Maine Department of Environmental Protection

Maine Compact Fluorescent Lamp Study

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TABLE OF CONTENTS

1 EXECUTIVE SUMMARY 7

2 INTRODUCTION 8

3 TOXICOLOGY INFORMATION 10

4 STUDY OBJECTIVE 11

5 MATERIALS AND METHODS

5.1 Study Scenarios, CFL Types, and Experiment Room 12

5.1.1. Original Study Design 14

5.1.2. Additional Scenarios 16

5.1.3. Container Study 18

5.2 Mercury Vapor Sampling Methodology 18

5.3 Data Evaluation Software 20

5.4 Quality Assurance/Quality Control 20

5.4.1. Instrument Checks 21

5.4.2. Decontamination Procedures 21

5.4.3. Data Files 24

5.4.4. Temperature 24

5.4.5. Multiple Trials 25

6 RESULTS AND DISCUSSION

6.1 General 25

6.2 Why be concerned about CFL breakage? 25

6.3 Comparing Results from Original Study Scenarios to Results from Additional Scenarios 29

6.3.1. Original Study Scenario Results 29

6.3.2. Additional Scenario Results 30

6.3.3. Original Study Rebound Evaluation 31

6.3.4. Additional Study Rebound Evaluation 32

6.4 Variability Among Lamp Types 33

6.5 Sources of Mercury Left in Flooring After Cleanup 36

6.5.1. Agitation of Flooring Surfaces 37

6.5.2. Spiking in Air Concentrations from Sources in Flooring 38

6.6 What effect does vacuuming have on cleanup?.....40

6.6.1. Effect of Vacuuming on Room Air Concentrations **40**

6.6.2. Effect on Room Air When Mercury Sources Left in Carpet are Vacuumed After Cleanup.....**41**

6.6.3. Effect of Mercury Sources in Flooring on Room Air even when Not Vacuumed **46**

6.6.4. Contamination of Vacuum.....**47**

6.6.5. Effect of Beater Vacuum **50**

6.6.6. Overall Assessment of Vacuuming.....**51**

6.7 What is the best container for containing the lamp debris that a homeowner would likely have in the home?.....51

6.8 Evaluation of Pre-Study Cleanup Guidance 54

6.8.1. Never use a vacuum. A standard vacuum can spread dust throughout the area and potentially contaminate the vacuum. **54**

6.8.2. Keep people and pets away from the breakage area to prevent mercury in the powder from being tracked. **55**

6.8.3. Ventilate the area by opening windows. **55**

6.8.4. If possible, reduce the temperature. **56**

6.8.5. Wear appropriate personal protective equipment, such as rubber gloves, safety glasses, old clothing or coveralls, and a dust mask to keep bulb dust and glass from being inhaled. **57**

6.8.6. Carefully remove larger pieces and all waste and materials used to clean up a break and place them in a secure closed container or airtight plastic bag.**58**

6.8.7. Collect smaller pieces and dust. Use a disposable broom and dustpan or two stiff pieces of paper to scoop up the pieces.....**58**

6.8.8. Pat the area with the sticky side of tape and wipe the area with a damp cloth or paper towel to pick up the fine particles. **58**

6.8.9. Consider using a drop cloth when changing a lamp so that any accidental breakage can be easily cleaned up. **58**

7 LESSONS LEARNED / CONSIDERATIONS FOR FUTURE STUDIES

7.1 Variability Among Manufacturers.....59

7.2 Unintentional Venting 59

7.2.1. Lumex Exhaust Lines **59**

7.2.2. Effect of Adjacent HVAC Systems **61**

7.3 Agitation of Flooring.....62

8 CONCLUSIONS AND DISCUSSION 62

APPENDIX A. Technical Results

Data Summary Table **67**

Scenarios for "Brand A" 60 Watt Equivalent CFL (original six scenarios)

Scenario 1: Wood Floor, No Venting, No Cleanup **75**

Scenario 2: Wood Floor, Venting, Cleanup **78**

Scenario 3: Short Nap Carpet, Venting, Cleanup **81**

Scenario 4: Longer Carpet, Venting, Cleanup **86**

Scenario 5: Short Nap Carpet, Venting, Vacuuming **90**

Scenario 6: Shag Carpet, Venting, Vacuuming **97**

Additional Cleanup Scenarios

Scenario A: "Brand B" 90 Watt Equivalent, Wood, Venting, Cleanup **102**

Scenario B: "Brand C" 60 Watt Equivalent, Short Nap Carpet, Venting, Cleanup ("duplicate" broken on wood) **105**

Scenario C: "Brand D" 60 Watt Equivalent, Wood, Venting, Cleanup **109**

Scenario D: "Brand A" 60 Watt Equivalent, Hot Lamp, Wood, Venting, Cleanup **112**

Scenario E: "Brand B" 100 Watt Equivalent, Wood, Venting, Cleanup **116**

Scenario F: "Brand B" 100 Watt Eq., Wood, Venting, Wait Before Cleanup **119**

Scenario G: "Brand D" 100 Watt Eq., Wood, Venting, Wait Before Cleanup **120**

Scenario H: "Brand E" 60 Watt Eq., Wood, Venting, Wait Before Cleanup **122**

Scenario I: "Brand F" 50 Watt Eq., Wood, Venting, Wait Before Cleanup **123**

Scenario J: "Brand A" 60 Watt Eq., Cracked Instead of Thoroughly Broken, Wood, Venting, Cleanup **125**

Scenario K: "Brand B" 90 Watt Eq., Shag Carpet, Venting, Vacuuming **126**

S5T3 Re-vacuum: Re-vacuum of a Scenario 5 carpet **131**

SB Vacuum: Carpet from Scenario B was vacuumed **133**

Scenario L: "Brand B" 100 Watt Eq., Short Nap Carpet, No Venting, Vacuuming Four Different Times **139**

Container Study Additional Results **146**

APPENDIX B. Additional Photographs **155**

APPENDIX C. Temperature Log **157**

APPENDIX D. Work Plan/QAPP with Pre-Study Broken CFL Cleanup Guidance

APPENDIX E. Revised Broken CFL Cleanup Guidance

APPENDIX F. Lumex SOP

APPENDIX G. CFL Brands Used in Study

APPENDIX H. Vacuum Data

APPENDIX I: Instrument Calibration and Background Contamination Checks

APPENDIX J: Temperature Corrected One Hour Average Mercury Concentrations

APPENDIX K: Wood Floor Mercury Contamination Measurements

1 EXECUTIVE SUMMARY

Forty five (45) experimental trials where compact fluorescent lamps (CFLs) were broken in a small/ moderate sized room were conducted in May through September of 2007. Eighteen (18) trials, three trials each of six differing scenarios, were originally planned for this study; however, additional trials were added to attempt to more fully address potential cleanup concerns. Broken lamps were either not cleaned up, cleaned up using Maine Department of Environmental Protection (DEP) pre-study cleanup guidance, vacuumed, or cleaned up using variations of the pre-study cleanup guidance. The mercury concentrations at the five foot height (adult breathing zone) and one foot height (infant/toddler breathing zone)[1] above the study room floor were continuously monitored. The most notable finding of the study was how variable the results can be depending on the type of lamp, level of ventilation and cleanup method.

The pre-study cleanup guidance was generally found to be sound. However, as a result of this study, the cleanup guidance was modified to include:[2]

- Leaving the area/room and waiting 15 minutes after breakage before returning to begin cleaning up (mercury levels in the air will have fallen from their highest levels by then);
- Using a glass container, metal screw top lid with a seal, such as a canning jar, to contain the lamp pieces, powder, and cleanup materials;
- Immediately removing the lamp breakage from the home once containerized, especially if the homeowner did not have a glass container with a good seal;
- Continue ventilating the room for several hours;
- Suggesting that homeowners consider removal of the area of carpet where the breakage occurred as a precaution, particularly in homes with infants, small children or pregnant women;
- If carpet is not removed, the homeowner should consider ventilating the room during vacuuming for the next several vacuuming events;
- Suggesting that homeowners consider not utilizing fluorescent lamps in situations where they could easily be broken, in bedrooms used by infants, small children, or pregnant women, or over carpets in rooms frequented by infants, small children and pregnant women; and
- Avoiding the storage of too many used/spent lamps before recycling as that could increase the chances of breakage.

Mercury concentration in the study room air often exceeds the Maine Ambient Air Guideline (MAAG) of 300 nanograms per cubic meter (ng/m^3) for some period of time, with short excursions over 25,000 ng/m^3, sometimes over 50,000 ng/m^3, and possibly over 100,000 ng/m^3 from the breakage of a single compact fluorescent lamp. A short period of venting can, in most cases, significantly reduce the mercury air concentrations after breakage. Concentrations can sometimes rebound when rooms are no longer vented, particularly with certain types of lamps and during/after vacuuming. Mercury readings at the one foot height tend to be greater than at the five foot height in non vacuumed situations.

Although following the pre-study cleanup guidance produces visibly clean flooring surfaces for both wood and carpets (shag and short nap), all types of flooring surfaces tested can retain mercury sources even when visibly clean. Flooring surfaces, once visibly clean, can emit

[1] The one foot height was selected to be representative of the breathing zone for an infant sitting, crawling or standing up holding on to furniture and a two to four year old toddler sitting or laying on the floor.
[2] See Appendix E for the entire revised cleanup guidance.

mercury immediately at the source that can be greater than 50,000 ng/m^3. Flooring surfaces that still contain mercury sources emit more mercury when agitated than when not agitated. This mercury source in the carpeting has particular significance for children rolling around on a floor, babies crawling, or non mobile infants placed on the floor.

Cleaning up a broken CFL by vacuuming up the smaller debris particles in an un-vented room can elevate mercury concentrations over the MAAG in the room and it can linger at these levels for hours. Vacuuming tends to mix the air within the room such that the one foot and five foot heights are similar immediately after vacuuming. A vacuum can become contaminated by mercury such that it cannot be easily decontaminated. Vacuuming a carpet where a lamp has broken and been visibly cleaned up, even weeks after the cleanup, can elevate the mercury readings over the MAAG in an un-vented room.

Some container types were found to be better than others for containing mercury emissions from breakage. Of the containers tested, a glass jar with a metal cover and gum seal contained the mercury vapor best. Double re-sealable polyethylene bags, on the other hand, did not appear to retard the migration of mercury adequately to maintain room air concentrations below the MAAG. Other containers fell somewhere in the middle between the glass and double re-sealable polyethylene bags for retarding mercury vapor migration. The significance of this issue is that cleanup material may remain in the home for some period of time and/or be transported inside a closed vehicle, exposing occupants to avoidable mercury vapors when improperly contained.

The decision on whether or not to remove carpet where there was a broken lamp may depend on a number of factors including the location of the carpet (e.g. where a child plays or where the carpet is frequently agitated), the occupants of the household, or possibly the type of lamp broken. Finally, it is unclear what the exact health risks are from exposure to low levels of elemental mercury, especially for sensitive populations, so advising for the careful handling and thoughtful placement of CFLs may be important. Based on this study, DEP modified the cleanup guidance for a broken CFL (see Appendix E).

2. INTRODUCTION

The use of CFLs in Maine is increasing. In 2006 Efficiency Maine provided 700,000 rebates for the purchase of CFLs. This was an increase of over 500% from 2005.[3] In 2007 they issued 788,000 such rebates.[4] It is expected that these numbers will continue to rise. According to the US Environmental Protection Agency, Energy Star program, if everyone in the United States were to switch one incandescent light bulb to a CFL, it would prevent greenhouse gases equivalent to the emissions of more than 800,000 cars annualy.[5] In addition, there would be significant savings on individual monthly electric bills.[6]

However, CFLs contain a small amount of mercury and should be used carefully, recycled at end of use, and cleaned up properly if broken. Along with the benefits of CFLs come concerns with mercury releases and potential exposures if lamps are broken or not recycled when spent. At this point in technology development, mercury is a necessary part of a fluorescent lamp.

[3] Efficiency Maine 2006 Annual Report. Efficiency Maine is a program of the Maine Public Utilities Commission.
[4] Efficiency Maine 2007 Annual Report.
[5] US EPA, Energy Star website, www.energystar.gov/index.cfm?c=cfls.pr_cfls , December 28, 2007.
[6] US EPA, Energy Star website, www.energystar.gov/index.cfm?c=cfls.pr_cfls , December 28, 2007.

Without the mercury, the lamp would not produce visible light. The average amount of mercury in a CFL is 5 mg with a range of 0.9 to 18 mg.[7]

Elemental mercury is a liquid that releases mercury vapor at room temperature. This vapor can be inhaled into the lungs and then passed into the blood stream. Elemental mercury can also be absorbed through the skin and then into the blood stream. However, if this form of mercury is ingested, it is not absorbed by the stomach, and usually travels through the digestive system without being passed into the blood stream to a large degree. Symptoms of elemental mercury poisoning include the following: tremors; emotional changes (e.g., mood swings, irritability, nervousness, excessive shyness); insomnia; neuromuscular changes (such as weakness, muscle atrophy, twitching); headaches; disturbances in sensations; changes in nerve responses; and performance deficits on tests of cognitive function. According to the U.S. Environmental Protection Agency (EPA), elemental mercury can convert in the environment to the more toxic methylmercury and cause problems for wildlife as well as humans.[8] Human exposure to methylmercury can cause long-lasting health effects, especially on fetal development during pregnancy. Mercury releases, whether as a discharge through wastewater discharges or in vapor form, deposit in Maine waterways where some portion converts to methylmercury. Maine has fish consumption advisories due to the contamination of fish with methylmercury.

The Maine Ambient Air Guideline (MAAG) of 300 ng/m^3 is identical to the EPA reference concentration (RfC), which is designed to protect against chronic exposure. The RfC is based on a number of occupational studies, in which tremor, fine motor deficits, electroencephalography (EEG) and autonomic nervous system abnormalities, and cognitive deficits were observed. A no-effect level (the level at which no adverse affects are observed) was not identified in these studies. There is no information on effects on the fetus or children, or effects on reproduction. A total uncertainty factor of 30 was applied to the lowest observed adverse effect level (LOAEL), 10 for sensitive populations and the fact that the point of departure was a LOAEL, and 3 for significant gaps in the database. It is unclear the degree to which this RfC, and therefore the MAAG, is protective of infants and children. Based upon the uncertainty and the need to be protective, the Maine State Toxicologist's Office at the Center for Disease Control has determined that the MAAG is an appropriate guideline to view the data generated in this study, even though many of the situations are short to intermediate term exposures.[9] This is based upon the absence of a no-effect level in the studies used to determine the RfC; the lack of knowledge on sensitive populations[10] such as fetuses, infants, children, pregnant women, and elderly and infirm adults; the sometimes short windows of vulnerability during fetal development; and the small difference in mercury concentrations in

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[7] Interstate Mercury Education and Reduction Clearinghouse (IMERC) mercury-added products notifications filed by National Electronic Manufacturers Association (NEMA) members in 2001.

[8] United States Environmental Protection Agency Mercury Study Report to Congress Office of Air Quality Planning & Standards and Office of Research and Development Volume III: Fate and Transport of Mercury in the Environment, EPA-452/R-97-005, December 1997; section 2.2

[9] Short term exposure is defined as less than a 14 day exposure; an intermediate exposure is defined as a 15 to 364 day exposure, as defined by the Agency for Toxic Substances Disease Registry, Toxicological Profile for Mercury, March 1999.

[10] Sensitive populations are of particular concern with mercury exposures for a number of reasons. Mercury exposures have serious impacts on fetal and infant brain development. Elemental mercury can cross the placenta from a mother to fetus. For these reasons, acute peaks could be particularly problematic during pregnancy. Infants and toddlers have much more vulnerable brains. Neurotoxicants identified in adults may have different and more severe effects in developing organisms. Infants and toddlers also have a much higher rate of respiration than adults. Therefore they have a higher exposure to similar concentrations. They also are lower to the floor and therefore closer to the source of the exposure and presumably more apt to obtain a concentrated dose of mercury. Elderly and unhealthy individuals may already be at comprised health and be more susceptible to mercury effects than a healthy individual. For example, mercury does kidney damage which could exacerbate an already existing kidney disease.

urine between more recent studies that have shown no-effect levels (dental studies[11,12]) and effect levels (various studies[13]).

The purpose of this document and the related study is to reduce preventable mercury exposure through improving the broken CFL cleanup guidance that is available to homeowners. The basis for the pre-study cleanup guidance is a protocol put together for businesses as a part of the Department's Universal Waste Education program. Its genesis was from "liquid" mercury spill cleanup guidance in use in Maine and nationally. Prior to this study, there were limited data available on the appropriateness of the application of this guidance to CFL breakage. The focus of this report is on how best to clean up a broken CFL while minimizing exposure to mercury.

3. Toxicology Information

There are a number of studies documenting neurotoxicity as a consequence of inhalation of elemental mercury in adults as a consequence of occupational exposure (www.epa.gov/iris/). Studies documented changes in EEG, deficits in peripheral nerve function, autonomic effects, psychological and sleep changes, and deficits in fine motor performance, visuomotor coordination, visual reaction time, visual scanning, memory, concentration, and executive function. The U.S. EPA chronic reference dose is based on hand tremor, fine motor deficits, EEG and autonomic nervous system abnormalities, and cognitive deficits.

It is important to note that a no-effect concentration was not identified in any of these studies. Therefore, it is unknown where the concentrations reported in these studies lie on the dose-effect curve, including how far above any no-effect level they may be. In addition, these studies were performed in healthy workers, and therefore provide no information on the relative sensitivity of various lifestages (fetus, infant, child, or aging individual) or individuals with various disease states such as impaired kidney function (which is a target organ for mercury and would also result in compromised pharmacokinetics) or diabetes (which also produces peripheral neuropathy).

It is well established that the developing organism may be much more sensitive than the adult to neurotoxic agents. For example, methylmercury exposure can produce devastating effects in the fetus, including cerebral palsy, blindness, deafness, and even death, while producing no or minimal effects in the mother. The fetal brain develops according to a series of processes that are exquisitely choreographed spatially and temporally, such that the type and pattern of toxicity that may be produced in the fetal brain is not possible in the adult brain (Rice and Barone, 2000). Although there are some data on effects on the developing fetus in rodents (which is the basis for the California acute recommended exposure limit (REL), for example), the marked difference in kinetics between humans and rodents makes interpretation of these studies problematic. Much of the mercury in the rodent is bound to red blood cells, which is not the case in humans. For methylmercury, for example, the ratio of blood:brain mercury in adults is 1:5 in

[11] Bellinger, David C. et al., Neuropsychological and Renal Effects of Dental Amalgam in Children, The Journal of the American Medical Association. Vol. 295 No. 15, April 19, 2006.
[12] DeRouen, Timothy A. et al., Neurobehavioral Effects of Dental Amalgam in Children, The Journal of the American Medical Association. Vol. 295 No. 15, April 19, 2006.
[13] Integrated Risk Information System, Mercury, elemental, US Environmental Protection Agency www.epa.gov/ncea/iris.

the human and 16:1 in the rat (Rice, 1996). It is unclear how this difference in kinetics would affect transfer of elemental mercury across the placenta following short-term exposure.

The processes unique to the developing brain do not end at birth. Therefore, the brains of infants and young children are also at increased vulnerability to damage from chemical exposure. Infants and children are also at increased risk because at any given air concentration, the internal dose of mercury would be greater than that of the adult as a consequence of increased ventilation rate (breathing more air per unit of time) as well as less efficient ability to excrete mercury from the body. In this regard, it is also important to understand that mercury is transported directly into the brain following inhalation, as well as being absorbed into the blood from the lung.

An important issue for which there are no data is the relative importance of a short spike in exposure versus a longer-term lower exposure in producing toxicity. The U.S. EPA considers that a single exposure may be sufficient to produce effects in a developing organism because of the recognition of potential critical windows of vulnerability. This implies that any exposure over an accepted toxicity value is potentially cause for concern, since a single exposure may produce a perturbation in a single or multiple processes in discrete brain areas, depending on the developmental stage of the exposure. Any such perturbations may have "downstream" consequences: if A doesn't happen, then B and C cannot happen in a normal manner. Repeated exposures would presumably increase the probability of untoward consequences. In addition, the relative risk of various exposure metrics is unknown: whether the greatest risk is posed by short-term higher level peak exposures or by the total area under the curve including higher and lower exposures.

Because of the potential unique vulnerability of the brain of the fetus and infant, and the lack of information concerning the risk posed to vulnerable populations by various exposure scenarios, the most health-protective strategy is to consider that any exposure greater than the MAAG of 300 ng/m^3 may potentially result in adverse health consequences.

References

Rice, D.C. Sensory and cognitive effects of developmental methylmercury exposure in monkeys, and a comparison to effects in rodents. Neurotoxicology 17, 139-154, 1996.

Rice, D.C. and Barone, S. Critical periods of vulnerability for the developing nervous system: Evidence from humans and animal models, Environmental Health Prospectives Supplement 3, 511-533, 2000.

4. STUDY OBJECTIVE

The goal of this study was to collect data to support or revise an existing cleanup guidance for the breakage of a single CFL. The issue of primary concern was mercury exposure and mercury contamination. Answers to the following questions were sought:

- Will breaking one compact fluorescent lamp impact the air in a small to moderate sized room such that mercury concentrations will be above the Maine Ambient Air Guidelines (MAAG) of 300 ng/m^3 in the breathing zone for either adults or crawling infants?
- How long do you need to vent the room before concentrations of mercury are below the MAAG, and do concentrations stay below the MAAG after the room is no longer vented?
- How does vacuuming affect the air mercury concentrations?

- Do vacuum cleaners become irreversibly contaminated with mercury if they are used to clean up broken lamps, or are there any simple steps to decontaminate them?
- How does the type of floor surface affect cleanup efficiency, and if the surface is a rug, does it need to be removed?
- Are any changes needed for Maine's existing cleanup guidance for broken CFLs? (The pre-study cleanup guidance can be found in Appendix D.)

As the study progressed, and data were collected to help answer the questions above, it became apparent that the following additional questions needed to be answered to help determine how the cleanup guidance should be revised:

- Do different brands of CFLs emit different amounts of mercury that could change the details of a cleanup guidance?
- Do amalgam lamps release less mercury into the air when broken?
- Does a CFL that has been on for an hour (hot lamp) release more mercury to the air when broken than a "cold" CFL?
- Does waiting a short amount of time before cleaning up a broken lamp reduce exposure to mercury?
- Does a cracked CFL emit less mercury into the air than a thoroughly broken lamp?
- What happens to air concentrations of mercury with repeated vacuuming of a carpet where breakage occurred?
- What happens to the mercury source in the carpet with repeated vacuuming?
- What would be the best container that is readily available in a home, for containing the lamp debris and mercury vapor?

It is hoped that information obtained from this study can be used by regulators and public health officials to better advise the general public on how best to clean up a broken CFL.

5. MATERIALS AND METHODS

5.1 Study Scenarios, CFL Types, and Experiment Room

The study room setup and pre-study cleanup guidance are included in Appendix D: Work Plan/QAPP with Pre-Study Broken CFL Cleanup Guidance. A change was made to the Work Plan during the study to minimize unintended venting of the study room. Lumex mercury analyzer exhaust lines were routed back into the study room as discussed in report Section 7.2.

All scenarios were carried out in a room with dimensions 11'4" x 12'1" with 10' ceilings. There are windows on three sides of the room, but only one window was used during the study. The east facing window with dimensions 30" x 38", opening to the outside of the building, was closed during the non-vented trials, and was opened for discrete lengths of time as determined to be effective in the vented trials. Heat is delivered to the room via baseboard units and ceiling duct during the heating season. Heat was not operating during the time frame of the experimental trials. There is no room air conditioning or air-out vent; the only air exchange was through the door and window.

Figure 5-1 shows part of the study room with Lumex analyzers on the table outside of the study room. Lumex analyzers are linked to lap-top computers for continuous monitoring of study room mercury concentrations. Air intake lines are held in place adjacent to the lamp breakage area

and are set at one and five feet above the floor. A lamp is in place with a vinyl plastic covering, ready to be broken with the plastic encased hammer seen at the left hand side of test box under the Lumex intake lines. A heating duct (top of picture) is covered with plastic to reduce vapor transport from the room via heating duct. Heat was turned off during the testing period. Air exhaust tubes were added to the setup after this picture was taken and for Scenario 1 and all subsequent scenarios.

Figure 5-1. Study room and computer area on left

Figure 5-2 shows the different floor types utilized in the study. From left to right: long pile (shag) rug, short pile rug and new, pre-finished hardwood flooring. The painted hardware cloth at the top of the photo was placed on top of each floor type and under the lamp during breakage and used for clean up of the larger pieces of broken glass to avoid cutting researchers' fingers.

Figure 5-2. Floor types utilized in the study

New CFLs were used in this study since it is generally understood that the amount of mercury that easily vaporizes is higher in new lamps rather than in spent lamps (where mercury is bound to the phosphor coating in the lamps). One lamp model from the same manufacturer was used for the first six scenarios to minimize variability in the amount of mercury released. The "Brand A" Soft White A19, 14w=60 watt lamp was chosen based on past studies demonstrating lower variability for "Brand A" linear fluorescent lamps.[14] The "Brand A" lamps used in this study are marketed as having an average of 800 lumens and an average life of 8,000 hours.

CFLs were thoroughly broken on top of test flooring surfaces (Figure 5-3) with a hammer encased in a plastic bag to simulate a worst case break. Each flooring surface was placed on top of a vinyl plastic lining within a cardboard box to avoid contaminating the study room for future trials.

Figure 5-3. Thoroughly broken CFL

5.1.1 Original Study Design:

The plan for this study included measuring mercury air concentrations continuously over time for each of six scenarios where one CFL was thoroughly broken on different surfaces (Figure 5-2) and cleaned according to individual scenario criteria (see Table 5-1 below for scenario descriptions).

