN & HAMILTON

5299 DTC Blvd., Suite 840
Greenwood Village, Colorado 80111
303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client GPA Date 6/11/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description Pextrite Device

Overnight Air Sample - placed near inlet feed tube

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3705-D-A-6/11-79 Pump # 1177 Media Hydrex

Calibration: 0.154 ppm -80 Time: 5:53 PM On 7:15 AM Off
Pre 153 cc/min Post 156 cc/min Volume 123.50
802 min

Substance	OSHA PEL	Concentration	8 Hour TWA
-----------	----------	---------------	------------

<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS: 360 + 420 + 7 + 15

Industrial Hygienist: _____

Reviewed By: _____

BOOZ-ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client GPA Date 6/11/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description Pcxrite Device

Overnight air sampler placed outside conference room

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3705-D-A-6/11-81 Pump # 11152 Media # ydrac

Calibration: 0.141 lpm Time: 5:53 pm 6/11
Pre H2 calibrator Post 140 c/min On 7:15 pm OFF 6/11/03 Volume 113.1 L
-82 802 ml

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>H₂</u>	<u>0.1 mg/m³</u>		

COMMENTS:

Industrial Hygienist: _____

Reviewed By: _____

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840
Greenwood Village, Colorado 80111
303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client GPA Date 6/11/03 Job Code _____

Employee Ted SSN # _____ Job Title _____

Work Description Dextrose Penic

Work Location U-TUBE Study on Teds Left Shoulder

Respirators/PPE _____

Controls _____

Sample # 3705-D-A-6/11-83 Pump # 12664 Media Hydra

Calibration: 0.200 lpr Time: _____
Pre 199 cc/min Post 201 cc/min On 1:23 OFF 1:35 Volume 2.42
12 min

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS:

Industrial Hygienist: _____ Reviewed By: _____

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 6/11/03 Job Code _____
 Employee Tad SSN # _____ Job Title _____
 Work Description Dextrose Dewice
U-TUBE Study on Tad's Right Shoulder
 Work Location _____
 Respirators/PPE _____
 Controls _____

Sample # 3705-0-A-6/11-85 Pump # 11308 Media Hydram
in CEF
 Calibration: 0.197⁻⁸⁶ Open Time: _____
 Pre 196 cc/min Post 199 cc/min On 1:23 Off 1:35 Volume 2.42
12

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hy</u>	<u>0.1 mg/m³</u>		

COMMENTS:

Industrial Hygienist: _____ Reviewed By: _____

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client QPA Date 6/11/03 Job Code _____

Employee Tad SSN # _____ Job Title _____

Work Description Dextite Device

~~W-Tube Study on Tad's~~

Work Location Inside Containment near Exhaust - U-TUBES

Respirators/PPE _____

Controls _____

Sample # 3705-D-A-6/11-87 Pump # 11177 Media Hydraz

Calibration: 0.198⁻⁸⁸ Open Time: _____
Pre 201 cc/min Post 196 cc/min On 1:23 Off 1:35 Volume 2.42
12

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS:

Industrial Hygienist: _____

Reviewed By: _____

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840
Greenwood Village, Colorado 80111
303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 6/11/03 Job Code _____

Employee Tad SSN # _____ Job Title _____

Work Description Dextrose dust

Inside containment near feed tube - UTUBE 5

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3705-DA-6/11-89 Pump # 12708 Media Hydran

MCEF

Calibration: 0.205 ⁻⁹⁰ Open Time: _____
Pre 20 cc/min Post 205 cc/min On 1:23 Off 1:35 Volume 2.5 L

12

Substance: OSHA PEL Concentration 8 Hour TWA

Hg 0.1 mg/m³

COMMENTS: _____

Industrial Hygienist: _____

Reviewed By: _____

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840
Greenwood Village, Colorado 80111
303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 6/11/03 Job Code _____
Employee Tad SSN # _____ Job Title _____
Work Description Dextrose Dewice
Equip Comparison Phase 2 - one hour
Work Location Personal sampling on RIGHT shoulder
Respirators/PPE _____
Controls _____

Sample # 3705-D-A-611-91 Pump # 13681 Media Hydra
MCEF
Calibration: 0.200 ⁻⁹² Pre Time: _____
202 cc/min Post 198 cc/min On 4:43 Off 5:17 Volume 10.8 l
34 min

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>H₂</u>	<u>0.1 mg/m³</u>		

COMMENTS:

Industrial Hygienist: _____ Reviewed By: _____

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840
Greenwood Village, Colorado 80111
303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 6/11/03 Job Code _____
Employee Teal SSN # _____ Job Title _____
Work Description Dextre Dente
Equip Comparison Phase 2 - one drum
Work Location Personal sampling on LEFT shoulder
Respirators/PPE _____
Controls _____

Sample # 305-D-A-6/11-93 Pump # R2992 Media Hydr 1.
-94 MCEF
Calibration: 0-200 Lpm Time: _____
Pre 203cc/min Post 198cc/min On 4:43 Off 5:17 Volume 6.82
34

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1mg/m³</u>		

COMMENTS:

Industrial Hygienist: _____ Reviewed By: _____

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840
Greenwood Village, Colorado 80111
303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 6/11/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description Dextrite device

Equipment comparison Phase 2

Work Location Inside Containment at Exhaust on
fiber drum

Respirators/PPE _____

Controls _____

Sample # 3705-D-A-4/11-95 Pump # 112711 Media Hydra

-96
Calibration: 0.212 Exp

Pre 211 cc/min Post 214 cc/min Time: On 4:43 Off 5:17 Volume 7.2 l

34

Substance OSHA PEL Concentration 8 Hour TWA

Hg 0.1 mg/m³ _____

COMMENTS:

Industrial Hygienist: _____

Reviewed By: _____

BOOZ-ALLEN & HAMILTON

5299 DTC Blvd., Suite 840
Greenwood Village, Colorado 80111
303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 6/11/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description De-trike device

Equipment Competition Phase 2 - one drum

Work Location Inside Containment near exhaust on fiber drum

Respirators/PPE _____

Controls _____

Sample # 3705-0-A-411-97 Pump # 11249 Media Hydro

Calibration: 0.198 L/min Time: _____
Pre 198 cc/min Post 198 cc/min On 4:43 Off 5:17 Volume 6.7 L
34

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>11g</u>	<u>0.1 mg/mg</u>		

COMMENTS:

Industrial Hygienist: _____

Reviewed By: _____

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client GPA Date 6/11/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description Dextric device

Work Location Equip. room Companion Phase 2 - one drum

Respirators/PPE _____
Controls _____

Sample # 3705-D-A-6/11-99 Pump # 13914 Media Hydram

Calibration: ⁻¹⁰⁰ Pre 204 cc/min Post 201 cc/min Time: On 4:43 Off 5:17 Volume 6.90
34

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1mg/m³</u>		

COMMENTS: _____

Industrial Hygienist: _____

Reviewed By: _____

BOOZ-ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 5/11/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description Dextroite Device

Work Location Equipment Comparison phase 2 - one drum

Inside containment near feed tube on
fiber drum

Respirators/PPE _____

Controls _____

Sample # 3705-D-A-411-101 Pump # 11308 Media Hydrax
-102 MCEF

Calibration: 0.200 Pre 200 cc/min Post 200 cc/min Time: On 4:43 Off 5:17 Volume 6.82
351

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hy</u>	<u>0.1 mg/m³</u>		

REMARKS:

Industrial Hygienist: _____

Reviewed By: _____

BOOZ-ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client SFA Date 6/11/03 Job Code _____

Employee Tad SSN # _____ Job Title _____

Work Description Dextrok device

Work Location Equipment comparison Phase 2

Dixiey Drum Change

Respirators/PPE _____

Controls _____

Sample # 3705-D-A-6/11-103 Pump # K2015 Media Hydram

-104 MCET

Calibration: 0.257 Lpm Time: _____
Pre 258 cc/min Post 2.56 cc/min On 7:46 Off 7:58 Volume 3.10

12

Substance OSHA PEL Concentration 8 Hour TWA

Hg 0.1 mg/m³ _____

COMMENTS: _____

Industrial Hygienist: _____

Reviewed By: _____

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 6/11/03 Job Code _____
Employee Tad SSN # _____ Job Title _____
Work Description Dextrite Device
Work Location Equipment Comparison Phase 2 - ore drums
Personal sampling during Ceiling #1
Respirators/PPE 4 min sample
Controls _____

Sample # 3705-D-A-6/11-105 Pump # 12664 Media Hydro
-106 mCF
Calibration: 0.260 Lpm Time: _____
Pre 260 cc/min Post 260 cc/min On 7:46 Off 7:50 Volume 1.0 L
cf

Substance	OSHA PEL	Concentration	8 Hour TWA

COMMENTS:

Industrial Hygienist: _____ Reviewed By: _____

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 6/11/03 Job Code _____

Employee Tad SSN # _____ Job Title _____

Work Description D-Extrite Device

Work Location Equipment Comparison Phase 2 - mod na
Personal Sampling during ceiling H₂

Respirators/PPE _____

Controls 4 min sample

Sample # 3705-D-A-6/11-07 Pump # 12664 Media Hydrex

Calibration: 0-200 ¹⁰⁸ Open Time: _____
Pre ✓ 2.60cc/min Post 2.61cc/min On 7:51 Off 7:55 Volume 1.0 l
4

Substance	OSHA PEL	Concentration	8 Hour TWA

COMMENTS:

Industrial Hygienist: _____

Reviewed By: _____

BOOZ-ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 6/11/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description Box Test

Work Location Taken after finished filling 2 drums for Dextite and doing U-TUBE Study

East containment next to broken

Respirators/PPE boxes of tubes on fiber down

Controls _____

Sample # 3705-T-A-6/11-109 Pump # 12664 Media Hydra

-110

MCEF

Calibration: 0.201 lpm Time: _____

Pre 201 cc/min Post 201 cc/min On 2:57 Off 3:13 Volume 72.2

36

Substance	OSHA PEL	Concentration	8 Hour TWA
-----------	----------	---------------	------------

<u>Hg</u>	<u>0.1 mg/m³</u>		
-----------	-----------------------------	--	--

COMMENTS:

Industrial Hygienist:

Reviewed By:

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840
Greenwood Village, Colorado 80111
303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client S.P.A. Date 6/11/03 Job Code _____
Employee _____ SSN # _____ Job Title _____
Work Description Box Test
Work Location Taken after finished filling drums for Dextrite and doing U-TUBE study west containment near Jerome.
Respirators/PPE _____
Controls _____

Sample # 3705-T-A-6/11-111 Pump # 11308 Media Hydrex MCEF
Calibration: 0.199 ⁻¹¹² Open Time: _____
Pre 199 cc/min Post 200 cc/min On 2:37 Off 3:13 Volume 7.28
36

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1mg/m³</u>		

COMMENTS:

Industrial Hygienist: _____ Reviewed By: _____

BOOZ-ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client GPA Date 6/11/03 Job Code _____

Employee Brian SSN # _____ Job Title _____

Work Description Test on Brian, an AERC Facility employee

to wear personal air sample while working

Work Location LEFT shoulder

Respirators/PPE _____

Controls _____

Sample # 3705-F-A-6/11-113 Pump # 12708 Media Hydram

Calibration: 0.202 ⁻¹¹⁴ Open Time: _____
Pre 205 Post 199 On 2:31 Off 4:00 Volume 180 l

59

Substance	OSHA PEL	Concentration	8 Hour TWA
-----------	----------	---------------	------------

<u>Hg</u>	<u>0.1 mg/m³</u>		
-----------	-----------------------------	--	--

COMMENTS: _____

Industrial Hygienist: _____

Reviewed By: _____

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPIC Date 6/11/03 Job Code _____

Employee Brian SSN # _____ Job Title _____

Work Description Test on Brian, an AERC Facility Employee

to wear personal air sample while

Work Location working. RIGHT Shoulder

Respirators/PPE _____

Controls _____

Sample # 3705-FA-6/11-115 Pump # 11152 Media Hydrov

Calibration: 0.202 ⁻¹¹⁶ Pre Post 200 cfm cfm Time: 2:31 On 4:00 Off Volume 18.00

89

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>H3</u>	<u>0.1 mg/m³</u>		

COMMENTS:

Industrial Hygienist: _____

Reviewed By: _____

Appendix B
Air Sampling Data Forms

Sample Shipping Information

Samples were placed in an oversized, sturdy box with packing material to fill voids and protect the samples during shipping. The sampling personnel then signed the chain-of-custody forms, and placed them in the box with the samples. Samples were shipped via Federal Express to the laboratory.

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840
Greenwood Village, Colorado 80111
303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client: SFA Date: 6/12/03 Job Code: _____

Employee: Tad SSN: _____ Job Title: _____

Work Description: Air Cycle device - real world

Work Location: LEFT shoulder, entire 2 days

Respirators/PPR: _____

Controls: _____

Sample # 3705-AH-610-117 Pump # 11308 Media Hydrex

Calibration: 0.202 Time: 10:05 11:24 79

Pre 204 Post 12.25 Off 1.7 52 Volume 20.50
131

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____

COMMENTS: _____

Industrial Hygienist: _____

Reviewed By: _____

BOOZ-ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 6/12/03 Job Code _____

Employee Tad SSN # _____ Job Title _____

Work Description Air Cycle Dewar - Real World

LEFT Shoulder - 1st DRUM

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3705-AA-6/12-119 Pump # 11249 Media Hydram

Calibration: 0.200 ⁻¹²⁰ Time: 7:1
Pre 203 cc/min Post 197 On 10:05 Off 11:24 Volume 15.8.0
MCF F

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS:

Industrial Hygienist:

Reviewed By:

BOOZ-ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 6/12/09 Job Code _____

Employee Tad SSN # _____ Job Title _____

Work Description Arc welder - Real world
RIGHT Shoulder - 1st Draw

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3705-AA-6/12-121 Pump # 112711 Media Hydram
-122 ~~13711~~ mCEF

Calibration: 0.211 Time: 79
Pre 20/10/09 Post 211 On 10:05 OFF 11:24 Volume 16.70

212 cc/min

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hy</u>	<u>0.1mg/m³</u>		

COMMENTS:

Industrial Hygienist:

Reviewed By:

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 6/12/03 Job Code _____

Employee Wade SSN # _____ Job Title _____

Work Description Air Cycle Device - Real World

LEPA Inside Containment - Exhaust

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3705-AA-6/12-123 Pump # R2992 Media MCEFF Hydrom
-124 MCEFF

Calibration: 0-200 Time: 10:05 11:24 79
Pre 202 cc/min Post 199 cc/min On 12:25 Off 1:18 53 Volume 26.4L
132

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS:

Industrial Hygienist:

Reviewed By:

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client CPA Date 6/12/03 Job Code _____

Employee Twd SSN # _____ Job Title _____

Work Description Air Cycle - Real World

Inside containment - Feed Tube

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3705-PA-6/12-125 Pump # 13914 Media Hydrom

Calibration: Pre 0.201 Post 0.199 Time: 10:05 11:24 79
On 12:25 Off 1:18 53 Volume 26.5 l

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS: _____

Industrial Hygienist:

Reviewed By:

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client QPA Date 6/13/03 Job Code _____

Employee Tad SSN # _____ Job Title _____

Work Description Air Cycler Real world

Filter change #1

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3705-A-A-6/12-127 Pump # 12708 Media Hydra

Calibration: 0.255 ⁻¹²⁸ lpm Time: 12
Pre 256 cc/min Post 255 cc/min On 10:30 Off 10:42 Volume 3.10

Substance	OSHA PEL	Concentration	8 Hour TWA
-----------	----------	---------------	------------

<u>Hg</u>	<u>0.1mg/m³</u>		
-----------	----------------------------	--	--

COMMENTS: _____

Industrial Hygienist: _____

Reviewed By: _____

BOOZ-ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 6/13/03 Job Code _____

Employee Tad SSN # _____ Job Title _____

Work Description Air Cycle - Real World
Filter Change #2 / Drum #1

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3705-AA-6/a-129 Pump # 12708 Media Hydro

Calibration: 0.255 lpm Time: 12
Pre 256 c/min Post 255 c/min On 11:12 Off 11:24 Volume 3.10

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS:

Industrial Hygienist:

Reviewed By:

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 6/12/03 Job Code _____

Employee Tach SSN # _____ Job Title _____

Work Description Air cycle device - Real world
Ceiling #1

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3705-A-A-412-131 Pump # 12664 Media Hy drum
nick

Calibration: 0.260 Time: 4
Pre 261 cal Post 259 cal On 11:12 Off 11:16 Volume 1.02

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS:

Industrial Hygienist:

Reviewed By:

BOOZ-ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 6/12/03 Job Code _____

Employee Tad SSN # _____ Job Title _____

Work Description Air cycle device - Real World
Ceiling H₂

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3205-AA-6/12-133 Pump # 12664 Media Hydrom
-134 WCF

Calibration: 0.260 Time: 4
Pre 261 cc/min Post 259 cc/min On 11:17 Off 11:21 Volume 1.0 l

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>H₂</u>	<u>0.1 mg/m³</u>		

COMMENTS:

Industrial Hygienist:

Reviewed By:

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840
Greenwood Village, Colorado 80111
303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 6/12/03 Job Code _____

Employee Ted SSN # _____ Job Title _____

Work Description Air Cycle Device - Real World
LEFT Shoulder - 2nd drum

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3705-A-A-6/12-135 Pump # 11249 Media Hydrom

Calibration: 0.198 lpm Time: 52
Pre 197cc/min Post 199cc/min On 12:25 Off 1:17 Volume 10.3.0

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Itg</u>	<u>0.1mg/m³</u>		

COMMENTS:

Industrial Hygienist:

Reviewed By:

BOOZ-ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 6/12/07 Job Code _____

Employee Tad SSN # _____ Job Title _____

Work Description Air Cycle Device - Real world
RIGHT SHOULDER, 2nd draw

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3705-AA6/12-137 Pump # 112711 Media _____

Calibration: -138
Pre 211 cfm Post 214 cfm Time: 52
On 12:25 Off 1:17 Volume 1602

Substance	OSHA PEL	Concentration	8 Hour TWA

COMMENTS:

Industrial Hygienist: _____ Reviewed By: _____

AIR SAMPLING DATA FORM

Client EPA Date 6/12/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description 2 Air Cycle Device - Real World

Work Location Overnight Sample - placed near exhaust on
fiber drum

Respirators/PPE _____

Controls _____

Sample # 3705-A-A-4/2-139 Pump # R 2992 Media Hydra-MCEP

Calibration: 0.144 liter Time: 5:49 pm 7/6/12
Pre 146cc/min Post 142cc/min On 7:30 AM Off 6/13 Volume 118.2L
821

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1mg/m³</u>		

COMMENTS: 11 + 360 + 420 + 30

Industrial Hygienist: _____ Reviewed By: _____

BOUZ-ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 6/12/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description ~~Chromatography~~ Arcycle Device Real World

Work Location Ovenight Sample - placed near feed tube on fiber down

Respirators/PPE _____

Controls _____

Sample # 3705-A-A-6/12-141 Pump # 11249 Media Hydax

Calibration: 0.157 Lpm Time: 5:49 AM 6/12
Pre 157cc/min Post 158cc/min On 7:30 AM Off 6:13 Volume 128.92
821

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS:

Industrial Hygienist: _____

Reviewed By: _____

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA

Date 6/12/03

Job Code _____

Employee _____

SSN # _____

Job Title _____

Work Description

Air Cycle Devic - Real world

Work Location

Overnight sample placed on fiber drum
outside of containment

Respirators/PPE _____

Controls _____

Sample # 3705-AA-6/12.143 Pump # _____

13914

Media

Hydron

MCEP

Calibration:

0.150 μm

Time:

5:49 pm 6/12

Pre

150 cc/min

Post

50 cc/min

On

7:30 ADEF 6/13

Volume

123.1 L

821

Substance

OSHA PEL

Concentration

8 Hour TWA

Hg

0.1 mg/m³

COMMENTS:

Industrial Hygienist: _____

Reviewed By: _____

BOOZ-ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367



AIR SAMPLING DATA FORM

Client EPA Date 6/12/03 Job Code _____

Employee Tad SSN # _____ Job Title _____

Work Description Air Cycle Device - Equipment Comparison Phase II
on Tad's RIGHT Shoulder

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3705-A-A-6/12-145 Pump # 12664 Media Hydram

Calibration: 0.199 ⁻¹⁴⁶ Pre Time: 37 min MCET
200cc/min Post 199 cc/min On 4:30 Off 5:07 Volume 74.8

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS: _____

Industrial Hygienist: _____ Reviewed By: _____

BOOZ-ALLEN & HAMILTON

5299 DTC Blvd., Suite 840
Greenwood Village, Colorado 80111
303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 6/14/03 Job Code _____

Employee Tad SSN # _____ Job Title _____

Work Description Air Cycle Benic Equip Comp. Phase II
On Tad's LEFT shoulder

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3705-A-A-6/14-147 Pump # 11308 Media Hydro

Calibration: 0.203 ⁻¹⁴⁸ lp Time: 37 min MUF
Pre 203 cc/min Post 203 cc/min On 4:30 Off 5:07 Volume 7.5 l

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS: _____

Industrial Hygienist: _____

Reviewed By: _____

BOOZ ALLEN & HAMILTON



5299 DTC Blvd., Suite 840
Greenwood Village, Colorado 80111
303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client E/A Date 6/12/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description Air Cycle Service Equip Comparison Phase II

Inside Containment near Exhaust

Work Location on fiber down

Respirators/PPE _____

Controls _____

Sample # 3705-A-A-412-H1 Part # 13681 Media Hydrom

Calibration: 0.200 ⁻¹⁵⁰ 199 cal/min Time: 31 min on 4:22 off 5:00 Volume 7.18

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1mg/m³</u>		

Comments: _____

Industrial Hygienist: _____ Released By: _____

RAND
*

AIR SAMPLING DATA FORM

Client EPA Date 6/12/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description avg Cycle Device - Equip Comparison Phase II

Inside Containment near Exhaust

Work Location on fiber drum

Respirators/PPE _____

Controls _____

Sample # 3705-A-A-6/12-151 Pump # 11177 Media Hydro MUEF

Calibration: 0.206 ⁻¹⁵² Open Time: 37 min
Pre 203 calms Post 209 calms On 4:30 Off 5:07 Volume 7.6 l

Substance	OSHA PEL	Concentration	8 Hour TWA

COMMENTS:

Industrial Hygienist: _____ Reviewed By: _____

BOOZ-ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 6/12/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description Air cycle device - Equip Comparison Phase II
Inside containment near feed inlet tube

Work Location on fiber drum

Respirators/PPE _____

Controls _____

Sample # 3705-A-A-6/12-153 Pump # 11152 Media Hydran

Calibration: 0.209 ⁻¹⁵⁴ 209 cc/min Time: 37 MCEP
Pre 209 cc/min Post 209 cc/min On 4:30 OFF 5:07 Volume 7.7 l

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS: _____

Industrial Hygienist: _____

Reviewed By: _____

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX, 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 6/22/07 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description Air Cycle Equip Commission Phase II

Inside containment a feed tube inlet on

Work Location fiber drum

Respirators/PPE _____

Controls _____

Sample # 3705-A-A-612-R5 Pump # 11254 Media Hydrom

Calibration: 0.205^{-15L} Lpm Time: 37 min

Pre 20/leafan Post 20/leafan On 4:30 Off 5:07 Volume 7.5L

Substance OSHA PEL Concentration 8 HOUR TWA

H₂ 0.1 mg/m³ _____

COMMENTS: _____

Prepared By: _____

Reviewed By: _____

BOOZ-ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 6/12/03 Job Code _____

Employee Tad SSN # _____ Job Title _____

Work Description Air Cycle Dewice - Equipment Comparison Phase II
on Tad's shoulder for Filterchange #1

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3705-AA-6/12-157 Pump # 12708 Media Hydrox

Calibration: 0.255 Lpm Time: 12
Pre 256 Post 253cc/min On 4:55 Off 5:07 Volume 3.12

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>H₂</u>	<u>0.1mg/m³</u>		

COMMENTS:

Industrial Hygienist: _____

Reviewed By: _____

AIR SAMPLING DATA FORM

Client EPA Date 6/12/03 Job Code _____

Employee Tad SSN # _____ Job Title _____

Work Description Air cycle device - equip comparison phase II
on Tad's shoulder for filter Δ #2 & drum Δ #1

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3705-A-A-6/12-159 Pump # 12708 Media Hydian

Calibration: 0.255 14 Time: 14 mCF
Pre 256 Post 255 cc/min On 7:46 Off 8:00 Volume 3.6 l

Substance	OSHA PEL	Concentration	8 Hour TWA
-----------	----------	---------------	------------

<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS:

Industrial Hygienist:

Reviewed By:

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 6/12/03 Job Code _____

Employee Tal SSN # _____ Job Title _____

Work Description ~~Sampling~~ Air Cycle Equip. Comparison Phase I

Work Location Ceiling #1 - during drive Δ

Respirators/PPE 4 min personal sample

Controls _____

Sample # 3705-A-A-46-161 Amp # 112711 Media Hydrex

Calibration Pre 253 Post 253 Flow 0.254 lpm Time On 7:46 Off 7:51 Volume 1.02

Substance	OSHA PEL	Concentration	8 Hour TW
<u>H₂</u>	<u>0.1 mg/m³</u>		

REMARKS:

Industrial Hygienist:

Revised By:

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 6/12/03 Job Code _____

Employee Tad SSN # _____ Job Title _____

Work Description Air cycle Equip Comparison Phase II
Ceiling #2 - during down Δ

Work Location _____
4 min personal sample

Respirators/PPE _____

Controls _____

Sample # 3705-A-4-6/11-163 Pump # 112711 Media Hydran
mCEF

Calibration: -164 Time: 4
Pre 253 cal/cm Post 0.254 dpy On 7:51 Off 7:55 Volume 1.0 L
256 cc/min

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>H₂</u>	<u>0.1 mg/m³</u>		

COMMENTS:

Industrial Hygienist: _____ Reviewed By: _____

AIR SAMPLING DATA FORM

Client CPA Date 6/13/03 Job Code _____
Employee Tal SSN # _____ Job Title _____
Work Description Air Cycle - Real world
Filter Change #3
Work Location _____
Respirators/PPE _____
Controls _____

Sample # 3705-AA-6/12-165 Pump # 12708 Media Hydran
-166 12 MCEF
Calibration: 0.255 liter Time: _____
Pre 256cc/min Post 255cc/min On 12:50 Off 1:02 Volume 3.18

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1mg/m³</u>	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____

COMMENTS:

Industrial Hygienist: _____ Reviewed By: _____

BOOZ-ALLEN & HAMILTON

5299 DTC Blvd., Suite 840
Greenwood Village, Colorado 80111
303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client S/A Date 6/13/07 Job Code _____
Employee Taj SSN # _____ Job Title _____
Work Description Air Cycle - R2al mixed
Draw Δ#2
Work Location _____
Inspirators/PPH _____
Controls _____

Sample # 3705-AA-6/12-67 PMP # 12708 Media Hydrom
Calibration: 0.255 168 15 nicef
Pre 25 kcal/min Post 255 cal/min Timer On 1:52 Off 2:15 Volume 330

Substance	OGRA FIL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS _____

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 6/13/07 Job Code _____

Employee Tal SSN # _____ Job Title _____

Work Description Air Cycle - Real world

Drum Δ #2

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3705-AA-6/12-167 Pump # 12708 Media Hydran

Calibration: 0.255 lpm Time: 13 m LCF
Pre 256 cc/min Post 255 cc/min On 1:52 Off 2:05 Volume 3.3 l

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS: _____

Industrial Hygienist: _____

Reviewed By: _____

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

1-A

AIR SAMPLING DATA FORM

Client S.P.A. Date 6/12/03 Job Code _____

Employee _____ SSN # _____ Job Title _____

Work Description BOX TEST in Air Cycle Containment

West containment on fiber down

Work Location _____

Respirators/PPE _____

Controls _____

Sample # 3705 T-A-4/12-169 Pump # 11308 Media Hydram

Calibration: 0.201 ⁻¹⁷⁰ lpm Time: 45 min
Pre 200 cc/min Post 203 cc/min On 2:32 Off 3:17 Volume 9.0 l

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____

COMMENTS: _____

Industrial Hygienist: _____

Reviewed By: _____

BOOZ ALLEN & HAMILTON



5299 DTC Blvd., Suite 840
Greenwood Village, Colorado 80111
303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 6/12/03 Job Code _____

Employee Tad SSN # _____ Job Title _____

Work Description UTUBES - AN Cycle

Work Location processing UTubes - on Tad's LEFT shoulder

Respirators/PPE _____

Controls _____

Sample # 3705-AA-6/12-~~171~~ Pump # 11/52 Media Hydro

Calibration: Pre 209 cc/min Post 209 cc/min Time: On 1:21 Off 1:35 Volume 29.8

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0d mg/m³</u>		

COMMENTS:

Industrial Hygienist:

Reviewed By:

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367



AIR SAMPLING DATA FORM

Client EPA Date 6/12/03 Job Code _____

Employee Tad SSN # _____ Job Title _____

Work Description U TUBES Air Cycle

Work Location Processing UTubes - on Tad's RIGHT Shoulder

Respirators/PPE _____

Controls _____

Sample # 3705-A-A-6/12-¹⁷³~~174~~ Pump # 11254 Media Hydro MCF

Calibration: 207 Pre 209 Post 206 Time: On 1:21 Off 1:35 Volume 29.0

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS: _____

Industrial Hygienist:

Reviewed By:

BOOZ ALLEN & HAMILTON

5299 DTC Blvd., Suite 840

Greenwood Village, Colorado 80111

303.694.4159 FX. 303.694.7367

AIR SAMPLING DATA FORM

Client EPA Date 6/12/03 Job Code _____

Employee Tad SSN # _____ Job Title _____

Work Description U TUES Air Cycle

Work Location Inside Containment - near exhaust on fiber drum

Respirators/PPE _____

Controls _____

Sample # 3705-A-A-6/12-175 Pump # 11177 Media Hydra

Calibration: 0.205 Pre 208 Post 203 Time: 14 min On 1:21 Off 1:55 Volume 2.8 l

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS:

Industrial Hygienist:

Reviewed By:

BOOZ-ALLEN & HAMILTON

5299 DTC Blvd., Suite 840
Greenwood Village, Colorado 80111
303.694.4159 FX. 303.694.7367

Under
Lant
★

AIR SAMPLING DATA FORM

Client GDA Date 6/12/03 Job Code _____

Employee Tad SSN # _____ Job Title _____

Work Description UV TUBES Air Cycle

Work Location Inside containment - near feed tube on fiber drum

Respirators/PPE _____

Controls _____

Sample # 3705-AA-¹⁷⁷178 Pump # 13681 Media Hydrom

Calibration: 0.201 Lpm Time: 14 min

Pre 202 u/m² Post 201 u/min On 1:21 Off 1:35 Volume 2.8 L

Substance	OSHA PEL	Concentration	8 Hour TWA
<u>Hg</u>	<u>0.1 mg/m³</u>		

COMMENTS: _____

Industrial Hygienist: _____ Reviewed By: _____

Appendix C

Data Chem Laboratory Reports

Sample Shipping Information

Samples were placed in an oversized, sturdy box with packing material to fill voids and protect the samples during shipping. The sampling personnel then signed the chain-of-custody forms, and placed them in the box with the samples. Samples were shipped via Federal Express to the laboratory.



ANALYTICAL REPORT

Form ARF-AL
Page 1 of 3
Part 1 of 1
03060316572135RX

Date MAR 07 2003
Laboratory Group Name 03I-0545-04
Account No. 07003

Booz Allen Hamilton
Attention: Steve Coffee
5299 DTC Blvd.
Suite 840
Greenwood Village, CO 80111

FAX (303) 694-7367
Telephone (303) 221-7559

E-mail _____

Sampling Collection and Shipment

Sampling Site _____ Date of Collection February 25, 2003
Date Samples Received at Laboratory March 03, 2003

Analysis

Method of Analysis NMAM 6009
Date(s) of Analysis March 06, 2003

Analytical Results

Field Sample Number	Laboratory Number	Sample Type	Mercury $\mu\text{g}/\text{sample}$	Mercury mg/m^3	Air Volume L				
BG-2/25-02	03I06658	TUBE	0.23	0.0039	58.94				
BG-2/25-04	03I06659	TUBE	0.27	0.0047	58.24				
A/A-2/26-06	03I06660	TUBE	0.19	0.012	15.30				
A/A-2/26-08	03I06661	TUBE	0.23	0.015	15.05				
A/A-2/26-10	03I06662	TUBE	0.066	0.0055	12.09				
A/A-2/26-12	03I06663	TUBE	0.15	0.010	15.00				
A/A-2/26-14	03I06664	TUBE	0.12	0.0095	12.56				
A/A-2/26-16	03I06665	TUBE	0.20	0.013	15.60				
A/A-2/26-18	03I06666	TUBE	0.059	0.019	3.07				
A/A-2/26-20	03I06667	TUBE	0.088	0.019	4.58				
BLANK2/26/03	03I06668	TUBE	0.040	**	0.00				
BLANK2/26-03	03I06669	TUBE	0.041	**	0.00				
R/A-2/27-22	03I06670	TUBE	0.21	0.012	17.19				

† See comment on last page.
ND Parameter not detected above LOD.
NR Parameter not requested.

** See comment on last page.
() Parameter between LOD and LOQ.

Analyst: Jason D. Kim

Reviewer: Neil A. Edwards

960 West LeVoy Drive / Salt Lake City, Utah 84123-2547
Phone (801) 266-7700 Web Page: www.datachem.com
FAX (801) 268-9992 E-mail: lab@datachem.com



ANALYTICAL REPORT

Form ARF-C
Page 3 of 3
03060316572135RX

Date MAR 07 2003
Laboratory Group Name 03I-0545-04

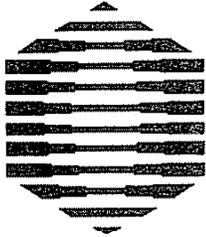
General Set Comments

Method Reference: NIOSH Manual of Analytical Methods(NMAM), 4th ed., 08/15/94.
Results are not blank-corrected.
Results obtained for media blanks prepared from SKC Carulite tubes are typically found to have concentrations approximately 0.035-0.045 µg/sample above the reporting limit of 0.01 µg/sample.
Results cannot be reported in mg/m³ or ppm for samples with no air volume.

General Lab Comments

The results provided in this report relate only to the items tested.
This page is the concluding page of the report.

960 West LeVoy Drive / Salt Lake City, Utah 84123-2547
Phone (801) 266-7700 Web Page: www.datachem.com
FAX (801) 268-9992 E-mail: lab@datachem.com



DATA CHEM

LABORATORIES, INC.

ANALYTICAL REQUEST FORM

1. REGULAR Status

03I-0545-04

RUSH Status Requested - ADDITIONAL CHARGE

RESULTS REQUIRED BY _____ DATE _____

CONTACT DATACHEM LABS PRIOR TO SENDING SAMPLES

2. Date 2/28/03 Purchase Order No _____ 4. Quote No _____
 3. Company Name Bacz Allen Hamilton DCL Project Manager Randa Potter
 Address 5299 DTC Blvd, Suite 840
Greenwood Village, CO 80111
 Person to Contact Steve Coffee
 Telephone (303) 221-7559
 Fax Telephone (303) 694-7367
 E-mail Address coffee_stephen@bah.com
 Billing Address (if different) on file

5. Sample Collection
 Sampling Site _____
 Industrial Process _____
 Date of Collection 2/26/03
 Time Collected _____
 Date of Shipment 2/28/03
 Chain of Custody No. 03

6. REQUEST FOR ANALYSES

Laboratory Use Only	Client Sample Number	Matrix*	Sample Volume	ANALYSES REQUESTED - Use method number if known	Units**
03FC6660	3705-A/H-2/26-06	HYDRAR	15.30L	NAM 6009	2
61	" 08	HYDRAR	15.05L	NAM 6009	2
62	" 10	HYDRAR	12.09L	NAM 6009	2
63	" 12	HYDRAR	15.00L	NAM 6009	2
64	" 14	HYDRAR	12.56L	NAM 6009	2
65	" 16	HYDRAR	15.80L	NAM 6009	2
66	" 18	HYDRAR	3.07L	NAM 6009	2
67	" 20	HYDRAR	4.58L	NAM 6009	2
68	BLANK 2/26/03	HYDRAR		NAM 6009	2
69	BLANK 2/26/03	HYDRAR		NAM 6009	2

* Specify: Solid sorbent tube, e.g. Charcoal; Filter type; Impinger solution; Bulk sample; Blood; Urine; Tissue; Soil; Water; Other

** 1 mg/sample 2 mg/m³ 3 ppm 4 % 5 _____ (other) Please indicate one or more units in the column entitled Units**

Comments _____

Possible Contamination and/or Chemical Hazards _____

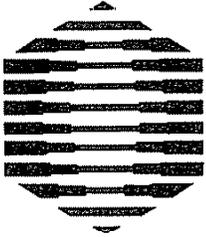
7. Chain of Custody (Optional)

Relinquished by <u>Steve D. Coffee</u>	Date/Time <u>2/28/03 1500</u>
Received by <u>Randa Potter</u>	Date/Time <u>3/3</u>
Relinquished by <u>Randa Potter</u>	Date/Time <u>2/3/03</u>
Received by _____	Date/Time _____

960 West LeVoy Drive / Salt Lake City, UT 84123

800-356-9135 or 801-266-7700 / FAX: 801-268-9992

DATACHEM LABORATORIES, INC.



DATA CHEM

LABORATORIES, INC.

ANALYTICAL REQUEST FORM

1. REGULAR Status 03I-CS45-04
 RUSH Status Requested - ADDITIONAL CHARGE
 RESULTS REQUIRED BY _____ DATE _____
 CONTACT DATACHEM LABS PRIOR TO SENDING SAMPLES

2. Date 2/28/03 Purchase Order No _____ 4. Quote No _____
 3. Company Name Booz Allen Hamilton DCL Project Manager Rand Potter
 Address 5299 DTC Blvd., Suite 940
Greenwood Village, CO 80111
 Person to Contact Steve Coffee
 Telephone (303) 221-7559
 Fax Telephone (303) 694-7367
 E-mail Address coffee.stephen@bah.com
 Billing Address (if different) on file

6. REQUEST FOR ANALYSES

Laboratory Use Only	Client Sample Number	Matrix*	Sample Volume	ANALYSES REQUESTED - Use method number if known	Units**
<u>13106670</u>	<u>3705-R/A-2/27-22</u>	<u>HYDRAR</u>	<u>17.19L</u>	<u>NAM 6009</u>	<u>2</u>
<u>71</u>	<u>"-24</u>	<u>HYDRAR</u>	<u>17.25L</u>	<u>NAM 6009</u>	<u>2</u>
<u>72</u>	<u>"-26</u>	<u>HYDRAR</u>	<u>16.97L</u>	<u>NAM 6009</u>	<u>2</u>
<u>73</u>	<u>"-28</u>	<u>HYDRAR</u>	<u>17.30L</u>	<u>NAM 6009</u>	<u>2</u>
<u>74</u>	<u>"-30</u>	<u>HYDRAR</u>	<u>16.97L</u>	<u>NAM 6009</u>	<u>2</u>
<u>75</u>	<u>"-32</u>	<u>HYDRAR</u>	<u>17.19L</u>	<u>NAM 6009</u>	<u>2</u>
<u>76</u>	<u>"-34</u>	<u>HYDRAR</u>	<u>3.03L</u>	<u>NAM 6009</u>	<u>2</u>
<u>77</u>	<u>Blank 2/27/03</u>	<u>HYDRAR</u>		<u>NAM 6009</u>	<u>2</u>
<u>78</u>	<u>Blank 2/27/03</u>	<u>HYDRAR</u>		<u>NAM 6009</u>	<u>2</u>

* Specify: Solid sorbent tube, e.g. Charcoal; Filter type; Impinger solution; Bulk sample; Blood; Urine; Tissue; Soil; Water; Other

** 1. mg/sample 2 mg/m³ 3 ppm 4 % 5 _____ (other) Please indicate one or more units in the column entitled Units**

Comments _____

Possible Contamination and/or Chemical Hazards _____

7. Chain of Custody (Optional)

Relinquished by <u>Jordan Murphy</u>	Date/Time <u>2/28/03 1500</u>
Received by <u>Rand Potter</u>	Date/Time <u>3/3</u>
Relinquished by <u>Rand Potter</u>	Date/Time <u>3/3</u>
Received by _____	Date/Time _____

960 West LeVoy Drive / Salt Lake City, UT 84123

800-356-9135 or 801-266-7700 / FAX: 801-268-9992

DATACHEM LABORATORIES, INC.

Appendix C

Data Chem Laboratory Reports

Sample Shipping Information

Samples were placed in an oversized, sturdy box with packing material to fill voids and protect the samples during shipping. The sampling personnel then signed the chain-of-custody forms, and placed them in the box with the samples. Samples were shipped via Federal Express to the laboratory.



ANALYTICAL REPORT

Form ARF-AL
Page 1 of 3
Part 1 of 1
04070311110402RX

APR 07 2003

Date _____
Laboratory Group Name 03I-0821-01
Account No. 07003

Booz Allen & Hamilton
Attention: Jordan Murphy
5299 DTC Blvd.
Suite 840
Greenwood Village, CO 80111

FAX (303) 684-7367
Telephone (303) 221-4446
E-mail murphy_jordan@bah.com

Sampling Collection and Shipment

Sampling Site _____ Date of Collection March 24, 2003
Date Samples Received at Laboratory March 31, 2003

Analysis

Method of Analysis NMAM 6009MOD
Date(s) of Analysis April 03, 2003

Analytical Results

Field Sample Number	Laboratory Number	Sample Type	Mercury $\mu\text{g}/\text{sample}$	Mercury mg/m^3	Air Volume L				
3705B324-01	03I09961	HYDRAR	0.43	0.014	31.78				
3705B024-03	03I09962	HYDRAR	0.16	0.0059	27.98				
3705RA324-05	03I09963	HYDRAR	2.0	0.074	26.49				
3705RA324-07	03I09964	HYDRAR	1.1	0.043	24.38				
3705RA324-09	03I09965	HYDRAR	1.1	0.045	25.27				
3705RA324-11	03I09966	HYDRAR	3.1	0.11	28.59				
3705RA324-13	03I09967	HYDRAR	0.43	0.075	5.65				
3705RA324-15	03I09968	HYDRAR	5.8	0.086	68.13				
3705RA324-17	03I09969	HYDRAR	1.4	0.021	66.36				
BLANK 3/24	03I09970	HYDRAR	0.078	**	0.00				
BLANK 3/24	03I09971	HYDRAR	0.086	**	0.00				
3705DA325-19	03I09972	HYDRAR	2.4	0.084	28.75				
3705DA325-21	03I09973	HYDRAR	0.27	0.016	16.94				

† See comment on last page. ** See comment on last page.
 ND Parameter not detected above LOD. () Parameter between LOD and LOQ.
 NR Parameter not requested.
 NA Parameter not applicable.

Tanya Cheklin for T.C.
 Analyst: Tanya Cheklin
Jason D. Kim
 Reviewer: Jason D. Kim

960 West LeVoy Drive / Salt Lake City, Utah 84123-2547
 Phone (801) 266-7700 Web Page: www.datachem.com
 FAX (801) 268-9992 E-mail: lab@datachem.com



ANALYTICAL REPORT

Form ARF-BL
 Page 2 of 3
 Part 1 of 1
 04070311110402RX

Date APR 07 2003
 Laboratory Group Name 03I-0821-01

Analytical Results

Field Sample Number	Laboratory Number	Sample Type	Mercury µg/sample	Mercury mg/m ³	Air Volume L					
3705DA325-23	03I09974	HYDRAR	0.60	0.035	17.00					
3705DA325-25	03I09975	HYDRAR	1.8	0.070	24.94					
3705DA325-27	03I09976	HYDRAR	0.32	0.13	2.54					
3705DA325-29	03I09977	HYDRAR	1.7	0.027	62.85					
3705DA325-31	03I09978	HYDRAR	1.8	0.026	69.40					
3705DA325-33	03I09979	HYDRAR	0.23	0.078	2.96					
BLANK 3/25	03I09980	HYDRAR	0.075	**	0.00					
BLANK 3/25	03I09981	HYDRAR	0.071	**	0.00					
3705AA327-43	03I09982	HYDRAR	0.89	0.030	29.69					
3705AA327-45	03I09983	HYDRAR	2.4	0.074	31.75					
3705AA327-47	03I09984	HYDRAR	0.40	0.014	29.20					
3705AA327-49	03I09985	HYDRAR	1.9	0.071	27.34					
3705AA327-51	03I09986	HYDRAR	0.41	0.0084	48.12					
3705AA327-53	03I09987	HYDRAR	0.53	0.16	3.40					
3705AA327-55	03I09988	HYDRAR	0.73	0.0095	77.60					
3705AA327-57	03I09989	HYDRAR	1.1	0.014	78.53					
3705AA327-59	03I09990	HYDRAR	0.065	0.021	3.05					
BLANK 3/27	03I09991	HYDRAR	0.073	**	0.00					
BLANK 3/27	03I09992	HYDRAR	0.071	**	0.00					
3705HA326-35	03I09993	HYDRAR	0.50	0.13	3.97					
3705HA326-37	03I09994	HYDRAR	0.33	0.11	3.12					
3705HA326-39	03I09995	HYDRAR	1.9	0.065	28.92					
3705HA326-41	03I09996	HYDRAR	0.66	0.022	29.85					
BLANK 3/26	03I10003	HYDRAR	0.28	**	0.00					
BLANK 3/26	03I10004	HYDRAR	0.21	**	0.00					
LAB BLK 3/24	03I10668	HYDRAR	0.056	**	0.00					
LAB BLK 3/24	03I10669	HYDRAR	0.060	**	0.00					
LAB BLK 3/24	03I10670	HYDRAR	0.065	**	0.00					
Reporting Limit			0.01							

† See comment on last page. ** See comment on last page.
 ND Parameter not detected above LOD. () Parameter between LOD and LOQ.
 NR Parameter not requested.
 NA Parameter not applicable.

960 West LeVoy Drive / Salt Lake City, Utah 84123-2547
 Phone (801) 266-7700 Web Page: www.datachem.com
 FAX (801) 268-9992 E-mail: lab@datachem.com



ANALYTICAL REPORT

Form ARF-C
Page 3 of 3
04070311110402RX

Date APR 07 2003
Laboratory Group Name 03I-0821-01

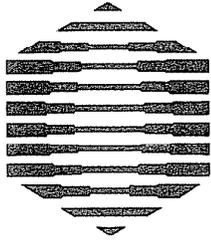
General Set Comments

Method Reference: NIOSH Manual of Analytical Methods(NMAM), 4th ed., 08/15/94.
Results are not blank-corrected.
Results obtained for media blanks prepared from SKC Carulite tubes are typically found to have concentrations approximately the 0.035-0.045 µg/sample above the reporting limit.
Recoveries of the Laboratory Control Samples (LCS) and the Laboratory Control Sample Duplicates (LCSD) are not within the historical quality control limits.
Nonconformance/Corrective Action Report (NC/CAR) # 624 is initiated.
Results cannot be reported in mg/m³ or ppm for samples with no air volume.

General Lab Comments

The results provided in this report relate only to the items tested.
This page is the concluding page of the report.

960 West LeVoy Drive / Salt Lake City, Utah 84123-2547
Phone (801) 266-7700 Web Page: www.datachem.com
FAX (801) 268-9992 E-mail: lab@datachem.com



DATA CHEM

LABORATORIES, INC.

ANALYTICAL REQUEST FORM

1. REGULAR Status 03I-0821-01
 RUSH Status Requested - ADDITIONAL CHARGE
 RESULTS REQUIRED BY _____ DATE _____
 CONTACT DATACHEM LABS PRIOR TO SENDING SAMPLES

2. Date 3/28/03 Purchase Order No. _____ 4. Quote No. _____
 3. Company Name Booz Allen Hamilton DCL Project Manager Rand Potter
 Address 5299 DTC Blvd, Suite 840
Greenwood Village CO 80111
 Person to Contact Sieve Jordan Murphy 5. Sample Collection
 Telephone (303) 221-4446 Sampling Site _____
 Fax Telephone (303) 494-7367 Industrial Process _____
 E-mail Address murphy_jordan@bah.com Date of Collection 3/24/03
 Billing Address (if different) see contract Time Collected _____
 Date of Shipment 3/28/03
 Chain of Custody No. 1

6. REQUEST FOR ANALYSES

Laboratory Use Only	Client Sample Number	Matrix*	Sample Volume	ANALYSES REQUESTED - Use method number if known	Units**
03I09961	3705-R-A-3/24-01	Hydcar	31.78L	N6009	2
09962	" -02	"	27.98L	"	2
09963	" -05	"	26.49L	"	2
09964	" -07	"	24.38L	"	2
09965	" -09	"	25.27L	"	2
09966	" -11	"	28.59L	"	2
09967	" -13	"	5.65L	"	2
09968	" -15	"	68.13L	"	2
09969	" -17	"	66.36L	"	2
09970	Blank 3/24	"	0	"	2
09971	Blank 3/24	"	0	"	2
03I06608	Lab Blank 3/24				
↓ 69	Lab Blank 3/24				
↓ 70	Lab Blank 3/24				

* Specify. Solid sorbent tube, e.g. Charcoal, Filter type, Impinger solution; Bulk sample, Blood; Urine, Tissue, Soil, Water; Other

** 1. mg/sample 2. mg/m³ 3. ppm 4. % 5. ____ (other) Please indicate one or more units in the column entitled Units**

Comments RTT No. 118

Possible Contamination and/or Chemical Hazards _____

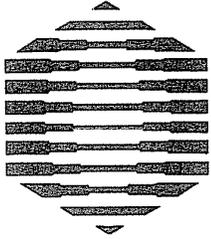
7. Chain of Custody (Optional)

Relinquished by <u>Jordan Murphy</u>	Date/Time <u>3/28/03 11.35</u>
Received by <u>Rand Potter</u>	Date/Time <u>3/21/03</u>
Relinquished by <u>Rand Potter</u>	Date/Time <u>3/31/03</u>
Received by _____	Date/Time _____

960 West LeVoy Drive / Salt Lake City, UT 84123

800-356-9135 or 801-266-7700 / FAX: 801-268-9992

DATACHEM LABORATORIES, INC.



DATA CHEM

LABORATORIES, INC.

ANALYTICAL REQUEST FORM

1. REGULAR Status 03L-0821-01

KUSH Status Requested - ADDITIONAL CHARGE

RESULTS REQUIRED BY _____ DATE _____

CONTACT DATACHEM LABS PRIOR TO SENDING SAMPLES

2. Date 3/28/03 Purchase Order No. _____ 4. Quote No. _____
 3. Company Name Booz Allen Hamilton DCL Project Manager Rand Potter
 Address 5299 DTC Blvd, Suite 840
Greenwood Village, CO 80111
 Person to Contact Jordan Murphy
 Telephone (303) 221-4446
 Fax Telephone (303) 694-7367
 E-mail Address murphy_jordan@bah.com
 Billing Address (if different) see contract

5. Sample Collection

Sampling Site _____
 Industrial Process _____
 Date of Collection 3/25/03
 Time Collected _____
 Date of Shipment 3/28/03
 Chain of Custody No. 3

6. REQUEST FOR ANALYSES

Laboratory Use Only	Client Sample Number	Matrix*	Sample Volume	ANALYSES REQUESTED - Use method number if known	Units**
03L09972	3705-DA-3/25-19	Hydrox	28.75L	N 6009	2
09973	"-21	"	16.94L	"	2
09974	"-23	"	17.0L	"	2
09975	"-25	"	24.94L	"	2
09976	"-27	"	2.54L	"	2
09977	"-29	"	39.6725L	"	2
09978	"-31	"	69.40L	"	2
09979	"-33	"	2.96L	"	2
09980	Blank 3/25	"	0	"	2
09981	Blank 3/25	"	0	"	2

* Specify: Solid sorbent tube, e.g. Charcoal; Filter type; Impinger solution; Bulk sample; Blood; Urine; Tissue; Soil; Water; Other

** 1. mg/sample 2. mg/m³ 3. ppm 4. % 5. _____ (other) Please indicate one or more units in the column entitled Units**

Comments DEXTRO DE VILE

Possible Contamination and/or Chemical Hazards _____

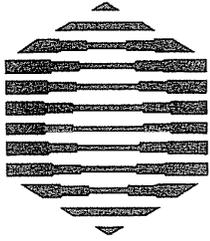
7. Chain of Custody (Optional)

Relinquished by <u>Jordan Murphy</u>	Date/Time <u>3/28/03 11:35</u>
Received by <u>Rand Potter</u>	Date/Time <u>3/31</u>
Relinquished by <u>Rand Potter</u>	Date/Time <u>3/31/03</u>
Received by _____	Date/Time _____

960 West LeVoy Drive / Salt Lake City, UT 84123

800-356-9135 or 801-266-7700 / FAX: 801-268-9992

DATACHEM LABORATORIES, INC.



DATA CHEM

LABORATORIES, INC.

ANALYTICAL REQUEST FORM

1. REGULAR Status OSI-0821-01

RUSH Status Requested - ADDITIONAL CHARGE

RESULTS REQUIRED BY _____ DATE _____

CONTACT DATACHEM LABS PRIOR TO SENDING SAMPLES

2. Date 3/28/03 Purchase Order No. _____ 4. Quote No. _____

3. Company Name Booz Allen Hamilton DCL Project Manager Rand Potter

Address 5299 DTC Blvd, Suite 840

Greenwood Village, CO 80111

5. Sample Collection

Person to Contact Jordan Murphy Sampling Site _____

Industrial Process _____

Telephone (303) 221-4446 Date of Collection ~~3/29/03~~ 3/27/03

Fax Telephone (303) 694-7367 Time Collected _____

E-mail Address murphy_jordan@bah.com Date of Shipment 3/28/03

Billing Address (if different) see contract Chain of Custody No. 6

6. REQUEST FOR ANALYSES

Laboratory Use Only	Client Sample Number	Matrix*	Sample Volume	ANALYSES REQUESTED - Use method number if known	Units**
OSI09982	3705-A-A-3/27-43	Hydrar	29.69L	N6009	2
09983	11-45	"	31.75L	"	2
09984	11-47	"	29.20L	"	2
09985	11-49	"	27.34L	"	2
09986	11-51	"	48.12L	"	2
09987	11-53	"	3.40L	"	2
09988	11-55	"	77.6L	"	2
09989	11-57	"	78.53L	"	2
09990	11-59	"	3.05L	"	2
09991	Blank 3/27/	"		N6009	2
09992	Blank 3/27/	"		N6009	2

* Specify: Solid sorbent tube, e.g. Charcoal; Filter type; Impinger solution; Bulk sample, Blood, Urine; Tissue, Soil, Water, Other

** 1. mg/sample 2. mg/m³ 3 ppm 4 % 5 _____ (other) Please indicate one or more units in the column entitled Units**

Comments Air cycle Device

Possible Contamination and/or Chemical Hazards _____

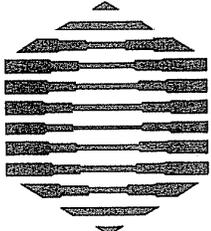
7. Chain of Custody (Optional)

Relinquished by <u>Jordan Murphy</u>	Date/Time <u>3/28/03 11:35</u>
Received by <u>Rand Potter</u>	Date/Time <u>3/31</u>
Relinquished by <u>Rand Potter</u>	Date/Time <u>3/31/03</u>
Received by _____	Date/Time _____

960 West LeVoy Drive / Salt Lake City, UT 84123

800-356-9135 or 801-266-7700 / FAX: 801-268-9992

DATACHEM LABORATORIES, INC.



DATA CHEM

LABORATORIES, INC.

ANALYTICAL REQUEST FORM

1. REGULAR Status 05I-0821-01

RUSH Status Requested - ADDITIONAL CHARGE

RESULTS REQUIRED BY _____ DATE _____

CONTACT DATACHEM LABS PRIOR TO SENDING SAMPLES

2. Date 3/28/03 Purchase Order No. _____ 4. Quote No. _____

3. Company Name Booz Allen Hamilton DCL Project Manager Rand Potter

Address 5299 DTC Blvd, Suite 840

Greenwood Village, CO 80111

5. Sample Collection

Person to Contact Jordan Murphy Sampling Site _____

Industrial Process _____

Telephone (303) 221-4446 Date of Collection 3/26/03

Time Collected _____

Fax Telephone (303) 694-7367 Date of Shipment 3/28/03

E-mail Address murphy_jordan@bah.com Chain of Custody No. 5

Billing Address (if different) see contract

6. REQUEST FOR ANALYSES

Laboratory Use Only	Client Sample Number	Matrix*	Sample Volume	ANALYSES REQUESTED - Use method number if known	Units**
05I09993	3705-H-A-3/26-35	Hydraz	3.97L	N 6 009	2
09994	" - 37	"	3.12L	"	2
09995	" - 39	"	28.92L	"	2
09996	" - 41	"	29.85L	"	2
09997	3705-H-A-3/26-36	MCEF	3.97L	N 9 103	2
09998	" - 38	"	3.12L	"	2
09999	" - 40	"	28.92L	"	2
10000	" - 42	"	29.85L	"	2
10001	Blank 3/26	"	0	"	2
10002	Blank 3/26	"	0	"	2
10003	Blank 3/26	Hydraz	0	N 6 009	2
10004	Blank 3/26	Hydraz	0	N 6 009	2

* Specify. Solid sorbent tube, e.g. Charcoal; Filter type, Impinger solution; Bulk sample; Blood; Urine; Tissue; Soil; Water; Other

** 1. mg/sample 2. mg/m³ 3 ppm 4 % 5 _____ (other) Please indicate one or more units in the column entitled Units**

Comments HMS Device

Possible Contamination and/or Chemical Hazards _____

7. Chain of Custody (Optional)

Relinquished by <u>Jordan Murphy</u>	Date/Time <u>3/28/03 11:35</u>
Received by <u>Rand Potter</u>	Date/Time <u>3/28</u>
Relinquished by <u>Rand Potter</u>	Date/Time <u>3/31</u>
Received by _____	Date/Time _____

Appendix C

Data Chem Laboratory Reports

Sample Shipping Information

Samples were placed in an oversized, sturdy box with packing material to fill voids and protect the samples during shipping. The sampling personnel then signed the chain-of-custody forms, and placed them in the box with the samples. Samples were shipped via Federal Express to the laboratory.



ANALYTICAL REPORT

Form ARF-AL
 Page 1 of 3
 Part 1 of 1
 05140322400528RX

Date MAY 15 2003
 Laboratory Group Name 03I-1146-06
 Account No. 07003

Booz Allen Hamilton
 Attention: Steve Coffee
 5299 DTC Blvd.
 Suite 840
 Greenwood Village, CO 80111

FAX (303) 694-7367
 Telephone (303) 221-7559
 E-mail coffee_stephen@bah.com

Sampling Collection and Shipment

Sampling Site AERC Melbourne Date of Collection April 29, 2003
 Date Samples Received at Laboratory May 05, 2003

Analysis

Method of Analysis NMAM 6009MOD
 Date(s) of Analysis May 12, 2003

Analytical Results

Field Sample Number	Laboratory Number	Sample Type	Mercury $\mu\text{g/sample}$	Mercury mg/m^3	Air Volume L					
3705B429-01	03I16295	HYDRAR	1.0	0.016	61.2					
3705B429-03	03I16296	HYDRAR	0.77	0.012	64.8					
3705DA429-05	03I16297	HYDRAR	3.7	0.14	25.8					
3705DA429-07	03I16298	HYDRAR	3.0	0.12	24.2					
3705DA429-09	03I16299	HYDRAR	3.3	0.13	24.9					
3705DA429-11	03I16300	HYDRAR	6.7	0.27	25.1					
3705DA429-13	03I16301	HYDRAR	0.044	0.015	3.0					
3705DA429-15	03I16302	HYDRAR	0.21	0.041	5.1					
3705DA429-17	03I16303	HYDRAR	3.7	0.035	104.9					
3705DA429-19	03I16304	HYDRAR	3.8	0.036	106.4					
3705DA429-21	03I16305	HYDRAR	2.3	0.021	109.2					
3705DA429-23	03I16306	HYDRAR	0.23	0.23	1.01					
3705DA429-25	03I16307	HYDRAR	0.65	0.64	1.01					

† See comment on last page.
 ND Parameter not detected above LOD.
 NR Parameter not requested.
 NA Parameter not applicable.

** See comment on last page.
 () Parameter between LOD and LOQ.

Jason D. Kim
 Analyst: Jason D. Kim
Neil A. Edwards
 Reviewer: Neil A. Edwards



ANALYTICAL REPORT

Form ARF-C
Page 3 of 3
05140322400528RX

Date _____
Laboratory Group Name MAY 15 2003 03I-1146-06

General Set Comments

Method Reference: NIOSH Manual of Analytical Methods(NMAM), 4th ed., 08/15/94.
Results are not blank-corrected.
Results cannot be reported in mg/m³ or ppm for samples with no air volume.

General Lab Comments

The results provided in this report relate only to the items tested.
This page is the concluding page of the report.



ANALYTICAL REPORT

Form ARF-AL
Page 1 of 3
Part 1 of 1
05140323403496RX

MAY 15 2003

Date _____
Laboratory Group Name 03I-1146-07
Account No. 07003

Booz Allen Hamilton
Attention: Steve Coffee
5299 DTC Blvd.
Suite 840
Greenwood Village, CO 80111

FAX (303) 694-7367
Telephone (303) 221-7559
E-mail coffee_stephen@bah.com

Sampling Collection and Shipment

Sampling Site AERC Melbourne Date of Collection May 01, 2003

Date Samples Received at Laboratory May 05, 2003

Analysis

Method of Analysis NMAM 6009MOD

Date(s) of Analysis May 12, 2003

Analytical Results

Field Sample Number	Laboratory Number	Sample Type	Mercury $\mu\text{g}/\text{sample}$	Mercury mg/m^3	Air Volume L					
3705RA501-61	03I16329	HYDRAR	0.40	0.018	21.9					
3705RA501-63	03I16330	HYDRAR	0.28	0.024	11.8					
3705RA501-65	03I16331	HYDRAR	0.31	0.026	12.0					
3705RA501-67	03I16332	HYDRAR	0.39	0.018	22.2					
3705RA501-69	03I16333	HYDRAR	0.14	0.0063	22.1					
3705RA501-71	03I16334	HYDRAR	0.23	0.075	3.07					
3705RA501-73	03I16335	HYDRAR	TBA	TBA	TBA					
3705RA501-75	03I16336	HYDRAR	0.17	0.17	1.01					
3705RA501-77	03I16337	HYDRAR	0.11	0.11	1.01					
3705RA501-79	03I16338	HYDRAR	0.16	0.017	9.32					
3705RA501-81	03I16339	HYDRAR	0.15	0.016	9.45					
3705RA501-83	03I16340	HYDRAR	1.7	0.013	134.6					
3705RA501-85	03I16341	HYDRAR	1.7	0.013	134.6					

† See comment on last page.
ND Parameter not detected above LOD.
NR Parameter not requested.
NA Parameter not applicable.

** See comment on last page.
() Parameter between LOD and LOQ.
TBA Parameter to be analyzed.

Analyst: Jason D. Kim

Reviewer: Neil A. Edwards



ANALYTICAL REPORT

Form ARF-C
Page 3 of 3
05140323403496RX

MAY 15 2003

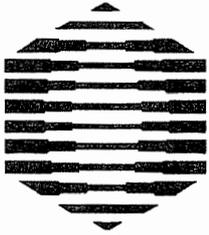
Date _____
Laboratory Group Name 03I-1146-07

General Set Comments

Method Reference: NIOSH Manual of Analytical Methods(NMAM), 4th ed., 08/15/94.
Results are not blank-corrected.
Results cannot be reported in mg/m³ or ppm for samples with no air volume.
Field sample 03I16335 was not submitted by the client.

General Lab Comments

The results provided in this report relate only to the items tested.
This page is the concluding page of the report.



DATA CHEM

LABORATORIES, INC.

ANALYTICAL REQUEST FORM

1. REGULAR Status 03I-1146-06

RUSH Status Requested - ADDITIONAL CHARGE

RESULTS REQUIRED BY _____ DATE _____

CONTACT DATACHEM LABS PRIOR TO SENDING SAMPLES

2. Date 5/2/03 Purchase Order No. _____

3. Company Name 3007 ALLEN HAMILTON DCL Project Manager Rand Potter

Address 5299 DTC BLVD., STE 840

GREENWOOD VILLAGE, CO 80111

5. Sample Collection

Person to Contact STEVE COFFE Sampling Site AERC, MELBOURNE

Industrial Process DIC DEVICE

Telephone (303) 221-7559 Date of Collection 4/29/03

Fax Telephone (303) 694-7367 Time Collected _____

E-mail Address COFFE STEPHEN @ BAH.COM Date of Shipment 5/2/03

Billing Address (if different) REFER TO CONTRACT Chain of Custody No. 1

6. REQUEST FOR ANALYSES

Laboratory Use Only	Client Sample Number	Matrix*	Sample Volume	ANALYSES REQUESTED - Use method number if known	Units**
<u>03I16295</u>	<u>3705-B-A/29-01</u>	<u>HYDRAR</u>	<u>61.2 l</u>	<u>NIOSH 6009</u>	<u>2</u>
<u>296</u>	<u>3705-B-7/29-031</u>		<u>64.8 l</u>		
<u>297</u>	<u>3705-D-A-7/29 050</u>		<u>25.8 l</u>		
<u>298</u>	<u>-070</u>		<u>24.2 l</u>		
<u>299</u>	<u>-090</u>		<u>24.9 l</u>		
<u>300</u>	<u>-110</u>		<u>25.1 l</u>		
<u>01</u>	<u>-130</u>		<u>3.0 l</u>		
<u>02</u>	<u>-150</u>		<u>5.1 l</u>		
<u>03</u>	<u>-170</u>		<u>104.9 l</u>		
<u>04</u>	<u>-190</u>		<u>106.4 l</u>		
<u>05</u>	<u>-210</u>		<u>109.2 l</u>		
<u>06</u>	<u>-230</u>		<u>1.01 l</u>		
<u>07</u>	<u>-250</u>		<u>1.01 l</u>		
<u>08</u>	<u>FIELD BLANK 4/290</u>				
<u>09</u>	<u>FIELD BLANK 4/290</u>				

* Specify: Solid sorbent tube, e.g. Charcoal; Filter type; Impinger solution; Bulk sample; Blood; Urine; Tissue; Soil; Water; Other

** 1. mg/sample 2. mg/m³ 3. ppm 4. % 5. _____ (other) Please indicate one or more units in the column entitled Units**

Comments _____

Possible Contamination and/or Chemical Hazards _____

7. Chain of Custody (Optional)

Relinquished by <u>Steve Coffe</u>	Date/Time <u>5/2/03 1310</u>
Received by <u>Rand Potter</u>	Date/Time <u>5/5/03</u>
Relinquished by <u>Rand Potter</u>	Date/Time <u>5/15/03 (RA)</u>
Received by _____	Date/Time _____



DATA CHEM

LABORATORIES, INC.

ANALYTICAL REQUEST FORM

1. REGULAR Status

03I-1146-00

RUSH Status Requested - ADDITIONAL CHARGE

RESULTS REQUIRED BY _____ DATE _____

CONTACT DATACHEM LABS PRIOR TO SENDING SAMPLES

2. Date 5/2/03 Purchase Order No. _____
 3. Company Name BOBZ ALLEN HAMILTON
 Address 5299 DTC BLVD, STE 840
GREENWOOD VILLAGE, CO 80111
 Person to Contact STEVE COFFEE
 Telephone (303) 221-7559
 Fax Telephone (303) 694-7367
 E-mail Address COFFEE-STEPHEN@BAM.COM
 Billing Address (if different) REFER TO CONTRACT

4. Quote No. _____
 DCL Project Manager Rand Potter
 5. Sample Collection
 Sampling Site AERC MELBOURNE
 Industrial Process DTC DEVICE
 Date of Collection 4/30/03
 Time Collected _____
 Date of Shipment 5/2/03
 Chain of Custody No. 3

6. REQUEST FOR ANALYSES

Laboratory Use Only	Client Sample Number	Matrix*	Sample Volume	ANALYSES REQUESTED - Use method number if known	Units**
03I16310	3705-A-A-4/30 ZP	HYDRAL	22.3 l	NAM 6009	2
11	-29		12.5 l		
12	-31		12.4 l		
13	33		22.8 l		
14	35		22.8 l		
15	37		2.98 l		
16	39		4.22 l		
17	41		2.98 l		
18	43		2.98 l		
19	45		0.99 l		
20	47		0.99 l		
21	49		150.6 l		
22	51		149.1 l		
23	53		154.1 l		
24	55		18.4 l		
25	57		18.1 l		
26	59		3.07 l		

* Specify: Solid sorbent tube, e.g. Charcoal; Filter type; Impinger solution; Bulk sample; Blood; Urine; Tissue; Soil; Water; Other

** 1. mg/sample 2. mg/m³ 3. ppm 4. % 5. _____ (other) Please indicate one or more units in the column entitled Units**

Comments 2 FIELD BLANKS 27 1 28 4/30 HYRAL NAM 6009 2

Possible Contamination and/or Chemical Hazards _____

7. Chain of Custody (Optional)

Relinquished by <u>Steph D. Coffey</u>	Date/Time <u>5/2/03 1310</u>
Received by <u>Rand Potter</u>	Date/Time <u>5/5</u>
Relinquished by <u>Rand Potter</u>	Date/Time <u>5/5</u>
Received by _____	Date/Time _____

Appendix C

Data Chem Laboratory Reports

Sample Shipping Information

Samples were placed in an oversized, sturdy box with packing material to fill voids and protect the samples during shipping. The sampling personnel then signed the chain-of-custody forms, and placed them in the box with the samples. Samples were shipped via Federal Express to the laboratory.



ANALYTICAL REPORT

Form ARF-AL

Page 1 of 3

Part 1 of 1

06230312005398RX

Date JUN 24 2003
 Laboratory Group Name 03I-1506-01
 Account No. 07003

Booz Allen Hamilton
 Attention: Steve Coffee
 5299 DTC Blvd.
 Suite 840
 Greenwood Village, CO 80111

FAX (303) 694-7367
 Telephone (303) 221-7559
 E-mail coffee_stephen@bah.com

Sampling Collection and Shipment

Sampling Site AERC Ashland Trip#4 Date of Collection _____
 Date Samples Received at Laboratory June 16, 2003

Analysis

Method of Analysis NMAM 6009
 Date(s) of Analysis June 19, 2003

Analytical Results

Field Sample Number	Laboratory Number	Sample Type	Mercury ug/sample	Mercury mg/m ³	Air Volume L				
3705BA6/9-01	03I19545	TUBE	0.77	0.013	58.3				
3705BA6/9-03	03I19546	TUBE	0.46	0.0086	54.1				
LAB BLANK	03I19547	TUBE	0.040	**	0.00				
LAB BLANK	03I19548	TUBE	0.047	**	0.00				
LAB BLANK	03I19549	TUBE	0.040	**	0.00				
FB 6/10	03I19550	TUBE	0.039	**	0.00				
FB 6/10	03I19551	TUBE	0.041	**	0.00				
FB 6/11	03I19552	TUBE	0.041	**	0.00				
FB 6/11	03I19553	TUBE	0.038	**	0.00				
FB 6/12	03I19554	TUBE	0.040	**	0.00				
FB 6/12	03I19555	TUBE	0.038	**	0.00				
FB 6/13	03I19556	TUBE	0.036	**	0.00				
FB 6/13	03I19557	TUBE	0.043	**	0.00				

† See comment on last page.
 ND Parameter not detected above LOD.
 NR Parameter not requested.
 NA Parameter not applicable.

** See comment on last page.
 () Parameter between LOD and LOQ.

Analyst: Jose G. Rocha
 Reviewer: Neil A. Edwards



ANALYTICAL REPORT

Form ARF-C

Page 3 of 3
06230312005398RX

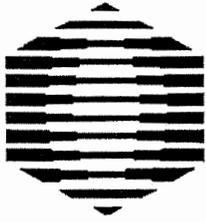
Date JUN 24 2003
Laboratory Group Name 03I-1506-01

General Set Comments

Method Reference: NIOSH Manual of Analytical Methods(NMAM), 4th ed., 08/15/94.
Results are not blank-corrected.
Results obtained for media blanks prepared from SKC Carulite tubes are typically found to have concentrations approximately 0.035-0.045 ug/Sample above the reporting limit.
Results cannot be reported in mg/m³ or ppm for samples with no air volume.

General Lab Comments

The results provided in this report relate only to the items tested.
This page is the concluding page of the report.



DATA CHEM

LABORATORIES, INC.

ANALYTICAL REQUEST FORM

1. REGULAR Status 03I-1506-01

RUSH Status Requested - ADDITIONAL CHARGE

RESULTS REQUIRED BY _____ DATE _____

CONTACT DATACHEM LABS PRIOR TO SENDING SAMPLES

2. Date 6/13/03 Purchase Order No. _____ 4. Quote No. _____

3. Company Name Booz Allen Hamilton DCL Project Manager Rand Potter

Address 5299 DTC Blvd., Suite 840
Greenwood Village, CO 80111

Person to Contact Steve Coffee

Telephone (303) 221-7559

Fax Telephone (303) 694-7367

E-mail Address coffee_stephen@bah.com

Billing Address (if different from above) refer to contract

5. Sample Collection

Sampling Site AERC Ashland Trip #4

Industrial Process DTC Device

Date of Collection 6/9 + 6/10 + 6/11 + 6/12

Time Collected _____

Date of Shipment 6/13/03

Chain of Custody No. 1

6. REQUEST FOR ANALYSES

Laboratory Use Only	Client Sample Number	Matrix*	Sample Volume	ANALYSES REQUESTED - Use method number if known	Units**
<u>03I 19545</u>	<u>3705-B-A-6/9-01</u>	<u>Hydrar</u>	<u>58.3 L</u>	<u>N 10SH 6009</u>	<u>2</u>
<u>546</u>	<u>" -03</u>		<u>54.1 L</u>		
<u>547</u>	<u>LAB Blank</u>		<u>na</u>		
<u>548</u>	<u>LAB Blank</u>		<u>na</u>		
<u>549</u>	<u>LAB Blank</u>		<u>na</u>		
<u>550</u>	<u>Field Blank 6/10</u>		<u>na</u>		
<u>551</u>	<u>Field Blank 6/10</u>		<u>na</u>		
<u>552</u>	<u>Field Blank 6/11</u>		<u>na</u>		
<u>553</u>	<u>Field Blank 6/11</u>		<u>na</u>		
<u>554</u>	<u>Field blank 6/12</u>		<u>na</u>		
<u>555</u>	<u>Field Blank 6/12</u>		<u>na</u>		

* Specify: Solid sorbent tube, e.g. Charcoal; Filter type; Impinger solution; Bulk sample; Blood; Urine; Tissue; Soil; Water; Other

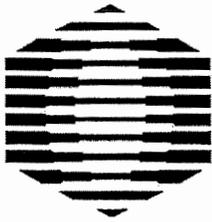
** 1. mg/sample 2. mg/m³ 3. ppm 4. % 5. ____ (other) Please indicate one or more units in the column entitled Units**

Comments _____

Possible Contamination and/or Chemical Hazards _____

7. Chain of Custody (Optional)

Relinquished by <u>Stephen D. Coffey</u>	Date/Time <u>6/13/03 10:03</u>
Received by <u>Rand Potter</u>	Date/Time <u>6/14</u>
Relinquished by <u>Rand Potter</u>	Date/Time <u>6/16/03</u>
Received by _____	Date/Time _____
Relinquished by _____	Date/Time _____
Received by _____	Date/Time _____



**DATA
CHEM**
LABORATORIES, INC.

ANALYTICAL REQUEST FORM

1. REGULAR Status

03I-1506-01

RUSH Status Requested - ADDITIONAL CHARGE

RESULTS REQUIRED BY _____
DATE

CONTACT DATACHEM LABS PRIOR TO SENDING SAMPLES

2. Date _____ Purchase Order No. _____ 4. Quote No. _____

3. Company Name Booz Allen Hamilton DCL Project Manager Rand Potter

Address 5299 DTC Blvd., Suite 840
Greenwood Village, CO 80111

Person to Contact Steve Coffee

Telephone (303) 221-7559

Fax Telephone (303) 694-7367

E-mail Address coffee_stephen@bah.com

Billing Address (if different from above) refer to contract

5. Sample Collection

Sampling Site AERC Ashland Trip #4

Industrial Process DTC Device RTI

Date of Collection 6/13 & 6/10

Time Collected _____

Date of Shipment 6/13/03

Chain of Custody No. 2

6. REQUEST FOR ANALYSES

Laboratory Use Only	Client Sample Number	Matrix*	Sample Volume	ANALYSES REQUESTED - Use method number if known	Units**
03I19556	Field blank 6/13	Hydrar	na	N105H 6009	2
557	Field blank 6/13		na		
03I19885	Field blank 6/13				
558	3705-R-A-6/10-05		25.2L		
559	" -07		13.4L		
560	" -09		13.5L		
561	" -11		29.1L		
562	" -13		29.1L		
563	" -15		3.1L		
564	" -17		3.1L		
565	" -19		1.0L		

* Specify: Solid sorbent tube, e.g. Charcoal; Filter type; Impinger solution; Bulk sample; Blood; Urine; Tissue; Soil; Water; Other

** 1. mg/sample 2. mg/m³ 3. ppm 4. % 5. _____ (other) Please indicate one or more units in the column entitled Units**

Comments field blank facility - 03I19885

Possible Contamination and/or Chemical Hazards _____

7. Chain of Custody (Optional)

Relinquished by	<u>Steve D. Coffey</u>	Date/Time	<u>6/13/03 10:00</u>
Received by	<u>Rand Potter</u>	Date/Time	<u>6/14</u>
Relinquished by	<u>Rand Potter</u>	Date/Time	<u>6/16/</u>
Received by	_____	Date/Time	_____
Relinquished by	_____	Date/Time	_____
Received by	_____	Date/Time	_____



ANALYTICAL REPORT

Form ARP-AL
 Page 1 of 3
 Part 1 of 1
 06869312244758RX

JUN 24 2003

Date _____
 Laboratory Group Name 03I-1506-02
 Account No. 07003

Booz Allen Hamilton
 Attention: Steve Coffee
 5299 DTC Bld.
 Suite 840
 Greenwood Village, CO 80111

FAX (303) 694-7367
 Telephone (303) 221-7559
 E-mail coffee_stephen@bah.com

Sampling Collection and Shipment

Sampling Site AERC Ashland Trip#4 Date of Collection June 10, 2003
 Date Samples Received at Laboratory June 16, 2003

Analysis

Method of Analysis NMAM 6009
 Date(s) of Analysis June 19, 2003

Analytical Results

Field Sample Number	Laboratory Number	Sample Type	Mercury ug/sample	Mercury mg/m ³	Air Volume L				
3705RA6/1021	03I19566	TUBE	0.047	0.047	1.0				
3705RA6/1023	03I19567	TUBE	0.19	0.015	12.3				
3705RA6/1025	03I19568	TUBE	0.19	0.015	12.3				
3705RA6/1027	03I19569	TUBE	0.37	0.0066	55.8				
3705RA6/1029	03I19570	TUBE	0.68	0.012	54.7				
3705RA6/1031	03I19571	TUBE	0.95	0.017	56.2				
3705RA6/1033	03I19572	TUBE	0.15	0.012	12.5				
3705RA6/1035	03I19573	TUBE	0.16	0.013	12.5				
3705RA6/1037	03I19574	TUBE	0.17	0.015	11.4				
3705RA6/1039	03I19575	TUBE	0.16	0.014	11.5				
3705RA6/1041	03I19576	TUBE	0.17	0.015	11.6				
3705RA6/1043	03I19577	TUBE	0.14	0.013	10.8				
3705RA6/1045	03I19578	TUBE	0.096	0.031	3.1				

† See comment on last page.
 ND Parameter not detected above LOD. ** See comment on last page.
 NR Parameter not requested. () Parameter between LOD and LOQ.
 NA Parameter not applicable.

Jose G. Rocha
 Analyst: Jose G. Rocha
[Signature]
 Reviewer: Neil A. Edwards



ANALYTICAL REPORT

Form ARF-C
Page 3 of 3
06240312244758RX

JUN 24 2003

Date _____
Laboratory Group Name 03I-1506-02

General Set Comments

Method Reference: NIOSH Manual of Analytical Methods(NMAM), 4th ed., 08/15/94.
Results are not blank-corrected.
Results obtained for media blanks prepared from SKC Carulite tubes are typically found to have concentrations approximately 0.035-0.045 ug/Sample above the reporting limit.

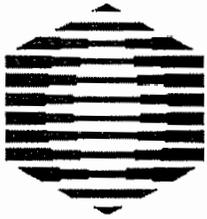
The result for sample 03I19580 exceeded the calibration range of the instrument. Due to an oversight, the sample was not diluted and reanalyzed. The reported result for this sample is therefore estimated.

Sample Comments

Laboratory Number	Comment
03I19580	See set comments.

General Lab Comments

The results provided in this report relate only to the items tested. This page is the concluding page of the report.



**DATA
CHEM**
LABORATORIES, INC.

ANALYTICAL REQUEST FORM

1. REGULAR Status 03L-1506-02

RUSH Status Requested - ADDITIONAL CHARGE

RESULTS REQUIRED BY _____

DATE

CONTACT DATACHEM LABS PRIOR TO SENDING SAMPLES

2. Date _____ Purchase Order No _____ 4. Quote No _____

3. Company Name Booz Allen Hamilton DCL Project Manager Rand Potter

Address 5299 DTC Blvd., Suite 840 5. Sample Collection

Greenwood Village, CO 80111 Sampling Site AERC Ashland Trip #4

Person to Contact Steve Coffee Industrial Process DTC Device RTD

Telephone (303) 221-7559 Date of Collection 6/10/03

Fax Telephone (303) 694-7367 Time Collected _____

E-mail Address coffee_stephen@bah.com Date of Shipment 6/13/03

Billing Address (if different from above) refer to contract Chain of Custody No 3

6. REQUEST FOR ANALYSES

Laboratory Use Only	Client Sample Number	Matrix*	Sample Volume	ANALYSES REQUESTED - Use method number if known	Units**
03L19566	3705-R-A-6/10-21	Hydrac	1.0 L	NIOSH 6009	2
567	" -23.		12.3 L		
568	" -25.		12.3 L		
569	" -27.		55.8 L		
570	" -29.		54.7 L		
571	" -31.		56.2 L		
572	" -33.		12.5 L		
573	" -35.		12.5 L		
574	" -37.		11.4 L		
575	" -39.		11.5 L		
576	" -41.	✓	11.6 L	✓	✓

* Specify: Solid sorbent tube, e.g. Charcoal; Filter type; Impinger solution; Bulk sample; Blood; Urine; Tissue; Soil; Water; Other

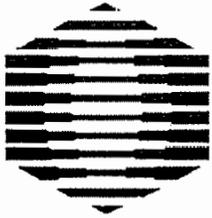
** 1. mg/sample 2 mg/m³ 3. ppm 4. % 5. ____ (other) Please indicate one or more units in the column entitled Units**

Comments _____

Possible Contamination and/or Chemical Hazards _____

7. Chain of Custody (Optional)

Relinquished by <u>Stephen Coffey</u>	Date/Time <u>6/13/03 10:01</u>
Received by <u>Rand Potter</u>	Date/Time <u>6/14</u>
Relinquished by <u>Rand Potter</u>	Date/Time <u>6/16/03</u>
Received by _____	Date/Time _____
Relinquished by _____	Date/Time _____
Received by _____	Date/Time _____



DATA CHEM

LABORATORIES, INC.

ANALYTICAL REQUEST FORM

1. REGULAR Status

03T-1506-02

RUSH Status Requested - ADDITIONAL CHARGE

RESULTS REQUIRED BY _____

DATE

CONTACT DATACHEM LABS PRIOR TO SENDING SAMPLES

2. Date _____ Purchase Order No. _____

3. Company Name Booz Allen Hamilton DCL Project Manager Rand Potter

Address 5299 DTC Blvd., Suite 840

Greenwood Village, CO 80111

Person to Contact Steve Coffee

Telephone (303) 221-7559

Fax Telephone (303) 694-7367

E-mail Address coffee_stephen@bah.com

Billing Address (if different from above) refer to contract

4. Quote No. _____

5. Sample Collection

Sampling Site AERC Ashland Trip #4

Industrial Process DTC Device RTI

Date of Collection 6/10/03

Time Collected _____

Date of Shipment 6/13/03

Chain of Custody No. 4

6. REQUEST FOR ANALYSES

Laboratory Use Only	Client Sample Number	Matrix*	Sample Volume	ANALYSES REQUESTED - Use method number if known	Units**
03T, 19577	3705-R-A-6/10-43	Hydra	10.8 L	N165H 6009	2
578	" -45.	↓	3.1 L	↓	↓
579	" -47.	↓	12.7 L	↓	↓
580	" -49.	↓	13.0 L	↓	↓
581	" -51.	↓	1.0 L	↓	↓
582	" -53.	↓	1.0 L	↓	↓
522					

* Specify: Solid sorbent tube, e.g. Charcoal; Filter type; Impinger solution; Bulk sample; Blood; Urine; Tissue; Soil; Water; Other

** 1. mg/sample 2. mg/m³ 3. ppm 4. % 5. ____ (other) Please indicate one or more units in the column entitled Units**

Comments _____

Possible Contamination and/or Chemical Hazards _____

7. Chain of Custody (Optional)

Relinquished by	<u>Steph O. Coffey</u>	Date/Time	<u>6/13/03 10:20</u>
Received by	<u>Rand Potter</u>	Date/Time	<u>6/14</u>
Relinquished by	<u>Rand Potter</u>	Date/Time	<u>6/16/03</u>
Received by		Date/Time	
Relinquished by		Date/Time	
Received by		Date/Time	



ANALYTICAL REPORT

Form ARF-AL
 Page 1 of 3
 Part 1 of 1
 06230316244303RX

Date JUN 24 2003
 Laboratory Group Name 03I-1506-04
 Account No. 07003

Booz Allen Hamilton
 Attention: Steve Coffee
 5299 DTC Blcd.
 Suite 840
 Greenwood Village, CO 80111

FAX (303) 694-7367
 Telephone (303) 221-7559
 E-mail coffee_stephen@bah.com

Sampling Collection and Shipment

Sampling Site AERC Ashland Trip#4 Date of Collection June 11, 2003
 Date Samples Received at Laboratory June 16, 2003

Analysis

Method of Analysis NMAM 6009
 Date(s) of Analysis June 20, 2003

Analytical Results

Field Sample Number	Laboratory Number	Sample Type	Mercury ug/Sample	Mercury mg/m ³	Air Volume L				
3705DA61155	03I19603	TUBE	1.2	0.064	19.20				
3705DA61157	03I19604	TUBE	0.68	0.058	11.7				
3705DA61159	03I19605	TUBE	0.90	0.076	11.8				
3705DA61161	03I19606	TUBE	1.5	0.074	20.1				
3705DA61163	03I19607	TUBE	0.98	0.047	20.8				
3705DA61165	03I19608	TUBE	1.0	0.20	5.2				
3705DA61167	03I19609	TUBE	0.20	0.065	3.1				
3705DA61169	03I19610	TUBE	0.10	0.10	1.0				
3705DA61171	03I19611	TUBE	0.19	0.19	1.0				
3705DA61173	03I19612	TUBE	0.62	0.081	7.7				
3705DA61175	03I19613	TUBE	0.59	0.11	5.5				
3705AA612117	03I19615	TUBE	0.77	0.029	26.5				
3705AA612119	03I19616	TUBE	0.77	0.049	15.8				

See comment on last page. ** See comment on last page.
 ND Parameter not detected above LOD. () Parameter between LOD and LOQ.
 NR Parameter not requested.
 NA Parameter not applicable.

Jose G. Rocha
 Analyst: Jose G. Rocha

 Reviewer: Neil A. Edwards



ANALYTICAL REPORT

Form ARF-C
Page 3 of 3
06230316244303RX

JUN 24 2003

Date _____

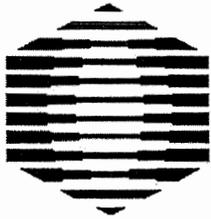
Laboratory Group Name 03I-1506-04

General Set Comments

Method Reference: NIOSH Manual of Analytical Methods(NMAM), 4th ed., 08/15/94.
Results are not blank-corrected.
Results obtained for media blanks prepared from SKC Carulite tubes are typically found to have concentrations approximately 0.035-0.045 ug/Sample above the reporting limit.
Samples 03I19603,606 required a 10X dilution.

General Lab Comments

The results provided in this report relate only to the items tested.
This page is the concluding page of the report.