[14] Maine Fluorescent Lamp Study , Maine Department of Environmental Protection, December 19, 2001; and Mercury Exposure Assessment and Work Practice Development for Cleaning Broken Fluorescent Lamps, URS Group, Inc., USPS Northeast Area, June 2, 2005

Table 5-1. Six Planned Scenarios

Scenario	Floor Type	Cleanup	Hg Measurements[a]
S1	Wood	No lamp cleanup/ no ventilation	Measure air concentrations continuously until highest concentration is reached
S2	Wood	Pre-study cleanup guidance with modification for 3/8" hardware cloth as per Appendix D	Measure continuously
S3	Short pile rug	Pre-study cleanup guidance with modification for 3/8" hardware cloth as per Appendix D	Measure continuously
S4	Long pile "shag" rug	Pre-study cleanup guidance with modification for 3/8" hardware cloth as per Appendix D	Measure continuously
S5	Short pile rug	Ventilate room. Clean up glass over 3/8" by hand, vacuum, and remove waste pieces and vacuum bag from room	Measure continuously/ take discrete measurements at vacuum locations
S6	Long pile "shag" rug	Ventilate room. Clean up glass over 3/8" by hand, vacuum and remove waste from room	Measure continuously/ take discrete measurements at vacuum locations

[a] All measurements were taken at one foot and five foot above site of lamp break.
Note: All six scenarios used the same "Brand A" soft white A19 14 watt lamp type.

All trials for cleanup scenarios (S2-S6) included the following basic steps:

1. Set up room with flooring in position adjacent to Lumex intake hoses, intakes set at 1' height from flooring and 5' height from flooring.
2. Close window and door. Record room temperature on the Project Daily Temperature Record each day.
3. Place CFL on hardware cloth over flooring surface and cover with vinyl plastic coverlet.
4. Begin monitoring room mercury concentrations as described in section 5.2.
5. Thoroughly break CFL by striking plastic covered CFL with hammer & move cover plastic to one side of box. (Figure 5-3)
6. Ventilate room by opening the 30" x 38" window to the outside of the building.
7. Clean up lamp using chosen scenario cleanup, see Appendix D.
8. Bag and properly dispose of broken lamp and cleanup materials outside study room.
9. Record mercury concentrations until measurements stabilize under 20 ng/m^3.
10. Close outside window and let mercury concentrations equilibrate to check for rebound.
11. Measure and record mercury vapor concentrations outside room door during study to confirm that levels do not exceed ambient air guidelines.
12. Bag and properly dispose of any remaining mercury contaminated materials and decontaminate room by venting. Room mercury concentrations must stabilize under 50 ng/m^3 before proceding to the next trial.

Scenario 1 included all of the above steps except that the room was not vented (step 6 in list) and the cleanup steps (steps 7, 8, 10 and 12 in list) were not completed.

The usual time between break and cleanup was one to five minutes. Table 5-2 details the time of each trial, room temperature during trial, time elapsed between break and cleanup and how long mercury concentrations were monitored after closing window and door.

Table 5-2. Trial Times and Temperature

Trial	Time of run (minutes)[a]	Inside Temperature During Trial (Degrees Centigrade)[b]	Wait btw break & clean (minutes)	Time rebound check (minutes)[c]
S1T4	83.4	19.9	n/a	n/a
S1T5	119.9	22.3	n/a	n/a
S1T6	105.0	23.2	n/a	n/a
S2T1	25.3	22.5	1	not evaluated
S2T2	117.6	22.5	1	100
S2T3	58.2	22.8	2	41
S3T1	28.9H/ 628.9L	23	2	605
S3T2	350.6	22.2	5	289
S3T3	267.5	21.5	5	214
S3T5	357.5	22.5	1	299
S4T1	359.6	20.6	1	312
S4T2	260.7	19.8	2	211
S4T3	592.2	20.3	2	542
S5T1	174.4	20.2	2	113
S5T2	86.1	21.5	1	not evaluated
S5T3	357.9	17.2	1	287
S6T1	82.8	17.6	1	19
S6T2	355.7	19.8	1	304
S6T3	254.7	19.3	1	200

[a] These times reflect how long mercury concentrations were monitored from the time of lamp breakage.
[b] Value represents the nearest temperature reading to the first hour of experimental trial.
[c] The tendency for mercury concentrations to rise again after a successful cleanup (rebound) was assessed at the one foot Lumex intake.

5.1.2 Additional Scenarios:

When the first six scenarios above had been completed, additional scenarios were evaluated to attempt to more fully address potential cleanup concerns. These scenarios involved thoroughly breaking various additional brands (SA, SB, SC, SE, SG, SH and SI), thoroughly breaking a hot lamp that had been turned on for an hour before breakage (SD) and cracking a lamp instead of thoroughly breaking it (SJ). Two carpets that had been cleaned up previously were vacuumed weeks after initial cleanup (S5T3 Re-vacuum and SB Vacuum). Results from SB Vacuum prompted three more vacuuming events on the same carpet. SK was another vacuuming scenario, and SF was a scenario where cleanup was delayed for approximately 40 minutes. Another lamp was broken on a new carpet, to create a worst case vacuum scenario (SL). In this scenario, a lamp that appeared earlier in the study to emit more mercury vapor than other brands was broken, with no venting. Cleanup consisted of picking up the big pieces and putting them in a trash can within the same room. The carpet was then vacuumed four times over the course of a week.

Table 5-3 summarizes all additional scenarios. Study room air mercury concentration was monitored continuously over the time of each experimental trial. Scenarios SA-SE were repeated twice with trials named (for example) SA and SA duplicate. Scenarios SB Vacuum and SL each consist of four vacuuming trials. Scenarios SF, SG, SH, SI, SJ, SK and S5T3 Re-vacuum each consisted of only one trial.

Table 5-3. Additional Scenarios

Scenario	CFL Type*	Floor Type	Cleanup
SA	"Brand B" 26w=90watts	Wood	Same as scenario 2
SB	"Brand C" 13w=60watts	Short pile rug	Same as scenario 2
SC	"Brand D" 14w=60watts	Wood	Same as scenario 2
SD	"Brand A" 14w=60watts	Wood	Same as scenario 2, except CFL turned on for approx. 1 hr before break to be "hot"
SE	"Brand B" 26w=100watt	Wood	Same as scenario 2
SF	"Brand B" 26w=100watt	Wood	Same as scenario 2, except vent for 46 minutes before cleanup.
SG	"Brand D" 23w=100watt	Wood	Same as scenario 2, except vent for 11 minutes before cleanup
SH	"Brand E", 15w=60watt	Wood	Same as scenario, except vent for 7 minutes before cleanup
SI	"Brand F" R30 15w=50watt	Wood	Same as scenario 2, except vent for 5 minutes before cleanup
SJ	"Brand A" 14w=60watt	Wood	Same as scenario 2 except CFL cracked instead of thoroughly broken.
SK	"Brand B" 26w=90watts	Long pile "shag" rug	Same as scenario 6
S5T3 Re-vacuum	Previously cleaned up "Brand A" 14w=60watt	Short pile rug from S5T3	No venting Re-vacuum once
SB Vac1	Previously cleaned up "Brand C" 13w=60watts	Short pile rug from SB	No venting Vacuum four times.
SB Vac2			
SB Vac3			
SB Vac4			
SL Vac1	"Brand B" 26w=100watt	Short pile rug	No venting, clean up big pieces and put in room trash, vacuum rest of debris and leave in room. Vacuum four times.
SL Vac2			
SL Vac3			
SL Vac4			

* "Brand A" soft white, 14w=60watts, ave. lumens=800, ave. life=8,000hrs.
* "Brand B" = Energy Choice, 26w=90watts, ave. lumens=1500, ave. life=10,000hrs.
* "Brand B" 26w=100watt, ave. lumens=1700, ave. life=8,000hrs
* "Brand C" = Soft White, 13w=60watts, ave. lumens=800, ave. life=8,000hrs.
* "Brand D" soft white, 14w=60watts, ave. lumens=900, ave. life=10,000hrs., model EDXO-14
* "Brand D" soft white, 23w=100watt, ave. lumens=1600, ave. life=10,000hrs.
* "Brand E", 15w=60watt, ave. lumens=1050, ave. life=10,000hrs., model H150275
* "Brand F" R30 soft white reflector (dimmable), 15w=50watt, ave. lumens=500, ave. life=6,000hrs., "amalgam technology"

Table 5-4 details the time of each trial, room temperature during trial, time elapsed between break and cleanup and how long mercury concentrations were monitored after closing window and door for the additional scenarios.

Table 5-4. Additional Scenario Times and Temperature

Trial	Time of run (minutes)[a]	Inside Temperature During Trial (Degrees Centigrade)[b]	Wait between break & clean up (minutes)	Time rebound check (minutes)[c]
SA	340.4	20.7	1	204
SA D	677.9	22	1	393
SB	343.1	23.1	1	554
SB D	345.8	21.3	2	278
SC	235.5	19.3	2	36
SC D	357.0	21.1	2	248
SD	408.2	20.3	1	353
SD D	259.8	24.3	1	221
SE	267.7	24.9	1	169
SE D	85.5	23.7	1	not evaluated
SF	81.8	24.7	46	not evaluated
SG	87.0	25	11	30
SH	136.8	23.9	5	87
SI	133.4	24.2	7	100
SJ	117.1	23.6	1	52
SK	471.3	24.4	0.3	371
S5T3Revac	481.4	24.9	n/a	not evaluated
SBVac1	91.0	22.3	n/a	not evaluated
SBVac2	361.0	24.2	n/a	not evaluated
SBVac3	481.4	20.6	n/a	not evaluated
SBVac4	361.0	19.4	n/a	not evaluated
SL Carpet	1,563.3	27.3	n/a	1563
SLVac1	1,507.4	22.3	1	not evaluated
SLVac2	1,181.3	24.9	n/a	not evaluated
SLVac3	1,231.2	22.9	n/a	not evaluated
SLVac4	1,190.7	25.7	n/a	not evaluated

[a] These times reflect how long mercury concentrations were monitored from the time of lamp breakage.
[b] Value represents the nearest temperature reading to the first hour of experimental trial.
[c] Rebound was assessed at the one foot Lumex intake.

5.1.3 Container Study:

An additional study was conducted to evaluate different container options for storing a broken CFL until it could be taken by an individual to a recycling facility. This study was conducted in two phases.

For the first phase, a CFL was broken inside a 1 quart polyethylene re-sealable plastic bag. The bag was then placed into a test container, opened, and the test container sealed. Twelve commonly available containers emptied of contents were evaluated. The test container was closed and placed into an enclosure (Universal Waste bucket with O-ring seal lid). Mercury concentrations were monitored inside the enclosure by carefully lifting the lid and inserting a Lumex intake hose at discrete sampling times. Concentrations were recorded until measurements inside the enclosure rose above 50,000 ng/m^3, the upper calibration limit of the Lumex.

For the second phase both the best and worst containers identified in phase one were re-evaluated as follows. A CFL was broken inside a 1 quart polyethylene re-sealable plastic bag. The bag was then placed into a test container, opened, and the test container sealed. The test container was then placed in the study room with the room window and door closed. Room air mercury concentrations were monitored five feet from the floor with a Lumex mercury analyzer. Two different containers were evaluated in the study room, double re-sealable polyethylene storage bags and glass containers with metal screw on lids and gum seals (such as canning jars). Each container was evaluated twice, once using "Brand B" 26w=100watt equivalent CFL and once with "Brand D" 14w=60watts equivalent CFL. Section 6.7 gives results for these tests.

5.2 Mercury Vapor Sampling Methodology

Three Lumex RA 915+ mercury analyzers, with a sensitivity of 2 ng/m^3 and a working quantitation limit of 20 ng/m^3, were used to measure mercury concentrations as described in the attached standard operating procedure (Appendix F). Two analyzers were connected to laptop computers (see Figure 5-4) to continuously monitor mercury concentrations at one foot and five foot heights during the initial lamp break and until mercury concentrations in the air decreased to the Lumex quantitation limit or to below the level deemed appropriate for a particular scenario. Lumex data-logging software was set to record five second average mercury concentrations continuously throughout each analytical trial. The two analyzers and laptops were located just outside the study room. Room air was introduced into the Lumex instruments via Tygon® tubing routed under the study room door, and exhausted from the analyzers back into the study room.[15]

A third Lumex analyzer was used for several purposes.

1. Mercury concentrations were measured within 1" of vacuum surfaces to demonstrate initial condition of the vacuum, document contamination after vacuuming and document effectiveness of decontamination procedures.
2. Mercury concentrations were measured near flooring surfaces after cleanup. The Lumex air intake nozzle was placed within an inch of the flooring surface to get a mercury concentration (calm), and then the floor surface was agitated with either a gloved hand or plastic encased hammer by rubbing and tapping the floor, and the Lumex measurement repeated (agitated). Flooring surfaces were placed outdoors on a loading dock during the day, and in a decontamination room at night between measurements.
3. Incidental fugitive mercury emissions under the study room door and from hazardous waste drums were measured.
4. Mercury concentrations were measured from container study enclosures as described in section 5.1.3.

Instruments are maintained according to section 5.6 of the standard operating procedure found in Appendix F, and are periodically factory calibrated. Calibration verification was performed and recorded for each instrument on each day of use, usually at the beginning and end of the day. All Lumex analyzers met calibration criteria established in the standard operating procedure. See Appendix I.

Inside and outside temperatures were recorded at approximately 8AM, noon and 4PM of each day. This temperature log can be found in Appendix C of this report.

[15] See discussion in section 7.2 about unintentional venting when exhaust lines are not returned to room.

Figure 5-4. Lumex RA 915+ mercury analyzers connected to laptops

5.3 Data Evaluation Software

All study room air monitoring data were collected using Ohio Lumex RA-915+ Software for Microsoft® Windows, Version 3.17 and stored as data files. Software can be downloaded from www.ohiolumex.com.

Two software packages were used for calculations and statistical evaluation of data. Data files were imported into Microsoft® Excel software for evaluation. All data graphs and associated calculations of one hour and other mercury vapor concentration averages and container study regression analyses were performed in Microsoft® Excel software. Statistical Software ProUCL 4.0 for Environmental Applications For Data Sets with and without Nondetect Observations, US Environmental Protection Agency (EPA), April, 2007 was employed for more involved statistical analyses of upper confidence limits. ProUCL software is available from EPA website at: http://www.epa.gov/nerlesd1/tsc/software.htm.

5.4 Quality Assurance/Quality Control

Quality assurance/ quality control for this project consists of limiting study variables to the extent possible, following standard operating procedures and performing daily instrument checks. All scenarios were performed within the same study room with mercury analyzer intakes in the same relative positions.

5.4.1 Instrument Checks:

All mercury analyzers were checked daily for calibration verification and contamination following the standard operating procedure in Appendix F of this report. All instrument checks passed acceptance criteria for calibration verification (±20%) and background contamination (<20 ng/m^3). Analyzers are periodically sent back to the factory for preventive maintenance including re-calibration. Daily instrument logs and dates of last factory maintenance are included in Appendix I.

5.4.2 Decontamination Procedures:

All materials used in the study were scanned for contamination prior to use within an inch of the surface with a Lumex mercury analyzer. New carpet sections were used for each carpet trial except when a carpet was re-vacuumed as part of a vacuuming scenario. Results for all new flooring surfaces were less than 20 ng/m^3. Wood flooring was re-used for new trials when testing indicated these surfaces were adequately decontaminated. Before reuse, flooring surfaces were cleaned, agitated and scanned with the Lumex within an inch of the floor surface with a scanning criterion of 300 ng/m^3 for the maximum observed reading. Cleaning was accomplished by wiping the surface with a wet-wipe and air drying the flooring outside the building. Agitation consisted of tapping and scraping the floor surface with a hammer enclosed in a clean plastic bag. A total of twelve experimental trials were performed on previously used wood flooring sections. Table 5-5 lists these trials along with information tracking what other trial was completed on the same piece of wood and the maximum mercury concentration measured within an inch of the surface when the flooring was agitated/ scanned prior to use.

For all trials, except those of Scenario B Vacuum and Scenario L, the study room 30" x 38" window was opened between trials until study room air fell consistently below 20 ng/m^3 when the window and door were re-closed. Data logging was initiated for several minutes before starting a new trial so that background air concentrations could be monitored and recorded to document study room mercury concentrations.

Room mercury concentrations were measured prior to breaking a CFL, and in all cases where wood was re-used, beginning room air mercury concentrations were less than 25 ng/m^3, or $^1/_{12}$ the MAAG of 300 ng/m^3.

Table 5-5.

Experimental Trial	Previously used for:	Highest 1" Hg concentration:[a]	Beginning Hg conc. at 1' intake[a]	Beginning Hg conc. at 5' intake[a]
S1T5	S1T4	<100	not recorded[b]	<20
S1T6	S1T5	<100	<20	<20
S2T2	S2T1	<100	<20	<20
S2T3	S2T2	<100	<20	<20
SA	S1T6	<100	<20	<20
SA Duplicate	S2T3	<100	<20	<20
SC Duplicate	SBD	<300	<20	<20
SD Duplicate	SD	<20	<20	<20
SE Duplicate	SDD	<20	<20	<20
SG	SE	<200	<20	23
SH	SG	<200	<20	<20
SJ	SI	<100	<20	<20

a Concentrations measured in ng/m^3

b S1T5 Lumex data logging started late due to technical difficulties.

The highest mercury measurement at one inch from the surface for re-used wood flooring was for trial SC Duplicate. Note that the beginning room air mercury concentration for that trial was <20 ng/m^3. Figure 5-5 shows Hg concentration at one foot intake vs. time for trial SC, performed on new wood; and Figure 5-6 shows Hg concentration at one foot intake vs. time for trial SC Duplicate, performed on the re-used wood. Note that results for trial SC, on the new wood, indicated a higher residual impact to room air mercury concentrations than does trial SC Duplicate performed on re-used wood. We conclude from these observations that re-using wood flooring that has been decontaminated such that a maximum reading less than 300 ng/m^3 taken within an inch of the flooring surface with a Lumex mercury analyzer will not adversely affect study results.

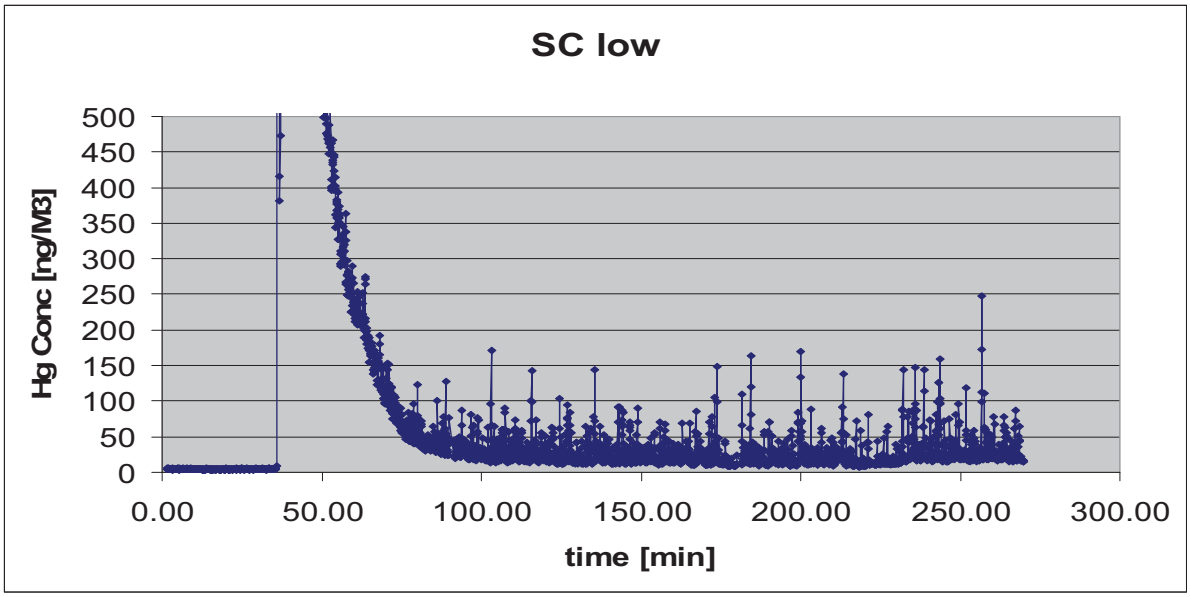


Figure 5-5. Trial SC performed on new wood surface at one foot intake

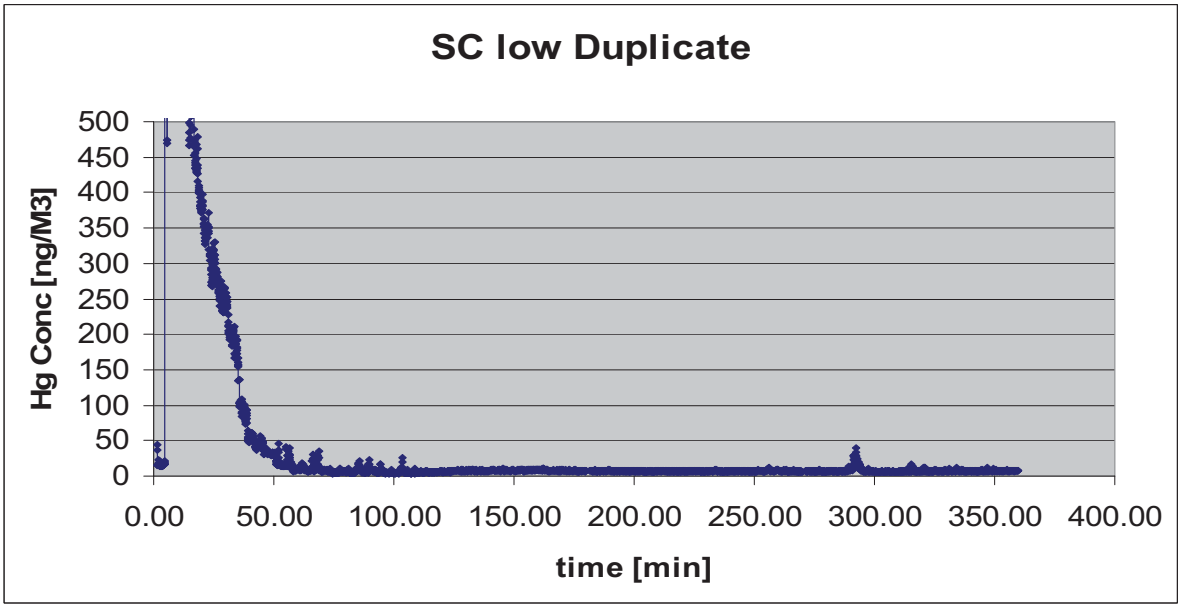


Figure 5-6. Trial SC Duplicate performed on re-used wood from Trial SB Duplicate at one foot intake

Surfaces for vacuum cleaners used for the study were scanned prior to use by holding the Lumex mercury analyzer intake hose within an inch of each measured surface. All results prior to initial use were less than or equal to 22 ng/m^3. Decontamination of vacuum cleaners between use consisted of removing and disposing of the vacuum bag, wiping accessible surfaces with wet wipes, disassembling vacuum parts and scanning surfaces with a Lumex mercury analyzer. Table 5-6 lists mercury (Hg) measurements before each vacuum trial.

Table 5-6.

Trial	Date/time trial began[a]	Vacuum	Vacuum parts Hg measurements prior to beginning of trial[b,c]
S5T1	6/1/07 9:25 AM	Kenmore	initial use, all <20
S5T2	6/1/07 1:06 PM	Kenmore	B-46, H-114, W-137
S5T3	6/4/07 8:56 AM	Kenmore	B-<20, H-52, W-41
S6T1	6/5/07 8:23 AM	Dirt Devil bagless	initial use, all <20
S6T2	6/5/07 11:17 AM	Dirt Devil bagless	B-22, C-21, Handle <20
S6T3	6/6/07 8:26 AM	Dirt Devil bagless	B-39, C-20, Handle <20
S5T3 revac	7/2/07 2:30 PM	Hoover 400	initial use, all <20
SK	6/26/07 4:21 PM	Hoover bagless	initial use, all <20
SB vac1	7/3/07 8:40 AM	Hoover 850	B = 22, all other <20
SB vac2	7/6/07 9:34 AM	Hoover 850	B <20, H-801, W-110
SB vac3	7/9/07 9:13 AM	Hoover 850	B-125, H-550, W <20
SB vac4	7/10/07 8:51 AM	Hoover 850	B <20, H-528, W-26
SL vac1	7/19/07 7:25 AM	Hoover 850	B-43, H-214, W-25
SL vac2[d]	7/23/07 8:35 AM	Hoover 850	not measured
SL vac3[d]	7/24/07 8:30 AM	Hoover 850	B-1755, H->50,000
SL vac4[d]	7/25/07 8:35 AM	Hoover 850	B-1421

a. Date and time taken from EXCEL spreadsheet *CFL_Study_Run_Dates_Times.xls*
b. Vacuum Hg measurements taken from EXCEL spreadsheet *Vacuum Parts Readings.xls*
c. B = beaters, H = hose, W = wand, C = cup
∗ No effort was made to clean Hoover 850 between trials for scenario SL.

Vacuum exhaust mercury concentration was not typically measured between trials. However, exhaust concentration was measured after trial S5T3 while operating the Kenmore vacuum to measure vacuum contamination on 6/8/07. Mercury concentration one inch from exhaust area was measured to be 22 ng/m^3. Vacuum concentrations measured at the same time are included in Table 5-7. These data suggest that vacuums with parts with mercury measurements less than those in Table 5-7 do not significantly contribute to study room air concentrations when used to vacuum a surface.

Table 5-7. Kenmore Vacuum Mercury Measurements 6/8/07 in ng/m^3

Location	Cold, un-agitated	Cold, agitated	Hot, un-agitated	Hot, agitated
Beaters	<20	**520**	72	**354**[a]
Wand	38		59	
Hose	184		247	
Filter	<20	251	33	**445**

[a] Bolded values are over MAAG of 300 ng/m^3.