**DATA
CHEM**
LABORATORIES, INC.

ANALYTICAL REQUEST FORM

1. REGULAR Status 03I-1506-04

RUSH Status Requested - ADDITIONAL CHARGE

RESULTS REQUIRED BY _____ DATE _____

CONTACT DATACHEM LABS PRIOR TO SENDING SAMPLES

2. Date 6/13/03 Purchase Order No. _____ 4. Quote No. _____

3. Company Name Booz Allen Hamilton DCL Project Manager Rand Potter

Address 5299 DTC Blvd., Suite 840

Greenwood Village, CO 80111

5. Sample Collection

Person to Contact Steve Coffee Sampling Site AERC Ashland Trip #4

Industrial Process DTC Device Dextrin

Telephone (303) 221-7559 Date of Collection 6/11/03

Fax Telephone (303) 694-7367 Time Collected _____

E-mail Address coffee_stephen@bah.com Date of Shipment 6/13/03

Billing Address (if different from above) refer to contract Chain of Custody No. 9

6. REQUEST FOR ANALYSES

Laboratory Use Only	Client Sample Number	Matrix*	Sample Volume	ANALYSES REQUESTED - Use method number if known	Units**
<u>03I19603</u>	<u>3705-D-A-6/11-55</u>	<u>Hydrar</u>	<u>19.2 L</u>	<u>NIOSH 6009</u>	<u>2</u>
<u>604</u>	<u>" -57</u>		<u>11.7 L</u>		
<u>605</u>	<u>" -59</u>		<u>11.8 L</u>		
<u>606</u>	<u>" -61</u>		<u>20.1 L</u>		
<u>607</u>	<u>" -63</u>		<u>20.8 L</u>		
<u>608</u>	<u>" -65</u>		<u>5.2 L</u>		
<u>609</u>	<u>" -67</u>		<u>3.1 L</u>		
<u>610</u>	<u>" -69</u>		<u>1.0 L</u>		
<u>611</u>	<u>" -71</u>		<u>1.0 L</u>		
<u>612</u>	<u>" -73</u>		<u>7.7 L</u>		
<u>613</u>	<u>" -75</u>	✓	<u>5.5 L</u>	✓	✓

* Specify: Solid sorbent tube, e.g. Charcoal; Filter type; Impinger solution; Bulk sample; Blood; Urine; Tissue; Soil; Water; Other

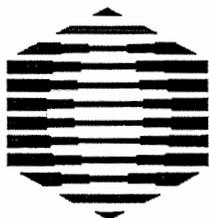
** 1. mg/sample 2. mg/m³ 3. ppm 4. % 5. _____ (other) Please indicate one or more units in the column entitled Units**

Comments _____

Possible Contamination and/or Chemical Hazards _____

7. Chain of Custody (Optional)

Relinquished by <u>Steve J. Coffey</u>	Date/Time <u>6/13/03 10:00</u>
Received by <u>Rand Potter</u>	Date/Time <u>6/14</u>
Relinquished by <u>Rand Potter</u>	Date/Time <u>6/16</u>
Received by _____	Date/Time _____
Relinquished by _____	Date/Time _____
Received by _____	Date/Time _____



**DATA
CHEM**
LABORATORIES, INC.

ANALYTICAL REQUEST FORM

1. REGULAR Status 03I-1506-04
 RUSH Status Requested - ADDITIONAL CHARGE
 RESULTS REQUIRED BY _____ DATE _____
 CONTACT DATACHEM LABS PRIOR TO SENDING SAMPLES

2. Date 6/13 Purchase Order No. _____ 4. Quote No. _____
 3. Company Name Booz Allen Hamilton DCL Project Manager Rand Potter
 Address 5299 DTC Blvd., Suite 840
Greenwood Village, CO 80111
 Person to Contact Steve Coffee
 Telephone (303) 221-7559
 Fax Telephone (303) 694-7367
 E-mail Address coffee_stephen@bah.com
 Billing Address (if different from above) refer to contract

5. Sample Collection
 Sampling Site AERC Ashland Trip #4
 Industrial Process DTC Device AIR CYCLE
 Date of Collection 6/12/03
 Time Collected _____
 Date of Shipment 6/13/03
 Chain of Custody No. _____

6. REQUEST FOR ANALYSES

Laboratory Use Only	Client Sample Number	Matrix*	Sample Volume	ANALYSES REQUESTED - Use method number if known	Units**
03I 19614	5705-A-A-412	HYDRAR		<u>NAAM (600 g)</u>	<u>2</u>
615	117.		26.5 l		
616	119.		15.8 l		
617	121.		16.7 l		
618	123.		26.4 l		
619	125.		26.5 l		
620	127.		3.1 l		
621	129.		3.1 l		
622	131.		1.0 l		
623	133.		1.0 l		
624	135.		10.3 l		

* Specify: Solid sorbent tube, e.g. Charcoal; Filter type; Impinger solution; Bulk sample; Blood; Urine; Tissue; Soil; Water; Other
 ** 1. mg/sample 2. mg/m³ 3. ppm 4. % 5. ____ (other) Please indicate one or more units in the column entitled Units**
 Comments _____

Possible Contamination and/or Chemical Hazards _____

7. Chain of Custody (Optional)

Relinquished by <u>Steve Coffee</u>	Date/Time <u>6/13/03 10:00</u>
Received by <u>Rand Potter</u>	Date/Time <u>6/14/</u>
Relinquished by <u>Rand Potter</u>	Date/Time <u>6/16/03</u>
Received by _____	Date/Time _____
Relinquished by _____	Date/Time _____
Received by _____	Date/Time _____



ANALYTICAL REPORT

Form ARF-AL
 Page 1 of 3
 Part 1 of 1
 06240312455882RX

JUN 24 2003

Date _____
 Laboratory Group Name 03I-1506-03
 Account No. 07003

Booz Allen Hamilton
 Attention: Steve Coffee
 5299 DTC Bldg.
 Suite 840
 Greenwood Village, CO 80111

FAX (303) 694-7367
 Telephone (303) 221-7559
 E-mail coffee_stephen@bah.com

Sampling Collection and Shipment

Sampling Site AERC Ashland Trip#4 Date of Collection June 11, 2003
 Date Samples Received at Laboratory June 16, 2003

Analysis

Method of Analysis NMAM 6009
 Date(s) of Analysis June 19, 2003

Analytical Results

Field Sample Number	Laboratory Number	Sample Type	Mercury ug/Sample	Mercury mg/m ³	Air Volume L				
3705DA61199	03I19583	TUBE	0.23	0.033	6.9				
3705DA61101	03I19584	TUBE	0.23	0.034	6.8				
3705DA61103	03I19585	TUBE	0.23	0.074	3.1				
3705DA61105	03I19586	TUBE	0.094	0.094	1.0				
3705DA61107	03I19587	TUBE	0.11	0.11	1.0				
3705DA61109	03I19588	TUBE	0.89	0.12	7.2				
3705DA61111	03I19589	TUBE	0.85	0.12	7.2				
3705DA61113	03I19590	TUBE	1.6	0.089	18.0				
3705DA61115	03I19591	TUBE	1.3	0.073	18.0				
3705DA61177	03I19592	TUBE	0.065	0.00052	125.9				
3705DA61179	03I19593	TUBE	6.0	0.049	123.5				
3705DA61181	03I19594	TUBE	0.059	0.00052	113.1				
3705DA61183	03I19595	TUBE	0.24	0.10	2.4				

† See comment on last page.
 ND Parameter not detected above LOD.
 NR Parameter not requested.
 NA Parameter not applicable.

** See comment on last page.
 () Parameter between LOD and LOQ.

Jose G. Rocha
 Analyst: Jose G. Rocha
Neil A. Edwards
 Reviewer: Neil A. Edwards



ANALYTICAL REPORT

Form ARF-C
Page 3 of 3
06240312455882RX

JUN 24 2003

Date _____

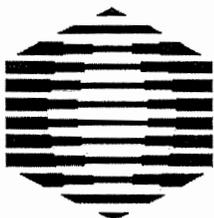
Laboratory Group Name 03I-1506-03

General Set Comments

Method Reference: NIOSH Manual of Analytical Methods(NMAM), 4th ed., 08/15/94.
Results are not blank-corrected.
Results obtained for media blanks prepared from SKC Carulite tubes are typically found to have concentrations approximately 0.035-0.045 ug/Sample above the reporting limit.
Samples 03I19590, 91 and 93 required a 10X dilution.

General Lab Comments

The results provided in this report relate only to the items tested.
This page is the concluding page of the report.



**DATA
CHEM**
LABORATORIES, INC.

ANALYTICAL REQUEST FORM

1. REGULAR Status

03I-1506-03

RUSH Status Requested - ADDITIONAL CHARGE

RESULTS REQUIRED BY _____

DATE

CONTACT DATACHEM LABS PRIOR TO SENDING SAMPLES

2. Date 6/13/03 Purchase Order No. _____ 4. Quote No. _____

3. Company Name Booz Allen Hamilton DCL Project Manager Rand Potter

Address 5299 DTC Blvd., Suite 840 5. Sample Collection

Greenwood Village, CO 80111 Sampling Site AERC Ashland Trip #4

Person to Contact Steve Coffee Industrial Process DTC Device Dextrite

Telephone (303) 221-7559 Date of Collection 6/11/03

Fax Telephone (303) 694-7367 Time Collected _____

E-mail Address coffee_stephen@bah.com Date of Shipment 6/13/03

Billing Address (if different from above) refer to contract Chain of Custody No. 11

6. REQUEST FOR ANALYSES

Laboratory Use Only	Client Sample Number	Matrix*	Sample Volume	ANALYSES REQUESTED - Use method number if known	Units**
03I19583	3705-D-A-6/11-99	Hydrar	6.9 L	NIOSH 6009	2
584	" -101	.	6.8 L		
585	" -103	.	3.1 L		
586	" -105	.	1.0 L		
587	" -107	.	1.0 L		
588	" -109	.	7.2 L		
589	" -111	.	7.2 L		
590	" -113	.	18.0 L		
591	" -115	↓	18.0 L	↓	↓

* Specify: Solid sorbent tube, e.g. Charcoal; Filter type; Impinger solution; Bulk sample; Blood; Urine; Tissue; Soil; Water; Other

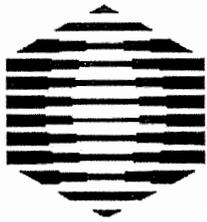
** 1. mg/sample 2. mg/m³ 3. ppm 4. % 5. _____ (other) Please indicate one or more units in the column entitled Units**

Comments _____

Possible Contamination and/or Chemical Hazards _____

7. Chain of Custody (Optional)

Relinquished by	<u>Stephen Coffee</u>	Date/Time	<u>6/13/03</u>	<u>10:00</u>
Received by	<u>Rand Potter</u>	Date/Time	<u>6/14</u>	
Relinquished by	<u>Rand Potter</u>	Date/Time	<u>6/16/03</u>	
Received by		Date/Time		
Relinquished by		Date/Time		
Received by		Date/Time		



DATA CHEM

LABORATORIES, INC.

ANALYTICAL REQUEST FORM

1. REGULAR Status

03I-1506-03

RUSH Status Requested - ADDITIONAL CHARGE

RESULTS REQUIRED BY _____ DATE _____

CONTACT DATACHEM LABS PRIOR TO SENDING SAMPLES

2. Date 6/13/03 Purchase Order No. _____ 4. Quote No. _____

3. Company Name Booz Allen Hamilton DCL Project Manager Rand Potter

Address 5299 DTC Blvd., Suite 840 5. Sample Collection

Greenwood Village, CO 80111 Sampling Site AERC Ashland Trip #4

Person to Contact Steve Coffee Industrial Process DTC Device Dextrite

Telephone (303) 221-7559 Date of Collection 6/11/03

Fax Telephone (303) 694-7367 Time Collected _____

E-mail Address coffee_stephen@bah.com Date of Shipment 6/13/03

Billing Address (if different from above) refer to contract Chain of Custody No. 10

6. REQUEST FOR ANALYSES

Laboratory Use Only	Client Sample Number	Matrix*	Sample Volume	ANALYSES REQUESTED - Use method number if known	Units**
03I19592	3705-D-A-6/11-77	Hydrar	125.9 L	M105H 6009	2
593	" - 79.		123.5 L		
594	" - 81.		113.1 L		
595	" - 83.		2.4 L		
596	" - 85.		2.4 L		
597	" - 87.		2.4 L		
598	" - 89.		2.5 L		
599	" - 91.		6.8 L		
600	" - 93.		6.8 L		
601	" - 95.		7.2 L		
602	" - 97.		6.7 L		

* Specify: Solid sorbent tube, e.g. Charcoal; Filter type; Impinger solution; Bulk sample; Blood; Urine; Tissue; Soil; Water; Other

** 1. mg/sample 2. mg/m³ 3. ppm 4. % 5. ____ (other) Please indicate one or more units in the column entitled Units**

Comments _____

Possible Contamination and/or Chemical Hazards _____

7. Chain of Custody (Optional)

Relinquished by <u>Steph D. Coffey</u>	Date/Time <u>6/13/03 10:00</u>
Received by <u>Rand Potter</u>	Date/Time <u>6/14</u>
Relinquished by <u>Rand Potter</u>	Date/Time <u>6/16/03</u>
Received by _____	Date/Time _____
Relinquished by _____	Date/Time _____
Received by _____	Date/Time _____



ANALYTICAL REPORT

Form ARF-AL
 Page 1 of 3
 Part 1 of 1
 06230316253074RX

Date JUN 24 2003
 Laboratory Group Name 03I-1506-05
 Account No. 07003

Booz Allen Hamilton
 Attention: Steve Coffee
 5299 DTC Blcd.
 Suite 840
 Greenwood Village, CO 80111

FAX (303) 694-7367
 Telephone (303) 221-7559
 E-mail coffee_stephen@bah.com

Sampling Collection and Shipment

Sampling Site AERC Ashland Trip#4 Date of Collection June 11, 2003
 Date Samples Received at Laboratory June 16, 2003

Analysis

Method of Analysis NMAM 6009
 Date(s) of Analysis June 20, 2003

Analytical Results

Field Sample Number	Laboratory Number	Sample Type	Mercury ug/Sample	Mercury mg/m ³	Air Volume L					
3705AA612137	03I19626	TUBE	0.43	0.039	11.0					
3705AA612139	03I19627	TUBE	6.8	0.057	118.2					
3705AA612141	03I19628	TUBE	7.4	0.058	128.9					
3705AA612143	03I19629	TUBE	5.5	0.044	123.1					
3705AA612145	03I19630	TUBE	0.13	TBA	TBA					
3705AA612147	03I19631	TUBE	0.29	TBA	TBA					
3705AA612149	03I19632	TUBE	0.29	TBA	TBA					
3705AA612151	03I19633	TUBE	0.32	TBA	TBA					
3705AA612153	03I19634	TUBE	0.32	0.042	7.7					
3705AA612155	03I19635	TUBE	0.29	0.039	7.5					
3705AA612157	03I19637	TUBE	0.12	0.039	3.1					
3705AA612159	03I19638	TUBE	0.26	0.072	3.6					
3705AA612161	03I19639	TUBE	0.10	0.10	1.0					

† See comment on last page.
 ND Parameter not detected above LOD.
 NR Parameter not requested.
 NA Parameter not applicable.

** See comment on last page.
 () Parameter between LOD and LOQ.
 TBA Parameter to be analyzed.

Jose G. Rocha
 Analyst: Jose G. Rocha

 Reviewer: Neil A. Edwards



ANALYTICAL REPORT

Form ARF-C
Page 3 of 3
06230316253074RX

JUN 24 2003

Date _____

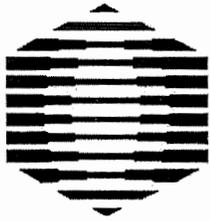
Laboratory Group Name 03I-1506-05

General Set Comments

Method Reference: NIOSH Manual of Analytical Methods(NMAM), 4th ed., 08/15/94.
Results are not blank-corrected.
Results obtained for media blanks prepared from SKC Carulite tubes are typically found to have concentrations approximately 0.035-0.045 ug/Sample above the reporting limit.
Samples 03I19627, 28 and 29 required a 10X dilution.

General Lab Comments

The results provided in this report relate only to the items tested.
This page is the concluding page of the report.



**DATA
CHEM**
LABORATORIES, INC.

ANALYTICAL REQUEST FORM

1. REGULAR Status 03E-1506-05

RUSH Status Requested - ADDITIONAL CHARGE
RESULTS REQUIRED BY _____
DATE _____
CONTACT DATACHEM LABS PRIOR TO SENDING SAMPLES

2. Date 6/13 Purchase Order No. _____ 4. Quote No. _____

3. Company Name Booz Allen Hamilton DCL Project Manager Rand Potter

Address 5299 DTC Blvd., Suite 840 5. Sample Collection

Greenwood Village, CO 80111 Sampling Site AERC Ashland Trip #4

Person to Contact Steve Coffee Industrial Process DTC Device AIR CYCLE

Telephone (303) 221-7559 Date of Collection 6/17/03

Fax Telephone (303) 694-7367 Time Collected _____

E-mail Address coffee_stephen@bah.com Date of Shipment 6/13/03

Billing Address (if different from above) refer to contract Chain of Custody No. _____

6. REQUEST FOR ANALYSES

Laboratory Use Only	Client Sample Number	Matrix*	Sample Volume	ANALYSES REQUESTED - Use method number if known	Units**
03E19625	<u>3705-A-A-9/2</u>	<u>HYDRAL</u>		<u>NAM 6009</u>	<u>2</u>
<u>626</u>	<u>137.</u>		<u>11.0 l</u>		
<u>627</u>	<u>139.</u>		<u>118.2 l</u>		
<u>628</u>	<u>141.</u>		<u>128.9 l</u>		
<u>629</u>	<u>143.</u>		<u>123.1 l</u>		
<u>630</u>	<u>145.</u>		<u>7.7 l</u>		
<u>631</u>	<u>147.</u>				
<u>632</u>	<u>149.</u>				
<u>633</u>	<u>151.</u>				
<u>634</u>	<u>153.</u>		<u>7.7 l</u>		
<u>635</u>	<u>155.</u>		<u>7.5 l</u>		

* Specify: Solid sorbent tube, e.g. Charcoal; Filter type; Impinger solution; Bulk sample; Blood; Urine; Tissue; Soil; Water; Other

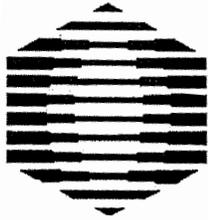
** 1. mg/sample 2. mg/m³ 3. ppm 4. % 5. ____ (other) Please indicate one or more units in the column entitled Units**

Comments _____

Possible Contamination and/or Chemical Hazards _____

7. Chain of Custody (Optional)

Relinquished by <u>Step D. Coffey</u>	Date/Time <u>6/13/03 10:00</u>
Received by <u>Rand Potter</u>	Date/Time <u>6/14</u>
Relinquished by <u>Rand Potter</u>	Date/Time <u>6/16</u>
Received by _____	Date/Time _____
Relinquished by _____	Date/Time _____
Received by _____	Date/Time _____



DATA CHEM

LABORATORIES, INC.

ANALYTICAL REQUEST FORM

1. REGULAR Status

03E-1506-05

RUSH Status Requested - ADDITIONAL CHARGE

RESULTS REQUIRED BY _____

DATE

CONTACT DATACHEM LABS PRIOR TO SENDING SAMPLES

2. Date 6/13 Purchase Order No. _____ 4. Quote No. _____

3. Company Name Booz Allen Hamilton DCL Project Manager Rand Potter

Address 5299 DTC Blvd., Suite 840 5. Sample Collection

Greenwood Village, CO 80111 Sampling Site AERC Ashland Trip #4

Person to Contact Steve Coffee Industrial Process DTC Device AIR CYCLE

Telephone (303) 221-7559 Date of Collection 6/12/03

Fax Telephone (303) 694-7367 Time Collected _____

E-mail Address coffee_stephen@bah.com Date of Shipment 6/13/03

Billing Address (if different from above) refer to contract Chain of Custody No. _____

6. REQUEST FOR ANALYSES

Laboratory Use Only	Client Sample Number	Matrix*	Sample Volume	ANALYSES REQUESTED - Use method number if known	Units**
03E19636	<u>3705-A-A-6/12</u>	<u>HYDRAN</u>		<u>NAM 6007</u>	<u>2</u>
<u>19637</u>	<u>157.</u>		<u>3.1 l</u>		
<u>19638</u>	<u>159.</u>		<u>3.6 l</u>		
<u>19639</u>	<u>1101.</u>		<u>1.0 l</u>		
<u>19640</u>	<u>1103.</u>		<u>1.0 l</u>		
<u>19641</u>	<u>1105.</u>		<u>3.1 l</u>		
<u>19642</u>	<u>1107.</u>		<u>3.3 l</u>		
<u>19643</u>	<u>3705-T-A-6/12</u>				
<u>19644</u>	<u>1167.</u>		<u>9.0 l</u>		
<u>19645</u>	<u>1169.</u>		<u>9.0 l</u>		

* Specify: Solid sorbent tube, e.g. Charcoal; Filter type; Impinger solution; Bulk sample; Blood; Urine; Tissue; Soil; Water; Other

** 1. mg/sample 2. mg/m³ 3. ppm 4. % 5. _____ (other) Please indicate one or more units in the column entitled Units**

Comments _____

Possible Contamination and/or Chemical Hazards _____

7. Chain of Custody (Optional)

Relinquished by <u>Steph. Coffee</u>	Date/Time <u>6/13/03 10:00</u>
Received by <u>Rand Potter</u>	Date/Time <u>6/14</u>
Relinquished by <u>Rand Potter</u>	Date/Time <u>6/16/03</u>
Received by _____	Date/Time _____
Relinquished by _____	Date/Time _____
Received by _____	Date/Time _____

Appendix D

Drum-Top Crushing Device Sampling and Study Plan

Mercury Lamps Drum-Top Crushing (DTC) Device Sampling and Study Plan

February 4, 2003
REPA3-0305-001v1

Objective

The basis of this study is to collect reliable measurements to document the potential release of mercury and human exposure to mercury during the processing of fluorescent lamps in a drum top crusher (DTC) device. Four manufacturers will provide DTC devices for evaluation and comparison. The data collected from the measurements will be used by EPA to assist in the development of a national policy for the use of DTC devices to process mercury containing fluorescent lamps. Part of the objectives are to be in compliance with and by the plans REPA Quality Management Plan (QMP), REPA Region 3 Quality Assurance Project Plan, and the Region 3 Health and Safety Program. For all sampling, analysis and handling procedures, where applicable, Booz Allen staff will follow REPA3 Standard Operating Procedures (SOPs).

Scope

Two different studies will be completed as part of the overall DTC device study. The detail methods for conducting each study are documented in this Sampling and Study Plan. The first study is the environmental validation study and is divided into two phases: Equipment comparison phase and mass balance phase. The second, real world study, is real world testing of the devices. A brief description of the tests for the DTC device study include:

Environmental Validation Study

- Equipment Comparison - Quantify mercury vapor emissions and measure personal mercury exposure during the operation of new devices provided by the manufacturer. Compare the emissions of mercury from the DTC devices, when new, to emissions after the DTC devices have filled a number of 55-gallon drums.
- Mass Balance - Conduct a mass balance study to quantify the mercury released during the processing of fluorescent lamps compared to the estimated quantity of mercury contained in the fluorescent lamps.

Real World Study

- Real World Testing - Conduct field sampling to quantify mercury vapor emissions and worker exposure during the operation of four different DTC devices at three locations in the continental United States.

Schedule

Four manufacturers will provide DTC devices for inclusion in this DTC device study. The following devices will be included in the study:

- Air Cycle Bulb Eater Model 55 VRS
- Resource Technology, Inc. (RTI) Model DTP
- The Hazardous Materials Specialist, Inc. (HMS) Fluorescent Lamp Disposal and Mercury Vapor Recovery System
- Dextrite Model ULC-55 FDA-E

Each manufacturer will provide one new DTC device for the DTC device study. Each of the four devices will be used for the validation testing and real world testing.

Biological monitoring will be incorporated into the study to further define potential mercury exposure. Each DTC device operator will participate in the biological monitoring process. Before the DTC device study begins, **the operators will provide urine samples to a medical clinic to establish background mercury levels.** The operators will submit urine samples at the conclusion of the study to determine whether there is an increase in mercury due to exposure while operating the DTC devices. Mercury levels will be examined and tested to ensure that they are not above acceptable bodily concentrations. All samples will be collected after operators have completed a 24 hour fasting.

Sample collection for the first stages of the equipment comparison phase and the mass balance study will be performed concurrently. The proposed site for these studies is the AERC facility in Ashland, Virginia. The expected time to complete the validation testing includes one day to set up and two days to complete the studies. **Once the results of the samples from these two phases are received and reviewed by Booz Allen, the proposed methods for sampling during the real world testing will be evaluated and modified as necessary by Booz Allen with assistance from the EPA WAM.** Once the methods for the real world testing are determined, Booz Allen and EPA (the team) will conduct tests starting at the Earth Protection Services Inspection (EPSI) facility in Arizona. Next, the team will travel to the Fluorocycle facility in Ingleside, IL. Finally, the team will conduct real world testing back at the AERC facility in Ashland. The real world testing at each location is expected to last the entire week. After completing the real world testing at the Ashland facility, the second stage of the equipment comparison phase will be conducted at this facility.

Sampling Strategy

ENVIRONMENTAL VALIDATION STUDY: Equipment Comparison

The purpose of the equipment comparison phase is to evaluate the potential release of mercury from new DTC devices compared to the same DTC devices after the devices have processed enough fluorescent lamps to have completed a number of drum and filter changes. The equipment comparison phase will be conducted in two stages. The first stage will be conducted before the real world sampling and the second stage will occur at the conclusion of the real world sampling. This will allow each device to have processed enough lamps to completely fill eight drums. Booz Allen will collect wipe samples from various surfaces and collect air samples to measure the concentration of mercury in the air. The first stage of the equipment comparison phase will be conducted concurrently with the mass balance study and some of the sample results will be incorporated into the mass balance equation.

All operations, for each of the devices, will be conducted as directed by the user manual and instructions. This includes the operation of the devices as well as scheduling filter changes and drum changes. Each DTC device will be operated for the time it takes to completely fill one 55-gallon drum. Filters and drums will be changed according to the manufacturer's recommendations. It is estimated that the typical device can fill the drum in 3.5 hours. Based on information provided by the manufacturers, a full drum may hold from 400 to 1,200 lamps depending on the device. Once the drum is full, the next device from another manufacturer will be tested in the same manner. During the operation of all DTC devices only 4-foot Alto T12 lamps by Philips Lighting will be processed. These lamps were chosen because T12 lamps are still the predominant lamps used today compared to the T8 lamps. The Philips Lighting Alto lamps were selected because the Alto lamps are more consistent in the quantity of mercury used in each lamp, although Alto lamps typically contain less mercury. EPA personnel and a Booz Allen Hamilton (Booz Allen) employee will operate and feed the lamps into the DTC devices.

EPA and Booz Allen personnel, with assistance from facility personnel, will build a containment constructed from a rigid tube frame and polyethylene (plastic) sheeting to isolate each DTC device during testing and assist in reducing potential interferences. The containment dimensions will be 12 feet by 12 feet in order to accommodate for the unique sizes of the different DTC devices. Each device will be operated in a containment with new plastic on the walls, floor, and ceiling. Therefore, once each drum has been filled and all samples have been collected, all the plastic sheets from the containment will be removed and new plastic sheets will be installed on the floor, walls, and ceiling before operating the next device. The old plastic will be decontaminated by washing with a water solution containing HGX compound. An appropriate portion of the plastic (determined by testing requirements), will then be tested and disposed of based on the results of the test by the team. **If the results indicate the plastic is contaminated with mercury that is above acceptable levels, the levels of mercury on the sheeting will be recorded and the plastic will be disposed of as mercury contaminated waste according to mercury disposal standards.**

Prior to the start of both the first and second stages of the equipment comparison phase, two background air samples will be collected by Booz Allen staff in the immediate location where the DTC

devices will be operated. Additionally, Booz Allen will use the Jerome Mercury Vapor Analyzer to collect direct measurements and data log the results. The Jerome Analyzer will be operated in accordance with Region 3 SOPs for calibration and measuring. Results of the air monitoring will identify background mercury concentrations that may need to be accounted for in the results and analysis of the study to be performed by Booz Allen.

During the operation of the DTC devices, air samples will be collected, by the team, in specified areas inside the containment and on the operator. All air sampling will be performed in accordance with acceptable industrial hygiene air monitoring procedures. Air samples will be collected in each containment in the following areas (see attached Table-1 for further detail). Booz Allen will perform all air monitoring according to Booz Allen SOPs:

- Two samples (one on each shoulder) will be collected on the operator for the entire duration of the device operation, including filter changes and the drum change.
- Two concurrent samples will be collected at each DTC device exhaust for the duration of the device operation. The results of this sampling during the first stage will be used in the mass balance study.
- Two concurrent samples will be collected at the DTC device feed tube for the duration of the device operation. The results of this sampling during the first stage will be used in the mass balance study.
- One sample will be collected on each operator during the change-out of the filters and drum. Particulate filter changes will occur based on manufacturer's recommendations. It is anticipated that the filter change and drum change will only take a few minutes to complete. In order to ensure a detection limit of less than 0.1 mg/m³ the sample pumps will operate after the filter change and drum change is complete in order to achieve sufficient air **volume, as was determined by EPA and Booz Allen. The schedule for each device's** filter change and subsequent air sample is as follows:
 - ? HMS—every 300 lamps = three samples/drum
 - ? Air Cycle—every drum change = one sample/drum
 - ? RTI—No filter changes, system back purges the filter every 15 minutes
 - ? Dextrite—every 2400 lamps = approximately every third drum.
- Two field blanks will be prepared for each day of sampling.
- One set of three laboratory blanks will be prepared for each stage of the equipment comparison study.

Air samples will be collected to measure airborne mercury concentrations in the vapor phase and aerosol phase. Air samples to measure mercury in the aerosol phase will be collected and analyzed in accordance with the Occupational Safety and Health Administration (OSHA) analytical method ID-145. Air samples to measure mercury in the vapor phase will be collected and analyzed in accordance with the National Institute for Occupational Safety and Health (NIOSH) analytical method 6009. The samples will be collected on a 37-mm mixed cellulose ester filter to capture aerosols connected to a

Hopcalite sample media or an equivalent sample media to capture vapors. The sample pump for every air sample will be pre-calibrated and post-calibrated against a primary standard to adjust the air flow to the proper flow rate.

Information to document each air sample will be recorded on air monitoring forms. The information required on each form includes:

- A sample number unique to that air sample
- Specific details of the sample location or name of the operator wearing the samples
- Pre-calibration and post-calibration results
- Time on and time off of the sample pump
- Volume of air collected—duration of the sampling multiplied by the air flow rate (average of the pre- and post-calibration)
- Number of fluorescent lamps processed during the sampling and categorized by wattage
- Other notable conditions that may effect the sample results.

In addition to air samples, the equipment comparison phase will also include wipe samples collected inside the containment on numerous surfaces. A set of wipe samples will be collected prior to the start of the DTC device operation and a set will be collected at the conclusion of the DTC device operation. A set of pre- and post-operation wipe samples will be collected for each of the manufacturer's devices. The wipe samples will be collected and analyzed in accordance with the NIOSH draft analytical method N9103 for wipe samples. Under this procedure, a 100 cm² wipe sample will be collected using a "Wash-n-Dry" towelette and placed into a vial provided by the laboratory. For each location two side-by-side wipe samples will be collected. The nine locations for the wipe samples inside each containment include:

- Floor—two feet from the device
- Floor—five feet from the device
- Floor—at the device exhaust
- Drum side
- DTC device
- Feed tube inlet exterior
- Ceiling
- Wall
- Wall

At the end of the each equipment comparison stage, the air samples and wipe samples will be collected, packaged, and submitted by the team to DataChem Laboratories, Inc. (DataChem) located in Salt Lake City, Utah, along with completed chain-of-custody forms. DataChem is an American Industrial Hygiene Association (AIHA) accredited laboratory. Samples will be placed in an oversized sturdy box with packing material to fill voids and protect the samples. The Booz Allen person shipping the samples will sign the chain-of-custody forms and will place the forms in the box with the samples. Samples will be submitted via Federal Express to the laboratory.

During the process of measuring mercury concentrations in the air using sampling pumps, two factory calibrated mercury vapor analyzers will be employed by the team to measure real-time mercury concentrations in the air. At least one of the mercury vapor analyzers will be equipped with a data logger to measure and record the mercury concentrations throughout the day. The analyzers, one stationary and one mobile, will be used to identify fluctuations in concentrations while the DTC devices operate and will also measure for leaks in the seals of the DTC devices.

At the conclusion of the device operations for the day, each DTC device will be placed on a drums containing crushed debris and be allowed to set for the night. Any operation of the devices will be performed in accordance with manufacturer instructions. Air samples will be collected next to the DTC device/drum assemblies during the night in between equipment comparison studies. The air samples will measure for any escaping mercury off-gassing that may occur when the devices are not in operation. Air sample pumps with in-line collection media will be set next to each device and the mercury vapor analyzer will log the concentrations throughout the night.

After completion of the first stage of the equipment comparison phase, the new devices will be shipped to the EPSI facility in Arizona. To prepare the devices for shipping the team, with assistance from facility personnel, will be wipe down each device, wrap each device in plastic, and place each device in the crates provided by the manufacturers. Plastic sheet roles and framing will not be shipped but will be purchased separately at each location. Upon receipt of the devices at each of the testing sites, the team will perform an inspection of the devices for damages that resulted from the transport.

In order to test the efficiency of the DTC devices and their performance in use with “U” shaped tubes, a study will take place at the completion of the validation phase. A defined number of lamps will be determined based on amount available at the AERC facility in Ashland, Virginia and used for testing in a final study and the required amount to gain an accurate sample collection. The “U” shaped lamps will be crushed using the devices provided by Air Cycle, Dextrite, and HMS. The RTI device is not equipped with an attachment for feeding “U” shaped tubes and therefore will not be included in this portion of the study. Air samples and wipe samples as described in Table-1 will be collected during the operation of the devices until tubes have been crushed.

ENVIRONMENTAL VALIDATION STUDY: Mass Balance Study

The mass balance study is intended to determine the capture efficiency of mercury vapors during the operation of the DTC devices. Only Alto T12 lamps will be used in the mass balance study. The study will take into account the different wattages of the T12 lamps (wattage 34/40 and 39/60). This study will incorporate the results of the air samples and wipe samples collected during the first stage of the equipment comparison phase. In addition, the team will collect bulk material samples and have them analyzed for mercury by DataChem. The bulk samples will be collected from the DTC devices after the devices have completely filled one drum during the equipment comparison phase prior to removing the device from the containment. The bulk samples will be collected and analyzed in accordance with EPA method SW-846 method 7471A and sampling directions provided by the analytical laboratory (DataChem).

The bulk samples to be collected from the each of the four DTC devices include:

- Three samples from the particulate pre-filters from the HMS device, Air Cycle device and Dextrite device. The RTI device is not equipped with a particulate pre-filter.
- Three samples from the HEPA filters from all four devices.
- Three samples from the carbon filters from all four devices.
- Three samples from the crushed material in the drums. This sample will include representative amounts of broken glass, metal end caps, and phosphor powder.

Before the DTC devices are operated, the filters and empty drums will be tared, to measure the weight of the filters and drum before crushing the lamps. After crushing enough lamps to fill a drum, the filters will be accessed with support from the device manufacturer's representatives and the bulk samples will be collected by cutting out portions of the particulate filters or removing the loose carbon from the top of the carbon filter container. The bulk material will be placed into collection vessels provided by the laboratory. Next, the devices will be removed from the drum, and bulk samples will be collected from the crushed debris below the top surface of debris. The debris samples will be placed in collection vessels provided by the laboratory.

In addition, five Alto T12 lamps (wattage 34/40 and 39/60) will be submitted to the analytical laboratory to confirm the quantity of mercury contained in the lamps. DataChem will crush the lamps in a similar manner as occurs in the devices to ensure that the measurement for mercury is accurate. These results will be used to confirm the amount of mercury reported by the manufacturer. These results will be used to calculate the quantity of mercury based on the number of lamps processed. The bulk samples and intact lamps will be submitted to DataChem for analysis along with completed chain-of-custody forms.

Booz Allen will select, based on accuracy determinations, wipe samples and air samples collected during the equipment comparison phase on the DTC devices will be incorporated into the mass balance study. These select samples include:

- Wipe samples from the exterior drum surface
- Wipe samples from the DTC device
- Air samples collected at the DTC device exhaust
- Air samples collected at the DTC device feed tube.

Upon return of the laboratory results for mercury, the data will be plugged into the mass balance equation by Booz Allen to determine the mercury capture efficiency of the DTC devices. The mass balance equation is:

$$\text{Total Hg} = \text{Hg retained in the DTC device} + \text{Hg released from the DTC device}$$

Total Hg is the quantity of mercury calculated by the quantity of mercury contained in a fluorescent lamp multiplied by the number of lamps processed. Hg retained is determined by the results of the bulk samples collected from the crushed debris in the drum and the bulk filter samples. Hg released is determined by the results of the air samples and wipe samples. Using the equation, the percent recovery of mercury can be calculated. The mass balance study is contained in Attachment 1.

REAL WORLD STUDY: Real World Testing

The real world testing phase will determine the release of mercury vapors and human exposure to mercury vapors during the normal operation of the DTC devices. The same DTC devices used in the equipment comparison phase will be evaluated in a real world industrial setting. The DTC devices will process a variety of four foot T12 lamps for an entire work shift. For this study, a work shift will include the time needed to completely fill two 55-gallon drums. The real world testing will be repeated at three separate locations. The DTC devices will be operated inside a containment equivalent to the containment used in the equipment comparison phase. Each device will be operated in a containment with new plastic on the walls, floor, and ceiling. Therefore, once the work shift has been completed and all samples have been collected, all the plastic sheets from the containment will be removed and new plastic sheets will be installed on the floor, walls, and ceiling before operating the next device. The old plastic will be decontaminated by washing with a water solution containing HGX compound. An appropriate portion of the plastic (determined by testing requirements), will then be tested and disposed of based on the results of the test by the team. **If the results indicate the plastic is contaminated with mercury that is above acceptable levels, the levels of mercury on the sheeting will be recorded and the plastic will be disposed of as mercury contaminated waste according to mercury disposal standards.**

Air samples will be collected over the entire work shift (two drum changes). The operation of the DTC device over the work shift will be performed by EPA and Booz Allen staff. The first person will operate the DTC device until the first drum is filled, including the filter changes and drum change. The second person will operate the DTC device until the second drum is filled, including the filter changes and changing the drum at the end of the day.

During the operation of the DTC devices, air samples will be collected in specified areas inside the containment and on the operator by the team. All air sampling will be performed in accordance with acceptable industrial hygiene air monitoring procedures as well as the Region 3 SOPs. Air samples will be collected in each containment in the following areas (see Attached Table-1 for more detail):

- Two samples (one on each shoulder) will be collected by the operator while they operate the device and completely fill the drum, including filter changes and the drum change.
- Two samples will be collected inside the containment at locations that will be determined based on the results from the equipment comparison phase.

- One sample will be collected on each operator during the change-out of the filters and drum. Particulate filter changes will occur based on manufacturer's recommendations. It is anticipated that the filter change and drum change will only take a few minutes to complete. In order to ensure a detection limit of less than 0.1 mg/m³ the sample pumps will operate after the filter change and drum change is complete in order to achieve sufficient air volume. The schedule for each device's filter change and subsequent air sample is as follows:
 - ? HMS - every 300 lamps = eight samples
 - ? Air Cycle - every drum change = two samples
 - ? RTI - no filter changes, system back-purges the filter every 15 minutes
 - ? Dextrite - every 2400 samples = one sample
- Two field blanks will be prepared for each day of sampling.
- One set of three laboratory blanks will be prepared for each location.

Air samples will be collected to measure airborne mercury concentrations in the vapor phase and aerosol phase. Air samples to measure mercury in the aerosol phase will be collected and analyzed in accordance with the OSHA analytical method ID-145. Air samples to measure mercury in the vapor phase will be collected and analyzed in accordance with the NIOSH analytical method 6009. The samples will be collected on a 37-mm mixed cellulose ester filter to capture aerosols connected to a Hopcalite sample media or an equivalent sample media to capture vapors. The sample pump for every air sample will be pre-calibrated and post-calibrated against a primary standard to adjust the air flow to the proper flow rate.

Information to document each air sample will be recorded on air monitoring forms by Booz Allen. The information required on each form includes:

- A sample number unique to that air sample
- Specific details of the sample location or name of the operator wearing the samples
- Pre-calibration and post-calibration results
- Time on and time off of the sample pump
- Volume of air collected—duration of the sampling multiplied by the air flow rate (average of the pre- and post-calibration)
- Number of fluorescent lamps processed during the sampling and categorized by type of lamp and wattage
- Other notable conditions that may effect the sample results.

In addition to air samples, the equipment comparison phase will also include wipe samples, collected by Booz Allen, inside the containment on numerous surfaces. A set of wipe samples will be collected prior to the start of the DTC device operation and a set will be collected at the conclusion of the DTC device operation. A set of pre- and post-operation wipe samples will be collected for each of the manufacturer's devices. The wipe samples will be collected by Booz Allen and analyzed by DataChem in accordance with the NIOSH draft analytical method N9103 for wipe samples. Under this

procedure, a 100 cm² wipe sample will be collected using a “Wash-n-Dry” towelette and placed into a vial provided by the laboratory. For each location two side-by-side wipe samples will be collected. The nine locations for the wipe samples inside each containment include:

- Floor—two feet from the device
- Floor—five feet from the device
- Floor—at the device exhaust
- Drum side
- DTC device
- Feed tube inlet exterior
- Ceiling
- Wall
- Wall

At the end of the each real world testing location, the air samples and wipe samples will be collected, packaged, and submitted by the team to DataChem located in Salt Lake City, Utah, along with completed chain-of-custody forms. DataChem is an AIHA accredited laboratory. Samples will be placed in an oversized sturdy box with packing material to fill voids and protect the samples. The chain-of-custody forms will be signed by the Booz Allen person shipping the samples and the form placed in the box with the samples. Samples will be submitted via Federal Express to the laboratory.

During the process of measuring mercury concentrations in the air using sampling pumps, two factory calibrated mercury vapor analyzer will be employed to measure real-time mercury concentrations in the air. At least one of the mercury vapor analyzers will be equipped with a data logger to measure and record the mercury concentrations throughout the day. The analyzers, one stationary and one mobile, will be used to identify fluctuations in concentrations while the DTC devices operate and will also measure for leaks in the seals of the DTC devices.

After completion of real world testing at each location, the DTC devices will be shipped to the next location by the team with assistance from facility personnel. The device surfaces will be wiped clean using a water solution containing the HGX compound. The cleaned devices will be capped or plugged at the feed tube intake and at the exhaust wrapped in plastic. The devices will then be placed in the crates or packaging provided by the manufacturers and prepared for transportation.