5.4.3 Data Files:

Analytical data in the form of DAT files were automatically saved by the Lumex RA-915+ software and have been named to uniquely identify the scenario and trial for each completed trial (example: S2T1.dat for trial one of scenario two). The one exception to this is scenario G duplicate run that was not automatically saved due to technical problems, and the data for that run have been lost. Field notes for scenario G duplicate indicate this trial was similar to scenario G. Analysis of data and data graphs were completed in Microsoft Excel® software, preserving the original DAT files.

5.4.4 Temperature:

Temperature can dramatically affect mercury evaporation. According to a 2004 New Jersey Department of Environmental Protection study, higher temperatures contributed to higher release rates of mercury from broken fluorescent lamps.[16] In this Maine DEP study, reported values for study room air mercury concentrations have not been adjusted to account for variations in room temperature. However, temperature was monitored during the study approximately three times each day. The range of temperatures for this study ran from 17.2 to 27.7 degrees Centigrade. Recorded temperatures inside the study room is available in Appendix C. Average temperatures were calculated for each experimental trial, and those averages were evaluated and presented in Table 5-8.

Table 5-8. Basic Statistics for Temperatures During Trials with ProUCL[17]

General Statistics for Temperature	
Number of Valid Samples*	45
Confidence Coefficient	95%
Number of Bootstrap Operations	2000
Minimum	17.2
Maximum	25.7
Mean	22.2
Median	22.3
SD	2.125
Coefficient of Variation	0.0957
Skewness	-0.355
95% Student's-t UCL	22.73

*45 trials for scenarios described in Tables 5-1 & 5-3

To evaluate whether or not correcting for temperature would significantly affect study conclusions, one hour average mercury concentrations from each of the 45 trials was corrected for temperature based on the Lumex RA-915+ User's Manual Appendix 2. Temperature corrected averages were compared with non-corrected averages. Relative percent difference (RPD) was calculated for each pair, corrected vs. non-corrected, of averages. Four (4) of eighty six (86) one hour average RPD was greater than 50%. Only three (3) values out of eighty six (86) resulted in changes over or under 300 ng/m^3. Scenario G, one foot intake changed from

[16] Release of Mercury From Broken Fluorescent Bulbs, Michael Aucott, Michael McLindenb , and Michael Winkac, February 2004, New Jersey Department of Environmental Protection, Division of Science, Research and Technology.

[17] Statistical Software ProUCL 4.0 for Environmental Applications For Data Sets with and without Nondetect Observations, US Environmental Protection Agency (EPA), April, 2007.

377 ng/m^3 to 295 ng/m^3; Scenario 1 trial 4 one foot intake changed from 269 ng/m^3 to 344 ng/m^3; and scenario C duplicate five foot intake changed from 298 ng/m^3 to 351 ng/m^3. These results indicate that correcting for temperature would not significantly affect study conclusions. Based on this review, temperature corrections were not included in this report. Mercury concentrations corrected to 23°C (73°F) and 32°C (90°F) are included in Appendix J of this report.

5.4.5 Multiple trials:

The original six scenarios for this study were run in triplicate. Subsequent "add-on" scenarios were run in duplicate where possible. Graphs for all trials evaluated in this report are included in Appendix A.

6. RESULTS AND DISCUSSION

6.1 General

Data files for forty-five (45) trials were collected for scenarios described in Section 5 of this report, including 45 files for the five foot (adult breathing zone) mercury analyzer intake and 45 files for the one foot (infant/toddler breathing zone) intake. Additional files were collected for the container study. Of the 45 trials for the one foot intake, 27 had one hour average room air mercury concentrations below the MAAG. In 31 trials the concentration fell below the MAAG within one hour. Of the 18 trials with one hour average mercury concentrations above the MAAG, 11 were from either un-vented or vacuuming (both initial vacuuming and re-vacuuming) scenarios.

For the five foot intake, 33 of 45 trials had one hour average room air mercury concentrations below the MAAG. In 35 trials the concentrations fell below the MAAG within one hour. For the 12 trials with one hour average mercury concentrations above the MAAG, seven were from either unvented or vacuuming (both initial vacuuming and re-vacuuming) scenarios. Results from all 45 trials are tabulated in Appendix A.

This study identified several potential exposures from the breakage of a CFL. The first is the air concentration from the initial break and cleanup. The next is the source left in the flooring surface. This ongoing emission affects both those using the surface in close contact and sometimes those more distant from the flooring, especially when the floor is agitated. The final piece is the emissions from the broken lamp debris once cleaned up. The three different potential mercury exposures each impact guidance for appropriate handling of a broken CFL. The discussions in Sections 6.2 to 6.8 include the knowledge from these three types of exposures.

A more detailed technical discussion of results by individual scenario is included in Appendix A of this report.

6.2 Why be concerned about CFL breakage?

Since CFLs contain small amounts of mercury, part of the study looked at what happens when a lamp breaks. Does a release of mercury occur that would put a room over the MAAG?

Thirty-six (36) CFLs were broken on one of the three types of flooring; almost all breaks resulted in initial air concentrations over the MAAG at the one foot level (infant/toddler breathing zone), and many also at the five foot level (adult breathing zone).

Table 6-1 presents a subset of the data that looks just at those scenarios where the CFL was not cleaned up initially. This table gives data from breaks from four different brands of lamps. This gives an idea of what can happen to room air concentrations if a lamp breaks and is not cleaned up immediately.

Table 6-1. CFLs that were broken and not cleaned up initially (results in ng/m^3)

Scenario	Cleanup Time (min)[a]	Maximum[b] at 1 foot	Maximum[b] at 5 foot	<300[c] at 1 foot	<300[c] at 5 foot	1 Hour Average[d] at 1 foot	1 Hour Average[d] at 5 foot
S1 (three trials, unvented, "Brand A" 14w=60watts)	60 60 60	8,533 34,954 23,244	176 962 499	19 11 60+	0 18 2	269 319 624	133 254 120
SF (one trial, vented, "Brand B" 26w=100watt)	46	54,142	8,285	90+	90+	2,745	2,992
SG (one trial, vented, "Brand D" 23w=100watt)	11	8,603	956	17	16	377	111
SH (one trial, vented, "Brand E" 15w=60watt)	5	17,178	4,543	12	16	263	232
SI (one trial, vented, "Brand F" 15w=50watt)	7	687	485	6	3	70	54

a This field represents time (in minutes) elapsed from lamp break until cleanup initiated.
b This field represents the maximum mercury concentration (ng/m^3) detected at the identified intake.
c This field contains time (in minutes) elapsed between lamp break and when room concentrations fall below 300 ng/m^3 at the identified intake.
d This field contains one hour average mercury concentrations (ng/m^3) at the identified intake.

Of the seven breaks that were not cleaned up initially, at least half were of concern. Four had one hour averages at the one foot height over 300 ng/m^3, with an additional two close to the 300 ng/m^3 level. At the five foot height, the results were lower but still over the 300 ng/m^3 standard in one run and nearing it in two others or almost half of the one hour averages in total. The one foot height is of particular concern since infants and children are apt to spend a fair amount of time in close contact or proximity to flooring surfaces. As referenced earlier in the Introduction and Toxicology sections, there are health concerns at the 300 ng/m^3 level even when there are short-term exposures.

SF, SG, SH and SI were all vented scenarios, which would bias these results low. These results are also unagitated readings. We know from other aspects of this study that agitation produces even higher concentrations. We would expect that agitation, such as with continued use of an area after a lamp break, would likely push all or some of the results that were nearing the 300 ng/m^3 level over this concentration. Table 6-2 shows a non-parametric statistical

analysis[18] of 140 paired flooring surface mercury concentrations where both calm (unagitated) and agitated measurements were taken, and demonstrates the clear effect of agitation.

Table 6-2. Statistical analysis of the effect of agitation on mercury concentrations near flooring

Non-Parametric Flooring Statistics	Calm	Agitated
Total Number of Data	140	140
Number of Non-Detect Data	51	2
Number of Detected Data	89	138
Minimum Detected	20 ng/m^3	31 ng/m^3
Maximum Detected	10,505 ng/m^3	50,000 ng/m^3
Percent Non-Detects	36.43%	1.43%
Mean of Detected Data	450 ng/m^3	2,998 ng/m^3
Median of Detected Data	89 ng/m^3	746 ng/m^3

See Table H-4 and Table K for specific examples of the effect of agitation on mercury concentrations near flooring surfaces.

In addition, one of the breaks ("Brand F" lamp) had an unusually low mercury concentration upon breakage. This was from what the researchers believe was the only vapor control amalgam technology lamp broken during the study and is likely not particularly representative of CFLs to be broken in the home. If this one lamp were excluded from the above analysis, three-quarters of the results would be over or approaching the 300 ng/m^3 level. Although the data are variable depending on lamp type and length of time to clean up, these data do suggest that refining proper cleanup guidance to reduce avoidable mercury exposure is warranted.

The one hour averages in the unvented study room would be similar to what would happen if someone did not take proper precautions by venting and cleaning up the breakage. Figure 6-1 displays a comparison of the one hour average mercury at the one foot and five foot height concentrations between Scenario 1 (Brand A, unvented, not cleaned up) and Scenario 2 (Brand A, vented, cleaned up). In Scenario 1 the break occurs in an unvented room and the debris is not cleaned up. In Scenario 2 the break occurs and the room is then vented and cleaned up.

Even with proper cleanup, CFL breaks can result in significant sources of mercury left in flooring. Figure 6-2 depicts one such example. This figure shows the results over time and with three additional vacuums simulating what can happen with revacuuming a break on carpet as a part of ongoing carpet cleaning. Sources left in flooring will be agitated with use and cleaned or vacuumed as a part of typical household cleaning, potentially releasing more mercury to the room air. Refer to Section 6.5.1. for a discussion of this in detail.

[18] ProUCL 4.0 for Environmental Applications For Data Sets with and without Nondetect Observations, US Environmental Protection Agency (EPA), April, 2007

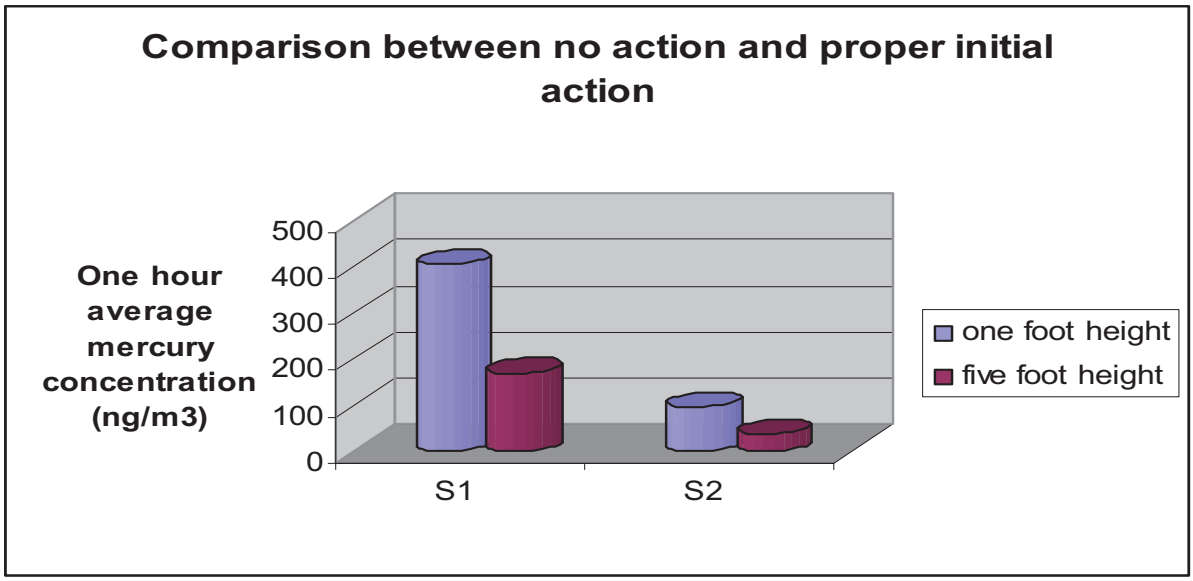


Figure 6-1. Comparing one hour average mercury concentrations between Scenario 1 and Scenario 2

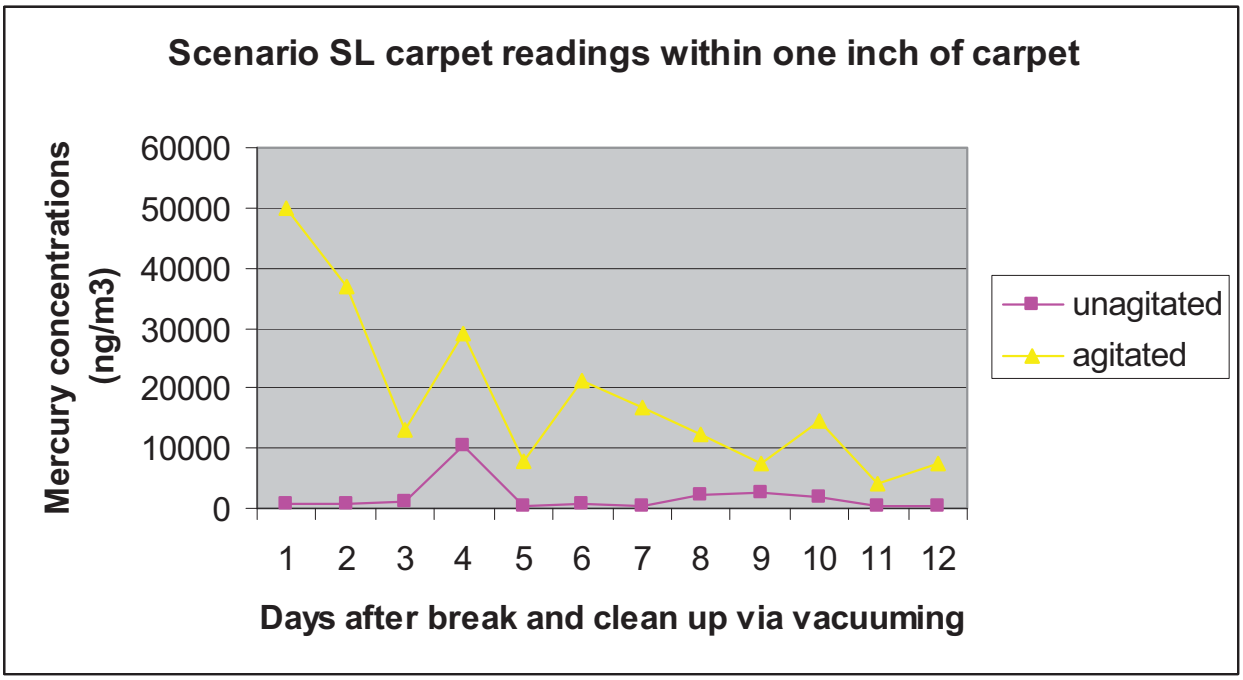


Figure 6-2. Example of mercury sources left in carpeting after cleanup via vacuuming

Finally, where and how CFL breakage debris is stored can also impact room air concentrations. Depending on whether breakage is placed in trash cans within the house or stored in inadequate containers, breakage emissions can have an impact on air concentrations. See section 6.7 for further details.

6.3 Comparing Results from Original Study Scenarios to Results from Additional Scenarios

6.3.1 Original Study Scenario Results

This study found that generally, regardless of flooring type and cleanup method, the concentration of mercury in the air one foot above the breakage peaked between 1,811 ng/m^3 and 22,176 ng/m^3 when a "Brand A" 60 watt equivalent CFL was broken, the room vented, and the lamp cleaned up. Concentrations at the one foot intake decreased to below 300 ng/m^3 within 9.5 minutes of breakage for all trials. At five feet above the breakage concentrations peaked between 236 ng/m^3 and 1,443 ng/m^3 and concentrations at this intake decreased below 300 ng/m^3 within 7.33 minutes of breakage for all trials.

When the window was not opened at all after breaking a "Brand A" 60 watt equivalent lamp, and the lamp was not cleaned up, mercury concentrations spiked between 8,533 ng/m^3 and 34,954 ng/m^3 at the one-foot height. At five feet over the broken lamp, concentrations of mercury spiked between 176 ng/m^3 and 962 ng/m^3. Mercury concentrations in the air lingered between 100 ng/m^3 and 600 ng/m^3 for the duration of the experimental trial.

Results from the original six scenarios of the study are summarized in Table 6-3 below. The table highlights 15 minute, 30 minute and 1 hour average mercury concentrations at both five foot (H) and one foot (L) Lumex intakes as well as the average time elapsed before instantaneous mercury concentrations fell consistently below 300 ng/m^3. Real time graphs of instantaneous mercury concentrations for all trials are included in Appendix A of this report. The only scenario with one hour average above 300 ng/m^3 was Scenario 1, where no venting and no cleanup was performed. Likewise Scenario 1 is the only scenario where the time elapsed between lamp breakage and when instantaneous mercury concentrations fell consistently below 300 ng/m^3 was longer than 60 minutes for either five foot or one foot intake.

Table 6-3. Summary of Average Results for Original Six Scenarios of Study

Scenario (Intake[a])	Ave of Max[b]	RSD of Max[c]	15 min ave[d]	15 min RSD	30 min ave (ng/m^3)	30 min RSD	1 hr ave (ng/m^3)	1 hr RSD	time <300[e]
S1 (H)	**546**[f]	72.4	193	50	186	50	169	44	6.47
S1 (L)	**22,244**	59.5	**775**	29	**572**	36	**404**	48	>60
S2 (H)	**666**	23.1	106	42	67	54	37	43	1.83
S2 (L)	**12,261**	37.7	**307**	43	176	41	95	42	2.22
S3 (H)	**770**	40.9	220	19	152	21	96	19	5.38
S3 (L)	**8,323**	33.0	**372**	26	225	18	126	14	6.38
S4 (H)	**484**	42.0	165	23	115	22	66	17	2.66
S4 (L)	**12,334**	69.4	**415**	40	232	38	119	37	4.75
S5 (H)	**424**	41.8	203	16	147	20	94	33	4.14
S5 (L)	**10,449**	71.3	**428**	55	248	48	136	46	5.25
S6 (H)	**333**	27.0	153	26	120	33	48	35	1.28
S6 (L)	**6,855**	127.4	251	66	154	57	87	53	2.86
All (H)	**549**	48.1	176	33.4	132	41.7	90	57.1	nc
All (L)	**11,880**	77.0	42.5	52.1	266	63.3	159	82.7	nc

a Scenario from Table 5-1 (Lumex intake heights, L = one foot above floor, H = five feet above floor)
b Averages here represent the average of maximum mercury concentrations for all scenario trials in ng/m^3.
c RSD = Relative Standard Deviation is computed as follows: RSD = 100 X (Standard Deviation of Trial averages)/(Average of Trial averages)

d Averages here represent the average of all scenario trial averages in ng/m^3. Three trials were run for all six scenarios. An additional trial was run for scenario 3. Two trials, S2T1 and S3T1 (one foot intake) did not include 1 hour average results due to shortened runs.
e This field represents the time in minutes elapsed between lamp breakage and when room mercury concentrations fell below 300 ng/m^3 at the identified Lumex intake.
f Bolded values are over MAAG of 300 ng/m^3.
nc = not calculated

As these data illustrate, breaking one "Brand A" CFL on pre-finished wood flooring, short nap carpet or long nap carpet (shag) can elevate mercury concentrations in a small/ medium sized room above the MAAG of 300 ng/m^3. However, when the room is vented by opening a window and the broken lamp is cleaned up and removed from the room, mercury concentrations fall below 300 ng/m^3 in less than ten minutes.

6.3.2 Additional Scenario Results

Conclusions based strictly on the original study scenarios cannot be made for all CFLs. Consider the subset of data included in Table 6-4. This table presents data for additional scenarios for which two trials were performed. Four different types of CFLs were included, and for all scenarios, lamps were broken on pre-finished wood flooring and cleaned up according to pre-study guidelines. Note here that all fifteen minute, thirty minute and one hour average mercury concentrations were above the MAAG. Also note that the time required for mercury concentrations to fall under the MAAG was longer than 20 minutes for three of the four scenarios. The only scenario for which the time required to fall under the MAAG was less than 10 minutes utilized the same Brand A 14w = 60w CFL as the original six study scenarios. These data illustrate the importance of considering variability among brands when setting cleanup guidance.

Table 6-4. Summary of Average Results for Additional Scenarios with two Trials

Scenario (Intake)[a]	CFL[b]	Ave of Max[c]	RPD Max[d]	15 min ave[e]	15 min RPD	30 min ave (ng/m^3)	30 min RPD	1 hour ave (ng/m^3)	1 hour RPD	<300[f]
SA (H)	"Brand B" 26w=90w	**5,767**[h]	143.1	**1,216.0**	130.9	**854.0**	123.4	**507**	121.5	40.5
SA (L)		**34,224**	156.7	**2,194**	157.0	**1,390**	154.0	**792**	153	131.4
SC (H)	"Brand D" 14w=60w	**5,092**	32.8	**810**	7.8	**637**	28.3	**361**	35	25.7
SC (L)		**16,694**	126.2	**1,558**	85.7	**930**	72.8	**497**	75.3	21.5
SD (H)	"Brand A" 14w=60w	**856**	137.3	**188**	79.5	132	81.4	76.5	87.6	1.7
SD (L)		**11,732**	4.9	**304**	43.8	178	51.7	96	57.6	1.5
SE (H)	"Brand B" 26w=100w	**5,747**	53.6	**1,664**	7.8	**1,125**	26.7	**667**	41.9	36.1
SE (L)		**45,247**	87.8	**2,664**	59.1	**1,588**	46.7	**893**	34.7	40.2
All (H)	Variable	**4,365**	74.6[g]	**1,248**	89.3[g]	**814**	79.5[g]	**464**	77.8[g]	nc
All (L)		**32,055**	73.6 [g]	**1,680**	85.3[g]	**1,021**	84.1[g]	**569**	84.6[g]	nc

a Scenario from Table 5-3 (Lumex intake heights, L = one foot above floor, H = five feet above floor)
b Brand and Power rating for CFL used in each scenario.
c Averages here represent the average of maximum mercury concentrations for all scenario trials in ng/m^3.
d RPD = Relative Percent Difference is computed as follows: 100 X $|Max_{trial1}-Max_{trial2}|$ / Average of trials
e Averages here represent the average two trial averages in ng/m^3.
f This field represents the time (min) elapsed between lamp breakage and when room mercury concentrations fell below 300 ng/m^3 at the identified Lumex intake.
g Since four rather than two trials are included here RSD, relative standard deviation, was calculated and presented. Relative Standard Deviation is computed as follows: RSD = 100 X (Standard Deviation of Trial averages)/(Average of Trial averages)
h Bolded values are over the MAAG of 300 ng/m^3.
nc = not calculated

6.3.3 Original Study Rebound Evaluation

After concentrations of mercury in the air fell below 20 ng/m^3 the window was closed to check if study room mercury concentrations would rebound and rise above 300 ng/m^3. Table 6-5 documents run length (length of time a trial was monitored with lumex), the time the window and door were closed and the time mercury concentrations were monitored to evaluate rebound for the five cleanup scenarios of the original study.

Table 6-5. Rebound Check for Original Scenarios 2-6 of Study

Trial Name	RUN LENGTH (minutes)	Time Lamp Broken (Minutes from Time Begin)	Corrected Run Lenth (minutes)	Time Window/ Door closed (minutes)	Rebound Check Time (minutes)
S2T2	121.4	3.83	117.6	17.58	100
S2T3	61.0	2.88	58.2	17.58	41
S3T1	631.0	2.08	628.9	24.42	605
S3T2	361.4	10.83	350.6	62.08	289
S3T3	271.0	3.50	267.5	53.17	214
S3T5	361.4	3.92	357.5	58.17	299
S4T1	361.4	1.83	359.6	47.67	312
S4T2	271.0	10.33	260.7	50.00	211
S4T3	601.4	9.25	592.2	50.58	542
S5T1	181.0	6.58	174.4	61.58	113
S5T3	361.4	3.50	357.9	71.42	287
S6T1	91.0	8.17	82.8	63.83	19
S6T2	361.4	5.75	355.7	51.83	304
S6T3	271.0	16.33	254.7	54.75	200

No rebound above 300 ng/m^3 was observed for any of these trials. One trial, S3T1, did show rebound above 50 ng/m^3 between 26 and 62 minutes after CFL break (4 to 40 minutes after closing window and door). The highest peak during this rebound was 138 ng/m^3. See Figure 6-3 for a graph of trial S3T1 rebound. A second period of elevated mercury concentrations between 350 and 460 minutes was well below 50 ng/m^3.

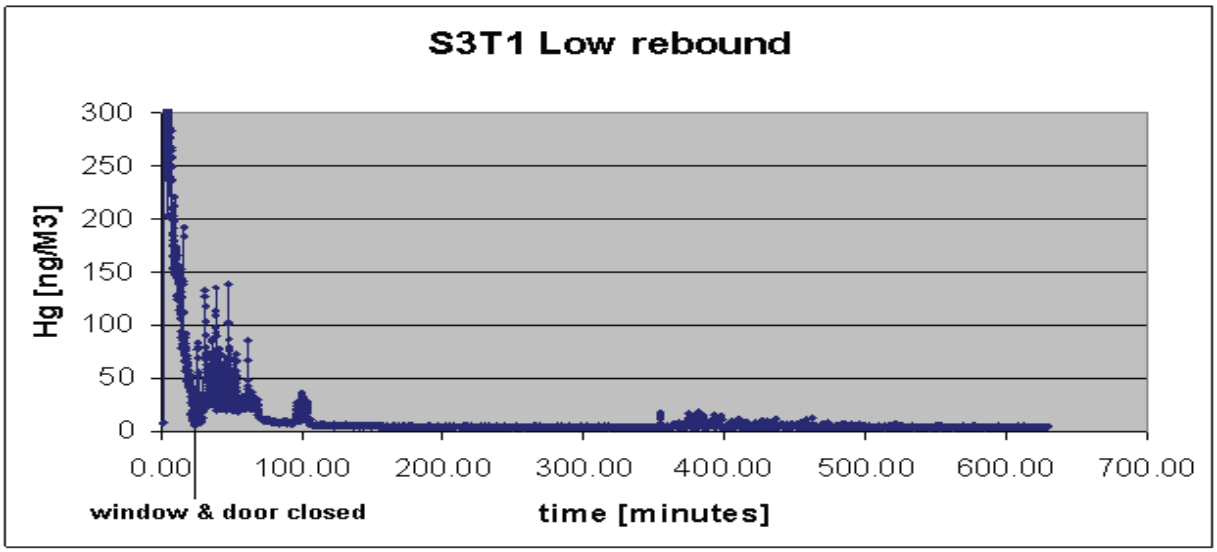


Figure 6-3: Trial S3T1 at 1' intake. Mercury concentration (Hg) scaled to evaluate rebound.

These data suggest that venting, cleaning up a broken CFL and removing the broken lamp from the room reduces mercury concentrations in the room below the MAAG with no significant rebound when the room is no longer vented. We did not notice a significant difference in room mercury concentrations among cleanup scenarios or flooring surfaces for the original study scenarios using "Brand A" CFL.

See Appendix A Figures A-78 and A-79 for graphs showing a small mercury rebound in the air when a "Brand A" CFL, broken on carpet and cleaned up/ vacuumed 28 days earlier, was re-vacuumed. The rebound from the re-vacuuming (non-beater type vacuum) of a "Brand A" 60 watt replacement CFL with the window closed did not exceed 300 ng/m^3.

6.3.4 Additional Study Rebound Evaluation

As with average mercury concentrations from Tables 6-3 and 6-4, there is a difference in rebound for the additional scenarios. The potential for study room mercury concentrations to rise after a successful cleanup (rebound) was evaluated for varying CFL types by closing the window and door when mercury concentrations fell below 20 ng/m^3 and monitoring room mercury concentrations for a period of time to see if concentrations rose above 300 ng/m^3. Table 6-6 documents run length (the amount of time a trial was monitored with lumex), time window and door were closed and the time mercury concentrations were monitored to evaluate rebound for CFL types in the additional study scenarios.

Table 6-6. Rebound for Additional Scenarios

Trial Name	Lamp Type	Run Length (minutes)	Lamp Broken (minutes Begin)	Corrected Run Lenth (minutes)	Time Window/ Door closed (minutes)	Rebound Time Check (minutes)
SA	"Brand B" 26w=90watts	361.4	21.00	340.4	136.67	204
SA-D		682.8	4.92	677.9	285.00	393
SB	"Brand C" 13w=60	772.8	18.33	704.5	150.42	554
SB-D		361.0	15.25	345.8	67.67	278
SC	"Brand C"	271.0	35.50	235.5	200.00	36

Trial Name	Lamp Type	Run Length (minutes)	Lamp Broken (minutes Begin)	Corrected Run Lenth (minutes)	Time Window/ Door closed (minutes)	Rebound Time Check (minutes)
SC-D	13w=60watts	361.4	4.42	357.0	109.17	248
SD	"Brand A" 14w=60watts	421.4	13.25	408.2	55.33	353
SD-D		271.0	11.25	259.8	38.83	221
SE	"Brand B" 26w=100watt	271.0	3.33	267.7	98.67	169
SG	"Brand D" 23w=100watts	91.0	4.00	87.0	57.25	30
SH	"Brand E" 15w=60watts	141.0	4.17	136.8	49.75	87
SI	"Brand F" 15w=50watt	141.0	7.58	133.4	33.08	100
SJ	"Brand A" 14w=60watts	121.4	4.33	117.1	64.67	52
SK	"Brand B" 26w=90watts	481.4	10.17	471.3	100.00	371

Trials SA, SC, SC-D (SC duplicate), SD, SD-D (SD duplicate), SG, SH, SI and SJ were all conducted on pre-finished wood flooring using pre-study cleanup guidance. No concentrations above 50 ng/m^3 after the window and door were closed were recorded for any of these trials. Trials SB-D (SB duplicate) and SE, both conducted on pre-finished wood flooring using pre-study cleanup guidance, had several spikes above 50 ng/m^3 but less than 300 ng/m^3.

Trial SK had frequent spiking above 50 ng/m^3 and one spike over 300 ng/m^3. This trial was conducted on carpet using a bag-less, non-beater style vacuum for cleanup, similar to scenario six in the original study scenarios.

Trial SB, conducted on short nap carpet using pre-study cleanup guidance, had frequent spiking above 300 ng/m^3 between 73-175, 327-405 and 675-696 minutes after break and may have continued if the experimental trial had been extended. The window and door were closed at 150 minutes, in the middle of the first mentioned spiking event.

Trial SA-D, conducted on pre-finished wood flooring, had frequent spiking above 300 ng/m^3 from the time the window and door were closed until near the end of the run 393 minutes later and may have continued if the experimental trial had been extended.

As with average mercury concentration data, these data illustrate the importance of considering variability among brands when setting cleanup guidance.

6.4 Variability Among Lamp Types

Variability among lamp types was further evaluated by comparing trials where lamps were broken on wood floors. The room was ventilated by opening the 30" x 38" window and cleanup was conducted using the pre-study cleanup guidance, which consisted of cleaning up glass over 3/8" by hand, cleaning smaller pieces with index cards, taping and wet wiping over the area, and removing waste from the room. Mercury vapor concentrations were measured continuously at 1' and 5' analyzer intakes. See Table 6-7 below for a comparison of trial results by lamp type.

Table 6-7. Comparison of results by lamp type (all of these breaks on wood flooring, room vented, cleanup)

Trial	Lamp type and equivalent wattage	Maximum mercury (ng/m^3) at 5' intake	Maximum mercury (ng/m^3) at 1' intake	Time above 300 ng/m^3 in minutes at 5' intake	Time above 300 ng/m^3 in minutes at 1' intake	1 Hr Average mercury (ng/m^3) at 5' intake	1 Hr Average mercury (ng/m^3) at 1' intake	Notes
SE	"Brand B" 100	7,288	65,094	23.67	40.50	527	1,048	
SED	"Brand B" 100	4,206	25,399	48.50	39.84	806	738	
SA	"Brand B" 90	1,640	7,410	15.5	10.41	199	185	older CFL
SAD	"Brand B" 90	9,893	61,037	65.5	252.42	815	1,398	older CFL
SF	"Brand B" 100wait	8,285	54,142	81+	81+	2,992	2,745	vented 46 minutes before cleanup
SI	"Brand F"50	485	687	2.67	5.50	54	70	amalgam
SH	"Brand E" 60	4,543	17,178	15.50	11.08	232	263	
SG	"Brand D" 100	956	8,603	16.00	16.08	111	377	
SC	"Brand D" 60	4,257	27,224	30.83	21.92	424	684	
SCD	"Brand D" 60	5,927	6,164	25.67	21.00	298	310	
S2 T1	"Brand A" 60	745	10,040	2.25	2.00	108 (30 minutes)	199 (30 minutes)	30 minute run
S2 T2	"Brand A" 60	765	9,173	1.83	0.66	26	50	
S2 T3	"Brand A" 60	489	17,569	1.42	4.00	29	126	
SBD	"Brand C" 60	1,139	9,523	11.75	14.58	155	220	

Table 6-8 displays 15 minute, 30 minute and one hour average mercury concentrations with 95% upper confidence limit (UCL)19 of the averages for study original scenario two (S2) using Brand A 14w=60watts lamps versus all scenario two type trials performed in the overall study (including additional scenarios SA, SB, SC, SE, SG, SH and SI as well as the original S2). Relative standard deviation (RSD) was calculated for each average as one way to assess variability.

Table 6-8.

Statistic	Intake	Original Scenario 2[d]	All Scenario 2[e]	Units
15 minute average[a]	H	106	**679**[g]	ng/m^3
15 minute 95% UCL[b]	H	182	**2394**	ng/m^3
15 minute RSD[c]	H	42	95	%
30 minute average	H	67	**477**	ng/m^3
30 minute 95% UCL	H	127	**1663**	ng/m^3
30 minute RSD	H	54	94	%
60 minute average	H	37	295	ng/m^3
60 minute 95% UCL	H	104	**1046**	ng/m^3
60 minute RSD	H	43	92	%
15 minute average	L	**307**	**1228**	ng/m^3
15 minute 95% UCL	L	**639**	**2630**	ng/m^3
15 minute RSD	L	43	98	%
30 minute average	L	176	**745**	ng/m^3
30 minute 95% UCL	L	298	**1589**	ng/m^3
30 minute RSD	L	41	97	%
60 minute average	L	95	**441**	ng/m^3
60 minute 95% UCL	L	not calculated[f]	**1500**	ng/m^3
60 minute RSD	L	42[g]	93	%

a Averages here represent the average mercury concentration of scenario trial averages. Three Brand A CFL trials are included for "Original Scenario 2" and fourteen trials are included in "All Scenario 2", three for Brand A CFL, four Brand B, two Brand C, three Brand D, one Brand E and one Brand F.

b UCL = Upper confidence limit of the mean as calculated by ProUCL in conjunction with Table 15-4 Recommended UCL95 Computation Methods for Full-Uncensored Data Sets without Nondetect Observations (nonparametric)

c RSD = Relative Standard Deviation is computed as follows: RSD = 100 X (Standard Deviation of Trial averages)/(Average of Trial averages)

d Averages and RSD computed for Brand A lamps from S2 of the study (original study scenarios).

e Averages and RSD computed for all Scenario 2 type trials including lamps from S2, SA, SB, SC, SE, SG, SH and SI.

f Sixty minute 95% UCL of the mean could not be calculated for S2 because S2T1 was stopped at 30 minutes.

g Sixty minute RSD could not be calculated for S2 because S2T1 was stopped at 30 minutes. Relative Percent Difference (RPD) was calculated as follows: RPD = absolute value of 100 X (Value 1-Value 2)/Average of Values.

* Bolded values are over 300 ng/m^3.

Note that averages as well as RSD for the "All Scenario 2" column are consistently higher than the averages and RSD for lamps from the "Original Scenario 2" column. RSD for "All Scenario 2" are approximately twice the value of RSD for "Original Scenario 2" and average mercury concentrations are much higher than twice the value.

Another way to view variability is given in Figure 6-4, where 15 minute, 30 minute and 1 hour average mercury concentrations are plotted by lamp type. Note that some groupings include only one lamp where others include two, three or four. Also note that some groupings include one brand but several power (watt) levels. To conclude that one brand has lower overall mercury emissions than another is not as straight forward as interpreting this graph.

19 ProUCL 4.0 for Environmental Applications For Data Sets with and without Nondetect Observations, US Environmental Protection Agency (EPA), April, 2007

These data do, however, demonstrate a significant level of variability in average room concentrations during and after cleanup of broken CFLs, and one hour average concentrations for some CFLs are almost three times the MAAG. This variability must be taken into account when devising a cleanup strategy that would be adequate in all cases.

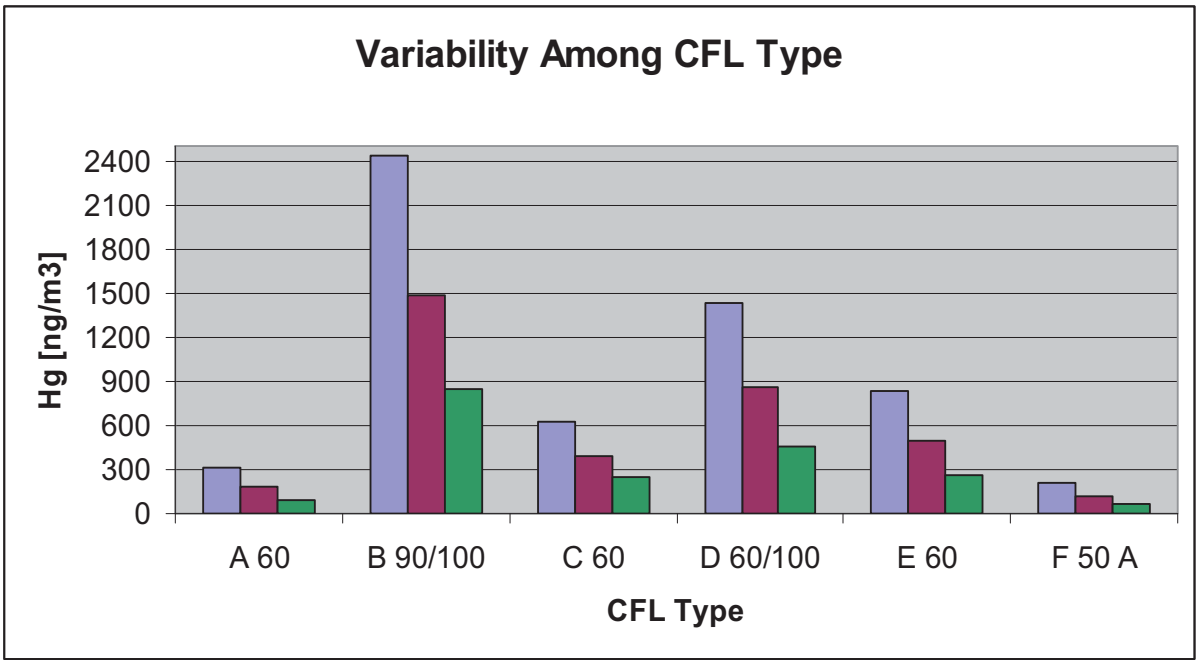


Figure 6-4. Variability by CFL Type where Type = Brand/ model

= 15 minute average

= 30 minute average

= 1 hour average

A 60 = results for average of three Brand A 14w=60watts lamps
B 90/100 = results for average of Brand B two 26w=90watts and two 26w=100watt lamps
C 60 = results for average of two Brand C 13w=60watts lamps
D 60/100 = results for average of Brand D two 14w=60watts and one 23w=100watt lamps
E 60 = results for one Brand E 15w=60watt lamp
F 50 A = results for one Brand F 15w=50watt amalgam technology lamp

6.5 Sources of Mercury Left in Flooring After Cleanup

When a flooring surface is cleaned up such that it appears clean, there is still a source of mercury left in the flooring. Even with wood flooring, a source could remain in the floor for weeks after the lamp breakage was cleaned up. In most cases however, wood flooring cleared within one week. Carpet was harder to clean than wood. Some carpets retained significant sources more than a month after a lamp breakage was cleaned up and after repeated vacuuming.

Measurements were taken for thirteen wood and six rug floor sections/ scenarios. Of the thirteen wood floors tested, ten were monitored until readings were under 300 ng/m^3. Two of the ten took over twenty days to clear. The other eight were cleared in four days or under. Measurements for the six rug sections were more variable. Some carpets, when agitated days and weeks after the breakage and cleanup of various lamps (one broken lamp per flooring), showed mercury concentrations in the air, close to the floor surface (approximately within an inch), as high as 29,000 ng/m^3. One cleared in six days, one in fifteen, one in thirty four and

one in fifty two. The other two rug sections did not clear in the time frame of the testing period (twenty seven days and fifty nine days).

6.5.1 Agitation of Flooring Surfaces

Mercury emissions are more significant when the flooring is agitated than when un-agitated (calm). This has particular significance if the breakage occurs in a high traffic area or where an infant or small child would be crawling or sitting. See Table 6-9 for a depiction of the difference in readings when agitated.

Table 6-9. Lumex readings of flooring in ng/m^3 (within approx. an inch of floor surface)

Scenario	SB-"Brand C" 60A	
Date of Break	6/12/2007	
Floor Type	short carpet	
Days after break	calm	agitated
1	532	1,418
2	<20	1,820
3	190	6,197
6	233	5,102
7	195	2,129
9	<20	1,220
10	289	2,900
13	215	947
14	351	6,531
15	1,004	9,197
16	207	4,697
17	544	1,983
20	233	570
(vacuumed) 21	195	5,694
23	1,803	13,010
(vacuumed) 24	1,686	12,750
(vacuumed) 27	253	2,317
(vacuumed) 28	2,077	3,717
29	959	2,297

See Figure 6-5 for another view of these data. A hammer encased in plastic or a gloved hand was used to rub and tap the flooring to get the agitated reading and was intended to simulate use of the carpet.

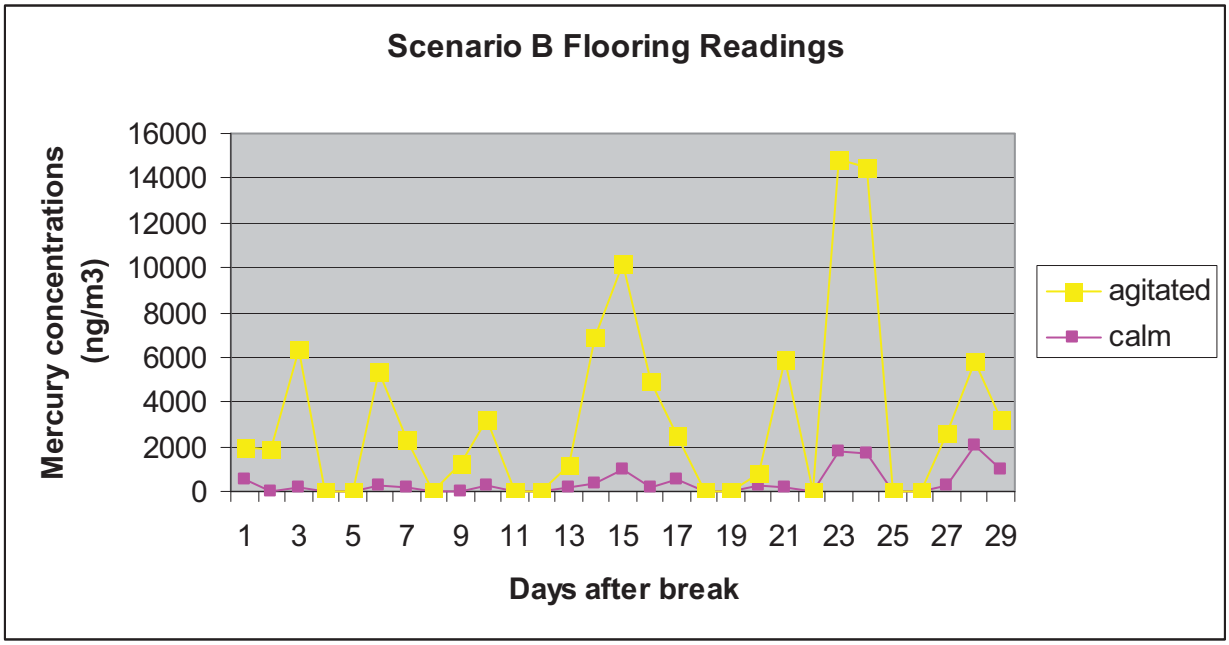


Figure 6-5. SB flooring readings over time taken one inch from carpet

6.5.2 Spiking in Air Concentrations from Sources in Flooring

In addition, mercury sources in flooring can continue to spike mercury concentrations in a room after the concentrations appear to be below the MAAG. It is unclear why this occurs or how long this phenomenon occurs. It is also unclear what the potential health effects might be from these spike exposures. See Figures 6-6 and 6-7 below for a depiction of two scenarios where significant spiking in mercury concentrations occurred, one on wood and one on carpeting. Figure 6-6 shows the significant spiking from a carpet where the room air at the one foot height was under the MAAG for over four hours before then exceeding the MAAG again for about an hour. Figure 6-7 shows the same spiking effect in air concentrations at the one foot height from a wood flooring scenario.

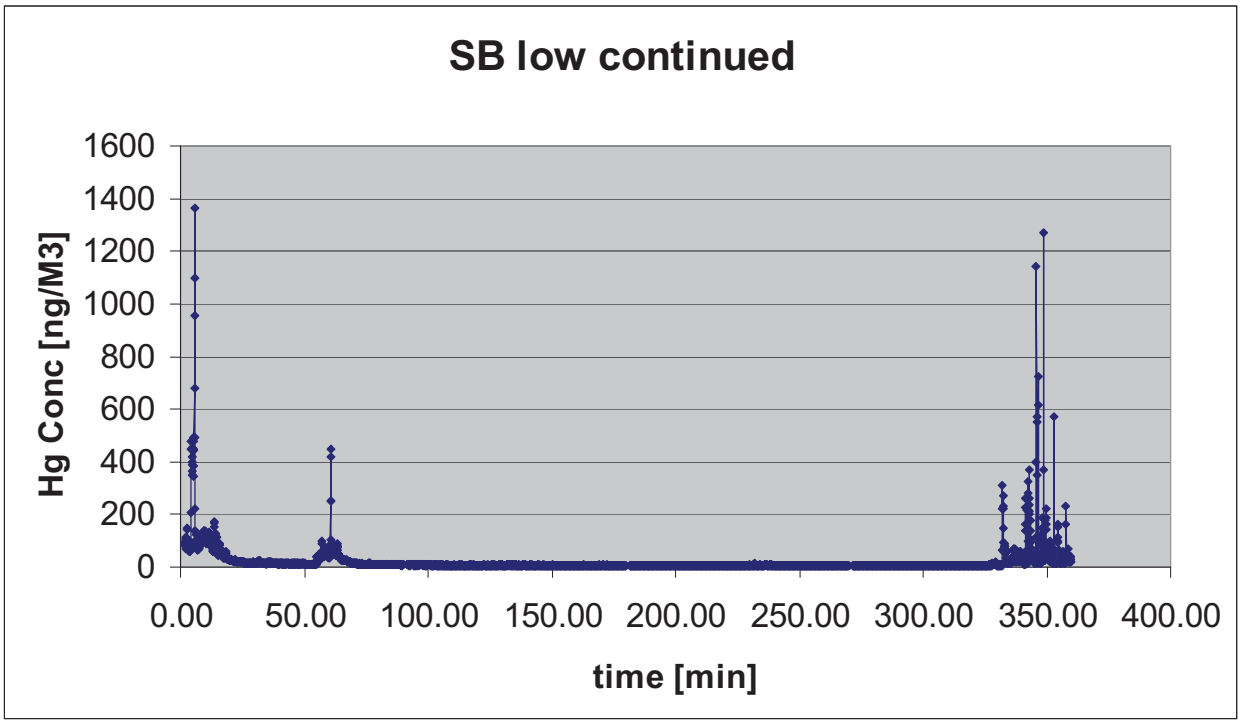


Figure 6-6. Spiking in Scenario B carpet at one foot height

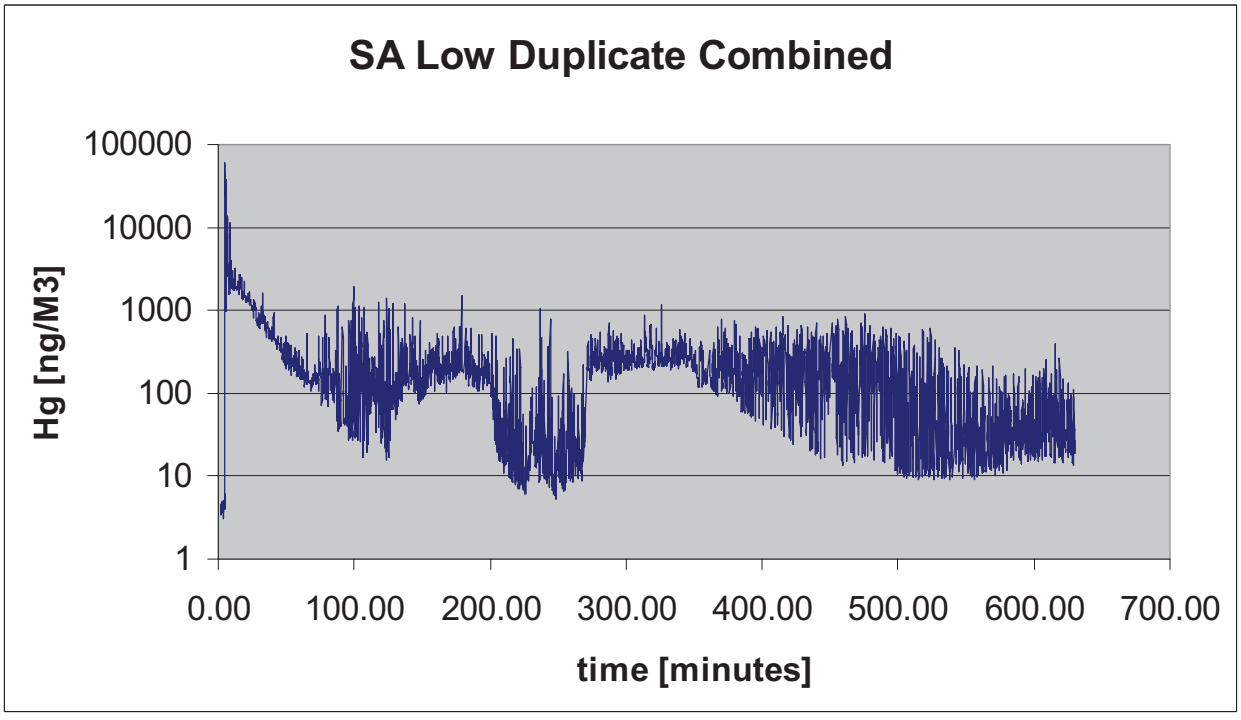


Figure 6-7. Spiking in Scenario A pre-finished wood flooring at one foot height

6.6 What effect does vacuuming have on cleanup?

Since flooring surfaces were visually clean after following the cleanup guidance, would vacuuming following cleanup be a problem and could vacuuming be added as a tool to clean up lamp breakage?

Four scenarios were conducted where the lamp breakage was cleaned up in part via vacuuming: S5, S6, SK and SL. See Table 6-10 for details. Eight scenarios were conducted that utilized vacuuming not as the initial cleanup but as a vacuuming of previously cleaned carpets: S5T3 Revacuum, SBvac1 through SBvac4, and SLvac2 through SLvac4. See Table 6-11. One previously vacuumed carpet was placed in the test room to monitor off-gassing from the carpet source, SLCarpet. See Table 6-13 and Figure 6-10 below for details. Various flooring measurements were taken over time to determine whether a source of mercury was left in flooring surfaces even when visually clean. See Appendix H-4. In addition, vacuum measurements were taken to determine if a vacuum could become irreversibly contaminated such that it could not be easily decontaminated. Vacuum measurements from two vacuums are contained in Tables H-5 and H-6, which show the difficulty in consistently cleaning vacuums of mercury contamination. See additional details on vacuuming results in Appendix H.