ATTACHMENT 1

Lamp Crusher Hg Mass Release/Mass Balance Study

Total Hg = Hg retained in crusher unit + Hg released from unit

Where:

Hg_T = Total Hg

Hg_U = Hg retained in crusher unit

Hg_R = Hg released from unit

1. Hg_T = Total Hg

= Total # lamps crushed X Hg/lamp

Hg/lamp based on: 1) manufacturer's claims/estimates; and/or
 2) testing of 5 lamps for total Hg

2. Hg_U = Hg retained in crusher unit

= Hg in crushed lamps + Hg retained in HEPA filter + Hg retained in carbon filter + Hg residual on interior surface of crusher

3. Hg_R = Hg released from unit

Hg_R = Hg released at exhaust port + Hg fugitive release

$Hg_{(EP)}$ = Hg exhaust conc X air flow rate X air flow duration

$Hg_{(F)}$ = (Hg conc. at fugitive release sites X est. air leakage rate) +
(drum change air conc X est. air release at drum change)

And/Or,

$Hg_{(R)}$ = (chamber ambient air Hg conc X chamber volume) +
(wipe sample Hg conc (in mass/SA) X surface area of chamber)

Field Monitoring, Sampling, and Analytical Methods

Sample Type	Location	Frequency	Number of samples			Limit of Detection	Analytical Method
			Vapor	Aerosol	Per Unit		
Equipment Comparison Phase 1 (consists of comparing four new units made by HMS, Air Cycle, RTI, and Dextrite) 3 DAYS							
Wipe samples (2 samples each) ¹	Floor – 2 feet from device	Pre & post samples	N/A	N/A	4	16	NIOSH N9103
	Floor – 5 feet from device	Pre & post samples	N/A	N/A	4	16	NIOSH N9103
	Floor – at device exhaust	Pre & post samples	N/A	N/A	4	16	NIOSH N9103
	Ceiling	Pre & post samples	N/A	N/A	4	16	NIOSH N9103
	Wall	Pre & post samples	N/A	N/A	4	16	NIOSH N9103
	Wall -	Pre & post samples	N/A	N/A	4	16	NIOSH N9103
	Exterior drum surface - side	Pre & post samples	N/A	N/A	4	16	NIOSH N9103
	DTC device	Pre & post samples	N/A	N/A	4	16	NIOSH N9103
	DTC device feed tube Inlet Exterior	Pre & post samples	N/A	N/A	4	16	NIOSH N9103
	Lab Blanks	Prior to each equipment run	N/A	N/A	2	6	NIOSH N9103
Wipe sample subtotal			150				
Air samples	Both shoulders of operator ²	During test run including drum and filter changes (all four units)	2	2	4	16	NIOSH 6009; OSHA ID-145
	DTC Exhaust ²	During test run including drum and filter changes	2	2	4	16	NIOSH 6009; OSHA ID-145
	DTC Feed Tube ²	During test run including drum and filter changes	2	2	4	16	NIOSH 6009; OSHA ID-145
	On operator ⁴	During drum and filter change	1	1	2	8	NIOSH 6009; OSHA ID-145
	On operator ³	During additional filter changes for HMS = every 300 lamps crushed	3	3	6	6	NIOSH 6009; OSHA ID-145
	Laboratory Blank	Prior to study	3	3	N/A	6	NIOSH 6009; OSHA ID-145

	Field Blanks	Prior to study	2	2	N/A	12	0.01 ug/sample	NIOSH 6009; OSHA ID-145
	Background	On each sampling day	2	2	N/A	4	0.01 ug/sample	NIOSH 6009; OSHA ID-145
	Air sample subtotal					84		
Bulk samples	Pre-filter for particulates	Air Cycle = every drum change	N/A	N/A	3	3	0.01 ug/in ²	EPA Method 7471A
		Dextrite = every 2,400 lamps crushed	N/A	N/A	3	3		
		HMS = every 300 lamps crushed	N/A	N/A	3	3		
		RTI = no filter change; filter back-purged every 15 minute	N/A	N/A	N/A	N/A		
	HEPA filter	For this demonstration, change filter when drum changed for HMS, Air Cycle, & Dextrite units	N/A	N/A	3	12	0.01 ug/in ²	EPA 7471A
	Carbon filter	For this demonstration, change filter when drum is changed for all units	N/A	N/A	3	12	0.02 ug/g	EPA 7471A
	Drum contents (crushed material)	When drum is full for each unit	N/A	N/A	3	12	0.02 ug/g	EPA 7471A
	Bulk sample subtotal					45		
Air Samples	DTC Exhaust and Feed Tube	Use results from Equipment Comparison Phase 1	N/A	N/A	N/A	N/A		
Wipe Samples	Drum-side and DTC Device	Use results from Equipment Comparison Phase 1	N/A	N/A	N/A	N/A		
Alto lamps	Alto T12 (34/40)	N/A	N/A	N/A	3	3	0.1 ug/Lamp	EPA 7470
	Alto T12 (39/60)	N/A	N/A	N/A	3	3	0.1 ug/Lamp	EPA 7470
	Alto lamp subtotal					6		
Air samples	Both shoulders of operator ⁶ (2 operators per unit)	During test run including drum and filter changes (All 4 units)	4	4	8	96	0.01 ug/sample	NIOSH 6009; OSHA ID-145
	Inside the containment ⁷	During test run including drum and filter changes (All 4 units)	2	2	4	48	0.01 ug/sample	NIOSH 6009 ; OSHA ID-145
	Inside the containment ⁷	Overnight next to DTC unit (<u>ONE LOCATION</u>)	2	2	4	16	0.01 ug' sample	NIOSH 6009; OSHA ID-145
	On operator ⁹	During drum and filter change (2 events per unit): HMS, Air Cycle, RTI, Dextrite	2	2	4	48	0.01 ug/sample	NIOSH 6009; OSHA ID-145
	On operator ⁸	During additional filter changes for HMS = every 300 lamps crushed	6	6	12	36	0.01 ug/sample	NIOSH 6009; OSHA ID-145

	Laboratory Blank	Prior to study	3	3	6	18	0.01 ug/sample	NIOSH 6009; OSHA ID-145
	Background	Prior to start of study at each facility	2	2	N/A	12	0.01 ug/sample	NIOSH 6009; OSHA ID-145
	Field Blanks ¹¹	At the start of each test day at each facility	2	2	N/A	48	0.01 ug/sample	NIOSH 6009; OSHA ID-145
	Air sample subtotal					322		
Wipe samples (2 samples each) ¹²	Floor – 2 feet from device	Pre & post samples	N/A	N/A	4	48	0.01 ug/sample	NIOSH N9103
	Floor – 5 feet from device	Pre & post samples	N/A	N/A	4	48	0.01 ug/sample	NIOSH N9103
	Floor – at device exhaust	Pre & post samples	N/A	N/A	4	48	0.01 ug/sample	NIOSH N9103
	Ceiling	Pre & post samples	N/A	N/A	4	48	0.01 ug/sample	NIOSH N9103
	Wall	Pre & post samples	N/A	N/A	4	48	0.01 ug/sample	NIOSH N9103
	Wall	Pre & post samples	N/A	N/A	4	48	0.01 ug/sample	NIOSH N9103
	Exterior drum surface - side	Pre & post samples	N/A	N/A	4	48	0.01 ug/sample	NIOSH N9103
	DTC device	Pre & post samples	N/A	N/A	4	48	0.01 ug/sample	NIOSH N9103
	DTC device feed tube Inlet Exterior	Pre & post samples	N/A	N/A	4	48	0.01 ug/sample	NIOSH N9103
	Field Blanks	Start of each day	N/A	N/A	2	24	0.01 ug/sample	NIOSH N9103
	Wipe sample subtotal					456		
Air samples At end of Phase II	Both shoulders of operator	TBD	2	2	4	12	0.01 ug/sample	NIOSH 6009; OSHA ID-145
	Inside the containment	TBD	2	2	4	12	0.01 ug/sample	NIOSH 6009; OSHA ID-145
	On operator ¹³	During drum and filter change (1 event per unit): HMS, Air Cycle, Dextrite	1	1	2	6	0.01 ug/sample	NIOSH 6009; OSHA ID-145
	On operator ³	During additional filter changes: HMS = every 300 lamps crushed	3	3	6	6	0.01 ug/sample	NIOSH 6009; OSHA ID-145
	Field Blanks ⁵	At the start of each day	2	2	N/A	8	0.01 ug/sample	NIOSH 6009; OSHA ID-145
	Air sample subtotal						44	

Wipe samples (2 samples each) ^{1,4}	Floor – 2 feet from device	Pre & post samples	N/A	N/A	4	12	0.01 ug/sample	NIOSH N9103	
	Floor – 5 feet from device	Pre & post samples	N/A	N/A	4	12	0.01 ug/sample	NIOSH N9103	
	Floor – at device exhaust	Pre & post samples	N/A	N/A	4	12	0.01 ug/sample	NIOSH N9103	
	Ceiling	Pre & post samples	N/A	N/A	4	12	0.01 ug/sample	NIOSH N9103	
	Wall	Pre & post samples	N/A	N/A	4	12	0.01 ug/sample	NIOSH N9103	
	Wall	Pre & post samples	N/A	N/A	4	12	0.01 ug/sample	NIOSH N9103	
	Exterior drum surface - side	Pre & post samples	N/A	N/A	4	12	0.01 ug/sample	NIOSH N9103	
	DTC device	Pre & post samples	N/A	N/A	4	12	0.01 ug/sample	NIOSH N9103	
	DTC device feed tube Inlet Exterior	Pre & post samples	N/A	N/A	4	12	0.01 ug/sample	NIOSH N9103	
	Field Blanks	Prior to each equipment run	N/A	N/A	2	4	0.01 ug/sample	NIOSH N9103	
	Wipe sample subtotal								
	112								
	Wipe samples (2 samples each)	Floor – 2 feet from device	Pre & post samples	N/A	N/A	4	16	0.01 ug/sample	NIOSH N9103
Floor – 5 feet from device		Pre & post samples	N/A	N/A	4	16	0.01 ug/sample	NIOSH N9103	
Floor – at device exhaust		Pre & post samples	N/A	N/A	4	16	0.01 ug/sample	NIOSH N9103	
Ceiling		Pre & post samples	N/A	N/A	4	16	0.01 ug/sample	NIOSH N9103	
Wall		Pre & post samples	N/A	N/A	4	16	0.01 ug/sample	NIOSH N9103	
Wall		Pre & post samples	N/A	N/A	4	16	0.01 ug/sample	NIOSH N9103	
Exterior drum surface - side		Pre & post samples	N/A	N/A	4	16	0.01 ug/sample	NIOSH N9103	
DTC device		Pre & post samples	N/A	N/A	4	16	0.01 ug/sample	NIOSH N9103	
DTC device feed tube Inlet Exterior		Pre & post samples	N/A	N/A	4	16	0.01 ug/sample	NIOSH N9103	
Field Blanks		Prior to each equipment run	N/A	N/A	2	4	0.01 ug/sample	NIOSH N9103	
Wipe sample subtotal									
148									

Air samples	Both shoulders of operator	During test run including drum and filter changes (all four units)	2	2	4	16	0.01 ug/sample	NIOSH 6009; OSHA ID-145	
	DTC Exhaust	During test run including drum and filter changes	2	2	4	16	0.01 ug/sample	NIOSH 6009; OSHA ID-145	
	DTC Feed Tube	During test run including drum and filter changes	2	2	4	16	0.01 ug/sample	NIOSH 6009; OSHA ID-145	
	On operator	During filter changes: HMS = every 300 lamps crushed	3	3	6	6	0.01 ug/sample	NIOSH 6009; OSHA ID-145	
	On operator	During drum and filter change	1	1	2	8	0.01 ug/sample	NIOSH 6009; OSHA ID-145	
	Laboratory Blank	Prior to study	3	3	6	6	0.01 ug/sample	NIOSH 6009; OSHA ID-145	
	Field Blanks Background	Prior to study	2	2	4	4	0.01 ug/sample	NIOSH 6009; OSHA ID-145	
	Field Blanks	On each sampling day	2	2	4	8	0.01 ug/sample	NIOSH 6009; OSHA ID-145	
	Air sample subtotal		17	17	34	80			

¹Number of wipe samples = number of samples per location (2) x number of sampling events (2) x number of devices tested (4) = $2 \times 2 \times 4 = 16$ samples

²Number of air samples calculated using the following formula and assumptions:
 Assumptions: Two air samples (a vapor and aerosol sample) are collected at each shoulder. Therefore, 4 air samples (2 vapor and 2 aerosol) will be collected for each unit tested.
 Number of samples to be collected = number of samples per unit (4) x number of units to be tested (4) = $4 \times 4 = 16$ samples

³Based on manufacturer's specs, the particulate filter is changed every 300 lamps. Assumed the HMS DTC drum could hold 1200 crushed lamps so the unit would require 4 filter changes. Assumed one filter change will coincide with the drum change. Sampling plan text (page 4) indicates one sample will be collected during filter change out.
 Number of air samples collected = number of samples per event (2 = one aerosol and one vapor) x number of filter changes (3) x number of units tested (1 – HMS unit) = $3 \times 2 \times 1 = 6$ samples

⁴Assumed one drum and filter change per unit.
 Number of samples collected = number of samples per event (2 = one vapor and one aerosol) x number of drum changes per unit (1) x number of units tested (4) = $2 \times 1 \times 4 = 8$ samples

⁵Used assumption on page 2 of the sampling plan that the test would take 2 days. Assumed two sets of field blanks are collected per day as listed on page 4 of sampling plan. One set of field blanks consists of a vapor and an aerosol blank.
 Number of samples collected = number of samples per day (4 = 2 vapor and 2 aerosol) x number of test days (2) = $4 \times 2 = 8$ samples

⁶Number of air samples calculated using the following formula and assumptions:
 Assumptions: Two air samples (a vapor and aerosol sample) are collected at each shoulder. 2 operators crushing lamps on each unit. Therefore, 8 air samples (4 vapor and 4 aerosol) will be collected for each unit tested.
 Number of samples to be collected = number of samples per unit (8) x number of units to be tested (4) x number of test facilities (3) = $8 \times 4 \times 3 = 96$ samples

⁷Number of samples = number of samples per unit (4 = two vapor and two aerosol) x number of units tested (4) x number of test facilities (3) = $4 \times 4 \times 3 = 48$ samples

⁸Based on manufacturer's specs, the particulate filter is changed every 300 lamps. Assumed the HMS DTC drum could hold 2400 crushed lamps so the unit would require 8 filter changes. Assumed two filter changes will coincide with two drum changes. Sampling plan text (page 4) indicates one sample will be collected during filter change out.
 Number of air samples collected = number of samples per event (2 = one aerosol and one vapor) x number of filter changes (6) x number of units tested (1 – HMS unit) x number of test facilities = $3 \times 6 \times 1 \times 3 = 36$ samples

⁹Assumed two drum and filter changes per unit.
 Number of samples = number of samples per unit (2 = one vapor and one aerosol) x number of drum changes per unit (2) x number of units tested (4) x number of test facilities (3) = $2 \times 2 \times 4 \times 3 = 48$ samples

¹⁰Assumed a field blank sample would be collected at each test facility prior to the start of the real world testing. Assumed two sets of field blanks are collected per day as listed on page 4 of sampling plan. One set of field blanks consists of a vapor and an aerosol blank.
 Number of samples collected = number of samples per day (4 = 2 vapor and 2 aerosol) x number of test facilities (3) = $4 \times 3 = 12$ samples

¹¹Used assumption on page 2 of the sampling plan that the test would take one week and that field blanks would be needed for four days. Assumed two sets of field blanks are collected per day as listed on page 4 of sampling plan. One set of field blanks consists of a vapor and an aerosol blank.
 Number of samples collected = number of samples per day (4 = 2 vapor and 2 aerosol) x number of test days (4) x number of test facilities (3) = $4 \times 4 \times 3 = 48$ samples

¹²Number of wipe samples = number of samples per location (2) x number of sampling events (2) x number of devices tested (4) x number of test facilities (3) = $2 \times 2 \times 4 \times 3 = 48$ samples

¹³Assumed one drum and filter changes per unit.
 Number of samples = number of samples per unit (2 = one vapor and one aerosol) x number of drum changes per unit (1) x number of units tested (3) = $2 \times 1 \times 3 = 6$ samples

¹⁴Number of wipe samples = number of samples per location (2) x number of sampling events (2) x number of devices tested (3) = $2 \times 2 \times 3 = 12$ samples

¹⁵The same assumptions used under Equipment Comparison Phase 1 are used to calculate the number of samples for Phase 2.

Summary of Samples:

Project Phase	# of Wipe Samples	# of Air Samples	# of Bulk Samples	# of Alto Lamps
Equipment Comparison Phase 1	150	84		
Mass Balance Study			45	6
Real World Testing	456	322		
U-Shaped Tube Testing	112	44		
Equipment Comparison Phase 2	148	80		
Total	866	530	45	6

Total All Samples: 1,447

Mercury Lamps DTC Device Sampling and Study Plan

Table 1 - Sampling Table

Sample Number Equipment Comparison	Location	Duration/Time of Sample	General	Four Devices					Total Samples (By Line Item)		
				Air Cycle Bulb Eater	Resource Technology, Inc. (RTI) Model DTP	The Hazardous Materials Specialist Inc. (HMS) VRS	Dextrite	Aerosol Sample		Vapor Sample	
Air Samples	One on each shoulder of operator	Entire study including Drum and Filter Changes		2	2	2	2	2	8	8	24
	DTC Device Exhaust	Entire study including Drum and Filter Changes		2	2	2	2	2	8	8	24
	DTC Device Feed Tube	Entire study including Drum and Filter Changes		2	2	2	2	2	8	8	24
	On Operator	During Drum and Filter Change		1	1	1	1	1	4	4	12
Wipe Samples (2 Each)	Field Blanks	Prior to Study	2						2	2	6
	Laboratory Blanks	Prior to Study	3						3	3	9
	Floor - 2 feet from Device	Pre and Post Operation		4	4	4	4	4	4	4	16
	Floor - 5 Feet from Device	Pre and Post Operation		4	4	4	4	4	4	4	16
	Floor - at the device Exhaust	Pre and Post Operation		4	4	4	4	4	4	4	16
	Drum Side	Pre and Post Operation		4	4	4	4	4	4	4	16
	DTC Device	Pre and Post Operation		4	4	4	4	4	4	4	16
	Feed Tube Inlet Exterior	Pre and Post Operation		4	4	4	4	4	4	4	16
	Ceiling	Pre and Post Operation		4	4	4	4	4	4	4	16
	Wall	Pre and Post Operation		4	4	4	4	4	4	4	16
	Wall	Pre and Post Operation		4	4	4	4	4	4	4	16
	Mass Balance Study										
Bulk Samples	Particulate Pre Filters	Per Device Instructions		3	3	3	3	0			9
	HEPA Filters	Per Device Instructions		3	3	3	3	3			12
	Carbon Filters	Per Device Instructions		3	3	3	3	3			12
Alto Lamps tested	Crushed Materials from Drums (Includes broken glass, metal end caps, and phosphor powder)										
	Alto T12	Upon completion of filling drum		3	3	3	3				12
Air Samples	DTC Device Exhaust	N/A	5								5
	DTC Device Feed Tube	Entire study including Drum and Filter Changes		2	2	2	2	2	8	8	24
Wipe Samples (2 Each)	Drum Side	Entire study including Drum and Filter Changes		2	2	2	2	2	8	8	24
	DTC Device	Pre and Post Operation		4	4	4	4	4	4	4	16
Real World Testing (To be performed at 3 Locations)	One on each shoulder of operator	Pre and Post Operation		4	4	4	4	4	4	4	16
	Inside the containment										
	On Operator	Entire Work Shift (2 Drum Changes)		6	6	6	6	6	24	24	72
	Field Blanks	Entire Work Shift (2 Drum Changes)		6	6	6	6	6	24	24	72
	Laboratory Blanks	During Drum and Filter Change		3	3	3	3	3	12	12	36
	Floor - 2 feet from Device	Prior to Study	2						2	2	6
	Floor - 5 Feet from Device	Prior to Study	3						3	3	9
	Floor - at the device Exhaust	Pre and Post Operation		12	12	12	12	12	12	12	48
	Drum Side	Pre and Post Operation		12	12	12	12	12	12	12	48
	DTC Device	Pre and Post Operation		12	12	12	12	12	12	12	48
	Feed Tube Inlet Exterior	Pre and Post Operation		12	12	12	12	12	12	12	48
	Ceiling	Pre and Post Operation		12	12	12	12	12	12	12	48
Wall	Pre and Post Operation		12	12	12	12	12	12	12	48	
Wall	Pre and Post Operation		12	12	12	12	12	12	12	48	

Mercury Lamps DTC Device Sampling and Study Plan

Table 1 - Sampling Table

Sample Number	Location (To be performed at 1 Location)	Duration/Time of Sample	General	Air Cycle Bulb Eater	Resource Technology, Inc. (RTI) Model DTP	Four Devices				Total Samples (By Line Item)		
						The Hazardous Materials Specialist Inc. (HMS) VRS	Dextrite	Aerosol Sample	Vapor Sample			
U-Shaped Tube Testing												
Air Samples												
	One on each shoulder of operator	TBD		2	N/A	2	2	2	6	6	6	18
	Inside the containment	TBD		2	N/A	2	2	2	6	6	6	18
	On Operator	During Drum and Filter Change		1	N/A	1	1	1	3	3	3	9
	Field Blanks	Prior to Study	2						2	2	2	6
	Laboratory Blanks	Prior to Study	3						3	3	3	9
Wipe Samples (2 Each)												
	Floor - 2 feet from Device	Pre and Post Operation		4	N/A	4	4	4				12
	Floor - 5 Feet from Device	Pre and Post Operation		4	N/A	4	4	4				12
	Floor - at the device Exhaust	Pre and Post Operation		4	N/A	4	4	4				12
	Drum Side	Pre and Post Operation		4	N/A	4	4	4				12
	DTC Device	Pre and Post Operation		4	N/A	4	4	4				12
	Feed Tube Inlet Exterior	Pre and Post Operation		4	N/A	4	4	4				12
	Ceiling	Pre and Post Operation		4	N/A	4	4	4				12
	Wall	Pre and Post Operation		4	N/A	4	4	4				12
	Wall	Pre and Post Operation		4	N/A	4	4	4				12
TOTAL SAMPLES			20	231	190	231	228	134	134	134	134	1168

Appendix E

Laboratory Methods and Modifications

NIOSH Draft Method 9103 – Modified: Analysis of MCE Filter

1. Transferred each filter sample to pre-cleaned individual 250-mL HDPE bottles.
 2. Added 10 mL of concentrated nitric acid to each sample and gently swirled until the filter was completely saturated.
 3. Placed caps loosely on the bottles and then set samples in a water bath maintained at 90 to 92 °C. After 2 minutes in the water bath, removed samples and cooled bottles to room temperature.
 4. Added 50 mL of ASTM Type II water to each sample and gently swirled to mix thoroughly.
 5. Added 25 mL of 5% potassium permanganate to each sample and gently swirled to mix thoroughly.
 6. Added 8 mL of 5% potassium persulfate to each sample and gently swirled to mix thoroughly.
 7. Placed caps loosely on the bottles and then set samples in a water bath maintained at 90 to 92 °C. After 30 minutes in the water bath, removed samples and cooled bottles to room temperature.
 8. Immediately prior to analysis, added 7 mL of 20% hydroxylamine hydrochloride to each sample, replaced and tightened caps, and shook the bottles to mix samples thoroughly. Allowed bottles to cool to room temperature and proceeded to analysis.
- All standards were prepared the same manner as the sample except no filter media was present.
 - One set of QC samples (QB, LCS, and LCSD) were prepared using MOE filter at the rate of 1 set per 20 field samples. (LCS & LCSD samples were prepared using 0.5 mL of 1.0 µg/mL Hg standard, yielding a spike target at 0.5 µg/sample.)

NIOSH Method 6009 - Modified: Analysis of Carulite (Hydrar) Tube

1. Carefully broke the edge of the sampling tube adjacent to sorbent material, and carefully transferred only the sorbent material of each sample to pre-cleaned individual 50-mL volumetric flasks.
 2. Added 2.5 mL of concentrated nitric acid to each sample and gently swirled until the sample was completely saturated.
 3. Added 2.5 mL of concentrated hydrochloric acid to each sample and gently swirled until the sample became dark. Placed the sample in a hood at least for 1 hour and swirled occasionally.
 4. Diluted each sample to 50 mL volume with ASTM Type II water and shook the flasks to mix thoroughly.
 5. Allowed samples to settle and proceeded to analysis.
- All standards were prepared the same manner as the sample except no sorbent media was present and no 1 hour waiting time was needed.
 - One set of QC samples (QB, LCS, and LCSD) was prepared using SKC Carulite (Hydrar) tubes at the rate of one set per 20 field samples. (LCS and LCSD samples were spiked using 0.5 mL of 1.0 µg/mL Hg standard, yielding spike targets at 0.5 µg/sample.)

NIOSH Draft Method 9103: Analysis of Wash'n Dri Wipe

1. Transferred each wipe sample to pre-cleaned individual 250-mL HDPE bottles.
 2. Added 5 mL of concentrated nitric acid to each sample and gently swirled until the wipe was completely saturated.
 3. Added 5 mL of concentrated sulfuric acid to each sample and gently swirled until the wipe was dissolved. Placed samples in a hood until all acid fumes were evolved and no further reaction was observed.
 4. Added 50 mL of ASTM Type II water to each sample and gently swirled to mix thoroughly.
 5. Added 10 mL of 10% potassium permanganate to each sample and gently swirled until purple color disappeared. Added another 10 mL of 10% potassium permanganate to each sample, gently swirling until the reaction subsided. Added an additional 30 mL of 10% potassium permanganate to each sample and gently swirled to mix thoroughly.
 6. Added 8 mL of 5% potassium persulfate to each sample and gently swirled to mix thoroughly.
 7. Placed caps loosely on the bottles and then set samples in a water bath maintained at 90 to 92 °C. After 30 minutes in the water bath, removed samples and cooled bottles to room temperature.
 8. Immediately prior to analysis, added 7 mL of 20% hydroxylamine hydrochloride to each sample, replaced and tightened caps, and shook the bottles to mix samples thoroughly. Allowed bottles to cool to room temperature and proceeded to analysis.
- All standards were prepared the same manner as the sample except no wipe media was presented.
 - One set of QC samples (QB = quality control blank = media blank, spiked LCS = laboratory control sample, and LCSD = duplicate spiked laboratory control sample) was prepared using Wash'n Dri wipes at the rate of one set per 20 field samples. (LCS and LCSD samples were spiked using 0.5 mL of 1.0 µg/mL Hg standard, yielding a spike target at 0.5 µg/sample.)

EPA Method 7470 – Modified/Phillips Lab Procedure – Modified: Analysis of Unbroken, Spent Lamp

1. Each entire lamp was cooled with dry ice for 1 hour and one end of the lamp was carefully broken.
 2. Inner contents of the lamp was washed out with 200 mL of concentrated nitric acid and mixed well.
 3. 1 mL of the acid leached sample was transferred to pre-cleaned 250-mL HDPE bottles.
 4. Added 99 mL of ASTM Type II water, 5 mL of concentrated sulfuric acid, 2.5 mL of nitric acid, 15 mL of 5% potassium permanganate, and 8 mL of potassium persulfate, then mixed well.
 6. Placed caps loosely on the bottles and then set samples in a water bath maintained at 90 to 92 °C. After 2 hours in the water bath, removed samples and cooled bottles to room temperature.
 7. Immediately prior to analysis, added 5 mL of 20% hydroxylamine hydrochloride to each sample, replaced and tightened caps, and shook the bottles to mix samples thoroughly. Allowed bottles to cool to room temperature and proceeded to analysis.
- All standards were prepared the same manner as the sample except no acid leaching was involved.
 - One set of QC samples were prepared using ASTM Type II water at the rate of one set per 20 field samples. (LCS and LCSD samples were spiked using 0.5 mL of 1.0 µg/mL Hg standard, yielding spike targets at 5.0 µg/L.)

EPA Method 7470 – Modified/Phillips Lab Procedure – Modified: Analysis of Lamp Debris (including glass, metal endcaps, and fines)

1. The lamp debris samples were preserved in a cooler and each sample was weighed (total weight – bottle weight = sample weight).
 2. Each sample was leached with 200 mL of concentrated nitric acid for 1.5 hours.
 3. 2 mL of homogeneous representative aqueous sample was transferred into pre-cleaned 250-mL HDPE bottles.
 4. Added 98 mL of ASTM Type I water, 5 mL of concentrated sulfuric acid, 2.5 mL of nitric acid, 15 mL of 5% potassium permanganate, and 8 mL of potassium persulfate, then mixed well.
 5. Placed caps loosely on the bottles and then set samples in a water bath maintained at 90 to 92 °C. After 2 hours in the water bath, removed samples and cooled bottles to room temperature.
 6. Immediately prior to analysis, added 5 mL of 20% hydroxylamine hydrochloride to each sample, replaced and tightened caps, and shook the bottles to mix samples thoroughly. Allowed bottles to cool to room temperature and proceeded to analysis.
- All standards were prepared the same manner as the sample except no acid leaching was involved.
 - One set of QC samples (LCS, and LCSD) were prepared using EPA reference soil at the rate of one set per 20 field samples. LCS and LCSD samples were obtained by leaching 0.5 g of EPA reference soil (target concentration of 12.3 µg/g) in 20 mL of concentrated nitric acid. 2 mL of the leachate solution was used to prepare the QCs.

NIOSH Draft Method 9103 – Modified: Analysis of HEPA Filter

1. Each HEPA filter container was opened and a representative portion of the main filter membrane was cut by 5 cm x 5 cm (= 25 cm²).
 2. Transferred each filter sample to pre-cleaned individual 250-mL HDPE bottles.
 3. Added 5 mL of ASTM Type II water to each sample and gently swirled until the filter was saturated.
 4. Added 5 mL of aqua regia to each sample and gently swirled until the filter was saturated.
 5. Added 50 mL of ASTM Type II water to each sample and gently swirled to mix thoroughly.
 6. Added 30 mL of 5% potassium permanganate to each sample and gently swirled to mix thoroughly.
 7. Added 8 mL of 5% potassium persulfate to each sample and gently swirled to mix thoroughly.
 8. Placed caps loosely on the bottles and then set samples in a water bath maintained at 90 to 92 °C. After 30 minutes in the water bath, removed samples and cooled bottles to room temperature.
 9. Immediately prior to analysis, added 7 mL of 20% hydroxylamine hydrochloride to each sample, replaced and tightened caps, and shook the bottles to mix samples thoroughly. Allowed bottles to cool to room temperature and proceeded to analysis.
- All standards were prepared the same manner as the sample except no filter media was present.
 - One set of QC samples (QB, LCS, and LCSD) were prepared using Whatman filters at the rate of 1 set per 20 field samples. (LCS and LCSD samples were spiked using 0.5 mL of 1.0 µg/mL Hg standard, yielding a target at 0.5 µg/sample.)

EPA Method 7470 – Modified: Analysis of Carbon Pellets, Fines from Lamp Debris Samples, and Pre-filter Samples

1. Weighed 0.5 g of each representative sample and transferred the sample to pre-cleaned individual 250-mL HDPE bottles.
 2. Added 5 mL of ASTM Type II water to each sample and gently swirled until the sample was wetted.
 3. Added 5 mL of aqua regia to each sample and gently swirled until the sample was fully wetted.
 4. Placed caps loosely on the bottles and then set samples in a water bath maintained at 90 to 92 °C. After 2 minutes in the water bath, removed samples and cooled bottles to room temperature.
 5. Added 50 mL of ASTM Type II water to each sample and gently swirled to mix thoroughly.
 6. Added 15 mL of 5% potassium permanganate to each sample and gently swirled to mix thoroughly.
 7. Placed caps loosely on the bottles and then set samples in a water bath maintained at 90 to 92 °C. After 30 minutes in the water bath, removed samples and cooled bottles to room temperature.
 8. Immediately prior to analysis, added 50 mL of ASTM Type II water and 5 mL of 20% hydroxylamine hydrochloride to each sample, replaced and tightened caps, and shook the bottles to mix samples thoroughly. Allowed bottles to cool to room temperature and proceeded to analysis.
- All standards were prepared the same manner as the sample except no bulk or soil media was present.
 - One set of QC samples (LCS and LCSD) were prepared using EPA reference soil at the rate of 1 set per 20 field samples. (LCS and LCSD samples were prepared using 0.5 g of EPA reference soil, which has a targeted mercury concentration at 12.3 µg/g.) Also, one matrix spike sample (MS) and one matrix spike duplicate sample (MSD) was prepared at the rate of one per 20 field samples by spiking 0.1 mL of 1.0 µg/mL Hg onto the field samples, yielding spike targets at 1 .0 µg/L.

Appendix F

Wipe Sample Data and Discussion

Wipe Sampling Results

Wipe samples were collected from various surfaces to evaluate the deposition of mercury condensate and mercury-contaminated particulates on surfaces inside the containment. A set of wipe samples from nine different locations was collected prior to testing each DTC device (pre-test wipes), and another set was collected near the same nine locations at the conclusion of the test for each device (post-test wipes). Refer to Section 3.3 for wipe sample locations. These analyses were conducted as part of the Mass Balance Study to help quantify the mass of mercury released (i.e., not captured by the DTC device).

The results of the pre-test wipes and the post-test wipes were compared to each other. Pre-test and post-test wipes were collected from approximately the same general locations within the containment, to account for any spatial variation in ambient conditions (e.g., sampling location relative to the crusher, difference in local ventilation patterns).

To review the individual wipe sample results, refer to Appendix A, Table 2.

Wipe Sample Results - PVS Phase I

The wipe sample analytical results from Phase I of the Performance Validation Study (PVS) indicated that baseline mercury concentrations were present inside the AERC Ashland facility prior to initiation of this study. The ranges of results for each device are listed in Table 1 below.

Table 1: Phase I Performance Validation Study Wipe Sample Results

Device	Wipe Sample Results ($\mu\text{g}/100 \text{ cm}^2$)	
	Pre-Test	Post-Test
Manufacturer A	0.016 - 0.49	0.013 - 0.19
Manufacturer B	ND - 0.17	ND - 0.64
Manufacturer C	ND - 0.71	0.021 - 3.1
Manufacturer D	0.028 - 0.40	ND - 0.1

Detectable concentrations of mercury were noted on pre-test wipes when testing all four devices. Approximately 44 percent of the total post-test wipes exhibited higher levels of mercury than the pre-test wipes.

Wipe Sample Results - EFT#1

The wipe sample analytical result indicated that baseline mercury concentrations were present during Extended Field Test (EFT) #1 in the EPSI facility. The ranges of results for each device are presented in Table 2.

Table 2: Extended Field Test #1 Wipe Sampling Results

Device	Wipe Sample Results ($\mu\text{g}/100\text{ cm}^2$)	
	Pre-Test	Post-Test
Manufacturer A	ND - 9.40	0.058 - 5.0
Manufacturer B	0.088 - 0.800	0.050 - 1.60
Manufacturer C	0.019 - 0.17	0.14 - 2.7
Manufacturer D	0.034 - 5.30	0.038 - 4.5

Detectable concentrations of mercury were noted on pre-test wipes when testing all four devices. Approximately 75 percent of the total post-test wipe results exhibited higher levels of mercury than the pre-test wipes.

Wipe Sample Results - EFT #2

Upon review of the wipe sample results collected during PVS Phase I and EFT #1, it was apparent that the baseline level of mercury contamination already present at the recycling facilities had the potential to confound the study results. One possible source of this contamination was the practice of measuring and cutting the polyethylene sheeting on the (contaminated) work area floor.

The team worked to reduce the interference from this contamination at the AERC Melbourne facility by measuring and cutting the polyethylene outdoors, in the parking lot behind the facility. A clean sheet of polyethylene was first laid on the ground to create an uncontaminated work surface. The polyethylene sheeting for the containment structure was cut and stored outside the facility on the clean, polyethylene work surface.

To further evaluate baseline the high levels of mercury found in pre-test wipes, it was also decided to collect two additional wipe samples inside the containment area the morning after the DTC devices were left idle in the containment overnight. One of the additional wipe samples was taken from the floor approximately two feet away from the device, and the other additional wipe sample was taken from the east wall of the containment. Field personnel attempted to collect these samples from approximately the same location as the earlier wipe samples.

Levels of mercury were still detected on the pre-test wipes collected for all three devices during EFT #2. The ranges of results for each device are presented in Table 3 below.

Table 3: Extended Field Test #2 Wipe Sampling Results

Device	Wipe Sample Results ($\mu\text{g}/100\text{ cm}^2$)	
	Pre-Test	Post-Test
Manufacturer A	0.015 - 0.860	0.052 - 3.6
Manufacturer B	0.035 - 0.63	0.050 - 1.60
Manufacturer C	0.08 - 0.25	0.02 - 0.49

Approximately 70 percent of the total post-test wipes exhibited higher detected levels of mercury than the pre-test wipes, which was similar to the EPSI facility.

Wipe Sample Results - EFT #3

As in EFT #2, to reduce the level of mercury contamination on the polyethylene used to construct the containment, the procedure of measuring and cutting the polyethylene sheeting was performed outdoors in the parking lot behind the Ashland AERC Facility. In addition, a separate piece of polyethylene was measured, cut, and placed on the facility floor beneath each prepared containment structure. This task was performed to attempt to further reduce the effects of the ambient level of mercury contamination on test results.

The wipe sample results indicate that there was a level of background contamination present in the AERC Ashland facility during EFT #3. The ranges of results for each device are presented in Table 4 below.

Table 4: Extended Field Test #3 Wipe Sampling Results

Device	Wipe Sample Results ($\mu\text{g}/100\text{ cm}^2$)	
	Pre-Test	Post-Test
Manufacturer C	0.020 - 0.17	0.092 - 2.8
Manufacturer B	0.024 - 0.23	0.055 - 3.8
Manufacturer A	ND - 0.73	0.11 - 1.7

All three DTC device studies resulted in the detection of mercury on pre-test wipes. Approximately 89 percent of the total post-test wipes exhibited higher detected levels of mercury than the pre-test wipes.

Wipe Sample Results - PVS Phase II

The ranges of wipe sampling results for each device are presented in Table 5.

Table 5: Phase II Performance Validation Study Wipe Sample Results

Device	Wipe Sample Results ($\mu\text{g}/100 \text{ cm}^2$)	
	Pre-Test	Post-Test
Manufacturer A	0.011 - 1.7	0.024 - 1.1
Manufacturer B	0.039 - 0.98	0.043 - 0.45
Manufacturer C	0.016 - 0.98	0.019 - 0.43

As during the Phase I test, the wipe sampling results from PVS Phase II indicated a baseline level of airborne mercury present in the AERC Ashland facility, most likely caused by the routine lamp crushing operations. All three DTC device tests resulted in the detection of mercury on pre-test wipes. Only 48 percent of all post-test wipes exhibited higher concentrations of mercury than the pre-test wipes.

Conclusions

Mercury was detected in the pre-test wipes, regardless of testing location. The higher mercury concentrations on pre-test wipes were not anticipated when the sampling and study plan was finalized. These elevated results indicated contamination prior to the operation of the DTC devices. Thorough review of the sampling and study plan by an individual with experience measuring mercury in field conditions would likely have helped the study team avoid or minimize these complications.

The mercury contamination on the polyethylene containment surfaces may have had several different sources. The ambient mercury vapor in the facilities may have deposited/sorbed onto on the polyethylene before the pre-test wipes were collected. Cross-contamination of the polyethylene sheeting may have occurred when it was sized and cut on the warehouse floor of the facility.

As described above, at the AERC Melbourne facility and the AERC Ashland facility (EFT #2, EFT #3, and PVS Phase II), the polyethylene sheeting was measured and cut outside the facility. Even after this methodology was adopted, many of the pre-test wipes were higher than the post-test wipes (during EFT #2, 30 percent were higher; during EFT #3, 11 percent were higher, and during PVS II, 52 percent were higher). This indicates that cutting the polyethylene sheets outdoors, away from the warehouse and on top of another polyethylene sheet, did not significantly decrease mercury contamination during construction of the containment.

In general, the two additional post-test wipes taken the day after testing at the AERC Melbourne facility and the AERC Ashland facility were higher than the corresponding post-test wipes taken the same day that the DTC device was

operated. This indicates that the ambient mercury most likely contributed to the high mercury levels detected for most of the pre-test wipes.

The wipe samples provided inconclusive data due to contamination. The study team determined that the wipe sample results would not be used as part of the Mass Balance Study.

Appendix G

Sampling Error and Correction Efforts For Mass Balance Study

Mass Balance Sampling Error

The initial sample results from the drum debris samples reported by the laboratory were much higher than the results used in the mass balance equation in Chapter 5. These higher concentrations were scrutinized by the team and upon further discussion with the laboratory, an error in the analytical method for the drum debris bulk samples was discovered. Table 1 presents the results from the initial analysis that was used in the original mass balance equation.

Table 1: Initial Drum Debris Bulk Sample Analytical Results

Device	Sample #	Result	Average Concentration
MFG A	R/B-2/27-16	160 µg/g	123.3µg/g
MFG A	R/B-2/27-17	100 µg/g	
MFG A	R/B-2/27-18	110 µg/g	
MFG B	D/B-2/28-35	140 µg/g	180.0 µg/g
MFG B	D/B-2/28-36	130 µg/g	
MFG B	D/B-2/28-37	270 µg/g	
MFG C	A/B-2/26-07	150 µg/g	145.3 µg/g
MFG C	A/B-2/26-08	200 µg/g	
MFG C	A/B-2/26-09	86 µg/g	

The quantity of mercury in the drum debris was calculated by multiplying the average of the drum debris results by the weight of the debris in the drum. The weight of the drum debris for the Mfg C device was 436 pounds that converts to 197766.3 grams. The weight of the drum debris for the Mfg A device was 466 pounds that converts to 211374 grams. The weight of the drum debris of the Mfg B device was 331 pounds that converts to 150139.1 grams. Based on the drum debris analytical results and debris weight the quantity of mercury in the debris for each device is:

- Mfg C 28,735.4 mg
- Mfg A 26,062.4 mg
- Mfg B 27,025.0 mg

When these quantities are added into the table presenting all the mass balance quantities, a large difference between the quantity of mercury processed Hg_T and the quantity of mercury in the drum debris is notable. Table 2 presents the results of the mass balance equation using the values presented for Hg_T , Hg_U , and Hg_R . Refer to Chapter 5 of the report for a description of how the other quantities were derived.

Table 2: Mass Balance Results

Device	Hg_T	Hg_U				Hg_R
		Drum Debris	Pre-filter	HEPA filter	Carbon filter	
MFG A	2675.4 mg	26,062.4 mg	NA	2.659 mg	1015.5 mg	0.38 mg
MFG B	2307.6 mg	27,025.0mg	12.45 mg	NA	7.3 mg	0.41 mg
MFG C	2934.5 mg	28,735.4 mg	47.35 mg	0.029 mg	57.9 mg	0.39 mg

Upon reviewing results in Table 3 below, the amount of mercury recovered is significantly greater than the calculated quantity of mercury processed in the study.

Table 3: Percentage of Mercury Recovery

Device	Hg Processed (HgT)	Hg Recovered (HgU+HgR)	% Recovery
MFG A	2675.4 mg	27080.8 mg	1012.2 %
MFG B	2307.6 mg	27045.0 mg	1172.0 %
MFG C	2934.5 mg	28841.0 mg	982.8 %

Due to significant error in the results of the Mass Balance Analysis, the study team re-evaluated the entire original mass balance study including the laboratory results to identify discrepancies in the study to account for the errors when balancing the equation. Upon further discussion with the laboratory it was discovered that when preparing the drum debris sample for analysis, only the “fines” were removed from the bulk sample for analysis. The “fines” consisted of the fine phosphor powder and possibly the very small pieces of glass. However, the content of the drum debris samples also consisted of larger glass pieces and metal end caps, which could also contain some of the unaccounted mercury and contributed mass to the calculation of the total mercury concentration. In an effort to obtain more accurate bulk sample results and account for mercury post crushing, the remainder of the original drum debris bulk samples were analyzed and the results were combined with the results from the first analysis.

The second analysis of the drum debris involved weighing the entire remaining content of the samples and digesting the entire sample. The results from the original analysis and the second analysis were combined mathematically and presented as $\mu\text{g}/\text{sample}$. The weights in grams from the original analysis and the second analysis were added together to get the total weight of the drum debris bulk samples. The final reported results shown below in Table 4, in $\mu\text{g}/\text{g}$, are a combination of the analytical results and the weights from the original and second analyses. The following table presents the drum debris bulk sample results from the second analysis and shows a comparison to the original analysis.

Table 4: Drum Debris Bulk Sample Results (2nd Analysis)

Sample #	Device	Combined Wt. ¹	Corrected Result	Original Result	% Difference
A/B-2/26-07	MFG C	74.8 g	6.07 $\mu\text{g}/\text{g}$	150 $\mu\text{g}/\text{g}$	- 95.9 %
A/B-2/26-08	MFG C	56.6 g	5.58 $\mu\text{g}/\text{g}$	200 $\mu\text{g}/\text{g}$	- 97.2 %
A/B-2/26-09	MFG C	95.2 g	2.43 $\mu\text{g}/\text{g}$	86 $\mu\text{g}/\text{g}$	- 97.2 %
R/B-2/27-16	MFG A	72.9 g	5.84 $\mu\text{g}/\text{g}$	160 $\mu\text{g}/\text{g}$	- 96.4 %
R/B-2/27-17	MFG A	79.2 g	2.70 $\mu\text{g}/\text{g}$	100 $\mu\text{g}/\text{g}$	- 97.3 %
R/B-2/27-18	MFG A	86.4 g	2.57 $\mu\text{g}/\text{g}$	110 $\mu\text{g}/\text{g}$	- 97.7 %
D/B-2/28-35	MFG B	67.7 g	5.17 $\mu\text{g}/\text{g}$	140 $\mu\text{g}/\text{g}$	- 96.3 %
D/B-2/28-36	MFG B	85.2 g	4.59 $\mu\text{g}/\text{g}$	130 $\mu\text{g}/\text{g}$	- 96.5 %
D/B-2/28-37	MFG B	79.0 g	5.56 $\mu\text{g}/\text{g}$	270 $\mu\text{g}/\text{g}$	- 97.9 %

1. The combined weight presented in the table was reported in the final analytical report as measured by the laboratory.

Analyzing the results between the original analysis and the corrected analysis has identified an approximate 96 % difference in the concentration of mercury in the drum debris bulk samples. This significant change in values is due to the significant increase in sample weight when the larger pieces of debris are included in the analysis. When the analysis included only the “fines”, where mercury is expected to be concentrated, it resulted in biased results and increased the concentration.

Table 5 presents the recalculated quantity of mercury in the drums compared to the original quantity:

Table 5: Re-calculated Mercury Amounts

Device	Total Weight Crushed Material and Drum Weight (Net)	Total Mass of Hg Corrected	Total Mass of Hg Original
MFG C	197,765 g	927.5 mg	28,735.3 mg
MFG A	211,373 g	782.1 mg	26,062.3 mg
MFG B	150,138 g	767.2 mg	27,024.8 mg

The new drum debris results above are inputted into the mass balance table to replace the original results. Refer to Chapter 5 of the report presents the mass balance study using the correct drum debris bulk sample results.

Appendix H

Procedures for Collection of Samples From Pollution Control Media

Samples were collected from the pollution control media for each device using the following procedures:

Manufacturer A

- The HEPA filter, located inside the filter canister, was accessed after the system had performed a filter purge where the device reverses the airflow to blow the collected particulates (purge) off the filter and back into the drum. Three bulk samples were collected from the filter by cutting approximately 100 cm² portions per sample out of the filter using a razor knife. The samples were folded in half, with any bulk material on the inside, and placed into separate sample containers.
- The top of the carbon filter canister was opened to access the carbon. The carbon filter consisted of three bags of carbon stacked on top of each other inside the canister. The top two bags were removed and opened. The carbon from each of the two bags was transferred to a separate generic plastic trash bag of sufficient size to accommodate its volume and each plastic bag of carbon was composited. Three bulk samples of carbon (approximately three ounces per sample) were collected from the top carbon bag, and three bulk samples of carbon (approximately 3 ounces per sample) were collected from the middle carbon bag using a clean plastic spoon. The samples were placed in separate sample containers.

Manufacturer B

- The pre-filter and carbon filter were all contained in a single cartridge. One bulk sample was collected from particulate contained in the pre-filter and placed in a sample container (there was only sufficient amount of particulate for one sample). Three carbon bulk samples (approximately two ounces per sample) were taken directly from the carbon container within the cartridge and placed into separate sample containers.

Manufacturer C

- Three samples of bulk particulate were collected inside the filter bag using a clean plastic spoon and placed in separate sample containers.
- The HEPA filter was removed, placed into a plastic Ziploc bag, and sealed.
- The top of the carbon filter canister was removed to access the loose carbon. The carbon was transferred to a generic plastic trash bag of sufficient size to accommodate its volume. The carbon was composited inside the bag, and

three bulk samples (approximately three ounces per sample) were collected using a clean plastic spoon and placed in separate sample containers.

Manufacturer D

- Three samples of bulk particulate were collected inside the filter bag using a clean plastic spoon and placed in separate sample containers.
- The HEPA filter was removed, placed into a plastic Ziploc bag, and sealed.
- The carbon filter bag was removed and cut open, and the carbon was transferred to a generic plastic trash bag of sufficient size to accommodate its volume. The carbon was composited in the bag, and three bulk samples (approximately three ounces per sample) were collected. Using a clean plastic spoon and placed in separate sample containers.

Appendix I

Letter from EPA Documenting Problems with Manufacturer D Device



UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION III
1650 Arch Street
Philadelphia, Pennsylvania 19103-2029

May 8, 2003

Mr. Edward J. Domanico
The Hazardous Materials Specialist, Inc
3200 S. Andrews Avenue
Suite 110
Fort Lauderdale, FL 33316

Dear Mr. Domanico:

The purpose of this letter is to document EPA's observations and provide Hazardous Material Specialist, Inc. (HMS) with a copy of the sampling data collected during testing of the Hazardous Material Specialist Fluorescent Lamp Disposal and Mercury Vapor Recovery System in Ashland, Virginia on February 27, 2003 and Phoenix, Arizona on March 26, 2003. The Equipment Validation Phase I and Real World Testing tasks in the Mercury Lamps Drum Top Crushers (DTC) Study are designed to evaluate how efficiently DTC devices capture mercury vapors emitted while crushing fluorescent lamps. Airborne mercury samples were collected and measured per the Sampling and Study Plan and following the NIOSH analytical methods. Furthermore, two Jerome mercury vapor analyzers were employed to collect and measure real-time airborne concentrations. Once the data has been collected, the results of the two studies are reviewed and compared against published mercury exposure limits. The results from the DTC device study are compared against the Occupational Safety and Health Administration (OSHA) regulated Permissible Exposure Limit (PEL) for mercury of 0.10 mg/m^3 , and the American Conference for Governmental Industrial Hygienists (ACGIH) recommended Threshold Limit Value (TLV) for mercury of 0.025 mg/m^3 .

EPA detected elevated levels of mercury vapor during testing of the HMS machine on February 27, 2003 during the Equipment Validation Phase I testing in Ashland, VA. Jerome readings collected during the operation of the HMS device measured a continuous increase in concentration that exceeded nominal limits. The operation of the HMS device was suspended when the readings measured 0.44 mg/m^3 (after crushing approximately 25- 30 bulbs) to allow for the operator to put on respiratory protection. Operation of the HMS device continued for approximately 45 minutes, where readings increased to measurements of 0.89 mg/m^3 . At this time the study was concluded. The HMS device exceeded the OSHA PEL within a short period of time from the start of the operation. Note that when comparing the Jerome reading to the analytical air sample measurements, the Jerome is providing real-time data at the specific point in time. The analytical air sample measurements are collected over a period of time at specified

locations, and represent a timed average exposure concentration. This accounts for differences in the results between the Jerome and analytical air samples.

Analysis of the analytical air sample results indicate that the HMS device was not efficient in capturing and retaining mercury vapor, and exceeded OSHA PEL and ACGIH TLV exposure limits. Out of eight samples collected during the operation of this device, one sample did not exceed the OSHA PEL, while the remaining seven samples did exceed the OSHA PEL (reference the "Ashland, VA AERC Facility Analytical Air Results February 2003" graph.)