Initially Scenario 5 (Brand A, beater vacuum, on short pile carpet) and Scenario 6 (Brand A, non aggressive beater vacuum, on long pile carpet) caused the researchers to be cautiously optimistic about vacuuming as a part of cleanup. However, after all vacuum runs were completed, it became clear that there is a wide variation in results depending on many variables including whether or not the room is ventilated during and after vacuuming, how aggressive the beater attachment is, and the type of lamp broken on the flooring surface.

6.6.1 Effect of Vacuuming on Room Air Concentrations

As with other aspects of the study, there is a great deal of variability present in the data on vacuuming.

For scenarios where breakage was cleaned up in part by vacuuming, virtually all initial mercury concentrations from breaking the lamps were over the MAAG. Of the sixteen trials (including both one foot and five foot readings), fifteen initial maximum concentrations are over 300 ng/m^3, some substantially higher than the MAAG. These scenarios included breaks from two brands of lamps (Brand A and Brand B). The six Brand A lamps had initial mercury readings over the MAAG in five out of six of the readings. The two Brand B lamps had initial mercury readings over the MAAG in four out of four of the readings. These higher initial mercury readings represent the mercury release from the initial lamp break. All lamp breaks occurred prior to venting; all but one of the vacuuming events was in a vented room.

Three of the sixteen one hour averages are over 300 ng/m^3. All six of the Brand A lamps were vented and had one hour averages under the MAAG. One of four Brand B lamps had a one hour average under the MAAG. This was the one hour average at the five foot height in the vented room with the non beater vacuum. Brand type, venting and aggressiveness of beaters seem to have an effect on one hour average vacuum concentrations. See Table 6-10.

Vacuum Scenario Results

Table 6-10. Initial Vacuum Results where vacuum was used to clean up broken lamp

Scenario	Maximum concentration of mercury (ng/m^3)	Time above 300 ng/m^3 in minutes	Average mercury concentration for 1 hour (ng/m^3)	Average mercury concentration for 8 hours (ng/m^3)	Average mercury concentration for 24 hours (ng/m^3)
S5 Brand A Beater vacuum Short pile carpet	**At 5 feet**: 628 328 315 **At 1 foot:** 18,578 8,815 3,953	**At 5 feet**: 5.25 1.66 5.5 **At 1 foot:** 7.83 2.08 5.83	**At 5 feet**: 97 123 61 **At 1 foot:** 202 128 77		
S6 Brand A Non aggressive beater vacuum Long pile carpet	**At 5 feet**: 350 414 236 **At 1 foot:** 1,811 16,942 1,811	**At 5 feet**: 2.16 1.67 0 **At 1 foot:** 3.33 3.08 2.16	**At 5 feet**: 99 72 48 **At 1 foot:** 86 133 41		
SK Brand B Non beater vacuum Long pile carpet	**At 5 feet**: 2,034 **At 1 foot:** 2,392	**At 5 feet**: 24.0 **At 1 foot:** 32.67 Spike at 193.84	**At 5 feet**: 241 **At 1 foot:** 368		
SL Brand B Beater vacuum Short pile carpet	**At 5 feet**: 23,720 **At 1 foot:** 133,955	**At 5 feet**: >1,500 **At 1 foot:** >1,500	**At 5 feet**: 16,814 **At 1 foot:** 21,262	**At 5 feet**: 12,364 **At 1 foot:** 14,384	**At 5 feet**: 4,490 **At 1 foot:** 5,130

For vacuuming scenarios completed on previously cleaned carpet, 13 of the 16 initial mercury concentrations (including both one foot and five foot heights), exceed the 300 ng/m^3. It is important to note that unlike Table 6-10 above, these higher initial mercury readings do not represent a lamp break but rather the disturbance of the mercury source left in the carpet. This

is a scenario representative of vacuuming as a part of regular housekeeping following a lamp break and clean up.

Twelve of the 16 one hour averages are over the MAAG, again including both one foot and five foot heights. Three brands of lamps were involved in these revacuuming events (Brand A, Brand B, and Brand C). Two of two of the Brand A readings were under the MAAG. This scenario was also the only vented room scenario. Six of six Brand B readings were over the MAAG. Four of six of the Brand C readings were over the MAAG. The two that were under the MAAG were from the fourth vacuum event of the same carpet, suggesting that vacuuming might eventually reduce mercury concentrations in the room air after a number of revacuums. All but one of the scenarios were in an unvented room; which is a likely scenario for homes where a lamp break occurred days or weeks previous to the vacuum event. This raises concerns about vacuuming carpet where a lamp was previously broken, particularly depending on the brand of lamp broken earlier on the carpet.

Table 6-11. Vacuum Results where carpet was vacuumed where a lamp had previously been broken and cleaned up but where the vacuum in these trials was not used to clean up the initial breakage. These trials were vacuuming the residual source left in the carpets.

Scenario	Maximum concentration of mercury (ng/m^3)	Time above 300 ng/m^3 in minutes	Average mercury concentration for 1 hour (ng/m^3)	Average mercury concentration for 8 hours (ng/m^3)	Average mercury concentration for 24 hours (ng/m^3)
S5T3 Revacuum Brand A Beater vacuum Short pile carpet	**At 5 feet**: 72 **At 1 foot:** 130	**At 5 feet**: 0 **At 1 foot:** 0	**At 5 feet**: 57 **At 1 foot:** 40	**At 5 feet:** <20 **At 1 foot:** 13	
SBvac1 Brand C Beater vacuum Short pile carpet	**At 5 feet**: 4,529 **At 1 foot:** 14,779	**At 5 feet**: >81 **At 1 foot:** >350spikes	**At 5 feet**: 3,406 **At 1 foot:** 2,554	**At 5 feet**: No data **At 1 foot:** 677(6 hour average)	
SBvac2 Brand C Beater vacuum Short pile carpet	**At 5 feet**: 3,090 **At 1 foot:** 3,077	**At 5 feet**: 88.08 **At 1 foot:** >350spikes	**At 5 feet**: 1,207 **At 1 foot:** 714	**At 5 feet**: 266 (6 hour average) **At 1 foot:** 223 (6 hour average)	

Scenario	Maximum concentration of mercury (ng/m^3)	Time above 300 ng/m^3 in minutes	Average mercury concentration for 1 hour (ng/m^3)	Average mercury concentration for 8 hours (ng/m^3)	Average mercury concentration for 24 hours (ng/m^3)
SBvac3 Brand C Beater vacuum Short pile carpet	**At 5 feet**: 680 **At 1 foot:** 2,001	**At 5 feet**: 167.08 **At 1 foot:** 146.33	**At 5 feet**: 584 **At 1 foot:** 422	**At 5 feet**: 253 **At 1 foot:** 180	
SBvac4 Brand C Beater vacuum Short pile carpet	**At 5 feet**: 228 **At 1 foot:** 427	**At 5 feet**: 0 **At 1 foot:** 0[20]	**At 5 feet**: 172 **At 1 foot:** 113	**At 5 feet**: 79 (6 hour average) **At 1 foot:** 52 (6 hour average)	
SLvac2 Brand B Beater vacuum Short pile carpet	**At 5 feet**: 3,135 **At 1 foot:** 36,397	**At 5 feet**: 530.75 **At 1 foot:** >1,200 spikes[21]	**At 5 feet**: 2,623 **At 1 foot:** 2,444	**At 5 feet**: 1,429 **At 1 foot:** 1,471	**At 5 feet**: 691 (20 hour average) **At 1 foot:** 729 (20 hour average)
SLvac3 Brand B Beater vacuum Short pile carpet	**At 5 feet**: 3,708 **At 1 foot:** 19,270	**At 5 feet**: 539.33 **At 1 foot:** >1,200 spikes[22]	**At 5 feet**: 2,671 **At 1 foot:** 2,768	**At 5 feet**: 2,590 **At 1 foot:** 2,587	**At 5 feet**: 1,038 (20.5 hour average) **At 1 foot:** 1,236 (20 hour average)
SLvac4 Brand B Beater vacuum Short pile carpet	**At 5 feet**: 3,288 **At 1 foot:** 12,367	**At 5 feet**: 523.75 **At 1 foot:** >1,200 spikes[23]	**At 5 feet**: 1,986 **At 1 foot:** 1,871	**At 5 feet**: 1,502 **At 1 foot:** 2,244	**At 5 feet**: 574 (20 hour average) **At 1 foot:** 1,085 (20 hour average)

[20] Spikes at 0.25, 77.92, & 299.17
[21] Still spiking over 1,000 ng/m3.
[22] Still spiking above 1,000 ng/m3.
[23] Still spiking over 400 ng/m^3.

6.6.2 Effect on Room Air When Mercury Sources Left in Carpet are Vacuumed After Cleanup

The mercury sources left in flooring after cleanup can be released into the room air with vacuuming. See an example in Figures 6-8 and 6-9 of a mercury source left in carpet where a lamp break was cleaned up 21 days previous to the vacuuming. The carpet was vacuumed in an unvented room to simulate a likely homeowner scenario. A homeowner would not be likely to open a window prior to vacuuming when the breakage occurred three weeks earlier. When vacuumed, the mercury source in the carpet caused the room to exceed the MAAG at both the infant/toddler breathing zone[24] and the adult breathing zone.[25] See Table 6-12 for a summary of these data.

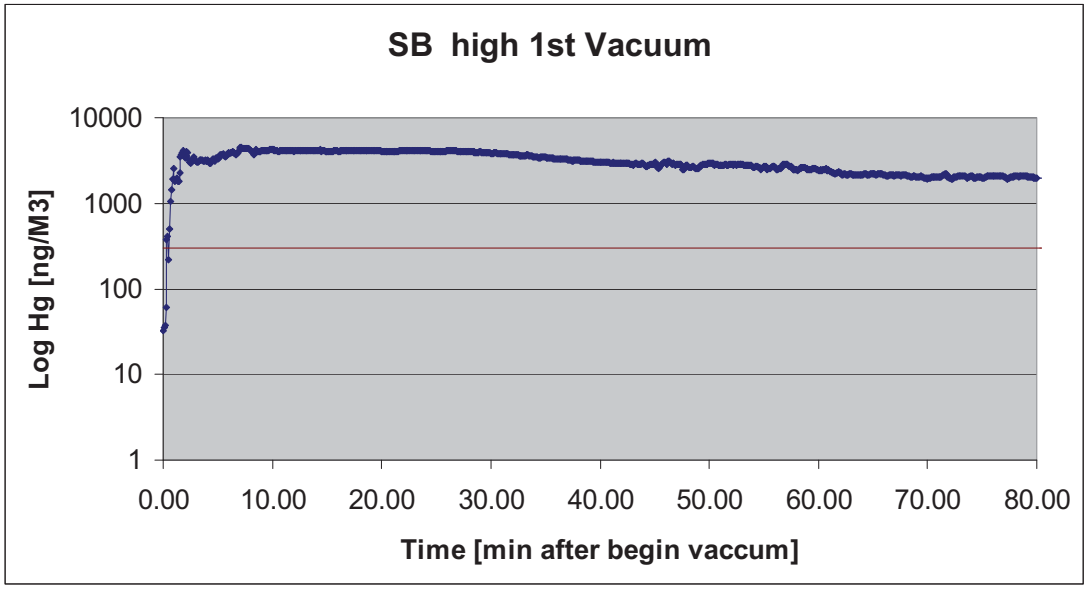


Figure 6-8. First Vacuum of previously cleaned carpet at 5' (6/12/07)

[24] Measured at 1' above floor surface
[25] Measured at the 5' intake

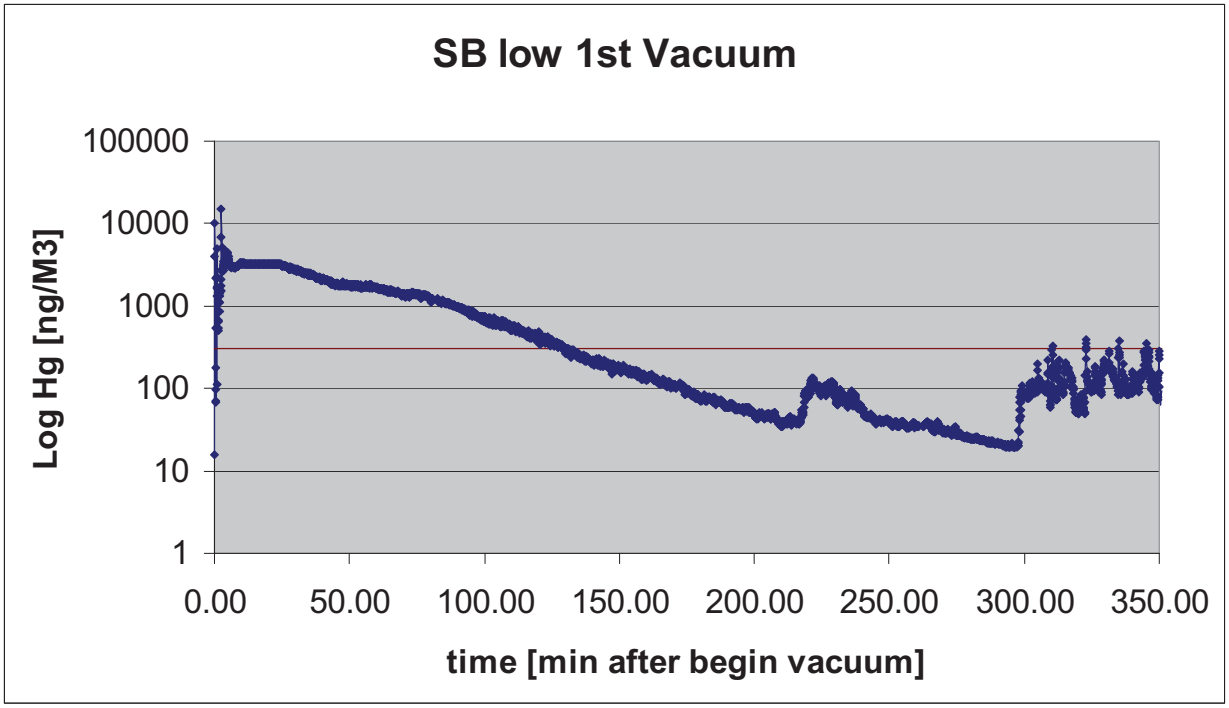


Figure 6-9. First Vacuum of previously cleaned carpet at 1' (6/12/07)

Table 6-12. Lumex readings after vacuuming a carpet where a lamp break had been cleaned up via non vacuum techniques 21 days earlier

Scenario	Maximum concentration of mercury (ng/m3)	Time above 300 ng/m3 in minutes	Average mercury concentration for 1 hour (ng/m3)	Average mercury concentration for 8 hours (ng/m3)
SBvac1	**At 5 feet**: 4,529 **At 1 foot:** 14,779	**At 5 feet**: >81 **At 1 foot:** >350spikes	**At 5 feet**: 3,406 **At 1 foot:** 2,554	**At 5 feet**: No data **At 1 foot:** 677(6 hour average)

6.6.3 Effect of Mercury Sources in Flooring on Room Air even when not Vacuumed

The source in the flooring can be significant enough that even when not being vacuumed the flooring can off-gas enough to cause the room air to exceed the MAAG. See Figures 6-10 and 6-11, Scenario L carpet combined high and low**,** which depict off-gassing from a carpet, causing the room air to exceed the Maine Ambient Air Guideline for over 26 hours at the infant/toddler breathing zone and for 11 hours at the adult breathing zone. See Table 6-13 for a summary of these data.

Table 6-13. Lumex readings of emissions from a carpet where a lamp break had been cleaned up via vacuuming 7 days earlier followed by three more vacuums

Scenario carpet	Maximum concentration of mercury (ng/m3)	Time above 300 ng/m3 in minutes	Average mercury concentration for 1 hour (ng/m3)	Average mercury concentration for 8 hours (ng/m3)	Average mercury concentration for 24 hours (ng/m3)
SLcarpet	**At 5 feet**: 1,186 **At 1 foot:** 5,679	**At 5 feet**: 652.42 **At 1 foot:** >1,600 spikes[26]	**At 5 feet**: 135 **At 1 foot:** 699	**At 5 feet**: 491 **At 1 foot:** 1,056	**At 5 feet**: 255 **At 1 foot:** 561

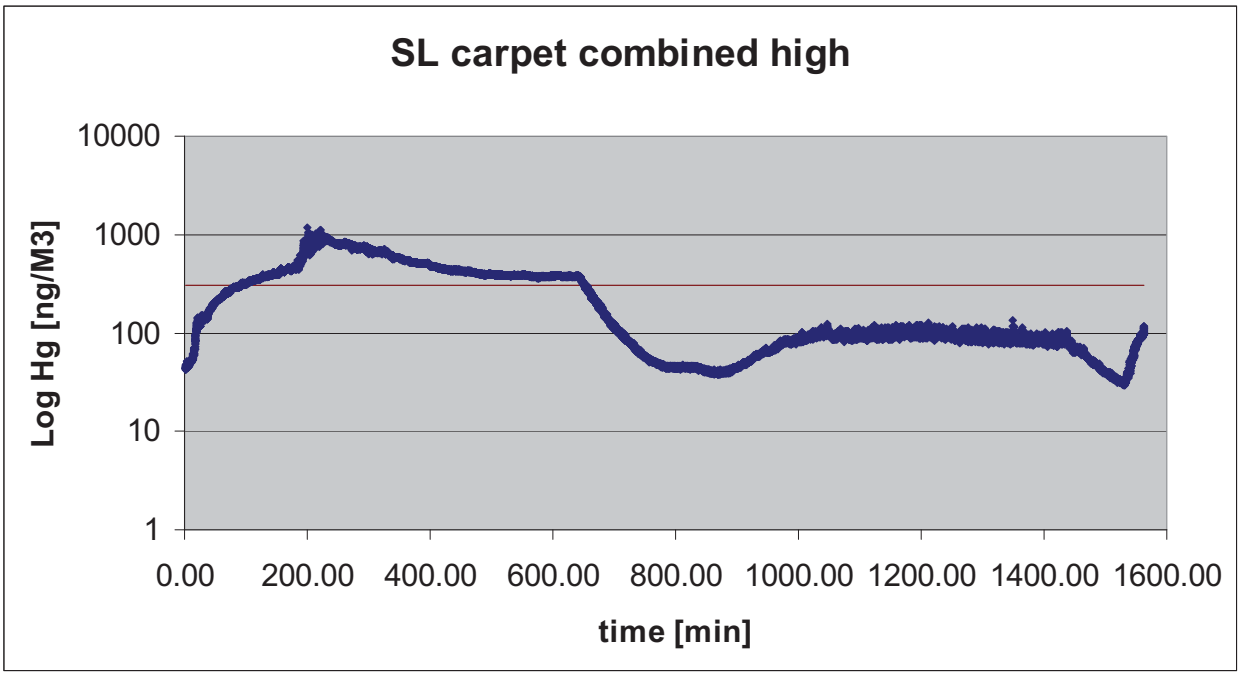


Figure 6-10. Off-gassing from carpet at 5' (7/26/07)

[26] Still Spiking over 800 ng/m^3.

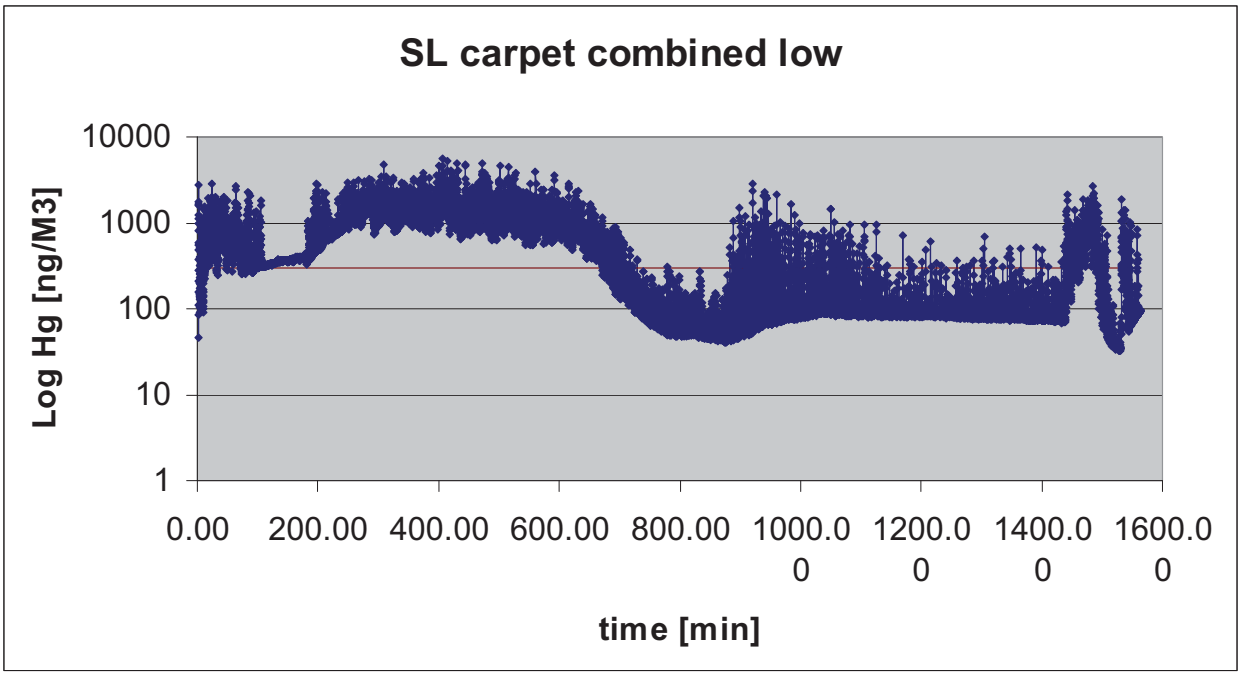


Figure 6-11. Off-gassing from carpet at 1' (7/26/07)

6.6.4 Contamination of Vacuum

The effect of contaminating a vacuum with mercury is unclear from this study. We do not know if the vacuum itself can spread contamination from room to room or elevate mercury levels in a room when operated after becoming contaminated.

However, it is clear that vacuums can become contaminated such that they are not easily decontaminated. Figures 6-12 and 6-13 show a vacuum scenario where the vacuum was not successfully decontaminated. Figure 6-14 and 6-15 show a vacuum scenario where the vacuum was substantially decontaminated after numerous targeted cleanings with wet wipes.

In general removing the vacuum bag and thoroughly wiping the beater or floor attachment and associated vacuum pieces with multiple wet wipes helps reduce mercury concentrations of the vacuum. See Table H-5 for this effect. However Table H-6 illustrates how wiping and or agitating vacuum parts can move mercury around on the vacuum. Table H-7 depicts the ineffectiveness of airing of a vacuum on reducing mercury concentrations to acceptable levels. Vacuums without aggressive beaters and hose type attachments were easier to decontaminate than more elaborate vacuums, which often had more metal parts and harder to reach pieces to the vacuum. The more elaborate vacuums were generally more expensive and therefore would be unlikely to be thrown away after using to clean up a lamp break. See Tables H-8, H-9 and H-10 for less elaborate vacuums which were decontaminated by using wet wipes.