At the conclusion of the HMS machine test in Ashland, HMS requested that EPA ship the unit back to the HMS facility in Fort Lauderdale, Florida so an evaluation into the cause of the elevated mercury readings could be determined. The unit was returned to HMS during the week of March 10, 2003. EPA requested a written report detailing the cause of the elevated mercury emissions and confirmation of the adequacy of the repairs by conducting an analysis for mercury vapors by a qualified industrial hygienist. See attached e-mail from Mr. Tad Radzinski to Mr. Ed Domanico outlining this request dated March 7, 2003. EPA had requested that HMS complete the evaluation and issue a report by March 17, 2003. However, due to shipping delays and problems reported by HMS in regard to obtaining a Jerome mercury analyzer, EPA received a fax summary of "Findings on the Malfunctioning Bulb Machine" on March 19, 2003, followed by a written report (dated December 17, 2002) on the HMS findings via fax on March 24, 2003, and a fax of Jerome Mercury Analyzer results on March 22, 2003. The Jerome data provided by HMS indicated several readings on hose connections that exceeded the OSHA PEL after processing only 30 lamps as well as elevated mercury levels from the charcoal discharge.

The HMS device that arrived to the Earth Protection Services Inc. facility in Phoenix, Arizona on March 25, 2003 was damaged. The vacuum assembly had a large crack, which appeared to be either shipping damage, or damage that occurred when the unit was packed by HMS for shipping. The unit received in Phoenix appeared to be a redesigned model from the unit originally tested in Ashland, Virginia. The unit tested in Ashland contained 24 ounces of carbon in a vacuum bag inside the activated charcoal canister. The unit received in Phoenix had an activated charcoal canister that was noticeably larger with the canister packed full of activated carbon estimated to be 40+ pounds. In addition the feed tube design appeared to be different and the drum to hand cart-mounting system was redesigned. EPA notified HMS regarding the equipment differences and the explanation was that the unit sent to Phoenix was a "field unit". EPA did not understand why HMS would send a different unit for testing and when asked for clarification, the response was that HMS had to build a unit quickly for the Ashland, Virginia test which had a different carbon system than field models.

To meet testing protocols established for this study each DTC device vendor was required to provide one machine that would be used throughout the entire test. Changing the design of the machine not only violated the testing protocol, which would make HMS ineligible to continue participation in the study, but also eliminated an opportunity to verify that repairs to the machine originally tested in Ashland, Virginia had corrected the mercury vapor release problem. Since the unit was damaged when received in Phoenix, EPA could not perform the complete "Real World" testing of the unit. However, EPA decided to take some Jerome readings and air samples of the HMS device with the cracked filter assembly. With this type of damage mercury levels

exceeded the OSHA PEL after processing only 16 lamps (see attached "Phoenix, AZ EPSI Facility Jerome Hg Vapor Analyzer Direct Reading Air Results March 2003" graph and "Phoenix, AZ EPSI Facility Analytical Air Results March 2003" graph.)

EPA recommends that HMS conduct an independent test of a machine that is identical to models that are in use in the field. This test should include processing of enough lamps to fill a drum in order to determine if the machine is operating in a manner to effectively control mercury emissions. If elevated mercury levels are detected, then HMS will need to take appropriate action to correct the problem and notify all facilities that are utilizing this equipment as outlined in Item (4) of the HMS fax from Mr. Edward Domanico to EPA (Subject: Findings on Malfunctioning Bulb Machine Tested in 1st EPA Validity Test") dated March 19, 2003.

Please contact me at 215-814-2394 if you have any questions.

Sincerely,

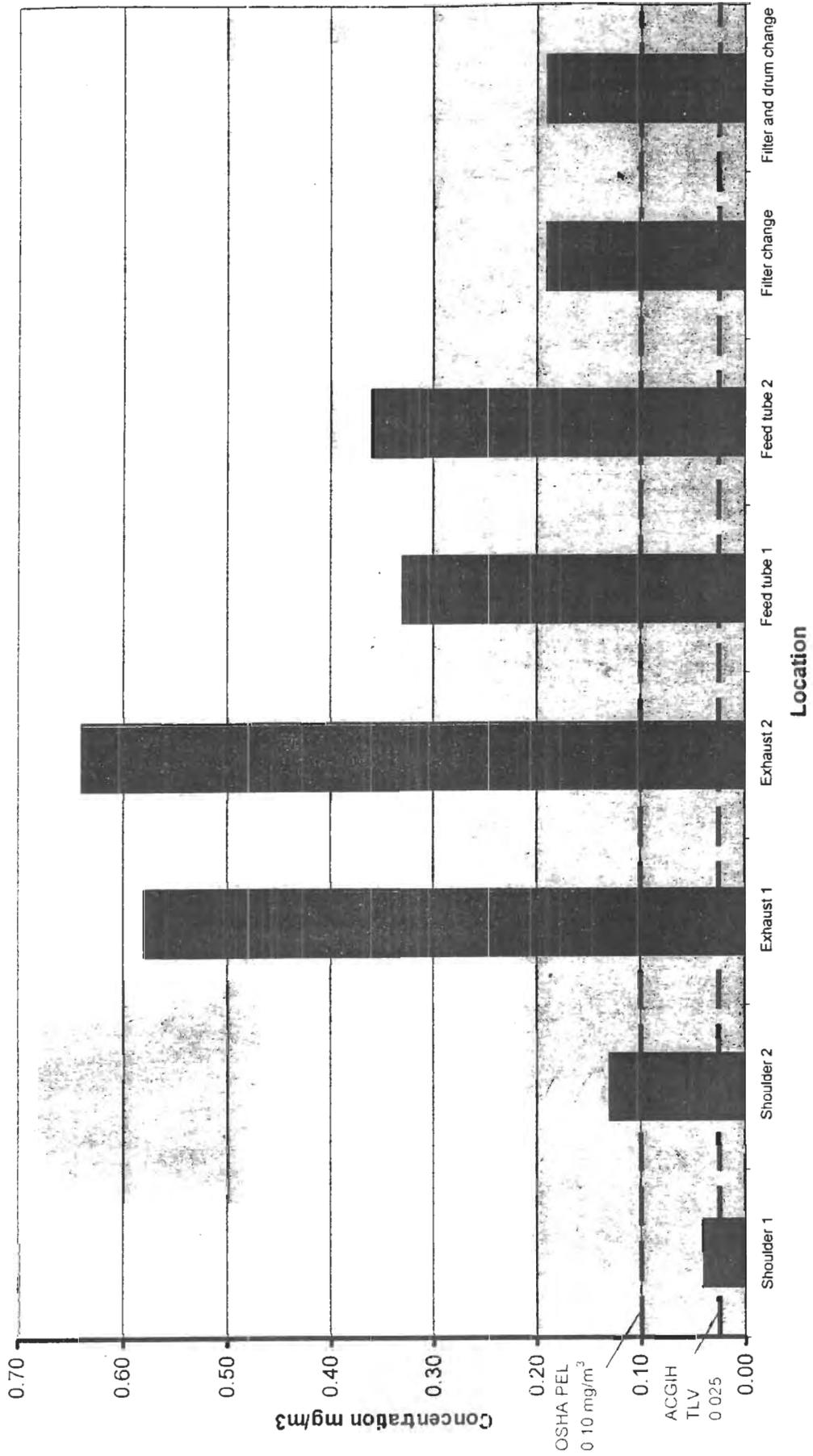


Tad Radzinski, P.E.

DTC Device Study Project Manager

Attachments

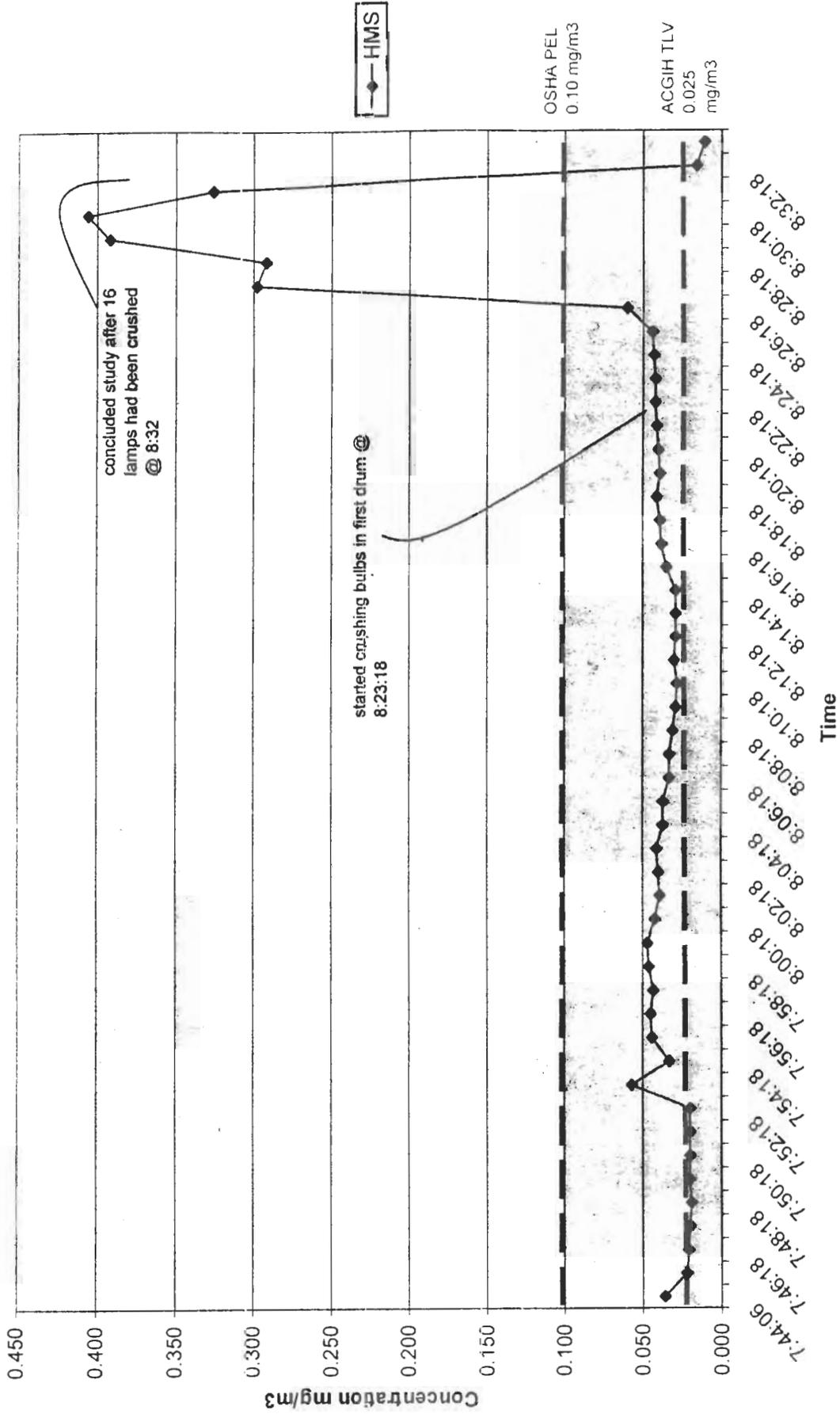
Ashland, VA AERC Facility Analytical Air Results February 2003



OSHA PEL
0.10 mg/m³

ACGIH
TLV
0.025

Phoenix, AZ EPSI Facility Jerome Hg Vapor Analyzer Direct Reading Air Results March 2003



HMS

OSHA PEL
0.10 mg/m³

ACGIH TLV
0.025
mg/m³

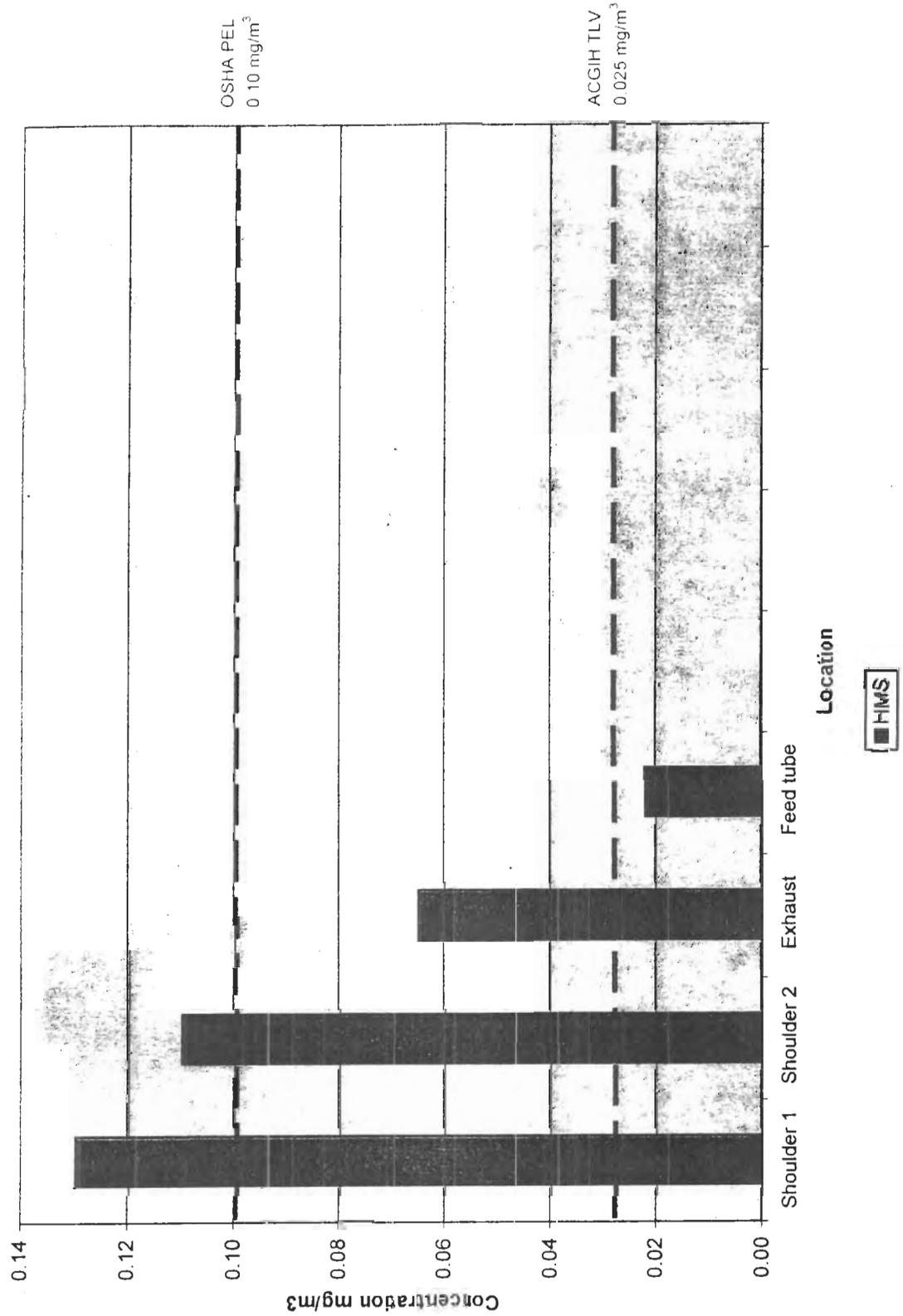
concluded study after 16
lamps had been crushed
@ 8:32

started crushing bulbs in first drum @
8:23:18

Time

Concentration mg/m³

Phoenix, AZ EPSI Facility Analytical Air Results March 2003



Tad Radzinski
03/07/2003 10:01 AM

To: hazmatspex@aol.com
cc:
Subject: Return of Your Equipment and Next Steps

Ed,

As we discussed today I have made arrangements for AERC to ship your DTC unit back to you COD via their freight company. When you receive the machine please evaluate to determine the cause of the elevated mercury emissions from your machine during the testing in Ashland, VA on February 27, 2003. I will need you to submit a written report to me with the results of your assessment. Once the machine is repaired you will need to test the machine including an analysis for mercury vapors using a Jerome or other mercury monitoring device by a qualified industrial hygienist. Please include the results of this test with your written report. We are planning to conduct the next round of testing in Phoenix, AZ during the week of March 24, 2003. I will need your report and testing results as soon as possible but no later than March 17 in order to confirm your continued participation in this study.

The contact for the Earth Protection Services Facility in Phoenix, AZ is Mr. John Chilcott and the shipping address and phone are listed below:

10 S. 48th Ave., Suite #4
Phoenix, AZ 85063-3820
Phone: 800-414-0443 - Fax: 602-353-9285
<http://www.earthpro.com/>

Please let me know if you have any questions. For shipping questions please contact Mr. Tom Downing of AERC at 804-798-9295.

Thank You,

Tad Radzinski
EPA Region III
Waste Minimization Team Leader
215-814-2394



THE HAZARDOUS MATERIALS SPECIALIST, INC.

ENVIRONMENTAL TRAINING, CONSULTING AND COMPLIANCE
INDUSTRIAL ♦ CRUISE ♦ MARINE

December 17, 2002

Mr. Tad Radzinski
Waste Minimization Team Leader
U.S. EPA Region 3
1650 Arch Street
Mail Stop 3WC11
Philadelphia, PA 19101-2029

REF: Equipment Comparison Phase I Sampling Results of THMSI Bulb Crushing Unit

Dear Tad,

Pursuant to our conversations, I apologize for the delay in providing you with this report. However, there have been several obstacles we have had to overcome. First, our unit did not arrive back here until March 13th late in the day. This was 2 full weeks from the test date in Virginia of February 27th. Once we received the unit the problem was quickly identified. However, lining up the test proved to be another challenge because of the unavailability of the Jerome 431X Meter. This combined with trucking companies not guaranteeing arrival times has made it a tough week. As you might recall, our unit did not arrive in Virginia until 1 hour before the test was to be performed. We landed at the airport when I phoned you and you said the unit had not even arrived yet and then it came in while we were on the phone. Regardless of these obstacles, I am providing the following report for you and your colleagues to review.

- 1) At the Virginia test site, after initializing our unit it was clear to Mike and I that something was wrong. When you were feeding bulbs into the machine they were not going in smoothly and Mike determined that the feeder tube was slightly bent. Apparently, this happened during shipping or unpacking. Mike bent it back a little and the feeder tube performed more normally. It wasn't perfect but it was better. This kind of a crate for us was new and both feeder tubes will be secured in a stronger manner so this doesn't happen again.
- 2) Unnecessarily High Readings of Mercury. As you might recall, just prior to starting the test on our unit you and your associates switched out the drum that came

MEMBER
NATIONAL SAFETY COUNCIL

3200 S. Andrews Ave. • Jacksonville, FL 32216, U.S.A. • Phone: 954.527.5135 • Toll Free: 1.800.816.3531 • Fax: 954.527.5137

Received Time: Mar. 24. 10:03AM

with our unit. As explained by you, this was because we had used our unit prior to shipping it and you needed a "clean" drum for the test. In placing the unit on top of the new drum we are not clear as to whether or not the side bolts were tightened down sufficiently. We do not believe they were and I will explain why.

a) When your initial readings were coming up high we could not understand why, especially based on other tests that we did independently. At the time of the first HEPA Filter change it became obvious to us that something was wrong because the HEPA filter was almost "clean" with no powder. The bag was almost clean and light. Again, normally the bag would be filled up, especially after 150 bulbs and it would be fully expanded, which it was not.

As you continued with the test and mercury levels rose, we were almost positive there was a vacuum or seal leak in the system somewhere. At that point, we left and as you might imagine, feeling very perplexed. Tad, I'm sure you realize we spent a lot of time and money to participate in this study and feel it is very useful and necessary. I consider myself one of the pioneers regarding this technology in making it a "real world product" and in no way want you or your management to think that this malfunction represents our standards.

3) Review of Unit Upon its Return to Florida for Evaluation. When the returned crate was opened we immediately observed the following:

a) The side set bolts were missing and the unit sitting on the drum had a good $\frac{3}{4}$ " play in it. When the unit was tilted on its side, it is our finding that it slipped off the upper seal that sits on the rolled metal edge of the drum. This would cause a vacuum leak allowing the unit to draw clean air allow mercury to escape.

Corrective Action: Replace and evenly tighten unit to top of drum. Increase seal size width at inner top of unit that sits on drum. Even if the screws were not put in it could not shift far enough to split off the seal.

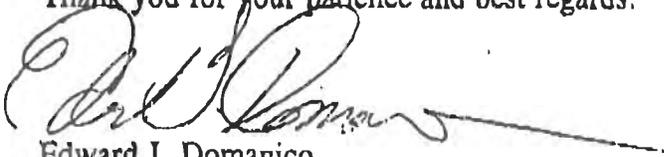
In addition to this, we feel that the charcoal filter may have somehow lost connection to the exhaust canister. This would account for the high readings at the exhaust point.

In addition to these corrective items we checked our CFM flow on the vacuum with and without the HEPA Filter. With the HEPA Filter removed, it is 55 cfm. With the HEPA Filter in place it drops to 30 cfm. This is considered normal. Also, the charcoal filter medium is the EPA recommended product in accordance with EPA method 245.1 specially treated charcoal #580-13.

We will provide you, by fax, late this afternoon, the field test results from our unit.
Also, it will be arriving in Phoenix on Monday according to Delta Freight.

If you require any additional details please advise me accordingly.

Thank you for your patience and best regards.

A handwritten signature in black ink, appearing to read 'E. J. Domanico', with a long horizontal line extending to the right.

Edward J. Domanico
Senior Certified Hazardous Materials Manager

cc: Mike Britton

10: TAD
From: ED

Hazardous Materials Specialist, Inc.
3200 S. Andrews Avenue
Fort Lauderdale, Florida
Mercury Testing

EHE Project # 03-023
Date: March 22, 2003

Test Location: Spray Booth

Test Run Quantity: 30 Bulbs

<u>Sample Location</u>	<u>Hg (mg/m3) During Process</u>	<u>Hg (mg/m3) After 30 Bulbs Processed with Unit running</u>
Booth Background-	.000	.000
Charcoal Discharge-	.000-.022	.059
Hose Connections:		
Charcoal Supply-	.160	.075
Vacuum Exhaust-	.207	.159
Vacuum Suction-	.062	.059
Vacuum Hose at Drum-	.070	.052
Seals:		
Drum Seal-	.056	.055

Testing Device: Jerome 431-X Mercury Analyzer

OSHA ceiling level for Mercury is 0.1 mg/m3.

Appendix J

Peer Review of Mercury Lamp Drum-Top Crusher Study: Response to Comments

Background

The universal waste regulations, set forth in 40 CFR 273, were formulated in order to ease the regulatory burden associated with the collection of universal waste and to thereby facilitate the entry of these hazardous wastes into the RCRA hazardous waste management system. The original federal list of universal wastes included certain hazardous waste batteries, pesticides, and mercury-containing thermostats. Hazardous waste fluorescent lamps were added to the federal list of universal wastes on January 6, 2000 (64 FR 36465). One of the issues raised during the notice and comment period of this rulemaking was the use of Drum Top Crusher (DTC) devices for lamp management. A DTC device fits over the top of a standard 55-gallon drum and crushes the spent lamps into the drum. The DTC device is used to simplify handling of the spent lamps by reducing their volume.

At the time that hazardous waste lamps were added to the universal waste list, some states already allowed the use of DTC devices. EPA provided some general guidance to states with regard to the appropriate use of DTCs for lamp management (64 FR 36477) and determined that further, more detailed information or guidance regarding the use of DTC devices needed to be informed by an assessment of DTC device performance. Therefore, in 2003, EPA performed a study assessing the performance of DTC devices.

EPA prepared a draft report for the DTC Device Study (the Study), *Mercury Lamps Drum-Top Crusher Study Report*. RTI International (RTI), under contract to EPA, arranged for an independent review of the draft report, dated September 20, 2004, by recognized technical experts. This review was conducted by letter format in a manner consistent with EPA's Office of Research and Development and Science Policy Council *Peer Review Handbook* (December, 2000). The peer review was sought so that EPA may benefit from additional viewpoints and perspectives. Each reviewer certified that they had no actual or potential conflicts of interest; therefore, these reviews provided impartial evaluations of the scientific information and study findings. The following experts served as reviewers of the report:

- Carl Herbrandson, Ph.D., Minnesota Department of Health
- Steven Lindberg, Ph.D., Corporate Fellow Emeritus (retired)
Environmental Sciences Division, Oak Ridge National Laboratory
- Michael McLinden, M.S., C.I.H., New Jersey Department of Environmental Protection

This report presents a compilation of the reviewers' verbatim comments on the draft report and the Agency's responses to these comments. Many substantive comments were made by the reviewers. As a result of these comments, EPA extensively revised the study report. Many sections of the report were rewritten, expanded upon, or moved in order to address the concerns of the commenters and provide a clear, thorough discussion of the DTC Device Study. Because of this extensive revision, several of the specific statements that the reviewers quoted and commented on are not in the revised report. Agency responses to these comments explain why the text was changed and addresses the substantive portions of the comments. The comments and responses are grouped by subject and generally follow the order of the report.

Comments Answering Questions Posed to the Reviewers by EPA

EPA posed the following specific questions to the reviewers:

1. General Design/Execution of the Study: Is the design and execution of the Study appropriate for evaluating the likely Hg releases from DTCs in use?
2. Laboratory Methods/QA/QC: Are the laboratory analytical methods and QA/QC procedures appropriate and adequate to generate reliable data?
3. General Results/Conclusions: Do the data generated by the Study support the conclusions presented in the report? If not, in what regard? Are other conclusions supported by the data generated?
4. Effects of Temperature and Humidity: DTC operations were performed at three locations under temperature and humidity conditions that varied at the different sites. The report does not attempt to quantify the effects of temperature and humidity on mercury releases from DTC devices in operation. Are the data generated by the Study adequate to assess the impacts of temperature and humidity on Hg release from DTCs in operation?
5. Background Hg: The DTC Study was conducted at operating commercial lamp recycling facilities. As a result, background mercury levels in the areas of the Study were much higher than would be expected to occur in buildings that do not use Hg in routine operations. How should the background levels of mercury be considered in assessing DTC releases of Hg?
6. Mass Balance Study: One portion of the Study consisted of a Mass Balance Study of mercury being put into the DTC devices, and the mercury released from the devices (Chapter 5). Estimated recoveries ranged from 34% to 67%. A number of possible reasons for the low recovery rates are discussed in the report. Do the sources of error described in the report adequately address the low recoveries? Are other sources of error plausible (and should be considered in any subsequent Mass Balance Study)?
7. Operator Observations: Are the operator observations presented in chapters 6 and 7 appropriate?
8. Study Limitations: Does the discussion of study limitations (Chapter 8) identify all important weaknesses in the Study not elsewhere identified in the report?

The reviewers' answers and the corresponding responses are presented below.

1. *General Design/Execution of the Study: Is the design and execution of the Study appropriate for evaluating the likely Hg releases from DTCs in use?*

Carl Herbrandson's Comment: Mercury emissions from DTCs, as mass of mercury released or as a fraction of mercury released from each fluorescent bulb, were not characterized in this study. The study was not designed appropriately for evaluating likely mercury releases during DTC use. The study measured containment area air concentrations, which was also an objective of the study. "The objective of the project was to evaluate the performance of the DTC devices in terms of mercury emissions and potential for worker exposure to adverse levels of mercury releases due to the operation of these devices." The potential for worker exposure to adverse levels of mercury releases due to operation of DTCs was effectively evaluated.

Response: EPA agrees that mercury emissions from DTCs in use were not measured in this Study. The discussion presented in this report has been modified to more clearly state that the Study was designed to evaluate DTC device performance in terms of worker exposure.

Steven Lindberg's Comment: No. The study was flawed, resulting in serious contamination which makes it difficult to quantify actual Hg releases.

Response: Mercury releases from DTC devices were not quantified in the Study. The Study was designed to evaluate mercury exposures that could result from the use of DTC devices and changes in mercury exposure over time. The data collected during the Study provide information about which activities involved in DTC device operation are associated with the highest mercury exposure and about how devices perform over time, in terms of their ability to prevent mercury exposure. Contamination, due to mercury present in the testing environment, was an issue. The limitations due to background mercury are discussed in Chapter 6 of the revised report, and background air sampling data (Jerome analyzer readings and analytical air samples) are presented in Chapter 4 of the revised report.

Steven Lindberg's Comment: Statements made in Section 7 suggest that the design was compromised to decrease costs of the study.

Response: The reviewer did not specify what statements in Section 7 suggest that cost concerns caused the study team to compromise the study design. However, one of the major concerns expressed was that the testing was conducted at lamp recycling facilities and thus, high background concentrations of mercury were present. (See next comment and response for specific response to this concern.) In addition, the study team made many ad hoc decisions in response to data that was collected during the early phases of the Study. A thorough review of the original study design by researchers more experienced in mercury sampling would most likely have lead to an improved study design. As with any large-scale study, cost and time considerations were important because inattention to these constraints (i.e., planning more sampling than could be completed in the amount of time allotted for a given test) would have made it difficult or impossible to complete the Study. However, the primary concern in designing the DTC Device Study was to assess the performance of the four DTC devices tested, and concerns about the cost of the testing were secondary to completing the objectives of the Study.

Steven Lindberg's Comment: The notion that these devices might be used at major existing recycling facilities seems poor justification for the chosen sampling locations. My experience in seeing these devices in the field is that they are used primarily at small to moderate-sized generators of used bulbs, such as small industries and hospitals.

Response: There were several reasons why lamp recycling facilities were used as the sites for the Study. Not all of these reasons were clearly explained in the draft study report. The revised report includes the following, more detailed explanation as to why the Study was conducted at lamp recycling facilities:

- These facilities possessed the appropriate permits to process mercury-containing fluorescent lamps.

- These facilities had ample supplies of lamps that were provided at no cost to the study team.
 - The facilities had the capacity to process and dispose of the drums of lamp debris, with no shipping, manifesting, or disposal arrangement required of the study team.
- The study team made every effort to isolate the study area from normal lamp processing operations. **(pg. 78)**

The study team considered other locations for the Study. However, some states require permits for the operation of a DTC device, and it was not feasible to obtain state permits within the timeframe of the Study.

The containment structure used for testing the DTC devices was constructed in order to simulate field conditions for DTC use by creating a small, confined space, similar to a boiler room or janitor's closet. The containment structure was also intended to isolate the test area from the rest of the lamp recycling facility, as best as possible.

Steven Lindberg's Comment: Perhaps the only questions these data could answer are "Do the tested DTC's have serious operating problems [yes], and do they capture all of the Hg from the feed lamps [no]?"

Response: EPA agrees that the data collected for this report should primarily be used to answer qualitative questions. The purpose of this Study was to provide information regarding possible worker exposures due to DTC device use. The agency believes that there are many insights that can be gained from the data collected in the Study. Chapter 7 of the revised report discusses the study results.

- Laboratory Methods/OA/QC: Are the laboratory analytical methods and QA/QC procedures appropriate and adequate to generate reliable data?

Carl Herbrandson's Comment: Generally, yes. The use of a realtime monitor (Jerome) also provided supporting confirmation of the analytical results. The effectiveness of the MCE filters, as the first stage of the sample collection train, to capture and retain aerosol Hg could be suspect and was not demonstrated.

Response: The effectiveness of the mixed cellulose ester (MCE) filters is discussed at the beginning of Chapter 4 of the revised report. It is possible that the MCE filters were not effective for capturing aerosol mercury; however, the total amount of mercury in the air sampled was effectively measured because any aerosol that was not captured in the MCE filter was captured by the Hydrar tubes (the second stage in the sample collection train).

Carl Herbrandson's Comment: Jang et al., 2005 shows an HCl / nitric acid solution removes a maximum of 36% of the Hg from bulb waste. Therefore, the effectiveness of the methods employed in this study to measure the amount of Hg in spent bulbs should be confirmed.

Response: In the revised report, a reference to Jang et al., 2005 is included in the section describing the extraction (in Chapter 5). Additionally, the need for a valid laboratory method

for quantifying the amount of mercury in spent lamps, with appropriate QA/QC procedures, is suggested in Section 7.4 as an area where further work is needed.

Steven Lindberg's Comment: In 3 decades of working with Hg I have never heard of Hydrar solid sorbent tubes. This does not mean they are unacceptable, but in the absence of strenuous QA tests, I was unable to verify the validity of data generated by this approach. My group has sampled Hg at levels in air and solids from background (pg of Hg) to highly enriched (mg of Hg), and our approaches have involved various sorbent traps (activated iodated C, gold), automated instruments (Jerome, Tekran, Lumex) and chemical extraction methods (such as for methylmercury). I found no QA testing of these tubes that provided any evidence of their ability to quantitatively collect Hg under conditions encountered. I would describe the methods as less than adequate (Appendix D titled Data Chem Methods was blank in my copy).

Response: According to OSHA's *Occupation Safety and Health Guideline for Mercury Vapor*, which can be found at <http://www.osha.gov/SLTC/healthguidelines/mercuryvapor/recognition.html>, "Determination of a worker's exposure to airborne mercury vapor is made using a Hydrar or Hopcalite tube (200 mg section), SKC brand with a prefilter/cassette." (The prefilter used in the Study was a mixed cellulose ester filter.) In addition to the OSHA guideline, Hydrar tubes are an acceptable medium for sampling mercury vapor in an industrial setting according to the National Institute for Occupational Safety and Health (NIOSH [1994]. NIOSH manual of analytical methods, 4th ed. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 94-113.).

Steven Lindberg's Comment: I was surprised that readily available, widely used and accepted methods were not employed. Although the Lumex data could have been very valuable, the users seemed to have encountered several problems deploying this instrument, which many others have used successfully.

Response: EPA agrees that the Lumex data would have been very valuable. The study team attempted to record data with the Lumex but was unable to do so because the instrument was not functioning properly.

Steven Lindberg's Comment: The Jerome is a valuable instrument when properly used. However, there seemed to be no serious attempt to perform a sampling or analytical intercomparison between these two methods (see comment on Section 4 below). This would have proved useful in evaluating the Hydrar method. Also, the most interesting Jerome data were relegated to the Appendices and the trends not discussed (see below).

Response: The study team found that the Jerome data were valuable, and EPA agrees with the reviewer that the importance of the Jerome data was understated in the draft report. Unfortunately, because of problems with the data loggers, there were not enough Jerome data for each device at each location to perform any rigorous statistical analyses. The revised report highlights the Jerome data. Also, averages of the Jerome data and the analytical air

sample (Hydrar tube) data were graphed together to better facilitate comparison of the results from the two air sampling methods; these graphs are in .Appendix A, Figures 26, 35 and 43, of the revised report.

Steven Lindberg's Comment: The supplied raw analytical data tables suggested that up to half of the samples were below detection. This seemed odd given the enriched background under which the study was performed.

Also, I noted that the detection limits seem to have varied by over an order of magnitude (<0.1 to <1.1 ug) which is worrisome.

Response: Aside from the blank Hydrar tube samples, the samples that were below the detection limit were the MCE filter samples. The report was revised to highlight the fact that the majority of the MCE filter results were below the detection limit. (See earlier comment and response under "Laboratory Methods/QA/QC" for specific response to this concern.) The actual detection limits were based on the actual sampling media (0.1 µg per Hydrar tube or MCE filter). The "less than" values in the raw data tables vary because the total volume of air sample varied for each MCE filter/Hydrar tube. The units used for the final reporting value reported were mg/m³, so the volume of air affected the "less than" value for each individual sample.

- *General Results/Conclusions: Do the data generated by the Study support the conclusions presented in the report? If not, in what regard? Are other conclusions supported by the data generated?*

Carl Herbrandson's Comment: Generally, the data supported the results and the conclusions of the report. With the following exceptions:

- There is no analysis of data showing that Manufacturer A's device performed better than the other devices in the PVS. While data from Phase 2 suggests this to be true, data from Phase 1 are equivocal.
- Data available are not sufficient to allow a mass balance calculation. Therefore, mentioning "a large fraction unaccounted for" may be misleading.

Response: An analysis was performed to support the assertion that there was a decrease in the performance of the devices from Manufacturer B and C but not the device from Manufacturer A. This is discussed in Chapter 4 of the revised report.

EPA agrees with the commenter regarding the Mass Balance Conclusions so the report was revised to eliminate the Conclusions section. The Mass Balance Study discussion was revised so that no definitive statements based on the data were made. Instead, the problems with the Mass Balance Study were presented along with the data so that this information could be used by future researchers.

Steven Lindberg's Comment: It would be difficult to draw any quantitative conclusions from the data presented in the report.

Response: EPA agrees, and thus, the conclusions presented in the report are primarily qualitative.

- *Effects of Temperature and Humidity:* DTC operations were performed at three locations under temperature and humidity conditions that varied at the different sites. The report does not attempt to quantify the effects of temperature and humidity on mercury releases from DTC devices in operation. Are the data generated by the Study adequate to assess the impacts of temperature and humidity on Hg release from DTCs in operation?

Carl Herbrandson's Comment: NO. There are too many variables. Differences between sites include: building configurations, proximity to industrial crushers, air currents within the buildings, potential changes in DTCs as a result of shipping, as well as seal leakage and potential maintenance issues could also confound a relationship. Differences between PVS phases 1 and 2 in Virginia may show a temperature/humidity effect, and some site related variables may be controlled, but showing a relationship between temperature/humidity and emissions would require showing that differences are outside any expected variability (i.e., multiple tests would be needed, at different times, and with cold temperature tests both before and after warm temperature tests).

Steven Lindberg's Comment: No, the data are not adequate. This question required a systematic approach under controlled conditions.

Michael McLinden's Comment: I expect temperature would directly influence the amount of mercury released from crushed/broken lamps as well as the amount escaping from the DTC devices, higher temperatures would volatilize more mercury. As for relative humidity, my guess is that since mercury is thirteen times as dense as water, it would not have a significant affect on mercury volatilization. As for your question "Are the data generated by the study adequate to assess the impacts of temperature and humidity on Hg release from DTCs in operation?" It may be helpful to graph results of a particular sampling location (e.g., all area air sample taken at feed tube) for all three Extended Field Tests. You could then compare the graph with ambient air temperatures to see if temperature affected the results.

Response: The Study was not designed to evaluate the effects of temperature on the measured mercury concentrations. After the Study began, the study team recognized that ambient temperature could significantly impact the amount of mercury that volatilized when the lamps were crushed, so temperature data was collected. The peer reviewers were specifically asked to comment on the adequacy of the temperature and humidity data for the purposes of assessing any possible effects that environmental conditions may have had on the results of the Study. Based on the comments made by the reviewers, no attempt was made to assess the impacts of temperature and humidity on DTC performance in the revised report.

- *Background Hg:* The DTC Study was conducted at operating commercial lamp recycling facilities. As a result, background mercury levels in the areas of the Study were much higher than would be expected to occur in buildings that do not use Hg in routine operations. How should the background levels of mercury be considered in assessing DTC releases of Hg?

Carl Herbrandson's Comment: High background mercury in the testing areas was handled properly in the report: background Hg was recorded and reported. Certainly if longterm testing had occurred in a pristine setting, wipe samples could have provided some useful data about the potential for DTCs to contaminate work areas. However, it is not clear how the background concentrations may have impacted the mercury vapor data acquired during the reported experiments. Background mercury vapor concentrations could be subtracted from the test data, but this would have required substantial data supporting the use of specific background concentrations.

Response: In the revised report, more complete background data are presented in the results section (Section 4.2). The background air sample data was compared to the air samples taken during testing to show that the mercury concentrations measured during testing were significantly higher than the background levels at each facility.

Carl Herbrandson's Comment: Data from Jerome #2 is not shown in the figures. As noted in the report, air leaks and exchanges occurred whenever the bay doors at the testing facilities were open. The readings from Jerome #2 could provide useful information for evaluating the variability of background mercury vapor concentrations.

Response: EPA agrees that the data from the Jerome Mercury Vapor Analyzer that was used to sample the air outside the containment structure during testing would have enhanced the analysis and discussion of the background data. Unfortunately, due to problems with the Jerome data loggers, the real-time background data is not available.

Carl Herbrandson's Comment: The report should note that the background concentrations in locations at some distance from the 'industrial' crushers suggest that exposures near operating industrial crushers may be above levels of concern for the general public; and that Hg contamination on floors near the containment areas suggests that tracking of mercury from facilities like these may be significant.

Response: The potential for exposure to the general public is discussed in Chapter 7 and several other sections of the revised report. The Study was not designed to measure possible migration of mercury off site from the lamp recycling facilities, so the report does not make any statement about the possibility of significant amounts of mercury being released due to tracking from the facilities.

Steven Lindberg's Comment: The decision to perform these tests under the chosen conditions represents a fatal flaw in this study. The problems of such serious contamination cannot be overcome without a revised study design. Since the background was never adequately controlled, or even quantified (too few samples, too much variability), I don't see how any quantitative conclusions can be drawn from the study as designed and performed.

Response: As stated above, there were many reasons that the lamp recycling facilities were chosen as the sites for this Study. EPA agrees that the background mercury is a serious confounding factor in the Study, and the majority of the conclusions drawn in the report are

qualitative. In response to the reviewers' concerns about the low number of background samples, a more thorough presentation of all available background mercury samples measured using the Hydrar tubes and using the Jerome Mercury Vapor Analyzer is included in the results section (Chapter 4) of the revised report, and the chapter about limitations (Chapter 6) discusses several ways in which the background samples may bias the results.

- *Mass Balance Study: One portion of the Study consisted of a Mass Balance Study of mercury being put into the DTC devices, and the mercury released from the devices (Chapter 5). Estimated recoveries ranged from 34% to 67%. A number of possible reasons for the low recovery rates are discussed in the report. Do the sources of error described in the report adequately address the low recoveries? Are other sources of error plausible (and should be considered in any subsequent Mass Balance Study)?*

Carl Herbrandson's Comment: Calculations and estimates used in the "mass balance" should not be reported. Instead, for the benefit of future investigators, the problems with attempting to show a mass balance with the available data should be detailed. Other potential sources of mass balance loss are described in accompanying comments.

Steven Lindberg's Comment: Considering all of the assumptions, analytical errors, and background problems, I would not accept that even the stated range of recoveries is accurate. Given the analytical and sampling errors, and the flawed design, it is not surprising that correction factors as large as 95% were applied in an attempt to close the mass balance. It is never explained why there was no attempt to quantify the losses based on the air concentration data.

Response: EPA agrees that the uncertainty in the Mass Balance Study is too high to estimate the different fractions of mercury. The discussion of the Mass Balance Study was revised to present the data collected, the calculations, and the problems encountered. The air concentration data was used to calculate the amount of mercury released; however, there was a significant mass of mercury unaccounted for.

- *Operator Observations: Are the operator observations presented in chapters 6 and 7 appropriate?*

Carl Herbrandson's Comment: Yes. Inclusion of operator observations can provide important subjective information and insight.

Steven Lindberg's Comment: These were possibly the most useful contribution. The DTC's as a whole seemed poorly designed, and the problems encountered were not surprising. The safety suggestions offered are valuable, although several were also noted in the manufacturer's guidelines. It is interesting to note that these manuals contained misinformation concerning Hg.

Response: The operator observations are included in Chapter 7 of the revised report.

- *Study Limitations: Does the discussion of study limitations (Chapter 8) identify all important weaknesses in the Study not elsewhere identified in the report?*

Carl Herbrandson's Comment: Additional study limitations are discussed in the accompanying comments.

Steven Lindberg's Comment: In general, the major limitations were noted, but several more could be listed, as noted both above and below.

Response: The study limitations are discussed in Chapter 6 of the revised report. EPA has responded to all comments in this document.

Additional Comments of Peer Reviewers and Agency Responses

The additional comments provided by the reviewers follow. General comments are presented first, and specific comments are organized to follow the order of the report.

General Comments

Carle Herbrandson's Comments: This study was a very good initial study of DTCs. The study showed operator exposures to mercury vapor may regularly be above the TLV (for the duration of operation) and often above the PEL. Adverse health effects are consistently seen in studies of workers exposed at the TLV (0.025 mg/m³ for 8-hour day). Therefore as a scientist in the field of public health, I would recommend to my state environmental agency that additional study should be conducted prior to allowing the use of DTCs. These studies should answer the following questions:

- a. Can contamination accumulate in areas where DTCs are used? Can this contamination be tracked? Is there a need to establish decontamination areas and procedures for operators?
- b. Can the circumstances of use of DTCs be controlled so that the general public is not exposed to potentially hazardous levels of mercury?
- c. What fraction of the mercury in a fluorescent bulb is emitted from DTCs, in all phases of operation?
- d. Are there regulations that will ensure control and proper disposal of full drums?
- e. How do emissions from currently operated 'industrial' recycling processors and DTC emissions compare? Can the use of DTCs reduce the overall emissions from spent fluorescent bulbs to the environment?
- f. Can we objectively evaluate the apparent tradeoff between potential decreased environmental emissions and the potential for significant exposures to more individuals – individuals exposed to emissions or contamination associated with DTCs?

I would hope that, without answers to the above questions, DTC usage does not increase.

Response: The questions posed by the reviewer are excellent research questions. While the Agency is not suggesting that DTC devices not be used until these questions are answered, EPA agrees that regulators should carefully consider the possible effects to human health and the environment that would come from allowing the use of DTC devices. This then can be compared to continuing to have the majority of mercury containing fluorescent lamps disposed of in MSW landfills.

Carle Herbrandson's Comments: The order of presentation of data on DTC devices in all tables and figures should be A, B, C, D. Data are always more confusing when they are listed in different order in different places. If the actual sampling order was different than the reporting order (A,B,C,D), then the sampling order should be noted in table/figure footnotes.

Response: The presentation of the data has been changed to A, B, C, D order.

Carle Herbrandson's Comments: Pg 92 last line – there is no section 3.6.2.1.

Michael McLinden's Comment: There is no Section 3.7, perhaps it should read Section 3.5.2.1. There is no section 3.9.1.

Response: All references within the report were checked and revised to ensure that they were correct.

Steven Lindberg's Comments: Although the nature of this project led to moderately difficult objectives, they should have been achievable by an experienced research group with sufficient planning. In my opinion, this project and the report do not meet the stated objectives. The primary reasons relate to the apparent inexperience of the project team in working with Hg and an inability to anticipate potential problems. Detailed comments follow the questions below.

Response: While some objectives of the Study were not met, the data collected in this Study provide valuable information to regulators and users of DTC devices. EPA agrees however, that a more thorough review of the sampling and study plan by researchers more experienced with mercury monitoring would have been beneficial to the study team to avoid some of the problems encountered during the Study.

Executive Summary

Note to the reader: The Executive Summary that was included in the draft report given to the reviewers was extensively revised. The Executive Summary in the revised report provides the reader with the background of the Study and the results of the Study, in a concise form. Many of the comments made by the reviewers are not directly relevant to the revised report; however, responses to the concerns raised by these comments are provided below.

Carl Herbrandson's Comment: The executive summary introduction says that the use of DTCs "will likely increase." This will certainly be true, in the absence of regulatory action. Does this report assume that there will be no regulatory action taken? Or that additional testing will not occur before DTC-use increases?

Response: EPA is not proposing any changes in regulations; the purpose of this Study was to provide information about the use of DTC devices. The statement that DTC use "will likely increase" is no longer in the Executive Summary. The issue of the use of DTC devices was discussed in the final notice for the addition of hazardous waste lamps to the federal list of universal waste (64 FR 36477). Authorized state programs have the authority to make regulatory decisions about the use of DTC devices as part of their universal waste management programs.

Carle Herbrandson's Comment: Pg 5 (TLV) of 0.25 mg/m³ - - should read 0.025 mg/m³

Response: The TLV listed in the Executive Summary now reads 0.025 mg/m³.

Carl Herbrandson's Comment: The conclusions and recommendations section of the Executive Summary includes the statement that "Additional recommendations for engineering controls, PPE, equipment isolation, and worker medical monitoring may apply in site-specific situations." Does this suggest a different level of regulation than is typically seen

in Haz Waste regulations? Are equipment isolation, PPE, ...controls EPA wants to recommend only at certain sites?

Response: EPA is not proposing any changes in regulations; the purpose of this Study was to provide information about the use of DTC devices. The statement quoted by the reviewer, which is no longer in the Executive Summary, reflects the fact that EPA expects that there will be a broad range of conditions under which DTC devices will be used. The members of the operator and operator's assistant wore Tyvek® coveralls, Kevlar® gloves, safety glasses, and, at times, full-face respirators while conducting the Study.

Michael McLinden's Comment:

Report Text:

The Manufacturer D device was removed from the study after the second round of testing due to its inability to control mercury emissions below Occupational Health and Safety Administration (OSHA) and the American Council of Governmental and Industrial Hygienists (ACGIH) standards.

Comment (Suggested Text Changes Highlighted): The Manufacturer D device was removed from the study after the second round of testing due to its inability to control mercury emissions below Occupational Safety and Health Administration (OSHA) and the American Conference of Governmental Industrial Hygienists (ACGIH) standards.

Response: The correction suggested in the above comment was made in the revised report.

Steven Lindberg's Comment: The accuracy and precision of the data are never mentioned. There seems to be a lack of any serious attempt to reproduce these results, and no replicates are discussed.

Response: There is no longer a discussion of the data in the Executive Summary. The study design did not call for replicate testing because one of the basic assumptions of the Study was that there would be changes in device performance over time. Multiple air samples were collected during each test. The variability between air samples collected for each device during a specific testing event were used to determine the variance associated with the measured mercury concentrations.

Steven Lindberg's Comment: Phrases suggesting that emissions were measured are inaccurate. There were no measurements of emissions performed in this Study, only estimates made, based on concentration data.

Response: The report has been revised to make it clear that emissions were not measured. The concentrations near the feed tube and exhaust port were measured.

Michael McLinden's Comment: Although this is a good recommendation [*medical monitoring program for device operators*], OSHA does not require specific biological monitoring in order to use respiratory protection, only a questionnaire and/or physical exam. I agree that respiratory protection should be used, however based on established industrial hygiene hierarchy to control workplace contaminants respiratory protection would be

recommended only after engineering and administrative controls were explored. Engineering controls should be instituted first in order to reduce employee exposure below the PEL. If engineering controls are not feasible (and I believe they would be feasible in this case) then administrative controls would be explored. Respiratory protection is used as a last resort or while instituting engineering controls.

Response: These recommendations are not in the Executive Summary, but some of the issues are discussed in Chapter 7 of the revised report. The revised report mentions the established industrial hygiene hierarchy (Chapter 7).

Michael McLinden's Comment: In order for an air purifying respirator to work (and be certified by NIOSH) it must have adequate warning properties to indicate when the filter/cartridge has reached break-through. Mercury cartridges do not have adequate warning properties; however, some manufacturers (e.g., MSA mersorb cartridge) have received approval for cartridges equipped with an end of service life indicator (ESLI) so employee can check for break through. Special SOPs (e.g., wearing a belt-mounted cartridge so employee can see the ESLI, or providing mirrors so a worker could see ESLI on his full-face APR) would have to be developed for using APR with Hg.

Response: This fact was not addressed in the revised report; however, EPA will consider this point in drafting additional guidance.

Scope of Study

Carl Herbrandson's Comment: The study objective was to evaluate the performance of DTCs with respect to potential mercury emissions and potential exposures to workers operating DTCs. The study does provide useful data and information on the potential exposures to DTC operators. However, mercury emissions from DTCs, as mass of mercury released or as a fraction of mercury released from each fluorescent bulb, were not characterized in this study.

Response: EPA agrees that the Study was designed to assess worker exposure due to operation of DTC devices and not to measure mercury emissions. The revised report reflects this point – that is, the fact that mercury emissions from DTC devices were not characterized in this Study.

Steven Lindberg's Comment: Several design decisions mentioned in this section are hard to reconcile with an assumed experience of working with environmental or occupational levels of Hg. The decision to locate the study at recycling facilities is surprising and suggests a lack of understanding of (or experience with) the behavior of elemental Hg vapor. It's surprising that someone didn't realize the impact of this decision sooner.

Response: There were several reasons why lamp recycling facilities were used as the sites for the Study. Not all of these reasons were clearly explained in the draft study report. The revised report includes the following, more detailed explanation as to why the Study was conducted at lamp recycling facilities:

- These facilities possessed the appropriate permits to process mercury-containing fluorescent lamps.
- These facilities had ample supplies of lamps that were provided at no cost to the study team.
- The facilities had the capacity to process and dispose of the drums of lamp debris, with no shipping, manifesting, or disposal arrangement required of the study team. The study team made every effort to isolate the study area from normal lamp processing operations. (pg. 78)

The study team considered other locations for the Study; however, it was not feasible to obtain permits for each site within the timeframe of the Study. The most important reason for using the lamp recycler facilities for the Study was the fact that they had permits for lamp crushing.

The containment structure used for testing the DTC devices was constructed in order to simulate field conditions for DTC use by creating a small, confined space, similar to a boiler room or janitor's closet, and also to isolate the test area from the rest of the lamp recycling facility.

EPA also agrees that future studies conducted in a testing environment with very low background mercury levels, involving the measurement of emissions, would be helpful in evaluating the effectiveness of DTC devices.

Data Collection Methodology

Michael McLinden's Comment: Which model, Jerome-411 or newer model?

Response: The model for the Jerome was 431-X. This information is included in the revised report.

Michael McLinden's Comment: Were any background samples collected at the end of the week to determine if background Hg levels had risen during the week due to normal facility processing of lamps? It may be possible that background levels on Monday are lower than Friday levels if the facility is shut down for the weekend.

Response: Background samples were not specifically taken at any point after the first day at each facility. However, during EFT #2, EFT #3, and PVS-II, one overnight air sample was taken outside of the containment structure after each day of testing. These air sample results are presented Table 4.1 and Table 4.2 in the revised report along with the other background sample data and the Jerome background sample data that was manually recorded throughout the Study. Based on this limited sampling, there was no observable trend indicating an increase in background concentrations throughout the week.

Carl Herbrandson's Comment: Table 3.1 is poorly designed – not very understandable.

Response: Table 3.1 in the draft report described the types of analytical air samples that were taken during each portion of the Study. This table has been replaced by four distinct

tables – Tables 3.1, 3.2, 3.3, and 3.4 – in the revised report, which describe the samples for each portion of the Study (the Performance Validation Study, Extended Field Test #1, Extended Field Test #2 and #3, and “U”-tube Test).

Carl Herbrandson’s Comment: Last sentence on page 26 – not clear. 2 samples “in sequence, for a total duration of 4 minutes per sample.” Does that mean a total duration of 8 minutes?

Steven Lindberg’s Comment: The intent of ceiling samples was never clearly described, but they seem to be interpreted as representative of maximum exposure. Why?

Response: The description of the ceiling samples that were described on page 26 of the draft report was clarified in the final report. The original description was:

Short-term ceiling samples were air samples collected over a short duration in time (for this study the sample period was 12 minutes) in order to evaluate the airborne concentration at a specific time. These samples were collected to attempt to quantify airborne concentrations at the estimated time of maximum exposure determined to be during the drum changes. Readings taken on the Jerome Mercury Vapor Analyzer indicated that maximum exposure conditions most probably occurred during drum changes. Thus, the ceiling samples were collected during one of the drum changes for each device. Two samples were collected on the operator’s shoulder, in sequence, for a total duration of four minutes per sample.

The revised description is:

The ceiling samples were another set of personal air samples, which were collected to attempt to quantify airborne mercury concentrations at the estimated time of maximum exposure. Readings taken on the Jerome analyzer indicated that maximum exposure conditions most probably occurred during drum changes. Thus, the ceiling samples were collected during one of the drum changes for each device during PVS-Phase II, EFT #2, and EFT #3. Two samples were collected on the operator’s shoulder, in sequence; each ceiling sample was collected for 4 minutes. (pg. 18)

Short-term ceiling air samples were introduced into the Study during this round of testing. As described above, ceiling samples were air samples collected over a short duration in time in an attempt to quantify airborne concentrations at the estimated time of maximum exposure.

Readings taken on the Jerome analyzer indicated that maximum exposure conditions most probably occurred during drum changes. Drum change sample results from EFT #1 showed that the ambient concentration of mercury is sufficiently high during drum changes such that the samples did not need to be 12 minutes in order to exceed detection limits. Thus, two short-term, personal air samples were collected in sequence during one of the drum changes for each device. The sampling time was four minutes per sample, for a total duration of eight minutes. (pg. 21)

Steven Lindberg’s Comment: The decision to cut the plastic on the floor was a fatal flaw.

Response: The study team attempted to rectify the problem with the contaminated wipes samples. Because many of the pre-test wipe results were higher than the post-test wipe

results, the wipe sample data were not used in the report and were only included in the Appendix. Later, the plastic was cut outside in the parking lot; however, the number of pre-wipe samples exhibiting high amounts of mercury did not decrease.

Steven Lindberg's Comment: The Lumex was “written off” with a brief comment regarding inoperability. Were any attempts made to rectify the problems?

Response: EPA agrees that the real-time data would have been an asset to the Study; however, although the study team attempted to correct the problems with the Lumex, the device obtained for the Study did not operate correctly.

Michael McLinden's Comment: Was the DTC decontaminated between EFT #3 and PVS-Phase II? Would contaminated DTC indicate lower performance when compared to Phase I using a clean DTC device?

Response: The DTC devices were not decontaminated between EFT #3 and PVS-II. This may have slightly elevated the results from PVS-II. This is discussed in the revised report.

Steven Lindberg's Comment: The NIOSH methods applied are never described in detail, but are simply defined as being unpublished. The normal set of QA tests one would expect are missing.

Response: Due to an error in distributing the report to reviewers, Appendix D was omitted, so the reviewers did not receive a copy of the analytical methods. The National Institute for Occupational Safety and Health (NIOSH) method for sampling mercury vapor in air, Method 6009, and the draft NIOSH method for sampling mercury aerosol in air, Method 9103, were used in the Study. Copies of all NIOSH methods and laboratory methods used are contained in Appendix E of the revised report. Method 6009 is published, and Method 9103 is unpublished. Field QA/QC samples results (i.e., trip blanks and field blanks) are in Chapter 4 of the revised report. All laboratory QA/QC procedures specified in the methods were followed by the laboratory analyzing the samples (Data Chem Laboratories), and, as is standard procedure for commercial analytical laboratories, the laboratory QA/QC data should be on file at Data Chem.

Steven Lindberg's Comment: The duration of the samples is not discussed, but the number of samples “below detection” suggests they were too short. Why was this not resolved with a simple change in design?

Response: The duration of the sample and the volume of air sampled are listed along with the raw data in Appendix A, Table 1. As discussed above, the majority of “below detection” samples were the MCE filter samples. This is discussed in the report in Chapter 4, footnote 12. The purpose of the MCE filter samples was to measure the concentration of mercury aerosols inside the containment structure during operation of the DTC device; the “below detection” results may indicate that no aerosols were formed or that the MCE filters were not the most appropriate media for the detection of mercury aerosols. The Study was not designed to make evaluate the likelihood of either possibility. Further study of this question

is suggested in Section 7.4 of the final report. The Hydrar tube samples were not “below detection”.

Steven Lindberg’s Comment: Hydrar tubes are never defined. Were the air flows checked during sampling? Were they recorded continuously?

Response: Hydrar tubes are one of the acceptable media for sampling mercury vapor in NIOSH Method 6009. Each air pump was calibrated before and after sampling. The two calibration values were averaged to determine the approximate velocity at which air was being drawn through the pump. The air flows on the pumps were not checked during sampling or continuously recorded.

Steven Lindberg’s Comment: The reliance on sorbent tubes for much of the data biased the concentrations measured to temporal means. Spikes in exposure were generally not detected unless the Jerome was being used.

Response: EPA agrees that the use of sorbent tubes resulted in measurements that did not allow for the measurement of spikes in exposure. The Jerome Mercury Vapor Analyzer was included in the study design to identify spikes in exposure; unfortunately, problems with the Jerome data-loggers prevented the study team from collecting Jerome data for every device at every location. In general, the Study was designed to measure worker exposure during device operation; this evaluation was best served by collecting samples that were a temporal average of mercury concentrations that the operator of a DTC device would be exposed to under test conditions.

Steven Lindberg’s Comment: Swipe samples are never quantitatively defined (surface area wiped, duration of wipe, composition of solvent, etc). Why were the pre/post swipe samples not collected at the same locations? How can they be quantitative? The extreme variability reflects these problems. The statement at the end of p. 29 regarding replicate sampling is wrong. Upon encountering high variability, one should attempt to increase the number of replicate samples, not decrease it.

Response: The wipe samples were moved from the main report to Appendix F in the revised report. The method for collection and the wipes used for sampling (Clorox® Wash N Dri) are described in greater detail in the revised report. The reviewer is correct in noting that the number of replicates should have been increased instead of decreased to account for sample variability.

Steven Lindberg’s Comment: Was any attempt made to sample the air in the drum headspace? The elevated concentrations one would expect to find there suggest a considerable Hg pool, unless the volume was very small.

Response: The air in the headspace of the drum was tested during EFT #1 and EFT #2 using the Jerome Mercury Vapor Analyzer. The results are given in Chapter 4.

Carl Herbrandson's Comment: It would be helpful to include, in the section on wipe samples and perhaps in the section on study limitations, some discussion of the Hg permeability of polyethylene. Hg can permeate through polyethylene. Polyethylene cannot be used for taking water-Hg samples because the water will take up some Hg from air, through the container. Does a wipe sample from the polyethylene containment wall take Hg that has permeated the material? Does it only take Hg that is oxidized, complexed or bound and cannot pass through the material? Or is it likely that this permeability is not significant enough to affect these data?

Steven Lindberg's Comment: The choice of polyethylene film was also a serious flaw. Most people experienced with sampling for Hg in air are aware of the well-known ability of Hg vapor to both penetrate through and sorb onto polyethylene, rendering any conclusions regarding the behavior of Hg within these enclosures highly uncertain and subject to considerable error. It is difficult to understand why these problematic approaches continued to be applied for so long before drawing attention.

Michael McLinden's Comment: Plastic absorbs mercury vapor, might this bias your results low due to Hg absorption by the plastic? It would have been helpful to collect a bulk sample of polyethylene before arriving at the facility to set up the containment and a bulk sample of the plastic containment wall just prior to dismantling to see how much Hg was absorbed by the plastic.

Response: EPA agrees that use of polyethylene most likely biased the measured mercury concentration in the air samples and in the wipe samples due to mercury's ability to permeate through and sorb onto polyethylene. Vinyl sheeting would have most likely been a better choice of materials for the containment structure. This issue is discussed in Chapter 6 in the revised report.

Michael McLinden's Comment:

Report Text:

Bulk samples were collected from the particulate filters and carbon filters for each device at the following frequencies:

Comment (Suggested Text Changes Highlighted): Bulk samples were collected from the particulate filters and carbon filters for each device **using** the following procedures:

Response: The wording was changed as suggested. The description of the collection of samples from the pollution control media for each device was moved to Appendix H in the revised report.

Michael McLinden's Comment: Were any bulk samples collected and analyzed prior to the start of Phase I to detect background Hg contamination of the filter media (similar to hydrar Hg background contamination)?

Response: Blank samples of the pollution control media were taken and analyzed. The results are presented in Chapter 5. There was some background mercury in some of the pollution control media, but the mercury levels were quite low.

Michael McLinden’s Comment: Please elaborate on what this “mercury absorbing powder” [that was used to decontaminate the sampling spoons prior to use] is.

Response: The “mercury absorbing powder,” a product called “Hg-X,” is described in the revised report. Hg-X reacts with elemental mercury to form HgS, a reaction that occurs readily under ambient indoor conditions.

Michael McLinden’s Comment: Please elaborate a bit more on the condition of Manufacturer D DTC and any damage or modifications made to the device by the manufacturer. Sections 4.2.1 and 4.3.1 both give a bit more information but it is difficult to visualize the condition of the device and possible reason for such poor performance.

Response: Information about the problems with the Manufacturer D DTC device can be found in Section 3.5.3 and Appendix I of the revised report. There is a more detailed description than that presented in the draft report

Data Presentation and Evaluation

After reading the comments from the reviewers, EPA determined that the draft report contained insufficient data analysis. In order to answer many of the questions posed by the reviewers, the data collected during the DTC Device Study were reanalyzed, and the discussion of the data was expanded. Two significant changes to Chapter 4 of the report were the addition of background and blank data to this chapter (initially, this information was only presented in Chapter 8: Limitations) and the use of simple statistical comparisons, whenever possible, to evaluate study objectives.

Michael McLinden’s Comment: I agree with your conclusion [regarding whether the OSHA PEL is a ceiling or TWA], however, the regulated community will most likely disagree. The Ceiling limit is more difficult to comply with since a short (15 minute) excursion above the ceiling would indicate an over-exposure and violation where as when calculating the 8 hr TWA for the PEL a short excursion would be averaged out over the eight hour shift resulting in no violation. Critics will discount the argument that the PEL has been exceeded arguing that OSHA policy and intent is to enforce the standard as an eight hour TWA. It may be wise to also present a calculated/estimated 8 hr TWA based on Jerome readings. Either extrapolate to 8 hrs using an “average” Jerome Hg reading thought to be representative of the entire 480 minute workday or calculate the concentration (C1) during the actual duration of Jerome sampling (T1) and add to background dose (C2) for the remainder of the shift (T2).

$$8 \text{ hr TWA} = \frac{C1 T1 + C2 T2}{480 \text{ minutes}}$$

Response: The OSHA exposure limit for mercury is published in the CFR as a ceiling limit, so the PEL was treated as a ceiling limit for the purposes of this Study. It would be inappropriate for EPA to comment on the discretion that OSHA uses or may use when implementing its own regulations. Also, there is not sufficient Jerome data to perform TWA

calculations for each device. EPA did not extrapolate the data to 8 hours because of the potentially widely varying use patterns for DTC devices.

Michael McLinden's Comment: FYI while the TLV is an 8 hour TWA over a 40 hour week, the REL is a TWA based on a 10 hr workday in a 40 hr week to allow for extended work shifts such as overtime). Recommended exposure level (REL) should be recommended exposure limit.

Response: The REL was not used for evaluation in the Study, so the description of the REL was removed from the revised report.

Steven Lindberg's Comment: Background values are often mentioned, but rarely defined as to location. It is never quite clear how any "background or blank" data were treated. What is the meaning of values such as 0.0059/0.014 in Table 4.18? Are these reps? Is this a range? Was N=2?

Response: In the revised report, there is a more complete discussion of blank and background samples in both the data collection section (Chapter 3) and the results section (Chapter 4). The table is not in the revised report. The results for the background air samples can be found in Table 4.1 and Table 4.2.

Carl Herbrandson's Comment: Discussion of the implications of the vapor phase and aerosol data would be helpful. Does the very low level detected in only 7 of about 177 MCEF samples suggest that only Hg vapor is emitted from the DTCs? Or is Hg aerosol that sticks to the MCEF volatilized by the sampling vacuum pump? Does this study help to answer these questions? Should future studies assume that there is no aerosolization?

Response: The draft report did not discuss the low number of the MCE filter samples that had detectable levels of mercury. The revised report contains the following discussion to address this:

It is important to note that, out of the 199 analytical air samples collected, only eight mercury aerosol (MCE filter) samples had values above the detection limit, and all blank MCE filter samples were below the detection limit. Because the amount of mercury aerosol was not high enough to measure, the air results discussed in this chapter only address the mercury vapor (Hydrar tube) samples. The results for the MCE filters can be found in Appendix A, Table 1. Future research may be necessary to determine whether aerosols were not detected because no aerosolization occurred or because any aerosol mercury collected on the MCE filter was vaporized by the sampling vacuum pump and subsequently sorbed onto the Hydrar tubes.

(footnote 12, pg. 21)

The DTC Device Study was not designed to answer the questions posed by the reviewer. EPA agrees that these questions are important and that could be considered for future study.

Steven Lindberg's Comment: Comparisons with the Jerome are mentioned, but never discussed in detail or presented quantitatively. Was there a systematic approach to performing a method intercomparison? It would have been useful to see overlain plots of the Hydrar and Jerome data for periods both were used at the same location. The data

“comparison” is inadequate for evaluation of the validity of the airborne Hg data (see above). The only mention of the results of any method comparisons on p. 58 is inadequate (“analysis of Jerome...indicate a similar pattern...”), especially given the objective of the study (to evaluate performance, to quantify emissions, mass balance determination, etc.). The numbers of replicate samples collected was similarly inadequate.

Response: In the revised report, averages of the Jerome data and the analytical air sample (Hydrar tube) data were graphed together to better facilitate comparison of the results from the two air sampling methods. The Jerome data was not complete (due to the malfunctioning data loggers) and did not include enough sampling events to create an overlay plot or to justify statistical comparisons between the two types of data. The language in the report has been revised to reflect the fact that no quantitative comparisons between the Jerome data and the Hydrar data were made. Graphical comparisons of the data are presented in Appendix A, Figures 26, 35 and 43, of the revised report.

As noted above, the study design did not call for replicate testing because one of the basic assumptions of the Study was that there would be changes in device performance over time. Multiple air samples were collected for each device during each test.

Michael McLinden’s Comment: After being in the containment for such a long time I’m surprised the gold foil [on the Jerome] didn’t get overload/over-ranged. Did you have any “over-ranging” problems which necessitated purging the foil??

Response: The model 431-X Jerome analyzer has an improved film regeneration circuit, which makes the sensor last longer than earlier models. When the sensor became saturated while the Jerome analyzer (model 431-X) was attached to the data logger or computer, the analyzer automatically regenerated the sensor and then resumed sampling. The Jerome graphs in Appendix A note when the Jerome was regenerating.

Michael McLinden’s Comment: Why were the results inside containment lower than TLV while results outside containment were occasionally above the TLV? – is it due to data logger failing and no data gathered? Which Jerome data-logger failed? Please clarify.

Response: The results inside the containment structure that were lower than the TLV were collected at a different time than the results outside the containment structure that were above the TLV. Thus, there is no data suggesting that the mercury concentration was higher outside the containment structure than inside the containment structure at any point in time. These different Jerome analyzer readings do show that there was variability in the mercury levels. This is clearer in the revised report. Both Jerome data-loggers failed at different points during the Study.

Steven Lindberg’s Comment: The statement on p. 47 “as measured by the ambient airborne emissions” is in error. There were no measurements of emissions performed in this study, only estimates based on concentration data.

Response: The report has been revised to make it clear that emissions were not measured.

Michael McLinden's Comment: What size & wattage lamps were processed in Phase II, T-8, T-12? You provide the number of lamps but not the number of each size lamp and wattage of each lamp processed as you did in Table 4.1. In Phase II did you use all Phillips Lighting "Alto" lamps? If you used lamps other than Phillips "Alto" you would have processed more mercury, also if you processed larger lamps you would again process more mercury (in Phase I Manufactruer B device processed 611 T-8 lamps). This seems more likely to contribute to higher phase II result than the higher Phase II background levels.

Response: There were not sufficient Phillips Lighting "Alto®" lamps for use in PVS-II. Because the waste lamps were from different manufacturers, and therefore did not contain a standard amount of mercury, the types of waste lamps processed were not recorded during PVS-II. The possible effects of crushing waste lamps other than Alto® lamps could have impacted the results during PVS-II, and the possible impacts are discussed in the revised report.

Michael McLinden's Comment: Were these low results [*in PVS-phase I*] due to colder temperature resulting in less Hg being volatalized ?.

Response: The temperature most likely had some affect on the amount of mercury that was volatilized during the different parts of the Study; although, this could not be quantified. This is discussed in Section 6.2 of the revised report.

Carl Herbrandson's Comment:

- Location of background, TLV and/or PEL lines on figures 4.2, 4.3, 4.4 and 4.5 aren't at the correct locations. (no background line for Fig 4.1) Similarly, these lines in Appendix A don't always line up right.
- Table 5.2 – Is the "measured mercury" the "average mercury quantity"? Aren't you really reporting the mean of the measured values? Means and averages are confused in this table and others (e.g. Table 5.5).
- %CV is more informative than Std Dev in many of the tables, especially where the means have large ranges (e.g. Table 5.5). What, actually, does the "Standard Deviation" in Table 5.8 describe? This standard deviation may provide some (poor) measure of the mixing between a few locations in the containment area, but still, this column should be omitted. The column contains the standard deviation of measurements that are not realistically comparable. Each measurement describes a unique volume of the containment area. It isn't known if the air at these various locations was moving or quiescent, or if the volume that the concentration described was large or small.
- Appendix A, Table 2-5 label box described as "% valid data" should be renamed something like "% locations with increase".

Steven Lindberg's Comment:

- The term NA is not defined or explained (why not analyzed, or not attempted, or not applicable?).

- The % difference numbers in Table 4.6 are in error based on the definition of the validation (if the Phase II results are > Phase I, the differences would normally be expressed as + values, not -).
- Table 4.9 would have benefited by an inclusion of the corresponding Hydrar trap data.
- Several tables express data with a greater number of significant digits than are justified.
- Several tables show ranges in data, but means and SD would also be useful.
- The Figures (here and in App's) are inconsistently labeled.

Michael McLinden's Comment:

- TABEL ENTRY [Table 4.6]: MANUFACTURER C, On Operator during Filter Changes -118%/105% Should 105% be a negative number?

Response: There were several errors on the labels for the figures and tables throughout the draft report. These errors have been corrected, and the titles for the figures and tables have been changed to provide a more detailed description of the data being presented.

- The PEL and TLV lines were corrected for all figures, and lines for background concentrations were added.
- The “average mercury” actually is the calculated mean. The labels in the tables were corrected. Standard deviations were calculated to describe many means, but this statistic is only presented if it is valid for the measurements being averaged.
- The column describing “% valid data” was removed from the table in Appendix A.
- All notations in tables, such as NA or ND, are now defined in the revised report.
- The % differences column was deleted from Table 4.6 (Table 4.9 in the revised report). Other statistics were used to compare phase I and phase II of the PVS.
- Averages of the Jerome data and the analytical air sample (Hydrar tube) data were graphed together to better facilitate comparison of the results from the two air sampling methods.
- Means and standard deviations are included wherever these descriptive statistics are appropriate and valid.

Michael McLinden's Comment:

Report Text:

As noted in the table, the Hydrar sorbent tube appeared to capture a greater amount of ambient mercury during the sample acquisition period (i.e., when the sample pump was in operation). Furthermore, two of the operator breathing zone samples (one for the Manufacturer C and one for the Manufacturer B) equaled or slightly exceeded the PEL.

The remaining results for both devices **were above the TLV** and below the PEL. No U-tube tests were performed using the Manufacturer A or Manufacturer D devices.

Comment: In Table 4.19 the results for “Manufacturer B, Operator’s right shoulder” indicate 0.018 mg/m³ which is lower than the 0.025 mg/m³ TLV.

Response: The text was corrected to reflect the fact that one of the operator shoulder samples for Manufacturer B was below the TLV. The table is not in the revised report (air sampling results can be found in Appendix A, Table 1).

Carl Herbrandson's Comment: Wipe sample results should be reported as $\mu\text{g}/100\text{ cm}^2$, not $\mu\text{g}/\text{sample}$.

Steven Lindberg's Comment: Was any attempt made to wipe the insides of the drums to determine the sorbed Hg? Was wipe efficiency/extraction/analysis ever determined with knowns? Was the parking lot "wiped" to determine if this approach was an improvement? The other problems with the study design mentioned above would still apply however.

Response: Due to difficulties with contamination, the wipe sample data was not used in the report to support any of the findings or observations; therefore, wipe sample data is presented in Appendix F in the revised report, instead of Chapter 4. The wipe sample results are reported as $\mu\text{g}/100\text{cm}^2$ in the revised report in Appendix F. The insides of the drums were not wiped. The wipe sample extraction method was developed by Data Chem as a NIOSH method and has been tested by Data Chem. The parking lot was not wiped, and there is no evidence that the change from cutting the polyethylene on the facility floor to cutting the polyethylene outside in the parking lot decreased contamination of the plastic sheeting.

Carl Herbrandson's Comment: Manufacturer A's device was run in ventilation mode throughout the course of the tests – including over night. Is it possible to estimate the mass of overnight emissions from available data? While these emissions are likely to be only a small fraction of the overall emissions for B and C, it is unclear what fraction of A's emissions occur in the ventilation mode.

Response: The data collected for overnight samples is shown in the revised report in Figure 4.15: Overnight Test Sample Results (pg. 63). There is not sufficient data to estimate the mass of overnight emissions.

Steven Lindberg's Comment: The problem of atmospheric contamination ("background") due to broken bulbs in bulb boxes should have been anticipated, or at least recognized sooner. The "box test" is not clearly defined until after the data are presented.

Response: EPA agrees that a more thorough review of the sampling and study plan by researchers more experienced with mercury monitoring would have been beneficial to the study team. The study team added the "Box Test" to the Study in order to quantify the atmospheric contamination due to broken bulbs in bulb boxes; the revised report more clearly defines the Box Test.

Michael McLinden's Comment: Can you elaborate on what happened [*in Figure 4.6*] during the 6th minute and again at the 28th minute to explain these spikes? Was the spike at the 6th minute due to handling and opening the top of the boxes? Also, can you explain why the concentration levels off from about the 8th minutes to the 19th minute but then begins a steady rise? Was the DTC in operation at any point during the test (e.g., from the 8th to the 19th minute) to influence the results shown in Figure 4.6? It may be helpful to explain the box test in more detail, this data alone may have important implications regarding Hg concentrations in and around storage locations of spent/broken lamps in general industry as

well as at lamp recycling facilities. Were the air sampling results collected with the Jerome or with sampling pumps?

Response: There is not sufficient data to speculate about the cause of the spikes in measured mercury concentration in Figure 4.6 (Figure 4.14 in the revised report). There is a general increase in the ambient mercury concentration, which may be due to mercury release from the broken lamps in the boxes; however, there is not enough data to fully substantiate this hypothesis. The DTC device was not operated during the box test. The air sampling results for the box test in Table 4.17 (same table number in draft report and in revised report) were collected using the Hydrar tubes and sampling pumps.

Steven Lindberg's Comment: The phrase "outside the containment" is used, but never defined specifically. Some observations seem trivial (e.g. that the Hg sorbent is more efficient when the pump is running).

Response: The phrase "outside the containment" generally referred to the area that was not inside the containment structure but was inside the room in the facilities in which the Study was being conducted. Wherever possible, the revised report specifically describes the locations "outside the containment" where samples were taken.

Mass Balance

One of the questions posed to the peer reviewers by EPA concerned the validity of the discussion of the error associated with the Mass Balance Study. The reviewers generally commented that the amount of uncertainty in the Mass Balance Study was too high to draw any conclusions from that portion of the Study. Therefore, the revised report concentrates on presenting the data collected during the Mass Balance Study, explaining the difficulties encountered during the Study, and providing suggestions for future mass balance studies involving DTC devices.

Carl Herbrandson's Comment: The tenor of the mass balance discussion should be changed to focus on why available data can't provide the necessary information for a mass balance. Estimates and calculations should not be reported. A mass balance would be useful for determining the fraction of fluorescent bulb mercury that escapes into the environment from DTCs. However, even as a range estimating tool, this mass balance is not instructive.

Steven Lindberg's Comment: The issue of quantitative uncertainty must be addressed for all of these measurements. This is especially true for the mass balance. The uncertainties and assumptions of the mass balance computations must be clearly stated. A serious and critical assessment of uncertainties involved in this particular study might indicate the impossibility of drawing any quantitative conclusions.

Response: EPA agrees that the uncertainty in the Mass Balance Study is too high to estimate the different fractions of mercury. The discussion of the Mass Balance Study was revised to present the data collected, the calculations, and the problems encountered. While the high degree of uncertainty does limit the types of analyses that can be performed to evaluate the study results, the data were collected in the field under conditions that were as close to a

probable management scenario as possible. The revised report acknowledges the limitations of this set of data.

Michael McLinden's Comment: I agree with your decision not to use Jerome readings for this portion on the study [*Mass Balance Study*].

Michael McLinden's Comment: Hg_U [the amount of mercury captured by the device] missing the amount of Hg adhering to the inside of the DTC device. Hg may have been bound to interior metal and plastic parts of the DTC, this may lower your recovery. Mercury may have been absorbed by plastic containment, lowering your Hg_R [the amount of mercury released by the device] result. It might have been wise to collect a pre and post bulk sample of the plastic containment.

Response: These factors are discussed in the revised report in Chapter 5 and Chapter 6. (Note: Hg_U was changed to Hg_C in the revised report. Hg_C is the amount of mercury captured by the device.)

Steven Lindberg's Comment: How much Hg was added to these lamps during manufacturing? The amounts analyzed seem low, depending on date of manufacture.

Response: Table 5.1 in the report lists the amount of mercury added to each type of lamp. The Phillips Lighting Alto® lamps are specifically manufactured to avoid adding excessive amounts of mercury by precisely dosing each lamp.

Carl Herbrandson's Comment: The study design optimized the ability to measure potential exposure concentrations, not the mass emitted from the DTCs. These are two very different goals and require different tools. Attempts to calculate the mass emitted from many different air-Hg concentrations assumes each sample location represents a volume of air in the containment area that is characteristically similar to the other sample locations in: virtual volume, air flow, mixing, replacement rate (or containment area input rate) and removal rate (or containment area exhaust rate). It is likely that each measurement location was very different, and weighting of individual sample results would be necessary to calculate a reasonable emission rate/mass – an impossible task given the study design.

Steven Lindberg's Comment: Why was no attempt made to estimate the gaseous loss based on the air concentration measurements?

Response: EPA recognizes that the Mass Balance Study was not properly designed to achieve the goals stated in the study plan. Mercury emissions were not measured during the DTC Device Study. The air concentration data was used to estimate the amount of mercury released; however, because the study design was not optimal for precise measurement of mercury emissions, there was a significant mass of mercury unaccounted for.

Steven Lindberg's Comment: Given the uncertainties in all the raw data, the SD's shown in Table 5.8 seem much too low. What do they represent?

The number of air exchanges was never measured, but can have an important effect on the calculations. How was this evaluated?

Michael McLinden's Comment: Looking at Figures 27 and 28 in Appendix A it indicates that it took over four hours to fill two drums. Two air changes seems very low for this time period. Making an air tight containment, even sealing plastic with duct tape, is difficult to achieve as demonstrated in asbestos abatement containments which are similar in design and generally tighter than your containment. I suspect you are under estimating the air changes and under estimating fugitive emissions through the door and walls of the containment. As per Appendix C, [Manufacturer A] Drum Top Crusher process description - the fan draws 25 CFM:

$$25 \text{ CFM} = (1,440 \text{ CF}) / (57.6 \text{ Minutes})$$

$$\text{One Air Change in Minutes} = (\text{CF}) / (\text{CFM})$$

$$(1,440 \text{ CF}) / (25 \text{ minutes}) = 57.6 \text{ Minutes for one air change}$$

$$(60 \text{ minutes}) / (57.6 \text{ minutes}) = 1.04 \text{ Air Changes per hour}$$

$$(1.04 \text{ ACH}) \times (4 \text{ hours}) = 4.16 \text{ Air Changes over the four hour it takes to fill two drums.}$$

Please elaborate on how you estimated the number of air changes.

Response: The averages shown in Table 5.8 of the draft report were the averages of the air samples from the Performance Validation Study – Phase I. This portion of the Study had the lowest amount of variability between the air samples. The standard deviation is no longer included in this table.

Table 5.8 now includes the data used for the calculation of the number of air exchanges, in addition to the values for the amount of mercury released from the devices.

In the draft report, the numbers of air changes were estimated based on general knowledge.

In the revised report, the volumetric flow rate of the DTC device fan was used to estimate the number of air exchanges, following the suggestion of one of the reviewers.

The Mass Balance Study only involved filling one drum per device, so the duration ranged between 86 and 112 minutes. The calculations used to estimate the number of air exchanges for each device are explained in Chapter 5 of the revised report.

The assumption that the Manufacturer A device released a similar amount of mercury as the Manufacturer B and Manufacturer C devices is based on the calculations described in Chapter 5. While this assumption is most likely not correct, additional attempts were not made to correct the estimate for Hg_R because the amount of mercury estimated as being released was very small as a percentage of the total mercury processed through each DTC Device (Hg_R).

Carl Herbrandson's Comment: Problems in estimating barrel content. These problems are well documented in the report and appendix.

Response: As discussed in the limitations section (Chapter 6), the phosphor powder, which tends to contain the largest fraction of the mercury in the drum, sifts to the bottom due to the vibration of the drum in operation. Therefore, any sample taken from a full 55-gallon drum of crushed lamps would likely not be representative of the contents of the drum. Based on

such a sample, a determination, that the waste contained in such a drum is not hazardous, may be questionable.

Steven Lindberg's Comment: I could not find any blank data for the contents and components of the DTCs.

Michael McLinden's Comment: New drum filters may be contaminated with background Hg, did you test a filter for background?

Response: The blank data for the components of the DTC devices were presented in Table 5.11 in the draft report. These data are presented earlier in Chapter 5 (in Table 5.6) in the revised report.

Steven Lindberg's Comment: Detailed method descriptions for obtaining representative samples of any substrate are lacking.

Response: The description of the collection of samples from the pollution control media of the DTC devices is included in the revised report in Appendix H.

Carl Herbrandson's Comment: Problems with measuring filter/carbon content (e.g. high %CV in carbon samples implies non-uniform capture and poor capture/mass estimate).

Carl Herbrandson's Comment: Errors on the order of 2400, 1100 and 1800 times the estimated mercury vapor emissions; 2, 0.5 and 2 times the calculated barrel contents; or 18, 0.9 and 78 times the calculated filter/carbon mercury could account for the discrepancies in the quantitative mass balance. There is no apparent consistency to the possible error.

Steven Lindberg's Comment: Given the gross differences among the activated C weights used in each DTC, the conclusion that Mfg A device "released" about the same amount of Hg as DTC's B & C seems in error.

Carl Herbrandson's Comment: Jang et al. Waste Management 25 (2005) 5–14 showed a maximum of 36% recovery with an acid extraction of Hg from fluorescent bulbs. Can additional mercury can be released from the bulbs by heating them (part of QA/QCing the methods?)? (This could increase the discrepancy in the attempted mass balance.)

Steven Lindberg's Comment: Did the team attempt to test the method for measuring Hg in lamps? Although some Hg may condense, quantitative condensation seems unlikely.

Response: The study team did not test the method for measuring mercury in spent lamps. The values measured in the spent lamps were slightly lower than the amounts of mercury reported to be added to each Phillips Lighting, Alto® lamp as discussed in Section 5.2 and shown in Table 5.1 and Table 5.2 of the revised report. A reference to Jang et al., 2005 is also included in Section 5.2. Additionally, at the end of Chapter 5 of the revised report, EPA suggests that any future research quantifying the amount of mercury in spent lamps should develop and test a laboratory method with appropriate QA/QC procedures.

Steven Lindberg's Comment: The recovery data in Table 5.11 suggest serious analytical problems which could have influenced much of the other data. Where are similar data for the other sample types and analytical methods?

Response: The recovery data in Table 5.11 for the matrix spikes of the pollution control media do suggest serious analytical problems. These data were presented to help explain the problems with the mass balance. Data Chem Laboratories followed the appropriate QA/QC described in the analytical methods, which are included in Appendix E of the revised report. All QA samples met the criteria specified by the test method being used. The Data Chem Laboratory reports are included in Appendix B.

Operator Observations and Safety Concerns

Steven Lindberg's Comment: Statements made here, and elsewhere, refer to data which are not clearly identified as to their source (Table or Fig. #).

Response: The reviewer did not list specific instances in which data were not clearly identified; however, in the revised report, the actual table and/or figure numbers were included whenever a reference was made to specific data.

Michael McLinden's Comment:

Report Text:

Lamp breakage was a common issue for all devices. The fragile lamps often broke before they could be fed into the devices, causing, in some instances, visible release of mercury-containing phosphor powder. The ergonomic orientation of the feed tubes on several devices also exacerbated this problem, where, for example, the operator either had to lower the lamps to waist level or raise them up to shoulder level in order to insert them into the feed tube.

Comment: I'm not sure ergonomic is the best/correct word for this situation.

Response: "Ergonomic" was changed to "configuration".

[pg. 86]

Lessons Learned

Steven Lindberg's Comment: One is left with the impression that the study and sampling design was compromised to decrease costs.

Response: As discussed above, the study team made every effort to carefully collect field data that represented possible mercury exposures associated with DTC device operation. The primary concern in designing and conducting the DTC Device Study was to assess the performance of the four DTC devices tested with regard to operator exposure, and concerns about the cost of the testing were secondary to completing the objectives of the Study. Nevertheless, EPA recognizes that certain decisions made regarding the design of the Study do present problems in analyzing the data.

Limitations

Steven Lindberg's Comment: A statement such as “each facility had a measurable concentration of mercury in ambient air” misrepresents the severity of existing and ongoing contamination encountered during this study, and the degree to which this problem compromised this study and its conclusions. Blanks defined as containing “trace amounts of Hg” but in actuality containing microgram amounts of Hg are also misleading.

Response: The two statements commented on by the reviewer, as well as several other statements on the same topic, were changed in the revised report to better emphasize the degree to which background mercury levels may have impacted the study results. Background mercury concentrations are discussed in Chapter 6 of the revised report.

Steven Lindberg's Comment: Many comments in this section indicate that a thorough design evaluation should have been conducted prior to the study. Surely, some, if not many, of the problems encountered in the field could have been anticipated.

Response: EPA agrees that a review of the original study design by researchers more experienced in mercury sampling would likely have lead to an improved study design.

Steven Lindberg's Comment: Given the degree of variability noted in many of the samples, the assumption that each milliliter of air contains approximately the same concentration of mercury as the adjacent milliliter seems subject to large uncertainty.

Response: The analytical air samples collected thousands of milliliters of air under several different operating and non-operating conditions. These data provide information about possible worker exposure to mercury, as opposed to the specific concentration of mercury in each milliliter of air.

Steven Lindberg's Comment: The data in Table 8.3 should include the appropriate statistical summaries. These data do not support the conclusion drawn below the table regarding concurrence between lab and field blanks (e.g. data from 3/26).

Response: Table 4.4 contains the field blank data. This data was moved to Chapter 4 so that the blank data and the air sampling data could be discussed together. The averages and standard deviations are now presented with these data.

Michael McLinden's Comment: I agree with your conclusion, sample volume is the critical value for calculating concentration, flow rates need to be within the range specified by the analytical method.

Response: The discussion as to whether variations in air sampling pump flow rates may have affected the study results was removed from the revised report.

Conclusions and Recommendations

Carl Herbrandson's Comment: Data from this study shows: high mercury vapor concentrations in existing facilities; high levels of removable (trackable) mercury on floors of existing bulb recycling facilities; and, high mercury vapor concentrations near bulb-transport boxes containing broken bulbs. These data suggest that bulb transport containers and currently operating recycling facilities should be studied for ways to improve their mercury retention and control.

Response: This is an area where further study would be helpful. Some of these topics were included in Section 7.4 (Future Areas for Study).

Steven Lindberg's Comment: As discussed above, the application of any, much less several, correction factors adds significant uncertainty in any conclusions drawn from these data. This results in an inability to draw firm conclusions in my opinion. The study should have encouraged support for the design of improved DTC's, as those tested left much to be desired. The misinformation on Hg included in the manufacturer's manuals should also have been noted.

Response: The correction factors applied to the mass balance data are no longer included in the main body of the revised report. This information is included in Appendix G. The uncertainty associated with the data does limit the information and knowledge that can be drawn from this study; however, a significant amount of relevant information was gained in performing this study. The discussion presented in the revised report was written to provide information about DTC device performance. The report is not a guidance document; however, it provides observations noted in conducting the Study.

Michael McLinden's Comment: Venting outdoors would defeat the purpose of using the DTC device to control emission, suggest venting to a pollution control device rather than simply to outside air.

Response: The revised report does not suggest venting outdoors. The Study was not designed to make specific recommendations or determinations about the most appropriate ventilation for a room in which a DTC device is operated.

Appendices

Steven Lindberg's Comment: As mentioned above, these tables and figures relate poorly to the text, carrying in many cases different and undefined labels compared to comparable items in the main text. There were also no captions. Several experiments are illustrated here which are never described elsewhere (e.g. real world tests).