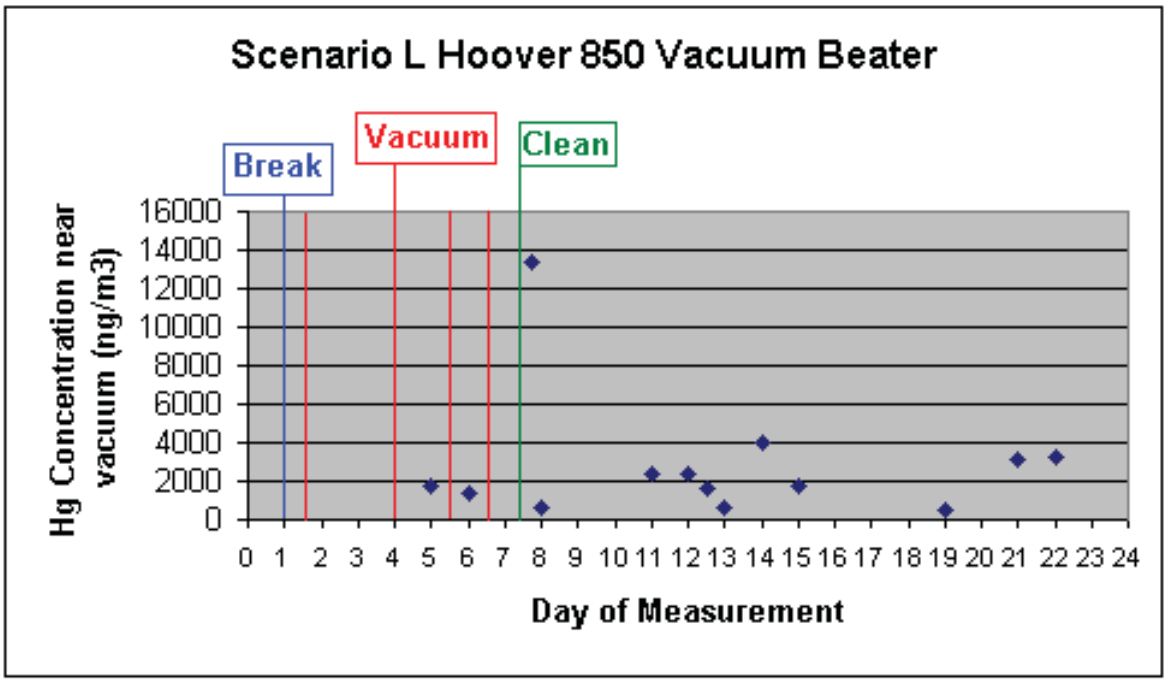


Figure 6-12. The effect of cleaning vacuum beaters during Scenario L (beater end value is 3,198 ng/m^3)

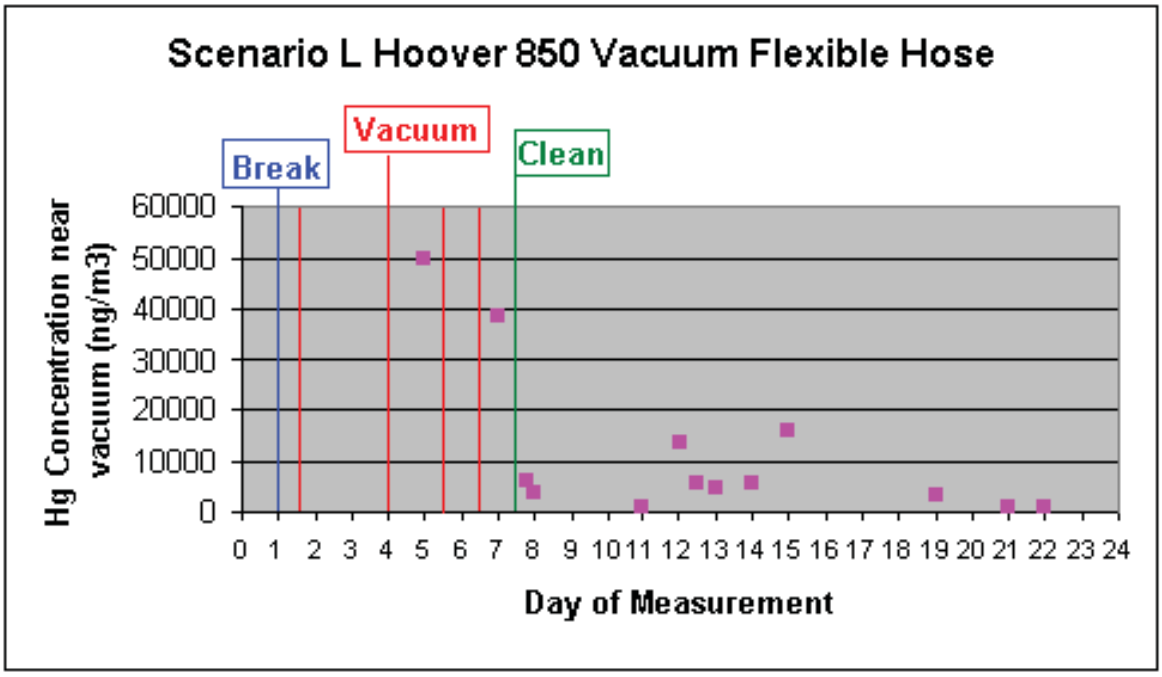


Figure 6-13. The effect of cleaning vacuum flexible hose during Scenario L (hose end value is 804 ng/m^3)

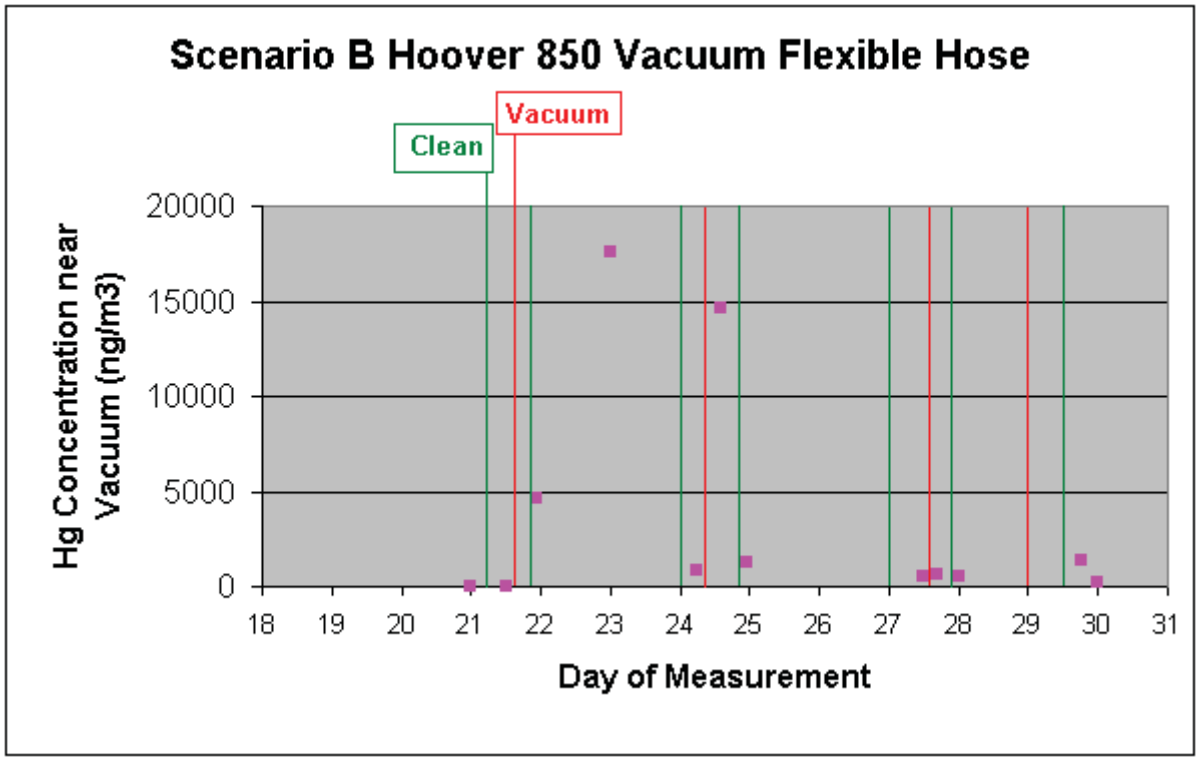


Figure 6-14. The effect of cleaning vacuum flexible hose during Scenario B (hose end value is 214 ng/m^3)

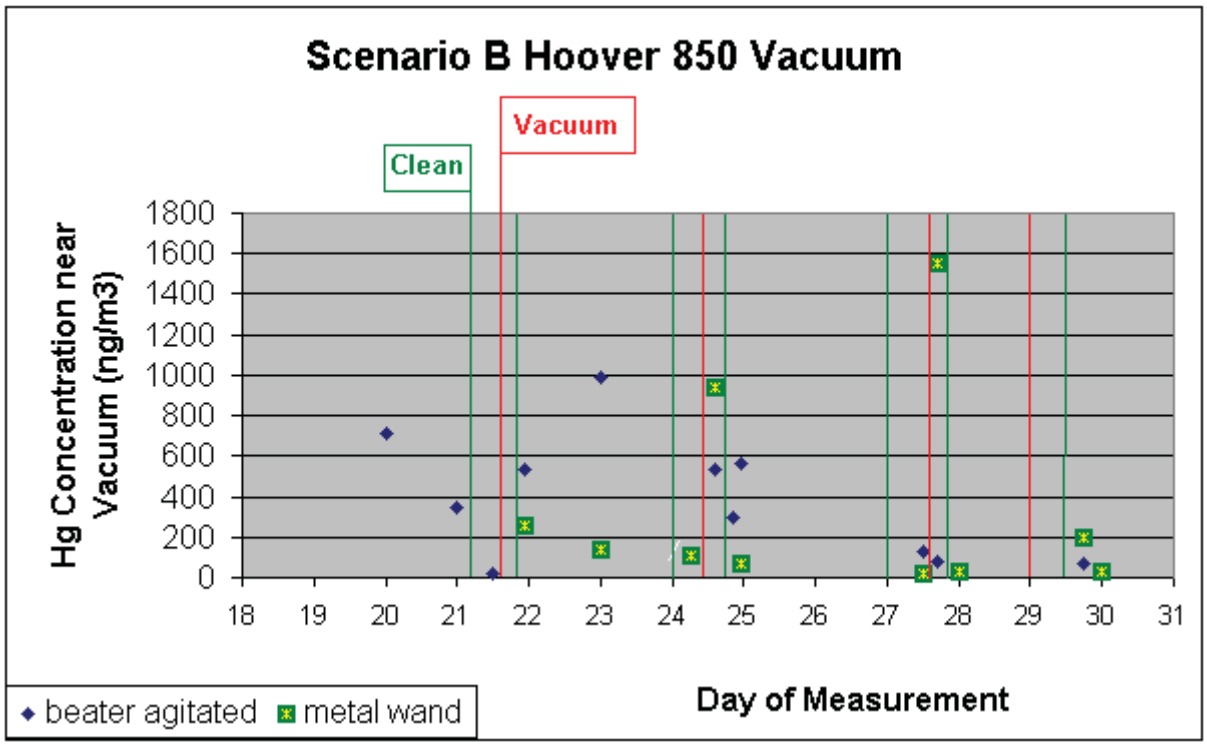


Figure 6-15. The effect of cleaning two vacuum parts during Scenario B (beater end value is 43 ng/m^3 and wand is 25 ng/m^3)

In addition vacuums exhibit the same increase in mercury concentrations when agitated as do carpets. See Table 6-14 for analysis of unagitated to agitated vacuum part readings. This table compares 63 paired vacuum part readings.

Table 6-14. Statistical comparison of vacuum parts when agitated and unagitated

Non-parametric vacuum statistics	**Calm (unagitated)**	**Agitated**
Total Number of Data	63	63
Number of Non-detected Data	14	0
Maximum Detected	4,941 (ng/m^3)	13,400 (ng/m^3)
Percent Non-detects	22.22%	0%
Mean of Detected Data	361 (ng/m^3)	917 (ng/m^3)
Median of Detected Data	75 (ng/m^3)	444 (ng/m^3)

Researchers had the benefit of advanced instruments and were able to identify where mercury resided in the vacuum. This allowed the vacuums to be re-cleaned to eliminate high mercury readings. This likely increased the number of vacuums that were cleaned adequately and the speed with which this occurred. Even with the instrumentation, not all vacuums were able to be decontaminated. A homeowner would not have the benefit of this instrumentation and would not be aware of whether a vacuum was slightly contaminated with mercury or significantly contaminated with mercury, nor would the homeowner be aware of where to focus cleaning attention on the vacuum.

6.6.5 Effect of Beater Vacuum

Vacuums with aggressive beater attachments elevated mercury concentrations in the room air over those vacuums with non aggressive beater attachments. Figure 6-16 illustrates the difference in this feature by comparing Scenario 5 (Brand A, beater vacuum, on short pile carpet) to Scenario 6 (Brand A, non aggressive beater vacuum, on long pile carpet) results.

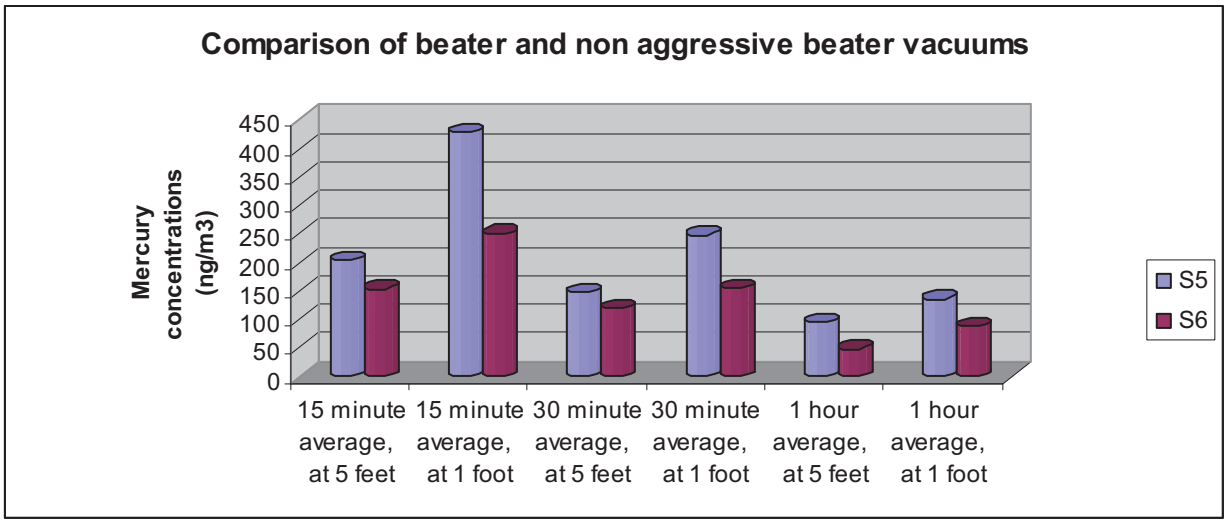


Figure 6-16. Comparison of S5 (beater vacuum) to S6 (non aggressive beater vacuum)[27]

[27] Note S5 was on a short pile carpet and S6 was on a long pile carpet.

6.6.6 Overall Assessment of Vacuuming

Mercury sources left in the carpets, the mercury levels in the air that this can cause in certain circumstances, and the potential to irreversibly contaminate the vacuum are all factors that point toward removal of the carpet section where the lamp has broken. This is the easiest and surest means of eliminating the mercury source that remains in the carpet. We realize this is unpleasant and could be the source of controversy. However, it seems the surest means of eliminating avoidable mercury exposure. It is also an area ripe for further research efforts by others to determine if other means may be effective in either reducing sources in carpeting or in reducing mercury emissions from such carpet sources.

6.7 What is the best container for containing the lamp debris that a homeowner would likely have in the home?

During the study, the researchers became aware that re-sealable plastic bags were not adequately containing mercury emissions from the lamp breakage.[28] Different empty containers were then evaluated to determine what would be the best container to retard mercury vapor emissions until the lamp could be transported safely to a universal waste handling facility. Table 6-15 lists the containers evaluated during phase 1 of the container study and their relative performance in adequately containing mercury emissions.

Table 6-15. Phase 1 Containers evaluated with relative performance

Run	Container	Enclosure	CFL	Performance[29]
1	1 gal #2 plastic Joint Compound bucket/ plastic snap-on lid	5 gal waste pail	"Brand G" 14w = 65w	OK
2	Amber glass jar/ plastic screw on lid	5 gal waste pail	"Brand C" 13w = 60w	Fail
3	Double poly bags*	1 gal waste pail	"Brand B" 26w = 90w	Fail
4	Double poly bags	1 gal waste pail	"Brand C" 13w = 60w	Fail
5	Double poly bags	5 gal waste pail	"Brand A" 14w = 60w	Fail
6	Double poly bags	5 gal waste pail	"Brand B" 13w = 60w	Fail
7	Double poly bags	5 gal waste pail	"Brand D" 14w = 60w	Fail
8	Double poly bags	5 gal waste pail	"Brand C" 13w = 60w	Fail

[28] After three broken CFLs with associated clean up materials and contained in sealed plastic bags were placed in the waste drum, it became clear to the researchers that significant mercury emissions were emitted from the drum when it was opened.

[29] Waste pail trials were evaluated for performance by the rate of increase in mercury vapor concentrations in the waste pails. Regression formulae were calculated by Microsoft® Excel for mercury concentration (Y) in ng/m^3 vs. time (x) in hours for linear regression lines forced through the origin. For $Y \leq 200x$, performance designation = best; for $200x \leq Y \leq 1000x$, designation = OK and for $Y \geq 1000x$ designation = fail. If container studies were terminated before enough data was collected for regression formulae to be calculated because they leaked immediately, the designation was also fail.

Run	Container	Enclosure	CFL	Performance[29]
9	Gladware®	5 gal waste pail	"Brand B" 13w = 60w	Fail
10	Glass peanut butter jar/ metal screw on lid w/ gum seal	5 gal waste pail	"Brand A" 14w = 60w	Best
11	Glass peanut butter jar/ metal screw on lid w/ gum seal	5 gal waste pail	"Brand D" 14w = 60w	Best
12	Glass peanut butter jar/ metal screw on lid w/ gum seal	5 gal waste pail	"Brand B" 13w = 60w	Best
13	Glass pickle jar/ metal screw on lid w/ gum seal	5 gal waste pail	"Brand D" 14w = 60w	Best
14	Mason jar/ metal screw on lid w/ gum seal	5 gal waste pail	"Brand C" 60	Best
15	Metal tea tin/ metal push on lid	5 gal waste pail	"Brand A" 14w = 60w	Fail
16	Paint can/ metal push on lid	5 gal waste pail	"Brand C" 13w = 60w	Fail
17	Plastic peanut butter jar/ plastic screw on lid	5 gal waste pail	"Brand B" 13w = 60w	Fail
18	Plastic yogurt / plastic snap on lid	5 gal waste pail	"Brand B" 13w = 60w	Fail
19	Tidy Cats Cat Litter #2 plastic/ plastic screw on lid	5 gal waste pail	"Brand A" 14w = 60w	OK

*Double poly bags = two re-sealable polyethylene storage bags one inside the other.

Phase 2: In addition, the best and worst containers evaluated in phase 1 were placed in the test room and the air concentrations were recorded. See Table 6-16.

Table 6-16. Phase 2 Containers evaluated with relative performance

Run	Container	Enclosure	CFL	Performance[30]
1	Double poly bags	study room	"Brand B" 26w = 100w	Fail
2	Double poly bags	study room	"Brand D" 14w = 60w	Fail
3	Glass peanut butter jar/ metal screw on lid w/ gum seal	study room	"Brand B" 26w = 100w	Pass
4	Glass peanut butter jar/ metal screw on lid w/ gum seal	study room	"Brand D" 14w = 60w	Pass

As expected, the glass jar with metal screw lid with seal performed well in keeping room air concentrations low in mercury. On the other hand, the double re-sealable bag performed poorly. Within an hour of placing the double re-sealable bag in the test room, mercury vapor concentrations climbed above the MAAG at the adult breathing zone. See Figures 6-17 and 6-18 below for this depiction.

[30]Study room trials were evaluated based on whether or not mercury concentrations at five foot intake were elevated above the MAAG of 300 ng/m^3.

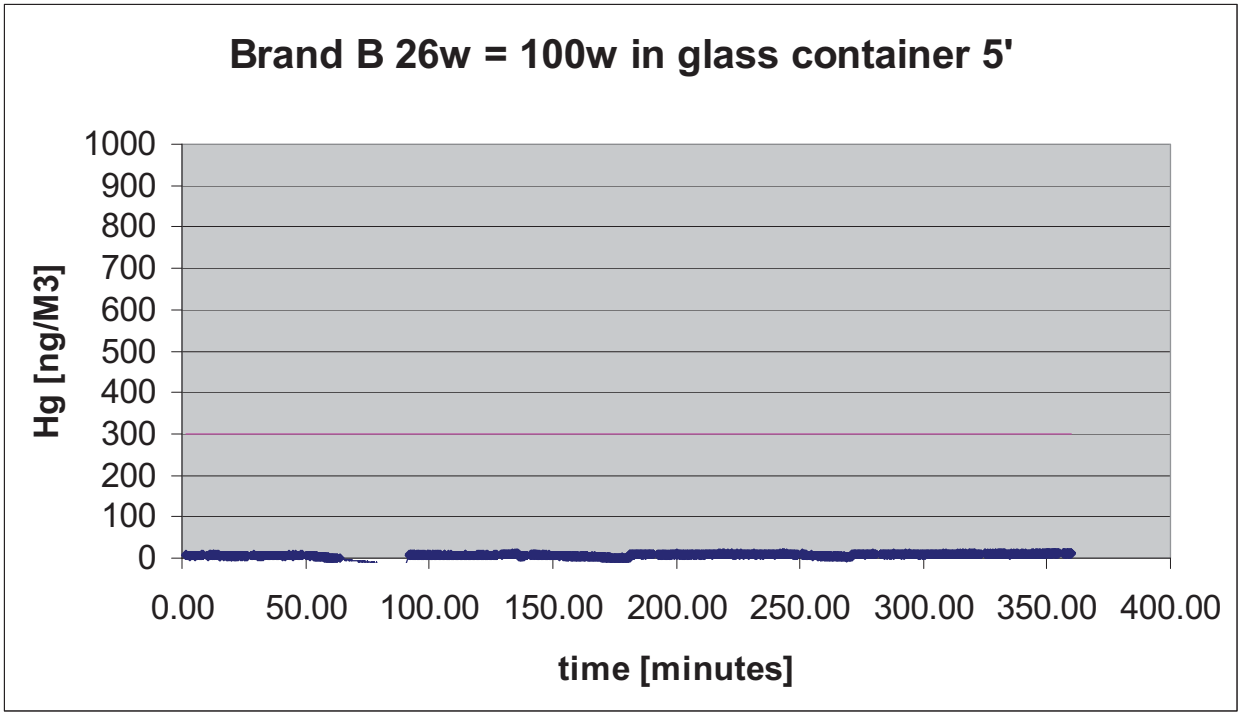


Figure 6-17. Lamp broken outside of study room, put in glass jar, then into unvented study room

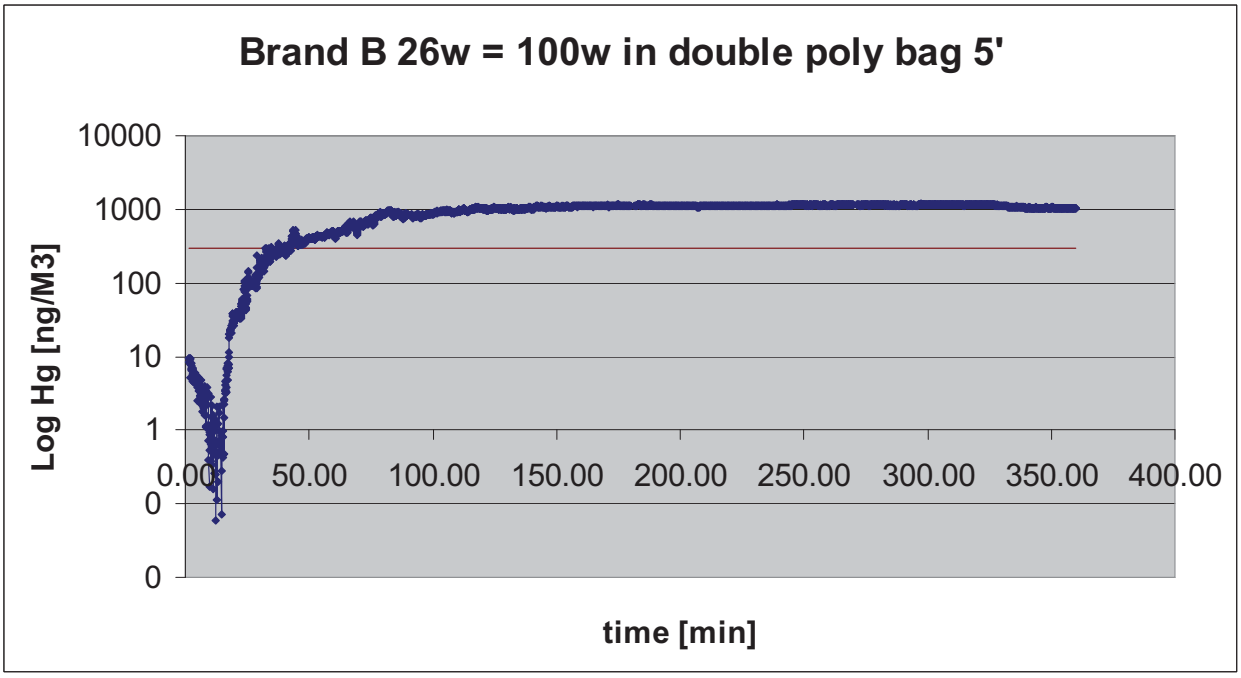


Figure 6-18. Lamp broken outside of study room, put in double plastic sealable bag, then into unvented study room

6.8 Evaluation of Pre-Study Cleanup Guidance

This portion of the study evaluated the cleanup guidance that was in use at the time of the study. The steps utilized in the pre-study cleanup guidance were ventilate room by opening a window, pick up bigger pieces of lamp debris with stiff paper, dab area with tape to pick up smaller pieces of lamp, finish with wiping the area with a wet wipe, and place the lamp debris and clean up materials in sealable bag. This produced visibly clean flooring surfaces for all three types of floors. Below is a discussion of each of the steps in the pre-study cleanup guidance (subsections numbered and in bold) as compared to the study findings.

6.8.1 Never use a vacuum. A standard vacuum can spread dust throughout the area and potentially contaminate the vacuum.

A more detailed discussion of vacuuming is contained in Section 6.6. The guidance to not vacuum was found to be supported by the study findings.

Cleaning breakage with a vacuum can elevate the mercury readings above the MAAG in a room where it can remain elevated for hours depending on if a beater vacuum is used, the lamp type and whether the room is ventilated. For example, in Scenario SL where large pieces of the lamp were manually picked up and then the smaller pieces and dust were vacuumed in an unventilated room with a beater style standard vacuum, the initial mercury readings were 23,720 ng/m^3 and 133,955[31] ng/m^3 at the adult and infant/toddler breathing zone, respectively. The one hour averages were 16,814 ng/m^3 and 21,262 ng/m^3 at the adult and infant/toddler breathing zone, respectively. The twenty four hour averages were 4,490 ng/m^3 and 5,130 ng/m^3 at the adult and infant/toddler breathing zone respectively. These values are well over the MAAG.

However, vacuuming a breakage from a different lamp type with a beater-style standard vacuum in a ventilated room produced different results. For example, in Scenario 5 first trial (S5T1) where the bigger pieces were manually picked up and the rest was vacuumed up, the initial mercury readings were 628 ng/m^3 and 18,578 ng/m^3 at the adult and infant/toddler breathing zone respectively. The one hour averages were 97 ng/m^3 and 202 ng/m^3 at the adult and infant/toddler breathing zone, respectively. These values are over the MAAG (300 ng/m^3) during the initial break. The unagitated one hour averages are under the MAAG however are approaching the level at the infant/toddler breathing zone. With agitation the infant/toddler breathing zone would likely be close or exceed the MAAG. While still of concern initially during breakage and vacuuming and at the infant/toddler level, this scenario produced a much lower mercury concentration than the above scenario.

The problem that a homeowner would have, given that our results were so variable, is determining where in the range of vacuuming results their particular break was. This guidance therefore needs to be protective for all common CFL and vacuums.

The vacuum can also become contaminated such that decontaminating the vacuum is difficult to impossible even when the researchers had the advantage of sophisticated instruments to determine where the contamination was present. For example, with one vacuum where a break had occurred on carpeting and been cleaned up three weeks prior to vacuuming, the beaters initially were contaminated at greater than 50,000 ng/m^3. After cleaning and airing for two days after the vacuuming, the unagitated beaters had mercury concentrations of 75 ng/m^3 and

[31] Lumex readings over 50,000 ng/m^3 are relative readings only and according to the manufacturer of the Lumex are biased low when above the calibration range of the Lumex.

agitated beaters were at 990 ng/m^3. The plastic flexible hose had mercury concentrations of 17,540 ng/m^3 and the metal wand had mercury concentrations of 142 ng/m^3. Contamination such as this could sometimes be cleaned with the use of wet wipes, airing and use of the Lumex to identify contaminated areas but sometimes could not. The homeowner would not be able to determine which situation they were dealing with and this guidance therefore is written to attempt to prevent vacuum contamination where possible.

6.8.2 Keep people and pets away from the breakage area to prevent mercury in the powder from being tracked.

The study supported the guidance of keeping unnecessary people and pets from being in the area of breakage. The initial mercury concentrations after breakage are nearly always elevated over the MAAG. See Tables 6-3 and 6-4, maximum mercury concentrations (ave. of max). Keeping unnecessary people and pets from the area would avoid unnecessary exposure to mercury vapor as well as ensure that someone did not step in the breakage unknowingly and then track any residue to other areas of the home.

6.8.3 Ventilate the area by opening windows.

Ventilating the room by opening the window proved particularly effective in reducing initial room air concentrations to below the MAAG. However, the data did suggest that venting a few minutes prior to beginning the active cleanup might reduce exposure to short term elevated mercury concentrations. Generally for un-vacuumed situations, the high initial mercury concentration is an abrupt spike in mercury concentration which drops dramatically in under 5 minutes after ventilation.

A comparison of SE, SED, and SF however showed the concern with waiting too long prior to beginning clean up. These three trials used the same brand lamp; two without a long wait (SE and SED) and one with a 46 minute long wait (while venting) prior to beginning clean up. Although SE and SF had similar initial mercury concentrations the long wait may have allowed mercury to dissipate into the room from the source material and resulted ultimately in higher average mercury concentrations. See Table 6-17 below for more information.

As a practical matter, it will take the homeowner some amount of time to gather the necessary cleanup supplies. This time will likely be in the neighborhood of a number of minutes. A 15 minute wait period is in place in international, national and some other states' guidance. Given the existence of a consistent strong peak in mercury concentrations followed by a steep drop following ventilation in the initial mercury concentrations for unvacuumed situations, the existence of a 15 minute wait period in other guidance, and the need to not wait too long, there is some benefit in waiting a short period of time prior to clean up, something in the neighborhood of 5 minutes but not a long period of time (46 minutes). For consistency with other guidance and because the data in this study shows a short wait is appropriate, a 15 minute wait time is suggested.

Table 6-17. Results for runs with different waiting periods between break and cleanup

Scenario	Lamp type	Wait time[a]	Maximum at 5'[b]	Maximum at 1'[b]	<300 at 5'[c]	<300 at 1'[c]	5' 1 Hr Average[d]	1' 1 Hr Average[d]
SE	"Brand B" 26w=100watt	1	7,288	65,094	23.67	40.50	527	1,048
SED		1	4,206	25,399	48.50	39.84	806	738
SF	"Brand B" 26w=100watt	46	8,285	54,142	81+	81+	2,992	2,745
SC	"Brand D" 14w=60watts	1.5	4,257	27,224	30.83	21.92	424	684
SCD		1.5	5,927	6,164	25.67	21.00	298	310
SG	"Brand D" 23w=100watt	11	956	8,603	16.00	16.08	111	377
SH	"Brand E" 15w=60watt	5	4,543	17,178	15.50	11.08	232	263
SI	"Brand F" 15w=50watt	7	485	687	2.67	5.50	54	70

a This field represents time (in minutes) elapsed from lamp break until cleanup initiated.
b This field represents the maximum mercury concentration (ng/m^3) detected at the identified intake.
c This field contains time (in minutes) elapsed between lamp break and when room concentrations to fall below 300 ng/m^3 at the identified intake.
d This field contains one hour average mercury concentrations (ng/m^3) at the identified intake.

The following data suggest that total venting times are somewhat dependent on the brand/ model lamp broken.

For all vented scenarios, study room air mercury concentrations at the 5' Lumex intake fell below the MAAG within one hour except for two scenarios. Scenario F, where researchers opened the window and then waited 46 minutes before cleaning CFL breakage according to pre-study cleanup guidance, had study room air mercury concentrations exceeding the MAAG for the entire experimental trial. The trial was terminated at 90 minutes with a study room air mercury concentration of 328 ng/m^3. Scenario SA duplicate had a 1 hour average mercury concentration of 815 ng/m^3, and concentrations fell under the MAAG at 65.5 minutes after the break.

Study room air mercury concentrations at the 1' level for vented scenarios fell below the MAAG within one hour in 28 of the 33 trials. Scenario F was terminated at 90 minutes with a study room air mercury concentration of 419 ng/m^3. Scenario B study room air mercury concentrations generally fell below the MAAG after 178 minutes, but continued to spike above the MAAG for the duration of the 700 minute trial. Scenario A duplicate study room air mercury concentrations fell below the MAAG at 252 minutes and Scenario K study room air mercury concentrations fell below the MAAG at 33 minutes, then spiked at 193.75 minutes and stayed below at 193.84 minutes. Data from this study suggest that venting should continue for several hours after lamp cleanup to be conservative.

6.8.4 If possible, reduce the temperature.

This aspect of the guidance was not directly tested as part of the study. Although as referenced in Section 5.4.4, studies exist that clearly identify that the warmer the temperature the more mercury vaporizes into the air. Therefore lower temperatures will help keep mercury levels lower while cleanup is occurring.

Table 6-18 displays the theoretical effect of temperature on the study results. The table includes 1 hour average results, room temperature during trial, 1 hour averages corrected for 23°C (73°F), the average room temperature, and for 32°C (90°F), a potential summer temperature, for trials where temperature correction elevated the average concentrations above the MAAG. As can be seen from this table, if the study had been conducted at 32°C (90°F), the mercury concentrations would have been significantly higher.

Table 6-18. One hour average mercury concentrations (ng/m^3) corrected for 23°C and 32°C

Trial	intake[a]	Run time [minutes]	Room Temperature During Trial[b]	1 Hour average[c]	1 hr ave at 23 C[d]	1 hr ave at 32 C[e]
S1T4	H	83.4	19.9	133	170	**355**[f]
S1T5	H	119.9	22.3	254	275	**574**
SA	H	340.4	20.7	199	234	**490**
SB	H	343.1	23.2	161	161	**336**
SB D	H	345.8	21.3	155	183	**382**
SBRevac4	H	361.0	19.4	172	239	**499**
SC D	H	357.0	21.1	298	**351**	**734**
SD	H	408.2	20.3	110	141	294
SD D	H	259.8	24.3	43	40	83
SH	H	136.8	23.9	232	214	**446**
SK	H	471.3	24.4	241	222	**464**
S3T3	L	267.5	21.5	142	154	**321**
S4T1	L	359.6	20.6	159	187	**391**
S4T3	L	592.2	20.3	126	161	**337**
S5T1	L	174.4	20.2	202	258	**540**
S6T2	L	355.7	19.8	133	170	**355**
SA	L	340.4	20.7	185	218	**455**
SB	L	343.1	23.2	264	264	**552**
SB D	L	345.8	21.3	220	259	**542**
SBRevac4	L	361.0	19.4	113	157	**328**
SD	L	408.2	20.3	123	157	**329**
SH	L	136.8	23.9	263	242	**506**

a. Lumex intake, H = five foot intake, L = one foot intake
b. Room temperature (in Centigrade) for first hour of study trial.
c. One hour average mercury concentration in ng/m^3.
d. One hour average mercury concentration in ng/m^3 corrected for 23°C (73°F).
e. One hour average mercury concentration in ng/m^3 corrected for 32°C (90°F).
Note: Bolded values are over 300 ng/m^3.

6.8.5 Wear appropriate personal protective equipment, such as rubber gloves, safety glasses, old clothing or coveralls, and a dust mask to keep bulb dust and glass from being inhaled.

This aspect of the guidance was not directly tested as part of the study. However, researchers' coveralls, gloves and booties were checked and were rarely found to be contaminated with mercury. Wearing rubber gloves is probably a good idea as a level of protection from glass cuts and as a physical barrier to the components of the lamp. However there was no indication that with careful handling of lamp waste that the other special protective equipment mentioned in this guidance (safety glasses, old clothing or coveralls and a dusk mask) is warranted.

6.8.6 Carefully remove larger pieces and all waste and materials used to clean up a break and place them in a secure closed container or airtight plastic bag.

As discussed in more detail in section 5.6, the choice of container (plastic bag) suggested in the guidance proved inadequate. Mercury vapor was found during the study to pass quickly through sealed plastic bags. Placing the plastic bag with a broken bulb in the test room caused the room air at the adult breathing zone (only level tested during this portion of the study) to exceed the MAAG within an hour. Of the 12 different types of containers tested during the 23 different tests, the plastic bag was found to be the worst choice for containing mercury emissions. Based upon this study, the DEP now suggests that a glass container with metal screw lid with a gum seal be used to contain debris. Containers that meet these criteria are readily available in grocery stores and at least one of them is likely to be present in homes. Homeowners may, however, need to empty the contents of a container in the event of a broken CFL. Glass containers in grocery stores found to meet the ideal criteria identified in the study include: pickle, spaghetti sauce, olive, canning, and peanut butter jars.

In addition, removal of the lamp debris immediately from the home upon cleanup would be a good idea particularly if the homeowner does not have a glass jar. Storage of the lamp debris in a garage or other well-ventilated area outside the living space would be prudent while awaiting transport to a universal waste facility for proper recycling.

6.8.7 Collect smaller pieces and dust. Use a disposable broom and dustpan or two stiff pieces of paper to scoop up the pieces.

In this study two stiff pieces of index paper were used to scoop up the pieces. This worked well in gathering the larger pieces of the CFL. The disposable broom and dustpan were not tested but due to the need to handle all cleanup debris in contact with the lamp as waste, limiting the value and size of these tools has significant advantages. Index cards are low cost easily bent into different size containers and were found to work well.

6.8.8 Pat the area with the sticky side of tape and wipe the area with a damp cloth or paper towel to pick up the fine particles.

In this study masking tape was first used followed by wet wipes to pick up the fine particles. These tools work well as a final polish to the other clean up techniques. This technique in conjunction with the index cards produced visibly clean surfaces on all three flooring types used. Masking tape and wet wipes are readily available, inexpensive and are easily placed in clean up containers.

6.8.9 Consider using a drop cloth when changing a lamp so that any accidental breakage can be easily cleaned up.

In the study, plastic sheeting was placed on the floor to limit contamination of the room. In addition a vinyl coated cloth was used under the flooring surface where the CFL was broken. When the test room was closed at the end of the study, Lumex readings were taken throughout the room and no significant mercury readings were obtained. Wipe samples were taken of the test room floor and were sent to the laboratory for analysis. No mercury was detected in any of the wipe samples. While the floor and breakage box liners were not specifically used in the study to test the value of placing a drop cloth, they do provide useful information on whether or not contamination is likely to migrate through drop cloths during management of a lamp break.

It appears that a drop cloth could contain mercury source material to allow for an easier cleanup. This may eliminate the need for carpet removal when the break occurs during the changing of a lamp.

7. LESSONS LEARNED / CONSIDERATIONS FOR FUTURE STUDIES

This section is written to document changes to our original study design and help potential future researchers avoid these problems. Generally lamps were broken, cleaned up and monitored according to the study work plan. However, observations throughout the study precipitated changes to study procedures as discussed below.

7.1 Variability Among Manufacturers

Mercury vapor release is much more variable among manufacturers than among the original scenarios completed with a single CFL brand/ type. In Figure 7-1 below, one hour average room mercury concentrations are plotted for the five foot mercury analyzer intake. The first seventeen trials represent "Brand A" scenarios excluding the first trial where no venting or cleanup was performed. The last ten trials represent other manufacturers with lamps broken on wood surfaces and cleaned according to pre-study cleanup guidance. It would be informative to test other manufacturers' CFLs according to the original six study scenarios in future studies.

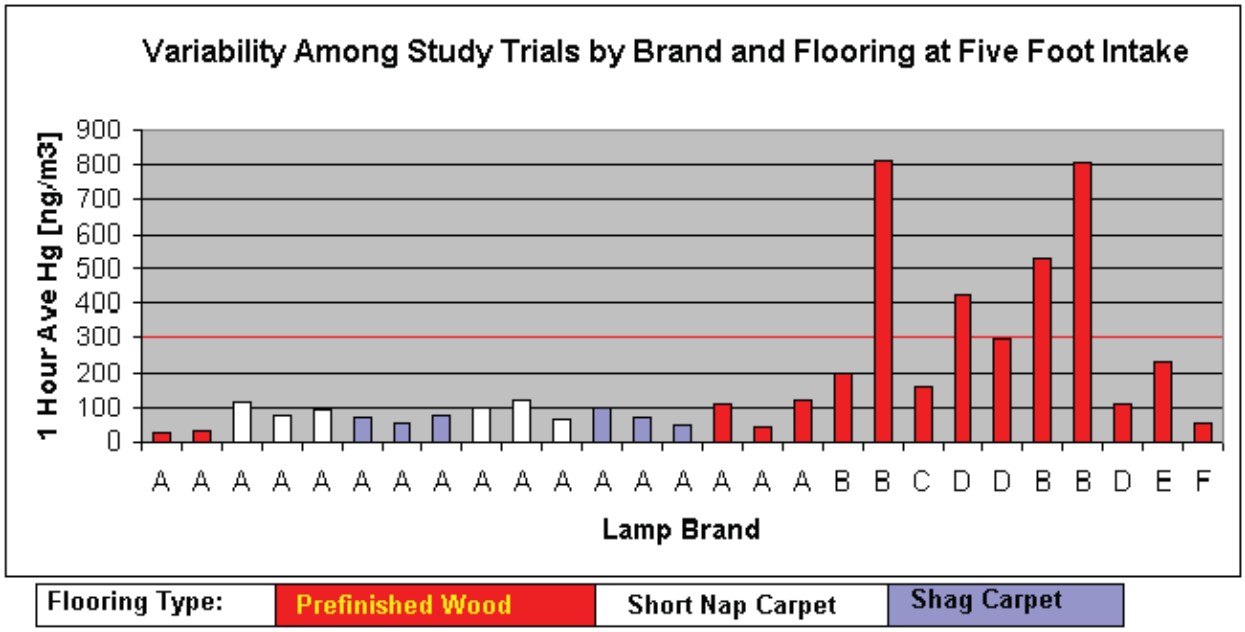


Figure 7-1. One hour average mercury concentrations by Brand and Flooring Type at Five Foot Intake

7.2 Unintentional Venting

7.2.1 Lumex Exhaust Lines

Sample exhaust air exiting the mercury analyzer must be returned to the study room to prevent unintended venting of the study room. Scenario 1 of this study was performed first with

analyzer exhaust not returned to the study room (see Figure 7-2). Figure 7-3 repeats Scenario 1 with exhaust lines returned to the study room.

Note the difference between lines exhausted outside versus inside the study room by comparing Figure 7-2 to Figure 7-3. This situation was corrected, and three more trials of the first scenario were completed. Results of the first three trials of scenario 1 were not included in evaluation of the scenarios in this report. The study plan was changed and all other scenarios were completed with analyzer exhaust lines returned to the study room.

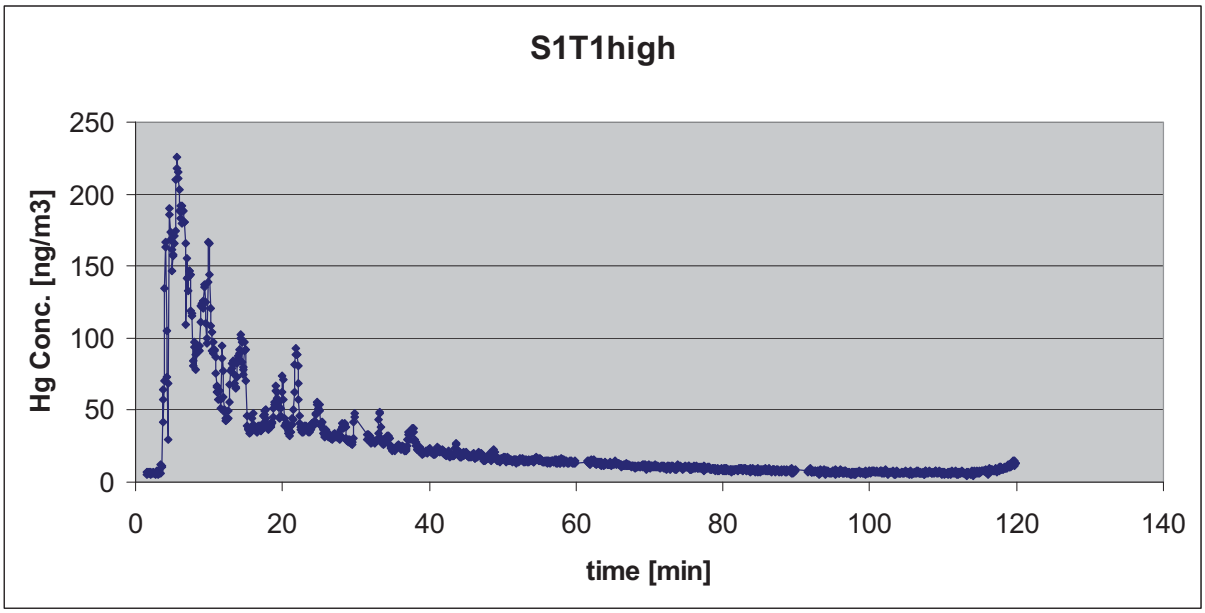


Figure 7-2. Trial S1T1 at five foot intake with Lumex exhausted outside study room

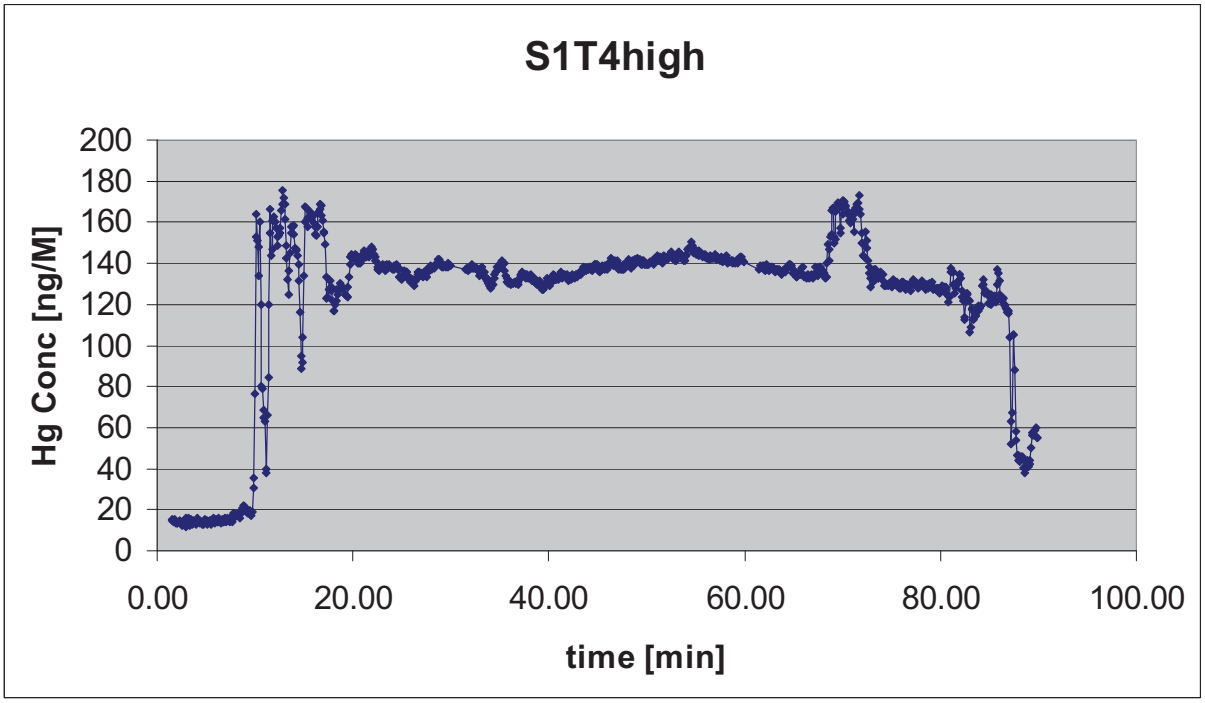


Figure 7-3. Trial S1T5 at five foot intake with Lumex exhausted inside study room

7.2.2 Effect of Adjacent HVAC Systems

Building HVAC systems external to the study room can cause unintentional venting of the study room by drawing room air under the door. Observations of precipitous drops in study room mercury air concentrations led researchers to investigate the causes of this phenomenon. It was observed that drops in study room mercury air concentrations would always happen when the overhead garage door was closed. See Figure 7-4 for experimental trial showing the effects of closing the garage door. Two rooms within the building are kept under negative pressure, a decontamination room and a storage room. It was surmised that make-up air added to other rooms in the building is not adequate to make up for the loss of air in these two rooms, and that study room air losses under the study room door are more extreme when the garage door is closed. This phenomenon tends to bias study results low, especially for trials that were continued after working hours. Typically the door was open during the day, but closed for security reasons generally during lunch and around 5:00 PM. Figure 7-5 below shows the (open) overhead door in relation to the study room and Figure 7-6 shows a diagram of relative positions for the study room, garage door and the two rooms under negative pressure.

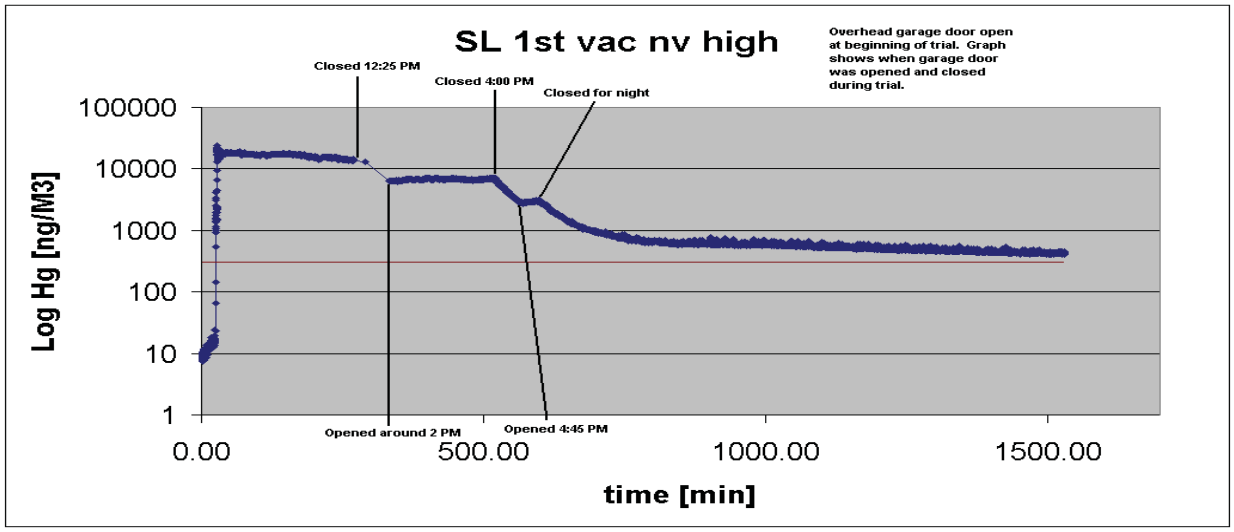


Figure 7-4. Sudden decreases in room Hg coincide with overhead door closing

Figure 7-5. Overhead door and study room through windows

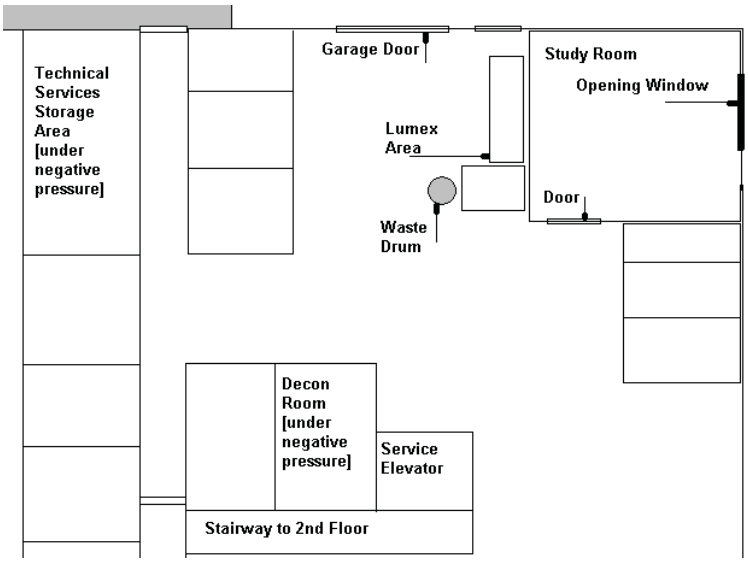


Figure 7-6. Warehouse section - study room, garage door and negative pressure rooms (not to scale)

7.3 Agitation of Flooring

Agitation appears to be a major factor in the release of mercury from a "cleaned" surface. Study observations suggest there would be a significant difference in mercury release from a breakage site when the site is located in an area of high traffic vs. a site located in a relatively isolated spot. Early study surface measurements did not include agitated readings of flooring and vacuum surfaces, and agitation procedures were added on June 7, 2007 while the study was in progress.