Response: The tables and figures in the appendices were extensively revised in the final report, including adding captions, to make them clearer and more consistent. The use of terminology such as "real world tests" was removed. The names used for the study

components in the original sample and study plan (now contained in Appendix D) were not the names that were used in the report. These inconsistencies have been corrected.

Steven Lindberg's Comment: The scale chosen for the Y axis (Hg concentration in mg/m³) would have been more readable if converted to ug/m³.

Response: The units of mg/m³ were chosen for the y-axis of the graphs because the OSHA PEL is reported as 0.1mg/m³.

Steven Lindberg's Comment: The Jerome data were buried in the appendices, with no discussion, despite the capture of several interesting temporal trends in airborne Hg. Why were these never compared directly to the Hydrar data?

Response: In the revised report, wherever possible, the Jerome data were highlighted, discussed, and compared to the Hydrar data. Due to problems with the data loggers, there were significant gaps in the Jerome data, making the uncertainty of the data too high to make quantitative comparisons.

Michael McLinden's Comment: Appendix C – initial paragraph and paragraph below Table AE both reference “the mass balance equation in section 6.0,” perhaps this should be Section 5.0.

Response: The discussion regarding the sampling errors and corrections for the Mass Balance Study is now in Appendix G; references to the Mass Balance Study in Appendix G were corrected in the revised report.

Steven Lindberg's Comment: Finally, Appendix D titled Data Chem Methods was blank.

Response: There was an error in distributing the report, and Appendix D was not included in the draft report received by the reviewers. All of the analytical methods and any modifications are included in Appendix E of the revised report.

Mercury Lamp Drum-Top Crusher Study Peer Reviewers:

- Carl Herbrandson, Ph.D., Minnesota Department of Health
- Steven Lindberg, Ph.D., Corporate Fellow Emeritus (retired)
Environmental Sciences Division, Oak Ridge National Laboratory
- Michael McLinden, M.S., C.I.H., New Jersey Department of Environmental Protection

Carl Herbrandson

Contact Information

Site Assessment and Consultation Unit
Environmental Surveillance and Assessment Section
Environmental Health Division
Minnesota Department of Health
121 East Seventh Place, Suite 220
St. Paul MN 55101
carl.herbrandson@health.state.mn.us
651/215-0925
fax: 651/215-0925

Education

1991 - 1996 **University of Minnesota**, Minneapolis, MN. Degree: Ph.D. in Toxicology

1969 - 1973 **Case Western Reserve University**, Cleveland, OH. Degree: B.A. in English

Research and Professional Experience

- 1996 – present **Research Scientist 3**, Minnesota Department of Health, St. Paul, MN
- Toxicologist and Health Assessor for Site Assessment and Consultation Unit, a cooperative partner grantee of the Agency for Toxic Substances and Disease Registry, Center for Disease Control, Atlanta GA
 - Review health hazards and risks associated with exposure to chemicals in the environment; evaluate data and conduct health assessments; model potential human exposures; investigate biomarkers which may indicate exposures; and determine the likelihood of conducting successful exposure or health investigations.
 - Focus is currently on complex multimedia evaluations with an emphasis on environmental chemistry. Two focus areas of work are fate, exposure and toxicity of heavy metals (primarily mercury and arsenic) and quantitative evaluation of the six potential routes of exposure to organic and inorganic compounds in sediments.
 - Recommend sampling and remediation criteria for environmental media.
 - Write technical evaluations of potential health impacts of environmental exposures to toxic chemicals for U.S. Agency for Toxic Substances and Disease Registry concurrence.
 - Write public health information sheets for affected communities about potential effects of exposure to environmental chemicals and procedures for prudent avoidance or reduction of exposure.
 - Represent the Minnesota Department of Health in meetings with responsible parties, state and federal agencies, in interviews with news media, and in interactions with the public.

1996 **Research Associate**, University of Minnesota, St. Paul, MN

- Design and perform experiments to identify a sex pheromone from Eurasian Ruffe (*Gymnocephalus cernuus*).
- Endocrine manipulation of fish reproductive cycle; extraction of steroids, prostaglandins and bile acids excreted by fish; *in vitro* receptor binding studies; and *in vivo* electrophysiological studies.

1992 - 1996 **Graduate Research Assistant**, University of Minnesota, Minneapolis, MN

- Develop laboratory model for investigating toxicodynamic and toxicokinetic interactions of a chemical and a physical stressor on a whole organism in an aquatic environmental system.
- Thesis: Toxicological Effects of Suspended Solids and Carbofuran on *Daphnia magna*, Graduate School of the University of Minnesota, February 1996

1984 – 1991 **Engineering Research Specialist**, Unisys, Eagan, MN

- Invented and developed a system for passively monitoring the growth rate of YIG crystals which are used as the active element in solid state magneto-optical switches and optical isolators.
- Designed and developed a system for mounting lasers into connectorized fiber optic packages while maintaining laser coupling efficiency into a 6 μm core over a 75° C temperature range.
- Designed and developed a computer automated station for testing superconducting tunnel junctions to be used as sensors.

Invited Lecturer/Instructor

2005 **Seminar**, University of Minnesota Duluth Medical School: Toxicology/Public Health response to a recent mercury spill. Public health concerns coupled with an emergency response incident required rapid development of public health clearance criteria, modeling likely juvenile exposure, and development of new biomarkers of exposure.

2004 **Grand Rounds**, Minnesota Poison Control System, Hennepin County Medical Center: Rosemount Woods Mercury Incident. The behavior of a chemical in the environment is important when evaluating exposures and undertaking a successful cleanup.

2004 **Grand Rounds**, Regions Hospital Department of Emergency Medicine: Rosemount Woods Mercury Incident. Problems related to understanding chemical exposures during an emergency incident: biomarkers, kinetics, analytical issues, and people.

2004 **Grand Rounds**, University of Minnesota School of Public Health: Public Health and a mercury spill. The responsibility of public health experts in an emergency is to support local officials, communities and medical practitioners.

2003 *Guest Lecturer*, Toxicology Program, University of Minnesota Graduate School: Toxicology in State Government. When and how we evaluate exposures and assess health.

2003 *Guest Lecturer*, University of Minnesota School of Public Health: Mercury. The environmental chemistry of mercury: sources, exposures, fate and toxicity.

2003, 2001 *Guest Lecturer*, Toxicology Program, University of Minnesota Graduate School: Aquatic Toxicology. An introduction to chemicals in the aquatic environment and how they affect aquatic species.

2002 *Guest Lecturer*, University of Minnesota School of Public Health: Mercury and Arsenic - two toxic heavy metals. How do they behave in the environment and why are we concerned about them?

2001 *Grand Rounds*, Minnesota Poison Control System, Hennepin County Medical Center: Mercury and Chromated Copper Arsenate. Presentation to poison control specialists, toxicologists and medical practitioners on the environmental chemistry, bioavailability, kinetics and toxicity of mercury and CCA. Included measuring mercury volatilization from the amalgam fillings of audience volunteers with a realtime mercury vapor analyzer and a discussion of the data.

2000 *Invited Presentation*, Minnesota Metal Finishers Association, Minneapolis, MN: Health concerns associated with metal finishing operations. A review of current epidemiology and toxicology related to aerosols and vapors emitted by metal finishing companies.

2000 *Invited Presentation*, Minnesota Environmental Health Association Annual Meeting, Brainerd, MN: Clandestine methamphetamine labs. A discussion of potential meth lab exposures and the cleanup criteria derived by the Minnesota Department of Health.

1999 *Invited Presentation*, Bi-National Forum Meeting, Thunder Bay, Ontario, Canada: Issues related to improving and assuring air quality. Air monitoring, dispersion modeling, chemical reactions in the troposphere, health effects, risk assessment and current regulations were discussed.

1996, 1998 *Assistant Professor / Instructor*, Department of Fisheries and Wildlife, University of Minnesota. FW 5460: Pollution Impacts on Aquatic Systems. Course was offered during the winter quarter every other year on the principles and experimental techniques for investigating the impacts of chemical pollutants in aquatic environments.

Presentations at ATSDR Partners in Public Health Meetings

2001 **Evaluating sediments at contaminated sites.** What do we know about the behavior of chemicals in sediments? How do groundwater and freeze-thaw cycles affect the integrity of large volumes of chemical wastes in sediments?

2001 **Are clandestine methamphetamine laboratories a public health concern?** Evaluating potential exposures to hazardous chemicals in Clan labs.

2001 **Air modeling or air monitoring?** While ambient air monitoring data are often requested by health assessors, dispersion modeling of stack testing data is typically more useful in evaluating potential hazards from facility emissions.

1999 **Weight of evidence in health assessments.** When quantitative health assessments cannot be performed it is often necessary to use a weight of evidence approach to qualitatively evaluate a potential public health hazard.

Peer reviewed / refereed publications

- Baker, B., C. Herbrandson, T. Eshenaur and R. Messing (2005). Measuring Exposure to an Elemental Mercury Spill — Dakota County, Minnesota, 2004. *Morbidity and Mortality Weekly Reports* 54(6): 146-149.
- Herbrandson, C., Bradbury, S.P., and Swackhammer, D.L. (2003). Influence of suspended solids on acute toxicity of carbofuran to *Daphnia magna*: I. Interactive effects. *Aquatic Toxicology*, 63(4):333-42
- Herbrandson, C., Bradbury, S.P., and Swackhammer, D.L. (2003). Influence of suspended solids on acute toxicity of carbofuran to *Daphnia magna*: II. An evaluation of potential interactive mechanisms. *Aquatic Toxicology*, 63(4):343-55
- Herbrandson, C., Bradbury, S.P., and Swackhammer, D.L. (1999) New Testing Apparatus for Assessing Interactive Effects of Suspended Solids and Chemical Stressor on Plankton Invertebrates. *Environmental Toxicology and Chemistry*, 18:4 679-684.

Selected, authored ATSDR Health Assessment Reports on mercury

2005 **Rosemount Woods mercury incident.** Report includes discussion of: decontamination; the need for exposure and medical screening during the incident; methods of evaluating individual exposures; the environmental chemistry of mercury; quality assurance and control issues related to the use of real-time mercury vapor analyzers; evacuation criteria; re-occupation criteria; vehicle clearance criteria; discussion on the clearance of personal property, and risk communication.

2003 **Drum-top bulb crusher demonstration at the Minneapolis-St. Paul International Airport.** Report reviews published information about mercury contained in and released from fluorescent light bulbs when they are discarded, as well as data acquired during a demonstration of a fluorescent bulb crusher. Regulatory restrictions on the use of this machine in Minnesota are discussed.

2003 **Onyx Special Services, Incorporated.** Report is a review of issues related to human health following attempts to cleanup a mercury recycling facility.

2002 **Chemically contaminated South Minneapolis residence.** Report reviews mercury vapor data acquired using hopkalite tubes (1998) and 2 different realtime monitors (2000, 2001) to evaluate indoor contamination in a house where an amateur chemist used many processes to reclaim precious metals from disposed products.

2001 **Mercury from a gas regulator spill.** Mercury in a low-pressure gas regulator was spilled in the basement of a residence. This report evaluates exposures that may have resulted from the spill and the cleanup.

2001 **Mercury in a Marine residence.** Report evaluates the potential exposures that may occur when thermometers (4) are broken in a home.

Steven E. Lindberg

Environmental Sciences Division
Oak Ridge National Laboratory
P.O. Box 2008, Oak Ridge, TN 37831-6038

email: lindbergse@ornl.gov
Phone: (865)574-7857
Fax: (865)576-8646

Education

Duke University **B.S.** 1969 Chemistry
Florida State University **M.S.** 1973 Chemical Oceanography
Florida State University **Ph.D.** 1979 Geochemistry

Professional Experience

1971-1974 **Graduate Fellow**, Florida State University Department of Oceanography, Tallahassee.
1974-1986 **Research Associate and Staff Member**, Oak Ridge National Laboratory, Oak Ridge, TN.
1987 **Visiting Professor**, Institute of Bioclimatology, University of Göttingen, Germany.
1994 **Visiting Scientist**, Swedish Environmental Research Institute, Göteborg, Sweden.
1995 **Visiting Professor**, University of Stockholm and University of Lund, Sweden
1996-1997 **Visiting Scientist**, Institute of Hydrophysics, GKSS Fed. Laboratory, Geestacht, Germany
1995-*present* **Adjunct Professor**, School of Public Health, University of Michigan, Ann Arbor, MI; Dept. of Ecology and Evolutionary Biology, The University of Tennessee, Knoxville, TN
1987-1999 **Senior Research Staff Member**, and Group Leader for Atmospheric and Biogeochemical Cycling
2000-*present* **ORNL Corporate Research Fellow**, Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, TN.
2002 **Visiting Scientist**, Institute of Ecosystem Studies, NY

Honors and Awards

- Alexander von Humboldt Foundation Fellowship Award, 1986-1987
- Elected Fellow, American Association for the Advancement of Science, 1992
- Lab-wide Publication and Technical Achievement Awards, 1985, 1986, 1997, and 2001
- Nominated for Ernest Orlando Lawrence Award, 1990, and ORNL Scientist of the Year, 2001
- American Men and Woman of Science, Who's Who in Science and Technology
- Environmental Sciences Scientific Achievement Award, 1984
- Oak Ridge National Laboratory Significant Achievement Awards: 1983, 1985, 1992, 1995

Professional Activities

- Associate Editor, Environmental Reviews, Science of the Total Environment, Tellus (Sweden)
- Member, Review Boards: EPA Science Advisory Board for Mercury, Swedish EPA Mercury Panel
- Chairman, International Conference on Mercury as A Global Pollutant, 1995-1996; 1999-2001
- Director for Atmospheric Research, Integrated Forest Study, 1986-1990
- Chairman, United States National Atmospheric Deposition Program, 1988-1989
- Conference Chairman (1986-87) and Member of Conference Honorary Committee (since 1983) for the International Conference on Heavy Metals in the Environment

Publications

Six books edited, and over 200 publications authored in the open literature, with more than 110 in refereed journals in the fields of atmosphere/surface exchange, trace metal chemistry, and biogeochemical cycling. Invited lecturer or plenary speaker on atmospheric deposition, mercury, and canopy interactions at more than 100 institutes and conferences in North America, Europe, South America, and Asia.

Funded Proposals, Contracts, and Grants (with ORNL collaborators unless otherwise noted):

1970-1979

- 1975-1976, "Trace Element Emissions from Coal Fired Power Plants" (with A Andren). US Dept. of Energy (DOE) (\$50,000).
- 1975-1976, "Geochemical Cycling of Hg in a River-Reservoir System" (with R Turner). NSF-RANN (\$90,000).
- 1978, "Mercury Emissions from Mine Spoils" (with D Jackson). NSF-RANN (\$75,000).
- 1977-1980, "Trace Element Deposition, Stream Chemistry, and Cycling in Forest Watersheds" (with R. Turner). US DOE (\$1,000,000).

1980-1989

- 1981-1982, "Dry Deposition to Petri Dish and Foliar Surfaces" (with C Davidson, CMU). US Environmental Protection Agency (EPA) (\$30,000).
- 1981-1983, "Acid Deposition/Forest Canopy Interactions: Mechanisms of Sulfur and Nitrogen Deposition to Forests." Electric Power Research Institute (EPRI) (\$675,000).
- 1981-1984, "Atmosphere/Canopy Interactions: Wet Deposition and Rain Chemistry." US DOE (\$900,000).
- 1985-1989, "Integrated Forest Study (IFS) of the Effects of Atmospheric Deposition on Forest Nutrient Cycles" (with D Johnson) EPRI (total project \$11,600,000).
- 1985-1989, "Atmosphere/Canopy Interactions: Development of Surface Analysis Methods for Dry Deposition." US DOE (\$920,000).
- 1987, "Deposition and Atmospheric Chemistry of Nitrogen Compounds" (with G. Gravenhorst, U. Gottingen). West German Federal Ministry for Technology and Alexander von Humboldt Foundation (\$45,000).
- 1989, "Atmospheric Deposition and Red Spruce Nutrition in the Great Smoky Mountains National Park" (with D Johnson and H Van Miegroet). USDA Forest Service (\$225,000).

1990-1999

- 1990, "A Soft Ionization Mass Spectrometer for the Simultaneous, Real-time Analysis of Biogenic Non-methane Hydrocarbons in the Forest Canopy Airspace" (with M Payne, W Chen, and P Hansen). ORNL Seed Money Committee (\$100,000).
- 1990, "Integrated Forest Study of the Effects of Atmospheric Deposition on Forest Nutrient Cycles: Synthesis of Results." (with D Johnson) EPRI (\$198,000).
- 1990, "Atmospheric Deposition and Red Spruce Nutrition in the Great Smoky Mountains National Park-Testing the AI Hypothesis" (with H Van Miegroet). USDA Forest Service (total project \$235,000).
- 1990-1991, "Development of Methods for Network Sampling of Air Toxics in Precipitation" (with S. Vermette, ISWS) USGS (\$70,000).

- 1991-1994, "Atmosphere/Canopy Interactions: Surface Analysis of Dry Deposition in Complex Terrain". US DOE (\$700,000).
- 1992-1996, "Air/Surface Exchange of Mercury (MASE): Development of Flux Methods and Models". EPRI (\$1,195,000).
- 1993-1995, "Elevational Trends in Deposition in the Smoky Mountains" (with S. Nodvin, USBS). NPS (\$150,000).
- 1994-1995, "Aerosols at the Sea/Land Interface". (with B Wiman, U Lund) Swedish NFR (NSF) (30,000Kr).
- 1996, "Emission of Mercury from Freshwater Lakes". USEPA (\$18,000).
- 1996-1997, "Emission of Mercury from soils in the Elbe River Floodplain". (with R. Ebinghaus, GKSS) German BMFT (15,000DM).
- 1996-1999, "Mercury Emissions from Wetlands in the Florida Everglades". South Florida Water Management District (\$400,000).
- 1997-1998, "Mercury Fluxes and Exposure over Contaminated Industrial Soils". ABB Engineering (\$32,000).
- 1997-2000, "Mercury Emissions from Landfills in Florida". Florida DEP (\$190,000).
- 1997-2000, "Natural Mercury Emission Study (NaMES): Their Role in the Global Cycle". (with M. Gustin, UNR) EPRI (total project \$580,000).
- 1997-2000, "Air/Surface Exchange of Mercury in the Lake Superior Watershed". Lake Superior Trust (\$250,000).
- 1998-1999, "Intercomparison of Speciation Methods for Reactive Gaseous Mercury in Ambient Air". (with
- W. Stratton, Earlham College) Florida DEP (\$20,000).
- 1998-2000, "Air Mass Trajectories of Mercury Transport in the Arctic Environment" (with T. Meyers, ATDD) NOAA (\$100,000).
- 1998-2003, "Atmospheric Deposition in Mountainous Terrain: Scaling up to the Landscape". (with K Weathers and G Lovett, IES) USEPA and NPS (total project \$580,000).
- 1999, "Pilot Studies with Stable Isotopes to Quantifying Air/surface Exchange Rates of Hg, USDOE (\$280,000).
- 1999-2000, "Dry Deposition of Mercury in the Florida Everglades". (with G. Keeler, UMAQL) Florida DEP (total project \$200,000).
- 1999-2000, "Emission of Mercury from Chlor-alkali Plants". (with J. Kinsey, NERL) USEPA (total project \$200,000).
- 1999-2000, "Chlor-alkali wastes: Assessing their Role as a Mercury Source in the Great Lakes". (with J. Nriagu, UM) Great Lakes Protection Fund (total project \$225,000).
- 1999-2000, "Evaluating a reactive gaseous mercury sampler for the Arctic". USEPA and Florida DEP (\$65,000).

2000

- 2000-2002, "The role of plants & soils in the biogeochemical cycling of Hg on an ecosystem level, (with UNR/DRI), EPA EPSCOR, (\$60,000).
- 2000-2002, "Mercury transport and fate through a watershed: The role of Hg reduction reactions, (with J. Nriagu), USEPA STAR Grant, (\$260,000).
- 2000-2004, "Applications of Stable Isotopes to Quantifying Air/surface Exchange Rates of Hg in Whole-ecosystem Manipulation Studies at the ELA, Canada, USDOE (\$1,270,000).
- 2000-2004, "Fugitive Mercury Emissions from Non-combustion Sources in the Great Lakes Region, (with Frontier Geosciences), USEPA, GLNPO, (\$200,000).

- 2001-2002, "Methylmercury Production in Florida Landfills". Florida DEP (\$140,000).
- 2001-2003, "Mercury Emissions from Natural Processes: Scaling to the Landscape". (with M. Gustin, UNR) EPRI (\$170,000).
- 2001-2004, "Dynamic Oxidation of Mercury in the Arctic Environment" (with S. Brooks, ATDD) NOAA (\$295,000).
- 2002-2005, "Assessment of Natural Source Mercury Emissions" (with UNR/DRI), EPA STAR, (total project \$891,500).

[grants last updated in Dec, 2002]

Students Supervised:

Advisor to ORNL Student Interns

- S. Henry, B.S., Chemistry, Earlham College (1976)
- S. Kimbrough, B.S., Biology, College of the South (1976)
- W. Petty, B.S., Biology, Grinnell College (1986)
- A. Pendergrass, B.S., Civil Engineering, Auburn University (1993)
- T. Kuiken, B.S., Chemistry, Rochester State (1999)
- J. Ramirez, Chemistry, U. Puerto Rico (2000)

Advisor to Postdoctoral Researchers at ORNL

- Dr. G. Lovett (Ph.D., Ecology, University of New Hampshire), ORAU Postdoctoral Fellow (1982–1984) (currently Sr. Scientist, Institute of Ecosystem Studies, NY)
- Dr. D. Schaefer (Ph.D., Biogeochemistry, University of New Hampshire), ORAU Postdoctoral Fellow (1986– 1988, currently Asst. Prof., University of Puerto Rico)
- Dr. K.-H. Kim (Ph.D., Marine Chemistry, University of South Florida), ORNL Postdoctoral Fellow (1992– 1994, currently Asst. Prof., University of Seoul, Korea)
- Dr. Hong Zhang (Ph.D., Soil Chemistry, University of Vermont), ORNL Postdoctoral Fellow (1998–2001, currently Assoc. Prof., Tennessee Tech. University, Cookeville)
- Dr. Weijin Dong (Ph.D., Plant Physiology, Tulane University), ORNL Postdoctoral Fellow (2000–2002, currently Assoc. Prof., McNeese State University)

Adjunct Faculty Committee Member for Graduate Students

- C. Potter, Ph.D. in Ecology, Emory University (1983–1985)
- M. Hoyer, Ph.D. in Atmospheric Chemistry, Air Toxics Laboratory, School of Public Health, University of Michigan (1992–1995)
- A. Rea, Ph.D. in Air Quality, Air Quality Measurements Laboratory, School of Public Health, University of Michigan (1994–1998)
- J. Shubzda, M.S. in Forestry, School of Fisheries, Forestry, and Wildlife, The University of Tennessee (1995–1999)
- A. Carpi, Ph.D. in Environmental Toxicology, Cornell University (1994–1996).
- A. Vette, Ph.D. in Air Quality, Air Quality Measurements Laboratory, School of Public Health, University of Michigan (1996–1999).
- M. Goodsite, Ph.D. in Atmospheric Chemistry, Department of Chemistry, University of Copenhagen, Denmark (2000-present).

Invited Faculty Opponent for Ph.D. Defense

- W. Ivens, Ph.D. in Biogeochemistry, University of Utrecht, The Netherlands (1989–1991)
- Z. Xiao, Ph.D. in Inorganic Chemistry, Chalmers University of Technology, Göteborg, Sweden (1994–1995)
- M. Coggin, Ph.D. in Atmospheric Chemistry, University of Galway, Ireland (1999-2000)
- J. Benesch, M.S. in Environmental Science, University of Nevada, Reno (2001-2002)

Expert External Reviewer for Habilitation to Professor

- Dr. D. Godbold, Habilitation candidate, University of Göttingen, Germany (1990)
- Dr. R. Ebinghaus, Habilitation candidate, University of Lüneberg, Germany (2002)

Informal PhD Advisor

- D. Walschläger, Ph.D. in Geochemistry, University of Hamburg, Germany (1995-1996)
- T. Frescholtz, M.S. in Environmental Science, University of Nevada, Reno (2001-2002)
- K. Scott, Ph.D. in Microbiology, University of Manitoba, Winnipeg, Canada (2001-2002)

Publications-(*in prep and submitted*) [*updated Apr 2003, published list starts below*]

Lindberg, S.E., G. Southworth, E.M. Prestbo, D. Wallschläger, M. A. Bogle, J. Price. Gaseous methyl-and inorganic mercury in landfill gas from landfills in Florida, Minnesota, and California. *Atmos. Envir.* (in prep).

Schroeder, W.H., A. Steffen, K. Scott, T. Bender, E. Prestbo, R. Ebinghaus, J.Y. Lu and S. E. Lindberg. First International Arctic atmospheric mercury research workshop. *Atmos. Envir.* (submitted).

Amyot, M., G. Southworth, S.E. Lindberg, H. Hintelmann, J.D. Lalonde, C. Gilmour, J.W.M. Rudd, C.A. Kelly, R. Harris, F.M.M. Morel, A.Poulain, Ken Sandilands. Evolution of dissolved

gaseous mercury in large lake enclosures amended with $^{200}\text{HgCl}_2$. Can J. Fish Aq Sci (submitted).

Southworth, G. R., S. E. Lindberg, H. Zhang, J. S. Kinsey, F. Anscombe, and F. Schaedlich. Fugitive mercury emissions from a chlor-alkali facility: sources and fluxes to the atmosphere. Atmos. Envir. (submitted).

Kinsey, J. S., Swift, J., Burse, J., Lindberg, SE, and Southworth, G. Characterization of mercury emissions from the cell building at a U. S. chlor-alkali plant. Atmos. Envir. (submitted).

Lindberg, S., G. Southworth, M. Bogle, T. Blasing, H. Zhang, T. Kuiken, D. Wallschlaeger, J. Price, D. Reinhart, H. Sfeir, J. Owens, and K. Roy. Airborne emissions of mercury from municipal solid waste—New measurements from three landfills in Florida. JAWMA, (submitted).

W. Dong, S.E. Lindberg, T. Meyers, and J. Chanton. A proposed mechanism of gaseous mercury emission mediated via aquatic plant in the Florida Everglades. Atmos. Envir. (in prep.)

Brooks, SB, K. Scott, and SE Lindberg. Surface Mercury $\text{Hg}(0)$ Emissions during Annual Snowmelt at Barrow, Alaska. J. Geophys. Res. (in prep. 5/02).

Brooks, SB, M. Goodsite, SE Lindberg, M Landis, and R. Stevens. Aircraft Studies of Atmospheric Mercury Conversion in the Arctic Marine/Coastal Boundary Layer. Nature (in prep. 6/02).

Tate, Scherbatskoy, Donlon, Keeler, Shanley, Lindberg. Dry Deposition of Hg to a Northern Hardwood Forest (in prep 5/02).

Brooks S., and S. E. Lindberg. Estimates of Springtime Atmospheric Mercury Deposition rates at Barrow, Alaska from Stable Boundary Layer Inverse Method. J. Geophys. Res. (in revision).

Publications (in print) [updated Apr 2003, new submissions listed above]

Books and Whole Journal Issues:

L. Levin, D. S. E. Lindberg, and D. Porcella (Guest Eds.). 2000. Special Issue on Mercury Biogeochemistry. Science of the Total Environment: Vols. 259-260-261, 511 pp. Elsevier Publ., N.Y.

Gustin, M-S., S. E. Lindberg, and M. A. Allan (Guest Eds.). 1999. Special Issue: Nevada STORMS mercury flux intercomparison study: Constraining mercury emissions from naturally enriched surfaces: Assessment of methods and controlling parameters. J. Geophys. Res: 104, No. D17, pp. 21829-21896. American Geophysical Union Publ., Washington.

Lindberg, S. E. (Sr. Guest Ed.). 1998. Special Issue: Atmospheric Transport, Chemistry and Deposition of Mercury. Atmospheric Environment: 32, No. 5, 134 pp. (807-940). Pergamon Press, U.K.

Johnson, D.W., and S.E Lindberg (Eds.). 1992. Atmospheric Deposition and Forest Nutrient Cycling, Ecological Studies Vol. 91, Springer-Verlag, New York, 707 pp.

Norton, S., S. E. Lindberg, and A. L. Page. (Eds.) 1990. Soils, Aquatic Processes, and Lake Acidification, Advances in Environmental Sciences Series Acidic Precipitation, Vol. 4. Springer Verlag, NY., 293 pp.

Lindberg, S. E., A. L. Page, and S. Norton. (Eds.) 1990. Sources, Deposition, and Canopy Interactions, Advances in Environmental Sciences Series Acidic Precipitation, Vol. 3. Springer Verlag, NY., 332 pp.

Lindberg, S. E. and T. C. Hutchinson (Eds.). 1987. Proceedings of the Sixth International Conference on Heavy Metals in the Environment, New Orleans, LA, September 15-18, 1987, CEP Limited Publishers, Edinburgh, UK.

Shriner, D. S., C. R. Richmond, and S. E. Lindberg (Eds.) 1980. Atmospheric Sulfur Deposition. Ann Arbor Science Publishers, Ann Arbor, MI, 568 pp.

Journal Papers and Book Chapters:

In Press

Gustin, M-S., and S.E. Lindberg. Understanding the role of natural ecosystems in the biogeochemical cycle of Hg. Proc. Air Quality-III (in press).

2000's

Johnson, D.W., Benesch, J.A., Gustin, M.S., Schorran, D.E., Coleman, J., and Lindberg, S.E. 2003. Soil gaseous Hg and CO₂ concentrations response to watering, plants, and evidence against diffusion control of Hg flux, Science of the Total Environment 304: 175-184.

Gustin, M.S, M. Coolbaugh, M. Engle, B. Fitzgerald, R. Keislar, S. Lindberg, D. Nacht, J. Quashnick, J. Ryuba, C. Sladek, H. Zhang, R. Zehner. 2003. Atmospheric Mercury Emissions from Mine Wastes and Surrounding Geologically Enriched Terrain. Envir. Geol. 43:339-351.

J. Ericksen, M.S. Gustin, D. Schorran, D. Johnson, S. Lindberg, and J. Coleman. 2003. Accumulation of atmospheric mercury in forest foliage, Atmos. Envir. 37:1613-1622.

Hintelmann, H., V. St.Louis, K. Scott, J.Rudd, S. E. Lindberg, D. Krabbenhoft, C. Kelly, A. Heyes, R. Harris, and J. Hurley. Reactivity and mobility of newly deposited mercury in a Boreal catchment, 2003. Envir. Sci. & Technol. 36:5034-5040.

Lindberg, S. E., W. Dong, and T. Meyers. 2002. Transpiration of gaseous mercury through vegetation in a subtropical wetland in Florida. Atmos. Envir. 36: 5200-5219.

Zhang, H, Lindberg, S, Gustin, M, and Xu, X. Towards A Better Understanding of Mercury Emissions from Soils. IN Cai, Y, and Braids, O. C. Eds., Biogeochemistry of Environmentally Important Trace Elements, ACS Symposium Series 835, American Chemical Soc, Washington.

Wallschlèger, D., Kock, H.H., Schroeder, W.H., Lindberg, S.E., Ebinghaus, R. and Wilken, R.D. 2002. Estimating gaseous mercury emissions from contaminated floodplain soils to the atmosphere with simplified field measurement techniques. *Water, Air, Soil, Pollut.* 135: 39-54.

Van Miegroet, H. I.F. Creed, N.S. Nicholas, D.G. Tarboton, K.L. Webster, J. Shubzda, B. Robinson, J. Smoot, D.W. Johnson, S.E. Lindberg, G. Lovett, S. Nodvin, S. Moore. 2001. Is there synchronicity in N input and output fluxes at the Noland Divide Watershed, a small N-saturated forested catchment in the Great Smoky Mountains National Park? In *Optimizing Nitrogen Management in Food and Energy Production and Environmental Protection Proceedings of the 2nd International Nitrogen Conference on Science and Policy*. TheScientificWorld 1 (S2), 480-492.

Lindberg, S. E., Brooks, S.B., C-J. Lin, K. J. Scott, M. S. Landis, R. K. Stevens, M. Goodsite, and A. Richter. 2002. The Dynamic Oxidation of Gaseous Mercury in the Arctic Atmosphere at Polar Sunrise, *Envir. Sci. & Technol.* 36: 1245-1256.

Zhang, H, Lindberg, SE, Barnett, MO, Vette, AF, Gustin, MS. 2002. Dynamic flux chamber measurement of gaseous mercury emission fluxes over soils, Part 1 Simulation of gaseous mercury emissions from soils measured with dynamic flux chambers using a two-resistance exchange interface model. *Atmospheric Environment* 36: 835-846.

Lindberg, SE, Zhang, H, Vette, AF, Gustin, MS, Barnett, MO, and Kuiken, T. 2002. Dynamic flux chamber measurement of gaseous mercury emission fluxes over soils, Part 2 Effect of flushing flow rate and verification of a two-resistance exchange interface simulation model. *Atmospheric Environment* 36: 847-859.

Zhang, H., and S.E. Lindberg. 2002. Dissolved gaseous mercury in Whitefish bay and the Taquemenon River watershed in the Michigan Upper Peninsula: Distribution and dynamics. *Water, Air, Soil, Pollut.* 133: 379-389.

Rea, A.W.; Lindberg, S.E.; Scherbatskoy, T. 2002. Mercury accumulation in foliage over time in two northern mixed-hardwood forests. *Water, Air, Soil, Pollut.* 133: 49-67.

Lindberg, S. E., S. Brooks, C-J Lin, K. Scott, T. Meyers, L. Chambers, M. Landis, and R. Stevens. 2001. Formation of reactive gaseous mercury in the arctic evidence of oxidation of Hg⁰ to gas-phase Hg-II compounds after arctic sunrise *Water, Air and Soil Pollution: Focus*, 1: 295-302.

Lindberg, S.E., S.B. Brooks, M. Landis, and R. Stevens. 2001. Comments on atmospheric mercury species in the European Arctic: Measurements and modeling, *Atmospheric Environment* 35:5377-5378.

Levin, L., Lindberg, S. and Gustin, M. 2001. Uncertainties in Mass Balance of U.S. Atmospheric Mercury Emissions. IN *Air-Surface Exchange of Gases and Particles Poster Proceedings* (D. Fowler,

C. E. R. Pitcairn, L. Douglas and J-W. Erisman, Eds.). Publ. By Center for Ecology and Hydrology, Edinburgh.

Lindberg S. E. and T. P. Meyers. 2001. Development of an automated micrometeorological method for measuring the emission of mercury vapor from wetland vegetation. *Wetland Ecology & Management*, 9: 333-347.

St.Louis, VL, JW Rudd, CA. Kelly, BD.Hall, KR. Rolfhus, KJ. Scott, SE. Lindberg, and W Dong. 2001. The importance of the forest canopy to fluxes of methyl mercury and total mercury to boreal ecosystems, *Envir. Sci. & Technol.* 35: 3089-3098.

Munthe, J., I. Wängberg, N. Pirrone, Å. Iverfeldt, R. Ferrara, P. Costa, R. Ebinghaus, X.Feng, K. Gårdfelt, G. Keeler, E. Lanzillotta, S. E. Lindberg, J. Lu, Y. Mamane, E.Nucaro, E. Prestbo, S. Schmolke, W. H. Schroeder, J. Sommar, F. Sprovieri, R.K.Stevens, W. Stratton, G. Tuncel, A. Urba. 2001. Intercomparison of methods for sampling and analysis of atmospheric mercury species. *Atmos. Env.* 35:3007-3017.

Lindberg, S.E., D. Wallschlaeger, E. Prestbo, N. Bloom, J. Price, and D. Reinhart. 2001. Methylated mercury species in municipal waste landfill gas sampled in Florida. *Atmospheric Environment* 35: 4011-4015.

Lindberg, S. E., Brooks, S., Lin, C-J., Scott, K., Richter, A., Meyers, T., Stevens, R., and Landis, M. 2001. Studies of interactions between reactive gaseous mercury and elemental mercury vapor during polar spring at Point Barrow, Alaska. *Proc. of International Symposium on the Measurement of Toxic and Related Air Pollutants Symposium held in Research Triangle Park, North Carolina, September 12-14, 2000.*

Rea, A.W., S.E. Lindberg, and G. Keeler. 2001. Dry deposition and foliar leaching of mercury and selected trace elements in deciduous forest throughfall. *Atmospheric Environment* 35: 1352-2310.

Zhang, H, and S.E. Lindberg. 2001. Sunlight and iron(III)-induced photochemical production of dissolved gaseous elemental mercury in fresh water. *Envir. Sci. & Technol.* 35: 928-935.

Stratton, W. J., S. E. Lindberg, and C.J. Perry. 2001. Atmospheric Mercury Speciation: Critical evaluation of a mist chamber method for measuring reactive gaseous mercury, *Envir. Sci. & Technol.* 35: 170-177.

Zhang, H., S. E. Lindberg, F. J. Marsik, and G. J. Keeler. 2001. Mercury air/surface exchange kinetics of background soils of the Taquamenon River watershed in the Michigan Upper Peninsula. *Water, Air, Soil, Pollut.* 126: 151-169.

Lindberg, S. E., S. Brooks, C-J Lin, K. Scott. 2001. Recent research on missing sources and sinks in the global mercury cycle: The role of the Arctic. *Proc. NIMD Forum-01*, publ. by the National Institute of Minamata Disease Press, pp. 53-58.

Gustin, M.S. and S. E. Lindberg. 2000. Assessing the contribution of natural sources to the global mercury cycle: The importance of intercomparing dynamic flux measurements. Invited paper for *Fresenius Journal of Analytical Chemistry*, 366: 417-422.

Zhang H., and S. E. Lindberg. 2000. Air/water exchange of mercury in the Everglades I: The

behavior of dissolved gaseous mercury (DGM). *Science of the Total Environment* 259: 123-134.

Lindberg, S. E., and Zhang H. 2000. Air/water exchange of mercury in the Everglades II: Measuring and modeling evasion of mercury from surface waters. *Science of the Total Environment* 259: 135144.

Gustin, M..S. and S. E. Lindberg, K. Austin, M. Coolbaugh, A. Vette, and H. Zhang. 2000. Assessing the contribution of natural sources to regional atmospheric mercury budgets. *Science of the Total Environment* 259: 61-72.

Rea, A.W., S.E. Lindberg, and G. Keeler. 2000. Development of a washing technique for measuring dry deposition of mercury to foliage and surrogate surfaces, *Envir. Sci. & Technol.* 34: 2418-2425.

Lindberg, S.E., S. Brooks, C-J Lin, T. Meyers, and L. Chambers. 2000. **BAMS- the Barrow Arctic Mercury Study**: a preliminary description of recent measurements of mercury depletion events at Point Barrow, Alaska. CD-ROM Proceedings, 25th International Conference on Heavy Metals in the Environment, Ann Arbor, MI (6-10 August, 2000).

Marsik, F.J., G. Keeler, E. G. Malcolm, J. T. Dvonch, J. A. Barres, S. E. Lindberg, H. Zhang, R. K. Stevens and M. S. Landis. 2000. FEDDS: The Florida Everglades Dry-Deposition Study. CD-ROM Proceedings, 25th International Conference on Heavy Metals in the Environment, Ann Arbor, MI (6-10 August, 2000).

Lindberg, S. E., P. J. Hanson, W. Stratton, T. Meyers, K. Kim, A. Carpi, H. Zhang, J. Owens, M. Gustin, R. Turner, J. Munthe, F. Schaedlich, J Price, M. Barnett, and D. Wallschlèger. 2000. The Role of Mercury Air/surface Exchange Processes in the Global Biogeochemical Cycle: a Brief Summary of Research by the ORNL Mercury Group, Proc. NIMD Forum-99, publ. by the National Institute of Minamata Disease Press.

Lindberg, SE, A. Vette, C. Miles, and F. Schaedlich. 2000. Application of an automated mercury analyzer to field speciation measurements: Results for dissolved gaseous mercury in natural waters. *Biogeochemistry*, 48(2), 237-259.

Lindberg, S. E., W. J. Stratton, P. Pai, and M. Allan. 2000. Measuring and modeling concentrations of a water-soluble gas-phase mercury species in ambient air. *Fuel Proc. Technol.* 1288: 65, 143-156.

Wallschlèger, D., Kock, H.H., Schroeder, W.H., Lindberg, S.E., Ebinghaus, R. and Wilken, R.D. 2000. Mechanism and significance of mercury volatilization from contaminated floodplains of the German river Elbe. *Atmos. Environ* 34:3745-3755.

1990's

Weathers, K.C., G.M. Lovett, S.E. Lindberg, S.M. Simkin, D.N. Lewis and M.L. Chambers. 1999. Atmospheric deposition in mountainous terrain: Scaling up to the landscape. *EOS, Trans. American Geophysical Union*: 80, 390.

Lindberg, S. E., D. Reinhart, P. McCreanor, and J. Price. 1999. Pathways of mercury release in municipal solid waste disposal: A preliminary data report. Proceedings Sardinia 99, Seventh International Waste Management and Landfill Symposium, 4-8 October, 1999, pp. 225-232. CISA, Environmental Sanitary Engineering Centre, Cagliari, Italy.

Gustin, M-S., S. E. Lindberg, and M. A. Allan. 1999. Preface to the Nevada StoRMS mercury emissions project special issue. *J. Geophys. Res.*: 104, 21829-21830.

Lindberg, S.E., Zhang, H., Gustin, M., Vette, A., Owens, J., Marsik, F., Casimir, A., Ebinghaus, R., Edwards, G., Fitzgerald, C., Kemp, J., Kock, H.H., London, J., Majewski, M., Poissant, L., Pilote, M., Rasmussen, P., Schaedlich, F., Schneeberger, D., Sommar, J., Turner, R., Walshlager, D., and Xiao, Z. 1999. Increases in mercury emissions from desert soils in response to rainfall and irrigation. *J. Geophys. Res.*: 104, 21879-21888.

Zhang, H. and Lindberg, S.E. 1999. Processes influencing the emission of mercury from soils: a conceptual model, *J. Geophys. Res.*: 104, 21889-21896.

Gustin, M-S., S. E. Lindberg, Casimir, A., Ebinghaus, R., Edwards, G., Fitzgerald, C., Kemp, J., Kock, H.H., London, J., Majewski, M., Owens, J., Marsik, F., Poissant, L., Pilote, M., Rasmussen, P., Schaedlich, F., Schneeberger, D., Sommar, J., Turner, R., Vette, A., Walshlager, D., Xiao, Z., and Zhang, H. 1999. The Nevada STORMS Project: Measurement of mercury emissions from naturally enriched surfaces. *J. Geophys. Res.*: 104, 21831-21844.

Lindberg, SE, and J Price. 1999. Measurements of the airborne emission of mercury from municipal landfill operations: A short-term study in Florida. *J. Air and Waste Man. Assoc.* 49:174-185.

Ebinghaus, R., Tripathy, R., Wallschlèger, D., and Lindberg, S.E. 1999. Natural and anthropogenic mercury sources and their impact on the air-surface exchange of mercury on the global scale. IN Ebinghaus, R., Turner, R., LaSerda, D., Vasiliev, O., and Salomons, W. (Eds.), *Mercury contaminated sites: Characterization, risk assessment, and remediation*, pp. 1-50. Springer-Verlag Environmental Science Series.

Lindberg, S. E., P. J. Hanson, T.P. Meyers, and K-Y Kim. 1998. Micrometeorological studies of air/surface exchange of mercury over forest vegetation and a reassessment of continental biogenic mercury emissions. *Atmos. Envir.* 32:895-908.

Carpi, A. and S.E. Lindberg. 1998. Application of a teflon dynamic flux chamber for quantifying soil mercury fluxes: tests and results over background soils. *Atmos. Envir.* 32:873-882.

Lindberg, S. E. 1998. A Listening and Liberating Science: The Ultimate Problem of Education. IN *The Art of Natural Resource Management: Poetics, Policy, Practice* (Eds.: B.L.B. Wiman, I. M. B. Wiman, S. L. Vanden Akker), pp. 348-351. Lund University Press.

Lindberg, S. E. and W. J. Stratton. 1998. Atmospheric mercury speciation: Concentrations and behavior of reactive gaseous mercury in ambient air. *Envir. Sci. & Technol.* 32:49-57.

Carpi, A., S. E. Lindberg, E. M. Prestbo, and N. S. Bloom. 1997. Global and regional impacts of elemental and methyl mercury emitted by soils to the atmosphere. *J. Env. Qual.* 26:1650-1655.

Hanson, P. J., T. Tabberer, and S. E. Lindberg. 1997. Emissions of Mercury Vapor from Tree Bark. *Atmos. Envir.* 31: 777-780.

Kim, K-H., P. J. Hanson, M. O. Barnett, and S. E. Lindberg. 1997. Biogeochemistry of mercury in the air-soil-plant system. *Met. Ions Biol. Syst.*, 34: 185-212.

Carpi, A. and S. E. Lindberg. 1997. The sunlight mediated emission of elemental mercury from soil amended with municipal sewage sludge. *Envir. Sci. & Technol.* 31:2085-2091.

Lindberg, S. E. 1996. Forests and the Global Biogeochemical Cycle of Mercury: The Importance of Understanding Air/vegetation Exchange Processes. IN: Baeyens, W., Ebinghaus, R., Vasiliev, O. (eds.): *Global and Regional Mercury Cycles: Sources, Fluxes and Mass Balances*. NATO-ASI-Series, Vol. 21, Kluwer Academic Publishers, Dordrecht, The Netherlands, 359-380.

Iverfeldt, A., S.E. Lindberg, S. Karamata, G. Anoshin, M. Horvat, T. Laperdina, A. Obolenskiy, K. Osmonbetov, C. Ramel, N. Roslyakov, and V. Tausen. 1996. Working group report on terrestrial mercury cycling. IN: Baeyens, W., Ebinghaus, R., Vasiliev, O. (eds.): *Global and Regional Mercury Cycles: Sources, Fluxes and Mass Balances*. NATO-ASI-Series, Vol. 21, Kluwer Academic Publishers, Dordrecht, The Netherlands, 543-546.

Meyers, T.P., M.E. Hall, and S.E. Lindberg. 1996. Use of the modified Bowen ratio technique to measure fluxes of trace gases. *Atmos. Envir.* 30: 3321-3329.

Meyers, T.P. and S. E. Lindberg, 1996: Use of the Modified Bowen Ratio technique for determining fluxes of mercury. *Proceedings of the 22nd Conference on Agriculture and Forest Meteorology with Symposium on Fire and Forest Meteorology*, January 28 - February 2, 1996, Atlanta, GA, American Meteorology Society, Boston, MA, pp. 11-14.

D. Holland, C. Simmons, L. Smith, T. Cohn, G. Baier, J. Lynch, J. Grimm, G. Oehlert, S. Lindberg. 1995. Long-term trends in NADP/NTN precipitation chemistry data: results of different statistical analyses. *Water, Air, Soil Pollut.* 85: 595-601.

Shubzda, J., S. E. Lindberg, C. T. Garten, and S. C. Nodvin. 1995. Elevational trends in the fluxes of sulfur and nitrogen in throughfall in the southern Appalachian Mountains: Some surprising results. *Water, Air, Soil, Pollut.* 85: 2265-2270.

Nodvin, S. C., H. VanMiegroet, S. E. Lindberg, N. S. Nicholas, and D. W. Johnson. 1995. Acidic deposition: Ecosystem processes and nitrogen saturation in a high elevation southern Appalachian watershed. *Water, Air, Soil, Pollut.* 85: 1647-1652.

Lindberg, S. E., Meyers, T. P., and J. Munthe. 1995. Evasion of mercury vapor from the surface of a recently limed acid forest lake in Sweden. *Water, Air, Soil, Pollut.* 85: 725-730..

Kim, K.-H., Lindberg, S. E., and Meyers, T. P. 1995. Micrometeorological measurements of

mercury fluxes over background forest soils in eastern Tennessee. *Atmos. Envir.* 27:267-282.

Stratton, W. J. and S. E. Lindberg. 1995. Use of a refluxing mist chamber for measurement of gas-phase water-soluble mercury (II) species in the atmosphere. *Water, Air, Soil, Pollut.* 80: 1269-1278.

Lindberg, S.E., K-H. Kim, T.P. Meyers, and J.G. Owens. 1995. A micrometeorological gradient approach for quantifying air/surface exchange of mercury vapor: Tests over contaminated soils. *Envir. Sci. Technol.* 29:126-135.

Lindberg, S. E., K.-H. Kim, and J. Munthe. 1995. The precise measurement of concentration gradients of mercury in air over soils: a review of past and recent measurements. *Water, Air, Soil, Pollut.* 80: 383-392.

Vermette, S.J., M.E. Peden, T.C. Willoughby, S.E. Lindberg, and A.D. Weiss. 1995. Methodology for the sampling of metals in precipitation: Results of the National Atmospheric Deposition Program (NADP) pilot network. *Atmos. Envir.* 29: 1221-1230.

Kim, K.-H and S. E. Lindberg. 1995. Design and initial tests of a dynamic enclosure chamber for measurements of vapor-phase mercury fluxes over soils. *Water, Air, Soil, Pollut.* 80: 1059-1068.

Vermette, S.J., S.E. Lindberg, and N. Bloom. 1995. Field tests for a regional mercury deposition network: Sampling design and test results. *Atmos. Envir.* 29: 1247-1252.

Johnson, D. W. and S. E. Lindberg. 1995. Sources, sinks, and cycling of Mercury in forested ecosystems. *Water, Air, Soil, Pollut.* 80: 1069-1077.

Lindberg, S.E. and S.J. Vermette. 1995. Workshop on sampling mercury in precipitation for the National Atmospheric Deposition Program. *Atmos. Envir.* 29: 1219-1220.

Hanson, P. J., S. E. Lindberg, T. A. Tabberer, J. G. Owens, and K.-H. Kim. 1995. Foliar exchange of mercury vapor: evidence for a compensation point. *Water, Air, Soil, Pollut.* 80: 373-382.

Lindberg, S.E., J.G. Owens, and W. Stratton. 1994. Application of throughfall methods to estimate dry deposition of mercury. IN J. Huckabee and C. Watras, (Eds.), *Mercury as A Global Pollutant*, pp. 261-272. Lewis Publ.

Kim, K.-H. and Lindberg, S. E. 1994. High-precision measurements of mercury vapor in air: Design of a six-port-manifold mass flow controller system and evaluation of mass flow errors at atmospheric pressure. *J. Geophys. Res.* 99: 5379-5384.

Erismann J. W., C. Beier, G. Draijers, and S. Lindberg. 1994. Review of deposition monitoring. *Tellus* 46B: 79-93.

Ross, H., and S.E. Lindberg. 1994. Atmospheric chemical input to small catchments. IN B. Moldan and J. Cerny (Eds.), pp. 55-84, *Biogeochemistry of Small Catchments: A Tool for*

Environmental Research, United Nations SCOPE Series Vol. 51, John Wiley and Sons.

Kim, K.K., S.E. Lindberg, P.J. Hanson, T.P. Meyers, and J. G. Owens. 1993. Application of micrometeorological methods to measurements of mercury emissions over contaminated soils. In Proceedings of the Ninth International Conference on Heavy Metals in the Environment, Vol I. pp. 328331. CEP Limited Publishers, Edinburgh, UK. Text also reproduced in Proceedings of the First Workshop on Emissions and Modelling of Atmospheric Transport of Persistent Organic Pollutants and Heavy Metals, J.M. Pacyna et. al. (Eds.), USEPA Report EMEP/CCC-Report: 7/93, 1993.

Lovett, G.M. and S.E. Lindberg. 1993. Atmospheric deposition and canopy interactions of nitrogen in forests. *Can. J. For Res.* 23:1603-1616.

Erismann J. W., C. Beier, G. Draaijers, and S. Lindberg. 1993. Deposition Monitoring: Background Document. Appendix 6, IN Lövblad G., J. Erismann, and D. Fowler (Eds), *Models and Methods for the Quantification of Atmospheric Input to Ecosystems*, Published by The Nordic Council of Ministers, pp 163-183.

Feier C., S. Braun, J. Brook, G. Campbell, G. Draaijers, K. Hansen, D. Kallweit, R. Lenz, S. Lindberg,

H. Staaf, and R. Stary. 1993. Deposition Monitoring. Chapter 7, IN Lövblad G., J. Erismann, and D. Fowler (Eds), *Models and Methods for the Quantification of Atmospheric Input to Ecosystems*, Published by The Nordic Council of Ministers, pp 37-41.

Lindberg, S. E. and J. G. Owens. 1993. Deposition to Edges and Gaps in Mountain Forests: Throughfall Studies at Two Elevations in The Smoky Mountains. *Biogeochemistry* 19:173-194.

Johnson, D.W., S.E. Lindberg, H. Van Miegroet, G.M. Lovett, D.W. Cole, M.J. Mitchell, and D. Binkley. 1993. Atmospheric deposition, forest nutrient status, and forest decline: Implications of the Integrated Forest Study. IN Huettl, R., and Mueller-Dombois (Eds.), pp. 66-81, *Proc. International Conf. on Forest Decline in the Pacific Rim.*, Springer-Verlag, NY.

Wu, Y-L., C.I. Davidson, Lindberg, and A. Russell. 1992. Resuspension of particulate chemical species at forested sites. *Envir. Sci. Technol.* 26:2428-2435.

Lindberg, S. E. and G. M. Lovett. 1992. Deposition and forest canopy interactions of airborne sulfur: Results from the Integrated Forest Study. *Atmos. Envir.* 26A:1477-1492.

Tjoelker, M.G., S. B. McLaughlin, R. DiCosty, S.E. Lindberg, and R.J. Norby. 1992. Seasonal Variation of Nitrate Reductase Activity in Needles of High-elevation Red Spruce Trees. *Can. J. For Res.* 22: 375-380.

Lovett, G.M., and Lindberg, S.E. 1992. Concentration and deposition of particles and vapors in a vertical profile through a forest canopy. *Atmos. Envir.* 26A:1469-1476.

Lindberg, S.E., T.P. Meyers, G.E. Taylor, R.R. Turner, and W.H. Schroeder. 1992. Atmosphere/surface exchange of mercury in a forest: Results of modeling and gradient

approaches. *J. Geophys. Res.* 97: 2519-2528.

Bredemeier, M. and S.E. Lindberg. 1992. Stoffeinträge in Einzelniederschlags und periodischen Gesamt Niederschlagsproben in einem Fichtenwald: Ein methodischer Vergleich. *Staub Reinhaltung der Luft* 52: 67-72.

Lindberg, S. E., Garten C. T. Jr., Cape J. N., and Ivens W. 1992. Can sulfate fluxes in forest canopy throughfall be used to estimate atmospheric sulfur deposition?-A summary of recent results. IN, Slinn,

W.G.N. *Precipitation Scavenging and Atmosphere-Surface Exchange*, Vol. 3, Applications and Appraisals, pp. 1379-1390. Hemisphere Publ., Washington, DC, 1808 pp.

Johnson, D. W., S. E. Lindberg, and L. F. Pitleka. 1992. Introduction. Chapter 1 IN Johnson, D.W., and S.E Lindberg (Eds.). *Atmospheric Deposition and Forest Nutrient Cycling* , Ecological Studies Vol. 91, Springer-Verlag, New York, pp. 1-7.

Lindberg, S.E. Atmospheric deposition and canopy interactions of sulfur. 1992. IN Johnson, D.W., and Lindberg, S.E. (Eds.). *Atmospheric Deposition and Forest Nutrient Cycling* , Ecological Studies Vol. 91, Springer-Verlag, New York, pp. 72-90 in Chapter 5: Sulfur cycles.

Lindberg, S. E., D. W. Johnson and E. A. Bondietti. 1992. Background on research sites and methods.

Chapter 2 IN Johnson, D.W., and S.E Lindberg (Eds.). *Atmospheric Deposition and Forest Nutrient Cycling* , Ecological Studies Vol. 91, Springer-Verlag, New York, pp. 8-26.

Mitchell, M. J., R. B. Harrison, J. W. Fitzgerald, D. W. Johnson, S. E. Lindberg, Y. Zhang, and A. Autry. 1992. Sulfur distribution and cycling in forests. IN Johnson, D.W., and S.E Lindberg (Eds.).

Atmospheric Deposition and Forest Nutrient Cycling , Ecological Studies Vol. 91, Springer-Verlag, New York, pp. 90-140 in Chapter 5: Sulfur cycles.

Ragsdale, H. L., S. E. Lindberg, G. M. Lovett and D. A. Schaefer. 1992. Atmospheric deposition and throughfall fluxes of base cations. IN Johnson, D.W., and S.E Lindberg (Eds.). *Atmospheric Deposition and Forest Nutrient Cycling* , Ecological Studies Vol. 91, Springer-Verlag, New York, pp. 235-253 in Chapter 8: Base cations.

Schaefer, D. A., S. E. Lindberg and G. M. Lovett. Canopy Interactions. 1992. Processing of acidic deposition. IN Johnson, D.W., and S.E Lindberg (Eds.). *Atmospheric Deposition and Forest Nutrient Cycling* , Ecological Studies Vol. 91, Springer-Verlag, New York, pp. 444-449 in Chapter 11: Processing of acidic deposition.

Lindberg, S. E. 1992. Summary and synthesis of the Integrated Forest Study: Atmospheric deposition and its interactions with the forest canopy. IN Johnson, D.W., and S.E Lindberg (Eds.). Atmospheric Deposition and Forest Nutrient Cycling , Ecological Studies Vol. 91, Springer-Verlag, New York, pp. 571-580 in Chapter 14: Synthesis and modeling of the results of the Integrated Forest Study.

Johnson, D. W. and S. E. Lindberg. 1992. Implications of the Integrated Forest Study for understanding forest nutrient cycles. IN Johnson, D.W., and S.E Lindberg (Eds.). Atmospheric Deposition and Forest Nutrient Cycling , Ecological Studies Vol. 91, Springer-Verlag, New York, pp. 580-582 in Chapter 14: Synthesis and modeling of the results of the Integrated Forest Study.

Vermette, S. J., Peden, M., Hamdy, S., Willoughby, T., Lindberg, S. E., Owens, J. G., and Weiss, A. 1992. A pilot network for collection and analysis of trace metal wet deposition. IN Verry, S. and Vermette, S. J. (Eds.) Trace Metals in Atmospheric Deposition, USDA Forest Service Report No. NC150, North Central Forest Experiment Station, St. Paul, MN.

Vermette, S. J., Peden, M., Willoughby, T., Lindberg, S. E., and Weiss, A. 1992. Pilot network for metals in wet deposition. Preprint # 92-69.06, Air and Waste Mgmt. Assoc. 85th Ann. Mtg., 12 pp.

Lindberg, S. E., R.R. Turner, T.P Meyers, G.E Taylor, and W.H. Schroeder. 1991. Atmospheric concentrations and deposition of airborne Mercury to Walker Branch Watershed. *Water, Air, Soil, Pollut.* 56:577-594.

Johnson, D.W., H. Van Miegroet, S.E. Lindberg, R. Harrison, and D. Todd. 1991. Nutrient cycling in red spruce forests of the Great Smoky Mountains. *Can. J. For. Res.* 21:769-787.

Hanson, P.J. and S.E. Lindberg. 1991. Dry deposition of reactive nitrogen compounds: A review of leaf, canopy, and nonfoliar measurements. *Atmos. Envir.* 25A:1615-1634.

Petty, W., and S.E. Lindberg. 1990. A comprehensive 1-month investigation of trace metal deposition, atmospheric concentrations, and throughfall at a mountain spruce forest. *Water, Air, Soil, Pollut.* 53:213-226.

Lindberg, S. E., M. Bredemeier, D. A. Schaefer, and L. Qi. 1990. Atmospheric concentrations and deposition of nitrogen compounds and major ions during the growing season in conifer forests in the United States and West Germany. *Atmos. Envir.* 24A:2207-2220.

Wiman, B., M. Unsworth, S. E. Lindberg, B. Bergqvist, R. Jaenicke, and H-C. Hansson. 1990. Perspectives on aerosol deposition to natural surfaces: Interactions between aerosol residence times, removal processes, the biosphere, and global environmental change. *J. Aerosol Science* 21:313-338.

Taylor, G.E., P.J. Hanson, and S.E Lindberg. 1990. Deposition and emission of trace gases in controlled environments: A conceptual model, experimental methodologies, and application of results to the disciplines of physiological ecology and biogeochemistry. IN Payer, H.D. (Ed.), *Environmental Research with Plants in Closed Chambers*, Air Pollution Research Report 26:

Commission of the European Communities, Brussels, pp. 194-215.

1980's

Lindberg, S. E. 1989. Application of surface analysis methods to studies of atmospheric deposition in forests. p. 269-283, IN Ulrich, B. (Ed.), International Congress on Forest Decline Research: State of Knowledge and Perspectives, Kernforschungszentrums Karlsruhe GmbH.

Hanson, P. J., K. Rott, G. E. Taylor, Jr., C. A. Gunderson, S. E. Lindberg, and B. M. Ross-Todd. 1989. NO₂ Deposition to forest landscape surfaces. *Atmos. Envir.* 23: 1783-1794.

Hicks, B. B., D. R. Matt, R. T. McMillen, J. D. Womack, M. L. Wesely, R. L. Hart, D. R. Cook, S. E. Lindberg, R. G. de Pena and D. W. Thomson. 1989. A field investigation of sulfate fluxes to a deciduous forest, *J. Geophys. Res.* 94: 13003-13011.

Schaefer, D. A., S. E. Lindberg, and W. A. Hoffman. 1989. Fluxes of undissociated acids to terrestrial ecosystems by atmospheric deposition. *Tellus* 41B: 207-218.

Lindberg, S. E., and T. Butler. 1989. On composition of particles dry deposited to an inert surface at Ithaca, NY, and Author's response. *Atmos. Envir.* 23: 279-280.

Ottar, B., Lindberg, S. E., Voldner, E., Lindqvist, O., Mayer, R., Steinnes, E., and Watt, J. 1989. Special topics concerning interactions of heavy metals with the environment. In Pacyna, J. and Ottar, B. (eds.). *Control and Fate of Atmospheric Trace Metals*, NATO Advanced Science Institute Series, Kluwer Academic Publishers, Dordrecht, Holland, pp. 365-372.

Lindberg, S. E. 1989. Behavior of Cd, Mn, and Pb in forest canopy throughfall, In Pacyna, J. and Ottar, B. (eds.). *Control and Fate of Atmospheric Trace Metals*, NATO Advanced Science Institute Series, Kluwer Academic Publishers, Dordrecht, Holland, pp. 233-258.

Johnson, D. W. and S. E. Lindberg. 1989. Acidic deposition on Walker Branch Watershed. In Adriano, D. and W. Salomons (eds.). *Acidic Precipitation, Vol. I: Case Studies*, Advances in Environmental Sciences Series, Springer Verlag, NY. pp. 1-33.

Lindberg, S. E., R. C. Harriss, W. A. Hoffman, G. M. Lovett, and R. R. Turner. 1989. Atmospheric chemistry, deposition, and canopy interactions. IN D. W. Johnson and R. I. Van Hook (eds.) *Analysis of Biogeochemical Cycling Processes in Walker Branch Watershed*. Springer Verlag, Berlin, pp. 961-63.

Lindberg, S. E., G. M. Lovett, D. A. Schaefer and M. Bredemeier. 1988. Coarse aerosol deposition velocities and surface-to-canopy scaling factors from forest canopy throughfall. *J. Aerosol Science* 19: 1187-1190.

Lindberg, S. E., D. Silsbee, D. A. Schaefer, J. G. Owens, and W. Petty. 1988. A comparison of atmospheric exposure conditions at high- and low-elevation forests in the southern Appalachian Mountains. In Unsworth, M. and Fowler, D. (Eds.). *Processes of Acidic Deposition in Mountainous Terrain*, Kluwer Academic Publishers, London, pp. 321-344.

Lindberg, S. E., and C. T. Garten, Jr. 1988. Sources of sulfur in forest canopy throughfall. Nature 336:148-151.

Lindberg, S. E. and R. R. Turner. 1988. Factors influencing atmospheric deposition, stream export, and landscape accumulation of trace metals in four forested watersheds. Water, Air and Soil Pollut. 39:123-156.

Richter, D. D. and S. E. Lindberg. 1988. Incident precipitation and forest canopy throughfall: Analyses of sampling methods. J. Envir. Qual. 17:619-622.

Johnson, D.W., A.J. Friedland, H. Van Miegroet, R.B. Harrison, E. Miller, S.E. Lindberg, D.W. Cole, D.A. Schaefer, and D.E. Todd. 1988. Nutrient status of some contrasting high elevation forests in the eastern and western United States. p. 463-469 IN: Proceedings of Symposium The Effect of Atmospheric Pollutants on Spruce Fir Forests in the Federal Republic of Germany and the Eastern United States, Burlington, VT, Oct. 18-23, 1987.

Lindberg, S. E., G. M. Lovett, and K. J. Meiwis. 1987. Deposition and canopy interactions of airborne nitrate. In T. C. Hutchinson and K. Meema (eds.) Proceedings Advanced NATO Workshop on Effects of Acidic Deposition on Ecosystems, Springer-Verlag, NY, pp. 117-130.

Johnson, D. W., S. E. Lindberg, E. A. Bondiotti, D. W. Cole, G. M. Lovett, M. Mitchell, L. H. Ragsdale, and L. F. Pitelka. 1987. The Integrated Forest Study: A status report. Proc. Air Pollut. Control. Assoc. Annual Meeting, Paper 87-34.4, New York, June 21-26, 1987.

Barrie, L. A., S. E. Lindberg, W. H. Chan, H. B. Ross, R. Arimoto, and T. M. Church. 1987. On the concentration of trace metals in precipitation. Atmos. Environ., 21:1133-1135.

Petty, W. and S. E. Lindberg. 1987. An intensive study of Pb deposition to a high elevation spruce forest in the Appalachian Mountains. In Proceedings of the sixth International Conference on Heavy Metals in the Environment, New Orleans, LA, September 15-18, 1987, CEP Limited Publishers, Edinburgh, UK.

Coe, J. M. and S. E. Lindberg. 1987. The morphology and size distributions of atmospheric particles deposited on foliage and inert surfaces. J. Air Pollut. Control Assoc., 37:237-243.

Lindberg, S. E., P. M. Stokes, E. Goldberg, C. Wren. 1987. Rapporteur's report on mercury. In T. C. Hutchinson and K. Meema (Eds.), Lead, Cadmium, and Mercury in the Environment, United Nations Scientific Committee on Problems in the Environment Series, John Wiley, NY, p. 17-34.

Lindberg, S. E. Emission and deposition of atmospheric mercury vapor. 1987. In T. C. Hutchinson and K. Meema (Eds.), Lead, Cadmium, and Mercury in the Environment, United Nations Scientific Committee on Problems in the Environment Series, John Wiley, NY, p. 89-106.

Lindberg, S. E. 1986. Collection and analysis of trace metals in continental precipitation at forested sites in southeastern U.S. In Barrie, L. (Ed.). Measurement of Metals in Precipitation, Atmospheric Environment Service Publishers, Toronto, Canada.

Hicks, B. B., M. L. Wesley, S. E. Lindberg, and S. M. Bromberg (Eds.), 1986. Proceedings of the Dry Deposition Workshop of the National Acid Precipitation Assessment Program. March 25-27, 1986. NOAA/ATDD, P. O. Box 2456, Oak Ridge, TN 37831.

Lovett, G. M. and S. E. Lindberg. 1986. Dry deposition of nitrate to a deciduous forest. *Biogeochemistry*, 2:137-148.

Lindberg, S. E., and S. B. McLaughlin. 1986. Current problems and future research needs in the acquisition, interpretation, and application of data in terrestrial vegetation - air pollutant interaction studies. IN. A. Legge and S. V. Krupa (Eds.), *Air Pollutants and Their Effects on the Terrestrial Ecosystem*, pp. 449-504. John Wiley and Sons, New York, NY.

Lindberg, S. E. 1986. Mercury vapor in the atmosphere: Three case studies on emission, deposition, and plant uptake. pp. 535-560, In Nriagu J. O., and C. I. Davidson (eds.) *Metals in the Air*. John Wiley and Sons, New York, 635 pp..

Lindberg, S. E., G. M. Lovett, D. R. Richter, and D. W. Johnson. 1986. Atmospheric deposition and canopy interaction of major ions in a forest. *Science* 231:141-145.

Mayer, R. and S. E. Lindberg. 1985. Deposition on heavy metals to forest ecosystems -- their distribution and possible contribution to forest decline. Proceedings Fifth International Conference on Heavy Metals in the Environment, CEP Consultants Ltd. Publishers, Edinburgh, UK, Vol. 1, 351-353.

Lindberg, S.E. 1985. The production history of the Waltham Maximus. *Bull. Nat. Assoc. Watch and Clock Coll.* 27:174-188.

Lovett, G. M., S. E. Lindberg, D. D. Richter, and D. D. Johnson. 1985. The effects of acidic deposition on cation leaching from a deciduous forest canopy. *Can. J. For. Res.* 15:1055-1060

Turner, R. R., S. E. Lindberg, and J. M. Coe. 1985. Comparative analysis of trace metal accumulation in forest ecosystems. Proceedings Fifth International Conference on Heavy Metals in the Environment, CEP Consultants Ltd. Publishers, Edinburgh, UK, Vol. 1, 356-358.

Lindberg, S. E. and R. C. Harriss. 1985. Mercury in rain and throughfall in a tropical rain forest. Proceedings Fifth International Conference on Heavy Metals in the Environment, CEP Consultants Ltd. Publishers, Edinburgh, UK, Vol. 1, 527-529.

Johnson, D. W., D. D. Richter, G. M. Lovett, and S. E. Lindberg. 1985. The effects of atmospheric deposition on K, Ca, and Mg cycling in two forests. *Can. J. For. Res.* 15:773-782.

Davidson, C. I., S. E. Lindberg, J. Schmidt, L. Cartwright, and L. Landis. 1985. Dry deposition of sulfate onto surrogate surfaces. *Journal Geophysical Research* 90:2121-2130.

Lindberg, S. E. and G. M. Lovett. 1985. Field measurements of particle dry deposition rates to foliage and inert surfaces in a forest canopy. *Envir. Sci. Technol.* 19:238-244.

Lindberg, S. E., J. M. Coe, and W. A. Hoffman. 1984. Dissociation of weak acids during Gran

plot free acidity titrations, *Tellus* 36B:186-191.

Lindberg, S. E., G. M. Lovett, E. A. Bondiotti, and C. I. Davidson. 1984. Recent field studies of dry deposition to surfaces in plant canopies. *Air Pollution Control Association Meeting Proceedings*, Vol. 6, Chapter 84-108.5, p. 1-15, APCA, Pittsburgh, PA.

Lovett, G. M. and Lindberg, S. E. 1984. Dry deposition and canopy exchange in a mixed oak forest determined from analysis of throughfall. *J. Appl. Ecol.* 21:1013-1028.

Lindberg, S. E., and R. R. Turner. 1983. Trace metals in rain at forested sites in the eastern United States. *Proceedings Fourth International Conference on Heavy Metals in the Environment*, pp. 107-114, CEP Consultants Ltd. Publishers, Edinburgh, UK, 1284 pp.

Lindberg, S. E., R. R. Turner, and G. M. Lovett. 1983. Mechanisms of the flux of acidic compounds and heavy metals onto receptors in the environment. In Löbel, J. and W. R. Thiel (Eds.) *Acid Precipitation: Origin and Effects*, p. 165-172. Lindau, FRG, June 1983. Verlag des Vereins Deutscher Ingenieure, Düsseldorf, FRG.

Lindberg, S. E. and G. M. Lovett. 1983. Application of surrogate surface and leaf extraction methods to estimation of dry deposition to plant canopies. IN H. R. Pruppacher, R. G. Semonin, and W. G. N. Slinn (Eds.), *Precipitation Scavenging, Dry Deposition and Resuspension*. Elsevier Science Publ., New York, Vol. 2, pp. 837-848.

Lindberg, S. E. and R. C. Harriss. 1983. Water and acid soluble metals in atmospheric particles. *Jour. Geophys. Res.* 88:5091-5100.

Johnson, D. W., G. S. Henderson, D. D. Huff, S. E. Lindberg, D. D. Richter, D. S. Shriner, D. E. Todd, and J. Turner. 1982. Cycling of organic and inorganic sulfur in a chestnut oak forest. *Oecologia* 54:141-148.

Lindberg, S. E., R. R. Turner, and G. M. Lovett. 1982. Processes of atmospheric deposition of metals and acids to forests. *Air Pollution Control Association Annual Meeting Proceedings*, Paper 82-55M.3, Vol. 4, Chapter 10, pp. 1-14, APCA, Pittsburgh, PA.

Hoffman, W. A., Jr., S. E. Lindberg, and R. R. Turner. 1982. Characterization of covalent constituents in coal conversion solid wastes, *Envir. Pollut.* 4:219-229.

Lindberg, S. E., R. C. Harriss, and R. R. Turner. 1982. Atmospheric deposition of metals to a forest canopy. *Science* 215:1609-1611.

Ferguson, N. M., S. E. Lindberg, and J. D. Vargo. 1982. A simple reverse-phase column clean-up for the determination of sulfate in aqueous leachates containing organic compounds. *International Journal of Environmental Analytical Chemistry* 11:61-65.

Lindberg, S. E., D. S. Shriner, and W. A. Hoffman, Jr. 1982. The interaction of wet and dry deposition with the forest canopy. Chapter 17. IN *Acid Precipitation: Effects on Ecological Systems*, pp. 385-409. Ann Arbor Science Publishers, Ann Arbor, MI, 506 pp.

- Hosker, R. P., and S. E. Lindberg. 1982. Review Article: Atmospheric deposition and plant assimilation of airborne gases and particles. *Atmos. Environ.* 16:889-910.
- Lindberg, S. E. 1982. Factors influencing trace metal, sulfate, and hydrogen ion concentrations in rain. *Atmos. Environ.* 16:1701-1709.
- Chen, N.C.J., R. E. Saylor, and S. E. Lindberg. 1982. Plume washout around a major coal-fired power plant: Results of a single storm event. Chapter 2. *IN Energy and the Environment*, pp. 11-22. American Chemical Society.
- Lindberg, S. E., R. R. Turner, D. S. Shriner, and D. D. Huff. 1981. Atmospheric deposition of heavy metals and their interaction with acid precipitation in a North American deciduous forest. *Proceedings Third International Conference on Heavy Metals in the Environment*, pp. 306-309. CEP Publishers, Edinburgh, U.K., 732 pp.
- Lindberg, S. E. and R. C. Harriss. 1981. The role of atmospheric deposition in an eastern U.S. deciduous forest. *Water, Air, Soil Pollut.* 15:13-31.
- Lindberg, S. E. 1981. The relationship between Mn and sulfate ions in precipitation. *Atmos. Environ.* 15:1749-1753.
- Lindberg, S. E. 1981. A reply on the efficiency of in-plume mercury vapor collection by activated charcoal. *Atmos. Environ.* 15:631-634.
- Lindberg, S. E. 1981. Mercury in the atmosphere - A new problem? *Laboratory News*, Oak Ridge National Laboratory, February 1981.
- Parker, G., S. E. Lindberg, and J. M. Kelly. 1980. Atmosphere canopy interactions in southeastern U.S. forested watersheds. IN D. S. Shriner, C. R. Richmond, and S. E. Lindberg (Eds.), *Atmospheric Sulfur Deposition*, pp. 477-493. Ann Arbor Science Publishers, Ann Arbor, MI, 568 pp.
- Lindberg, S. E., and R. P. Hosker. 1980. Effluent delivery and air mass/landscape interactions: An overview. IN D. S. Shriner, C. R. Richmond, and S. E. Lindberg (Eds.), Atmospheric Sulfur Deposition. pp 181-184. Ann Arbor Science Publishers, Ann Arbor, MI, 568 pp.
- Hoffman, W. A., S. E. Lindberg, and R. R. Turner. 1980. Some observations of organic constituents in rain above and below a forest canopy. *Environ. Sci. Technol.* 14:999-1002.
- Lindberg, S. E., and R. C. Harriss. 1980. Trace metal solubility in aerosols produced by coal combustion. IN J. Singh and A. Deepak (Eds.), Environmental and Climatic Impacts of Coal Utilization, Academic Press, NY, 655 pp.
- Lindberg, S. E. 1980. Mercury partitioning in a power plant plume and its influence on atmospheric removal mechanisms. *Atmos. Environ.* 14:227-231.
- Hoffman, W. A., S. E. Lindberg, and R. R. Turner. 1980. Precipitation acidity: The role of the forest canopy in acid exchange. *Jour. Environ. Quality* 9:95-100.

1970's

Lyon, W. S., S. E. Lindberg, J. F. Emery, J. A. Carter, N. M. Ferguson, R. I. Van Hook, and R. J. Raridon. 1979. Analytical determination and statistical relationships of 41 elements in coal from three coal-fired steam plants. IN *Nuclear Activation Techniques in the Life Sciences*, pp. 615-625. IAEA-SM-227/61, International Atomic Energy Agency, Vienna, Austria.

Lindberg, S. E., D. R. Jackson, J. W. Huckabee, S. A. Janzen, M. J. Levin, and J. R. Lund. 1979. Atmospheric emission and plant uptake of mercury from agricultural soils near the Almaden mercury mine. *J. Environ. Qual.* 8:572-578.

Turner, R. R., and S. E. Lindberg. 1978. Behavior and transport of mercury in a river-reservoir system downstream of an inactive chloralkali plant. *Environ. Sci. Technol.* 12:918-923.

Ausmus, B. S., S. Kimbrough, D. R. Jackson, and S. E. Lindberg. 1979. The behavior of hexachlorobenzene in pine forest microcosms: Transport and effects on soil processes. *Environ. Pollut.* 13:103-111.

Turner, R. R., S. E. Lindberg, and K. Talbot. 1977. Dynamics of trace element export from a deciduous watershed, Walker Branch, Tennessee. IN D. L. Correll (Ed.), *Watershed Research in Eastern North America*, pp. 661-681. Smithsonian Institution Press, Washington, DC, 419 pp.

Lindberg, S. E., and R. C. Harriss. 1977. Release of dissolved mercury and organic matter from resuspended near-shore sediments. *J. Water Pollut. Control Fed.* 7:2479-2487.

Lindberg, S. E., and R. R. Turner. 1977. Mercury emissions from chlorine production solid waste deposits. *Nature* 268:133-136.

Lindberg, S. E., R. R. Turner, N. M. Ferguson, and D. Matt. 1977. Walker Branch Watershed element cycling studies: Collection and analysis of wetfall for trace elements and sulfate. IN Correll, D. L. (Ed.), *Watershed Research in Eastern North American*. pp. 125-150. Smithsonian Institution Press, Washington, DC, 469 pp.

Andren, A. W., and S. E. Lindberg. 1977. Atmospheric input and origin of selected trace elements in Walker Branch Watershed, Oak Ridge, TN. *Water Air Soil Pollut.* 8:199-215.

Bate, L. C., S. E. Lindberg, and A. W. Andren. 1976. Elemental analysis of water and air solids by neutron activation. *J. Radioanal. Chem.* 32:125-135.

Lindberg, S. E., A. W. Andren, R. J. Raridon, and W. Fulkerson. 1975. Mass balance of trace elements in Walker Branch Watershed - The relation to coal-fired power plants. *Environ. Health Perspect.* 12:9-18.

Bate, L. C., S. E. Lindberg, and A. W. Andren. 1975. Analysis of water and air by neutron activation. *Trans. Am. Nucl. Soc.* 21(Suppl. 3):20-21.

Lindberg, S. E., A. W. Andren, and R. C. Harriss. 1975. Geochemistry of mercury in the estuarine environment. pp. 64-107. IN L. Cronin (Ed.), Estuarine Research, Vol. I: Chemistry and Biology. Academic Press, NY, 750 pp.

Lindberg, S. E., and R. C. Harriss. 1974. Mercury enrichment in estuarine plant detritus. Mar. Pollut. Bull. 5:93-95.

Lindberg, S. E., and R. C. Harriss. 1974. Mercury - organic matter associations in estuarine sediments and their interstitial water. Environ. Sci. Technol. 8:459-462.

Lindberg, S. E., and R. C. Harriss. 1973. Mechanisms controlling pore water salinities in a salt marsh. Limnol. Oceanogr. 18:788-791.

Reports

Marcy, S. M. Dam, D. Dasher, R. Dietz, L. Duffy, M. Evans, S. Juntto, S. Lindberg, L. Lockhart, S. Naido, T. O'Hara, J. Pacyna, A. Robertson, E. Yngvadottir, and G. Asmund. 2000. Mercury in the Arctic: An Update, In Arctic Monitoring and Assessment Program (AMAP) Report on Issues of Concern, AMAP Report 2000: 4, Stromsveien, Norway.

Lindberg, S. E., K. Roy, and J. Owens. 1999. PaMSWaD (Pathways of Mercury in Solid Waste Disposal): ORNL sampling operations summary and preliminary data report for PaMSWaD-I, Brevard County Landfill. A Report to the Florida Department of Environmental Protection.

Lindberg, S.E., Zhang, H., and Meyers, T.P. 1999. Final Report: Everglades Mercury Air/Surface Exchange Study (E-MASE). South Florida Water Management District, West Palm Beach, FL.

Lindberg, S.E. and Meyers, T.P. 1998. Everglades Mercury Air/Surface Exchange Study (E-MASE): Second Annual Report. South Florida Water Management District, West Palm Beach, FL.

Lindberg, S.E., Meyers, T.P., and Miles, C. 1997. Everglades Mercury Air/Surface Exchange Study (E-MASE): First Annual Report. South Florida Water Management District, West Palm Beach, FL.

Wilken, R-D.; Lindberg, S. E.; Horvat, M.; Petersen, G.; Porcella, D.; Schroeder, B.; Wisniewski, J. R.; Wisniewski, J.; Wheatley, B., Wheatley, M.; and Wyzga, R. 1996. Fourth International Conference on Mercury as a Global Pollutant: Conference Summary Report. GKSS Research Centre, Hamburg, Germany.

Expert Panel on Mercury (22 authors). 1994. Mercury Atmospheric Processes: A Synthesis Report. Workshop Proceedings, R. H. Osa (Coord. Ed.), EPRI/TR-104214, Electric Power Research Institute, Palo Alto, CA.

Turner, R.S., R.B. Cook, H. Van Miegroet, D.W. Johnson, J.W. Elwood, O.P. Bricker, S.E. Lindberg, and G.M. Hornberger. 1990. Watershed and Lake Processes Affecting Chronic

Surface Water Acid-Base Chemistry. National Acid Precipitation Assessment Program State-of-Science/Technology Report 10, 167 pp., NAPAP, Washington, DC.

Lindberg, S. E. 1990. Throughfall and foliar extraction. Section 5.3.2.2, pp. 206-208. In: Hicks, B.B., R. R. Draxler, D. L. Albritton, F. C. Fehsenfeld, M. Dodge, S. E. Schwartz, R. L. Tanner, J. M. Hales, T. P. Meyers, and R. L. Vong. Atmospheric Processes Research and Process Model Development. National Acid Precipitation Assessment Program State-of-Science/Technology Report 2, 298 pp., NAPAP, Washington, DC.

Lindberg, S.E. and D.W. Johnson (eds.). 1989. 1988 Annual Report of the Integrated Forest Study, ORNL/TM 11121, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Lindberg, S.E. and D.W. Johnson, (eds.). 1989. 1988 Annual Report of the Integrated Forest Study, ORNL/TM 11121, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Lindberg, S.E. and D.W. Johnson, (eds.). 1989. 1987 Annual Group Leader Reports of the Integrated Forest Study, ORNL/TM 11052, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Lindberg, S. E., D.W. Johnson, G. M. Lovett, G. E. Taylor, H. Van Miegroet, and J.G. Owens. 1989. Sampling and Analysis Protocols and Project Description for the Integrated Forest Study. ORNL/TM 11214, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Fox, D.G., A. Bartuska, J. Byrne, E. Cowling, R. Fisher, G. Likens, S. Lindberg, R. Linthurst, J. Messer, and D. Nichols. 1989. A screening procedure to evaluate air pollution effects on class I wilderness areas. U.S. Department of Agriculture Forest Service, Rocky Mt. Forest and Range Experiment Station, General Technical Report RM-168.

Lindberg, S. E. Bowersox, V., Bigelow, D., Knapp, W., Olsen, T. (Eds). 1985. Annual data summary of precipitation chemistry in the United States. National Atmospheric Deposition Program, Colorado State University, Fort Collins, CO.

Lindberg, S. E., Lovett, G. M., and Coe, J. M. 1984. Acid deposition/forest canopy interactions. Final report RP-1907-1, Electric Power Research Institute, Palo Alto, CA.

McLaughlin, S. B., D. J. Raynal, A. H. Johnson, and S. E. Lindberg. 1983. Forests, In the Acidic Deposition Phenomenon and Its Effects, Section E3, Effects on Vegetation. The Acid Deposition Phenomenon, Critical Assessment Review Papers, EPA-600/8-83-016BF.

Lindberg, S. E. 1983. Dry deposition to petri dish and foliar surfaces, Final report to Carnegie-Mellon University, In Davidson, C. I., and S. E. Lindberg, Final Report to EPA on Illinois Intercomparison Deposition Studies.

Turner, R. R., P. Lowry, M. Levin, S. E. Lindberg, and T. Tamura. 1982. Leachability and aqueous speciation of trace constituents in coal fly ash. EPRI report EA 2588. Electric Power Research Institute, Palo Alto, CA.

Hildebrand, S. G., S. E. Lindberg, R. R. Turner, J. W. Huckabee, R. H. Strand, J. R. Lund, and A. W. Andren. 1980. Biogeochemistry of Mercury in a River-Reservoir System: Impact of an Inactive Chloralkali Plant on the Holston River - Cherokee Reservoir, Virginia and Tennessee, ORNL/TM-6141, Oak Ridge, National Laboratory, Oak Ridge, TN.

Davidson, C. I., and S. E. Lindberg. 1980. Alternative viewpoints on surrogate surfaces. IN B. B. Hicks, M. L. Wesley, and J. L. Durham, Critique of methods to measure dry deposition: Workshop summary. pp. 66-70. EPA-600/9-80-050, Environmental Protection Agency, RTP, NC.

Lindberg, S. E., R. C. Harriss, R. R. Turner, D. S. Shriner, and D. D. Huff. 1979. Mechanisms and rates of atmospheric deposition of trace elements and sulfate to a deciduous forest canopy. ORNL/TM-6674. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 510 pp.

Turner, R. R., J. W. Elwood, C. Feldman, and S. E. Lindberg. 1978. Chemical speciation in fly ash leachates: Importance and determination with specific reference to arsenic. Project Completion Report to the Electric Power Research Institute, Palo Alto, CA.

Turner, R. R. and S. E. Lindberg. 1976. Interlaboratory comparison of trace metal analyses by graphite furnace atomic absorption spectroscopy. ORNL/TM-5422. Oak Ridge National Laboratory, Oak Ridge, TN. 21 pp.

Andren, A. W., S. E. Lindberg, and L. C. Bate. 1975. Atmospheric input and geochemical cycling of selected trace elements in Walker Branch Watershed. ORNL/NSF/EATC-13. Oak Ridge National Laboratory, Oak Ridge, TN. 68 pp.

Turner, R. R., S. E. Lindberg, and A. W. Andren. 1974. Concentrations of C, N, ¹³⁷Cs, and selected heavy metals in a sediment core from Lake Jackson, Florida. IN Job Completion Report for the State of Florida Game and Freshwater Fish Commission, Study VI, Lake Jackson Investigations.

Michael McLinden, M.S., C.I.H.
PO Box 1081, 112 Central Avenue
Island Heights, New Jersey 08732-1081
(732) 573 - 0560

EDUCATION:

M.S., Occupational and Environmental Health Science

Hunter College, City University of New York (1994)

B.S., Zoology

San Diego State University (1982)

A.A., History

Ocean County College (1978)

PROFESSIONAL ASSOCIATIONS:

Certified in the comprehensive practice of industrial hygiene by the American Board of Industrial Hygiene (ABIH)

Diplomat of the American Academy of Industrial Hygiene (AAIH)

Full member of the American Industrial Hygiene Association (AIHA)

EXPERIENCE:

Research Scientist I (Industrial Hygienist) (8/04 - Present)

Center for Occupational Medicine

New Jersey Department of Environmental Protection

Senior industrial hygienist responsible for the development and implementation of occupational health policies, procedures and health and safety programs throughout the Department. Performed workplace exposure evaluations, air monitoring and training in order to maintain compliance with applicable regulations. Major projects included work on asbestos management, bloodborne pathogens, chemical hygiene plans, confined space entry, ergonomics, indoor air quality, mercury and other metals, noise, nuclear emergency preparedness, pesticides and respiratory protection.

Research Scientist I (5/98 – 8/04)

Office of Pollution Prevention & Right to Know

New Jersey Department of Environmental Protection

Promote pollution prevention initiatives in an effort to reduce environmental and occupational health exposures. Provide regulatory and technical assistance to industrial facilities to help increase efficiency and reduce the quantity of toxic (TRI) substances used, generated as waste and released to the environment. Represent the Office of Pollution Prevention on the DEP Mercury Workgroup. Former co-chair of the Pollution Prevention workgroup for the National Environmental Performance Partnership System (NEPPS) Steering Committee. Under an EPA grant, provide industrial hygiene technical assistance to the Office of Occupational Training and Education Consortium (OTEC) at Rutgers University. This project develops training programs designed to integrate pollution prevention and occupational health. Chairmen of the health & safety committee for the Division of Environmental Safety and Health (DESH).

Research Scientist II (8/96 - 9/98)

Division of Environmental and Occupational Health

New Jersey Department of Health and Senior Services

Working as a Health Assessor in the Hazardous Site Health Evaluation Program, performed health hazard investigations to evaluate potential public exposure to chemical and physical hazards associated with National Priority List (NPL) sites in New Jersey. Working with the

Agency for Toxic Substances and Disease Registry (ATSDR) reviewed environmental, demographic and public health data and evaluated potential human exposure pathways. Primary responsibilities included assisting with the development of a dose reconstruction model of a municipal water distribution system and the development of the occupational exposure portion of an epidemiological case-control study in support of a childhood cancer cluster investigation in Toms River, NJ.

Research Scientist III (7/94 - 7/96)

Office of Air Quality Management

New Jersey Department of Environmental Protection

Acted as project manager for a team of administrators, engineers and scientists developing State air Pollution control regulations for stationary sources. Major rules included Mercury Emissions from MSWIs, VOC-RACT, and Architectural and Industrial Maintenance Coatings Rules. Member of the Air Toxics Steering Committee providing advice to the Department concerning health exposure issues.

Research Scientist II (Industrial Hygienist) (9/89 - 7/94)

Center for Occupational Medicine

New Jersey Department of Environmental Protection

Senior industrial hygienist responsible for the development and implementation of occupational health policies and program specific health and safety programs for approximately 4,000 employees throughout the Department. Performed workplace exposure evaluations, air monitoring and training in order to maintain compliance with applicable regulations. Major projects included work on asbestos management, bloodborne pathogens, chemical hygiene plans, confined space entry, ergonomics, indoor air quality, mercury and other metals, noise, nuclear emergency preparedness, pesticides and respiratory protection.

Occupational Health Consultant (12/87 - 9/89)

Division of Environmental and Occupational Health

New Jersey Department of Health and Senior Services

Responsible for industrial hygiene activities related to asbestos including review and approval of asbestos management plans, abatement project inspections and air monitoring, and emergency response activities. Participated in various NJDHSS / EPA research projects concerning environmental exposure to asbestos.

PUBLICATIONS

Release of Mercury from Broken Fluorescent Bulbs. Journal of the Air & Waste Management Association, (February 2003) 53: 143-151.

Chromium Exposure Assessment of Outdoor Workers in Hudson County, NJ. The Science of the Total Environment, (July 1992) 122: 291-300.