8. CONCLUSIONS AND DISCUSSION

The questions posed in the Study Objective can be better answered as a result of this study. One broken CFL does cause the concentration of mercury in the air in a small room to be greater than Maine's ambient air guideline of 300 ng/m^3 in the breathing zone for adults and the breathing zone for crawling infants/toddlers. However, in most situations, the initial mercury concentrations in the air will rapidly decrease with venting and proper cleanup, as seen in many of the scenarios in this study.

Variability among brands/models of CFLs appears to be significant. Only one brand/model CFL was tested for the original six scenarios of this study. While having one brand/model that has low variability in dosed mercury from lamp to lamp was useful to evaluate changes from one scenario to another, the chosen lamp did not adequately represent the exposure hazards of all lamps. It was important to test many brands/models to determine whether or not our cleanup guidance was appropriate. In addition to the original CFLs, seven additional brands/models were evaluated on hardwood flooring using the pre-study cleanup guidance. Variability among brands/models is significantly higher than the variability among the six original scenarios. Additional research with more brands/ models of CFLs would be useful to confirm study results.

This study identified some easily resolvable issues regarding CFL cleanup, but also some issues harder to address. For example, venting the room after a CFL break dramatically reduces the concentration of mercury in the room. There are two aspects to venting: first is a

question of how long to vent a room prior to cleanup, and the second is how long to continue venting to assure room concentrations remain below acceptable levels. Waiting a few minutes to clean up a broken lamp seems reasonable based on study results. A person cleaning up a broken CFL immediately (without waiting a few minutes) is exposed to higher levels of mercury in the air. However, waiting too long may allow more opportunity for the mercury to off-gas into the room air. National guidance [32] recommends venting and evacuating the room for 15 minutes prior to cleanup. This guidance seems reasonable given the results of this study. In addition, data from this study suggest that venting should continue for several hours after a lamp cleanup to be conservative.

Another easily resolvable issue is the matter of a container for spill debris. An important conclusion from this study is that re-sealable plastic bags do not adequately contain mercury vapor. After experimenting with a number of potential containers, it was determined that glass jars with a metal screw lid and gum seal were the most effective of those tested. Some heavy duty high density polyethylene (#2 plastic) containers with either screw caps or pressure fit seals were better than re-sealable plastic storage bags but not as good as glass jars with metal screw lids and seals. More research would be helpful to augment the list of suitable containers. Container study results warrant changes to lamp breakage cleanup guidance offered nationally.

A more troubling finding is that a residual mercury source can remain in flooring after cleanup, which when agitated, either through use or vacuuming, can cause mercury vapor to be emitted in the immediate area of breakage. All three flooring surfaces in this study (pre-finished hardwood, short nap carpet, and shag carpet) were able to be cleaned up with pre-study cleanup guidance so that they looked clean. However, mercury vapors emanating from all three surface types were detected, especially when agitated, for weeks after the cleanup of a break. Concentrations varied dramatically. Most mercury concentrations within 1" of a new pre-finished wood surface were below 300 ng/m^3 within one week and appear to be less problematic than carpeting in terms of cleaning up residual mercury sources. Carpet mercury sources can last for weeks after the CFL break is cleaned up and can result in mercury concentrations above the MAAG when agitated, either through use or vacuuming. This leads to the dilemma of what to do about residual mercury sources in flooring and whether or not carpet should be removed.

Mercury concentrations re-distributed in the room from re-vacuuming residual mercury in carpeting can vary significantly depending on the CFL brand/model and the type of vacuum. It appears from this study that in some instances the affected carpeting should be removed, especially when sensitive populations (infants, small children, pregnant women) use the area.

Higher mercury concentrations were recorded immediately after breaking a lamp, after vacuuming when a source remains in the carpet, and at varying times after the breakage and cleanup of certain lamp types (called "spiking" in this report). It is unclear what health effect these shorter term higher spikes in mercury concentrations might have. However, as stated in the Toxicological Section of this report, these events cause concern with their potential effect and this is part of the reason why carpet removal in certain circumstances may be warranted. It is hoped that future research may identify better cleanup options for carpets to avoid the need for cutting and disposing of them.

The study does not support recommending vacuuming as a cleanup option. Vacuuming is problematic because it tends to mix mercury concentrations in the room, promoting higher concentrations in the five foot breathing zone. In addition, the vacuum may become

[32] EPA website: http://www.epa.gov/mercury/spills/index.htm#flourescent

contaminated. Although using a wet wipe on some vacuum surfaces helped to lower residual mercury, expensive testing equipment was needed to evaluate cleanup effectiveness. Also some parts of the vacuum, such as the inside of the hose, are not as easy to wipe. The vacuum bag, when there is one, would need to be treated as universal waste if contaminated with mercury. It does appear that cheaper electric brooms or motorized sweepers are easier to decontaminate than more expensive vacuums with power heads and metal parts. It is not clear from this study what the exposure and hazards may be from handling a mercury-contaminated vacuum. Further study of vacuum decontamination procedures and exposure hazards would be useful.

The one scenario where a vapor control amalgam technology lamp was broken suggests that this type of CFL may emit less mercury vapor on breakage and may present fewer cleanup challenges than certain other CFLs. However, this study did not test enough of this type of amalgam technology lamps to draw any significant conclusions. Researchers believe that most lamps used in the study were manufactured with either liquid dosing or solid or "pellet" dosing amalgam technology, a method for introducing a limited amount of mercury into a CFL during manufacture. More research is needed for a meaningful assessment of amalgam technologies. In addition, this study cracked a lamp (Scenario J) to see if less mercury would be released than from a thoroughly broken lamp, and this study broke two lamps that had been turned on and were warm or "hot" (SD and SD duplicate) to see if there was a difference from the "cold" lamps that were broken in the study. Although the results from those three trials did not appear to be different from other trials, more data is needed to make findings.

The study supports changing the Maine Department of Environmental Protection cleanup guidance to include:[33]

- Leaving the area/room and waiting 15 minutes after breakage to begin cleaning up (mercury levels in the air will have fallen from their highest levels by then);
- Using a glass container with a metal screw top lid with seal [34] such as a canning jar to contain the lamp pieces, powder, and cleanup materials;
- Immediately removing the containerized lamp debris from the living quarters especially if the homeowner did not have a glass container with a good seal;
- Continue venting room for several hours;
- Suggesting that homeowners consider removal of carpeting sections where breakage has occurred as a precaution in some situations, particularly in homes with infants, small children or pregnant women;
- If carpet is not removed, the homeowner should consider ventilating the room during vacuuming for the next several vacuuming events;
- Suggesting that homeowners consider not utilizing fluorescent lamps in situations where they could easily be broken, in bedrooms used by infants, small children or pregnant women, or over carpets in rooms frequented by infants, small children or pregnant women; and
- Avoiding the storage of too many used/spent lamps before recycling that could increase the chances of breakage.

This study was intended to help refine Maine's cleanup guidance for broken compact fluorescent lamps. While the study presents valuable data toward providing a comprehensive

[33] See Appendix 5 for revised clean up guidance.

[34] Other jars that can be made of glass and meet this criteria are pickle, olive, spaghetti sauce, peanut butter and applesauce jars. Not ideal but also a good choice for containing breakage is a heavy duty #2 plastic container with either a screw lid or push on lid such as a joint compound bucket or certain kitty litter containers.

guidance, several areas for further research were also identified. The researchers welcome feedback on the Maine study, and hope that other studies will further our understanding. The following list provides our suggestions for follow up:

- More thoroughly test different CFL brands to define the range of mercury emissions and potentially refine the cleanup guidance.
- Ensure that worst case scenario lamps are included for testing given the variability among the types we tested both between brands and within brands.
- Investigate methods to clean up or reduce concentrations of residual sources of mercury in flooring, especially in carpet but also scarred and wide crack wood flooring.
- Determine the significance of contaminating vacuums with regard to spreading mercury within the home and elevating airborne mercury concentrations after reusing the vacuum. The focus here should be on vacuuming not as a part of the initial cleanup technique but after a period of time (weeks) once a lamp break is cleaned up.
- Investigate methods to decontaminate vacuums.
- Find additional suitable containers for containing lamp debris that a homeowner is likely to have in the home.
- More thoroughly test different amalgam technology lamps for reduced mercury concentrations and potentially modify cleanup recommendations for these sources.
- Perform “drop studies” to see if lamp design can provide protection from breakage or clean up when CFL are dropped from ceiling height.

APPENDIX A

Scenario Results Data Tables

Appendix A

Table A: Summary Results for All Scenarios (see notes for explanation of column titles)

Scenario	Lamp type	Maximum[a]	< 300[b]	1 hour Ave[c]	8 hour Ave[d]	24 hour Ave[e]
S1 Three trials at two heights • Break on wood floor with no lamp cleanup or ventilation. • Measure air concentration continuously until highest concentration is reached.	"Brand A" 14watt, 60 watt equivalent	**At 5 feet**: 176 962 499 **At 1 foot:** 8,533 34,954 23,244	**At 5 feet**: 0 18.00 1.41 **At 1 foot:** 18.75 10.34 60+	**At 5 feet**: 133 254 120 **At 1 foot:** 269 319 624		
S2 Three trials at two heights • Break on wood floor. Ventilate room. Clean up glass over 3/8" by hand, clean smaller pieces with index cards, tape and wet wipe, and remove waste from room. • Measure continuously	"Brand A" 14watt, 60 watt equivalent	**At 5 feet**: 745 765 489 **At 1 foot:** 10,040 9,173 17,569	**At 5 feet**: 2.25 1.83 1.42 **At 1 foot:** 2.00 0.66 4.00	**At 5 feet**: 108 (30 min. average) 26 29 **At 1 foot:** 199 (30 min. average) 50 126		
S3 Four trials at two heights • Break on short pile rug. Otherwise same as S2.	"Brand A" 14watt, 60 watt equivalent	**At 5 feet**: 1,200 811 533 535 **At 1 foot:** 10,788 6,033 10,606 5,866	**At 5 feet**: 5.5 7.33 4.83 3.84 **At 1 foot:** 5.67 7.08 6.17 6.59	**At 5 feet**: 121 (30 min. average) 115 78 94 **At 1 foot:** 140 127 142 108	**At 1 foot:** 23	

Appendix A

Scenario	Lamp type	Maximum[a]	< 300[b]	1 hour Ave[c]	8 hour Ave[d]	24 hour Ave[e]
S4 Three trials at two heights • Long pile "shag" rug. Otherwise same as S2.	"Brand A" 14watt, 60 watt equivalent	**At 5 feet**: 651 258 544 **At 1 foot:** 22,176 6,564 8,262	**At 5 feet**: 2.66 0 5.33 **At 1 foot:** 9.50 1.41 3.33	**At 5 feet**: 72 53 73 **At 1 foot:** 159 72 126		
S5 Three trials at two heights • Short pile rug. Ventilate room. Clean up glass over 3/8" by hand, vacuum with Kenmore canister vacuum, and remove waste pieces and vacuum bag from room. • Measure continuously/ take discrete measurements at vacuum locations.	"Brand A" 14watt, 60 watt equivalent	**At 5 feet**: 628 328 315 **At 1 foot:** 18,578 8,815 3,953	**At 5 feet**: 5.25 1.66 5.5 **At 1 foot:** 7.83 2.08 5.83	**At 5 feet**: 97 123 61 **At 1 foot:** 202 128 77		

Appendix A

Scenario	Lamp type	Maximum[a]	< 300[b]	1 hour Ave[c]	8 hour Ave[d]	24 hour Ave[e]
S5T3 Re-vacuum: One trial at two heights • No new bulbs were broken as part of this scenario. This was a revacuum of S5T3 short nap carpet. It was vacuumed by a Kenmore beater vacuum as part of S5T3. • During this scenario, a non beater Hoover 400 wand vacuum was used and the room was not ventilated[35].	"Brand A" 14watt, 60 watt equivalent Broken and cleaned up 28 days earlier.	**At 5 feet**: 72 **At 1 foot:** 130	**At 5 feet**: 0 **At 1 foot:** 0	**At 5 feet**: 57 **At 1 foot:** 40	**At 5 feet:** <20 **At 1 foot:** 13	
S6 Three trials at two heights • Long pile "shag" rug. Vacuumed with Dirt Devil Power Sweeper. Otherwise same as S5.	"Brand A" 14watt, 60 watt equivalent	**At 5 feet**: 350 414 236 **At 1 foot:** 1,811 16,942 1,811	**At 5 feet**: 2.16 1.67 0 **At 1 foot:** 3.33 3.08 2.16	**At 5 feet**: 99 72 48 **At 1 foot:** 86 133 41		
SA Two trials at two heights • Same as S2.	"Brand B" 26w, 90watt equivalent.	**At 5 feet**: 1,640 9,893 **At 1 foot:** 7,410 61,037	**At 5 feet**: 15.5 65.5 **At 1 foot:** 10.41 252.42	**At 5 feet**: 199 815 **At 1 foot:** 185 1,398		

[35] For the purposes of this table, references to "no ventilation" mean that no deliberate ventilation occurred such as with an open window in the study room or open door to the study room. It does not refer to unintentional ventilation from the closure of the overhead door in the area adjacent to the study room.

Appendix A

Scenario	Lamp type	Maximum[a]	< 300[b]	1 hour Ave[c]	8 hour Ave[d]	24 hour Ave[e]
SB Two trials at two heights • Break for the first trial on short pile rug and for the second trial on wood floor. • Otherwise same as S2.	"Brand C" 13w, 60watt equivalent	**At 5 feet**: 1,777 1,139 **At 1 foot:** 8,125 9,523	**At 5 feet**: 24.50 11.75 **At 1 foot:** >350spikes 14.58	**At 5 feet**: 161 155 **At 1 foot:** 264 220		
SBvac1 One trial at two heights • No new bulbs were broken as a part of this scenario. This was a vacuum of SB short nap carpet. This carpet had not been previously vacuumed but a lamp had been broken and cleaned up with traditional cleanup techniques 21 days earlier. It was vacuumed with a Hoover 850 beater vacuum. • This is the first vacuum of the carpet. No ventilation of room. • Measure continuously.	"Brand C" 13w, 60watt equivalent Broken and cleaned up 21 days earlier.	**At 5 feet**: 4,529 **At 1 foot:** 14,779	**At 5 feet**: >81 **At 1 foot:** >350spikes	**At 5 feet**: 3,406 **At 1 foot:** 2,554	**At 5 feet**: No data **At 1 foot:** 677 (6 hour average)	
SBvac2 One trial at two heights • This is the second vacuum of the carpet. The bulb was cleaned up 24 days earlier. • Otherwise same as SBvac1.	"Brand C" 13w, 60watt equivalent Broken and cleaned up 24 days earlier.	**At 5 feet**: 3,090 **At 1 foot:** 3,077	**At 5 feet**: 88.08 **At 1 foot:** >350spikes	**At 5 feet**: 1114 **At 1 foot:** 714	**At 5 feet**: 266 (6 hour average) **At 1 foot:** 223 (6 hour average)	

Appendix A

Scenario	Lamp type	Maximum[a]	< 300[b]	1 hour Ave[c]	8 hour Ave[d]	24 hour Ave[e]
SBvac3 One trial at two heights • This is the third vacuum of the carpet. The bulb was cleaned up 27 days earlier • Otherwise same as SBvac1.	"Brand C" 13w, 60watt equivalent Broken and cleaned up 27 days earlier.	**At 5 feet**: 680 **At 1 foot:** 2,001	**At 5 feet**: 167.08 **At 1 foot:** 146.33	**At 5 feet**: 584 **At 1 foot:** 422	**At 5 feet**: 253 **At 1 foot:** 180	
SBvac4 One trial at two heights • This is the fourth vacuum of the carpet. The bulb was cleaned up 28 days earlier. • Otherwise same as SBvac1.	"Brand C" 13w, 60watt equivalent Broken and cleaned up 28 days earlier.	**At 5 feet**: 228 **At 1 foot:** 427	**At 5 feet**: 0 **At 1 foot:** Spikes at 0.25, 77.92, & 299.17	**At 5 feet**: 172 **At 1 foot:** 113	**At 5 feet**: 79 (6 hour average) **At 1 foot:** 52 (6 hour average)	
SC Two trials at two heights • Same as S2.	"Brand D" 14w, 60 watt equivalent	**At 5 feet**: 4,257 5,927 **At 1 foot:** 27,224 6,164	**At 5 feet**: 30.83 25.67 **At 1 foot:** 21.92 21.00	**At 5 feet**: 424 298 **At 1 foot:** 684 310		
SD Two trials at two heights • Bulb on for one hour prior to break. • Otherwise same as S2.	"Brand A" 14w, 60 watt equivalent	**At 5 feet**: 1,443 268 **At 1 foot:** 12,016 11,447	**At 5 feet**: 3.41 0 **At 1 foot:** 1.75 1.17	**At 5 feet**: 110 43 **At 1 foot:** 123 68		
SE Two trials at two heights • Same as S2.	"Brand B" 26w, 100watt equivalent	**At 5 feet**: 7,288 4,206 **At 1 foot:** 65,094 25,399	**At 5 feet**: 23.67 48.50 **At 1 foot:** 40.50 39.84	**At 5 feet**: 527 806 **At 1 foot:** 1,048 738		

Appendix A

Scenario	Lamp type	Maximum[a]	< 300[b]	1 hour Ave[c]	8 hour Ave[d]	24 hour Ave[e]
SF One trial at two heights • Open window and wait 40 minutes to clean up • Otherwise same as S2.	"Brand B" 26w, 100watt equivalent	**At 5 feet**: 8,285 **At 1 foot:** 54,142	**At 5 feet**: >90 **At 1 foot:** >90	**At 5 feet**: 2,992 **At 1 foot:** 2,745		
SG One trial at two heights • Open window and wait 10-20 minutes to clean up • Otherwise same as S2.	"Brand D" 23w, 100watt equivalent	**At 5 feet**: 956 **At 1 foot:** 8,603	**At 5 feet**: 16.00 **At 1 foot:** 16.08	**At 5 feet**: 111 **At 1 foot:** 377		
SH One trial at two heights • Open window and wait 5 minutes to clean up • Otherwise same as S2.	"Brand E" 15w, 60watt equivalent	**At 5 feet**: 4,543 **At 1 foot:** 17,178	**At 5 feet**: 15.50 **At 1 foot:** 11.08	**At 5 feet**: 232 **At 1 foot:** 263		
SI One trial at two heights • Open window and wait 5 minutes to clean up • Otherwise same as S2.	"Brand F" 15w, 50watt equivalent	**At 5 feet**: 485 **At 1 foot:** 687	**At 5 feet**: 2.67 **At 1 foot:** 5.50	**At 5 feet**: 54 **At 1 foot:** 70		
SJ One trial at two heights • Crack lamp instead of crush. • Otherwise same as S2.	"Brand A" 14w, 60watt equivalent	**At 5 feet**: 617 **At 1 foot:** 7,412	**At 5 feet**: 2.58 **At 1 foot:** 2.16	**At 5 feet**: 122 **At 1 foot:** 133		
SK One trial at two heights • Break on long pile "shag" rug. After traditional cleanup was vacuumed using a Hoover Quick-Broom bag less vacuum. • Otherwise same as S2.	"Brand B" 26w, 90watt equivalent	**At 5 feet**: 2,034 **At 1 foot:** 2,392	**At 5 feet**: 24.0 **At 1 foot:** 32.67 Spikes at 193.84	**At 5 feet**: 241 **At 1 foot:** 368		

Appendix A

Scenario	Lamp type	Maximum[a]	< 300[b]	1 hour Ave[c]	8 hour Ave[d]	24 hour Ave[e]
SL One trial at two heights • Break on short pile rug. • No ventilation, clean up only big pieces and put in trash in room, vacuum rest of debris with a Hoover 850 beater vacuum. • Measure continuously.	"Brand B" 26w, 100 watt equivalent	**At 5 feet**: 23,720 **At 1 foot:** 133,955	**At 5 feet**: >1,500 **At 1 foot:** >1,500	**At 5 feet**: 16,814 **At 1 foot:** 21,262	**At 5 feet**: 12,364 **At 1 foot:** 14,384	**At 5 feet**: 4,490 **At 1 foot:** 5,130
SLvac2 One trial at two heights • No new bulbs were broken as a part of this scenario. This was a revacuum of SL short nap carpet. This carpet had been previously vacuumed as a means of cleaning up a lamp breakage 4 days earlier. It was vacuumed with a Hoover 850 beater vacuum. • This is the second vacuum of the carpet. • Otherwise same as SL.	"Brand B" 26w, 100 watt equivalent Broken and cleaned up 4 days earlier.	**At 5 feet**: 3,135 **At 1 foot:** 36,397	**At 5 feet**: 530.75 **At 1 foot:** >1,200 spikes[36]	**At 5 feet**: 2,623 **At 1 foot:** 2,444	**At 5 feet**: 1,429 **At 1 foot:** 1,471	**At 5 feet**: 691 (20 hour average) **At 1 foot:** 729 (20 hour average)
SLvac3 One trial at two heights • This carpet had been previously vacuumed as a means of cleaning up a lamp breakage 5 days earlier. • This is the third vacuum of the carpet w/ same vac. • Otherwise same as SL.	"Brand B" 26w, 100 watt equivalent Broken and cleaned up 5 days earlier	**At 5 feet**: 3,708 **At 1 foot:** 19,270	**At 5 feet**: 539.33 **At 1 foot:** >1,200 spikes[37]	**At 5 feet**: 2,671 **At 1 foot:** 2,768	**At 5 feet**: 2,590 **At 1 foot:** 2,587	**At 5 feet**: 1,038 (20.5 hour average) **At 1 foot:** 1,236 (20 hour average)

[36] Still spiking over 1,000 ng/m3.

Appendix A

Scenario	Lamp type	Maximum[a]	< 300[b]	1 hour Ave[c]	8 hour Ave[d]	24 hour Ave[e]
SLvac4 One trial at two heights • This carpet had been previously vacuumed as a means of cleaning up a lamp breakage 6 days earlier. • This is the 4th vacuum of the carpet with same vac. • Otherwise same as SL.	"Brand B" 26w, 100 watt equivalent Broken and cleaned up 6 days earlier.	**At 5 feet**: 3,288 **At 1 foot:** 12,367	**At 5 feet**: 523.75 **At 1 foot:** >1,200 spikes[38]	**At 5 feet**: 1,986 **At 1 foot:** 1,871	**At 5 feet**: 1,502 **At 1 foot:** 2,244	**At 5 feet**: 574 (20 hour average) **At 1 foot:** 1,085 (20 hour average)
SLcarpet One trial at two heights • Carpet alone in room after SLvac4. Room ventilated prior to placing carpet square in room. • Measure Continuously.	"Brand B" 26w, 100 watt equivalent Broken and cleaned up 7 days earlier.	**At 5 feet**: 1,186 **At 1 foot:** 5,679	**At 5 feet**: 652.42 **At 1 foot:** >1,600 spikes over 800 ng/m^3	**At 5 feet**: 135 **At 1 foot:** 699	**At 5 feet**: 491 **At 1 foot:** 1,056	**At 5 feet**: 255 **At 1 foot:** 561

a Maximum = the maximum mercury concentration observed during trial including lamp break and cleanup in ng/m^3
b below 300 = the time (minutes) elapsed between lamp break and when concentrations at the identified intake fell below 300 ng/m^3
c 1 hour average = the mercury concentration (ng/m^3) averaged over one hour from the lamp break
d 8 hour average = the mercury concentration (ng/m^3) averaged over 8 hours from the lamp break
e 24 hour average = the mercury concentration (ng/m^3) averaged over 24 hours from the lamp break

[37] Still spiking above 1,000 ng/m^3.
38 Still spiking above 300 ng/m^3.

Appendix A

APPENDIX A. Results for Individual Scenarios

Scenarios for "Brand A" 60 Watt Equivalent CFL (original six scenarios)

The first six scenarios were repeated three times each, using Philips 60 watt equivalent CFLs. Two graphs (one graph representing the air at five feet over the broken CFL (high) and one graph representing the air at one foot above the breakage (low)) were generated for each trial (each of the first six scenarios had three trials). Included below are the high and low graphs for all the trials. Scenarios and trials were labeled S2T1, S2T2, etc. to represent Scenario 2 Trial 1, Scenario 2 Trial 2, etc. For each scenario below, graphs for the trials with the highest peak of mercury were included first. The other trials and their graphs follow. A line at 300 ng/m^3 was added to each graph to show concentrations of mercury relative to this Maine Ambient Air Guideline (MAAG).

Scenario 1: Wood Floor, No Venting, No Cleanup

The first three trials for this scenario are not included in this report. For those trials, the air exiting the Lumex instruments was mistakenly not vented back into the study room. For the next three trials, S1T4, S1T5, and S1T6, and for the rest of the study, another plastic tube was attached to the front of each Lumex to carry analyzed air back under the door and into the study room.

For Scenario 1, a "Brand A" 60 watt equivalent CFL was thoroughly broken with a hammer and left in the room with the window closed and the door closed. For Scenario 1, Trial 5 (S1T5), on 5/25/07, mercury peaked at 962 ng/m^3 at the five foot height and peaked at 34,954 ng/m^3 at the one foot height. Concentrations of mercury in the room at both heights were less than 300 ng/m^3 after approximately 18 minutes. As expected, mercury in the air decreased more slowly over all in this scenario than the other scenarios when a "Brand A" lamp was broken and a window was opened. The other two trials for this scenario looked similar, although there was some variability in the initial peaks of mercury. Mercury peaked at 23,244 ng/m^3 at the one foot height on one of the other trials and 8,533 ng/m^3 at the one foot height on the other.

Appendix A

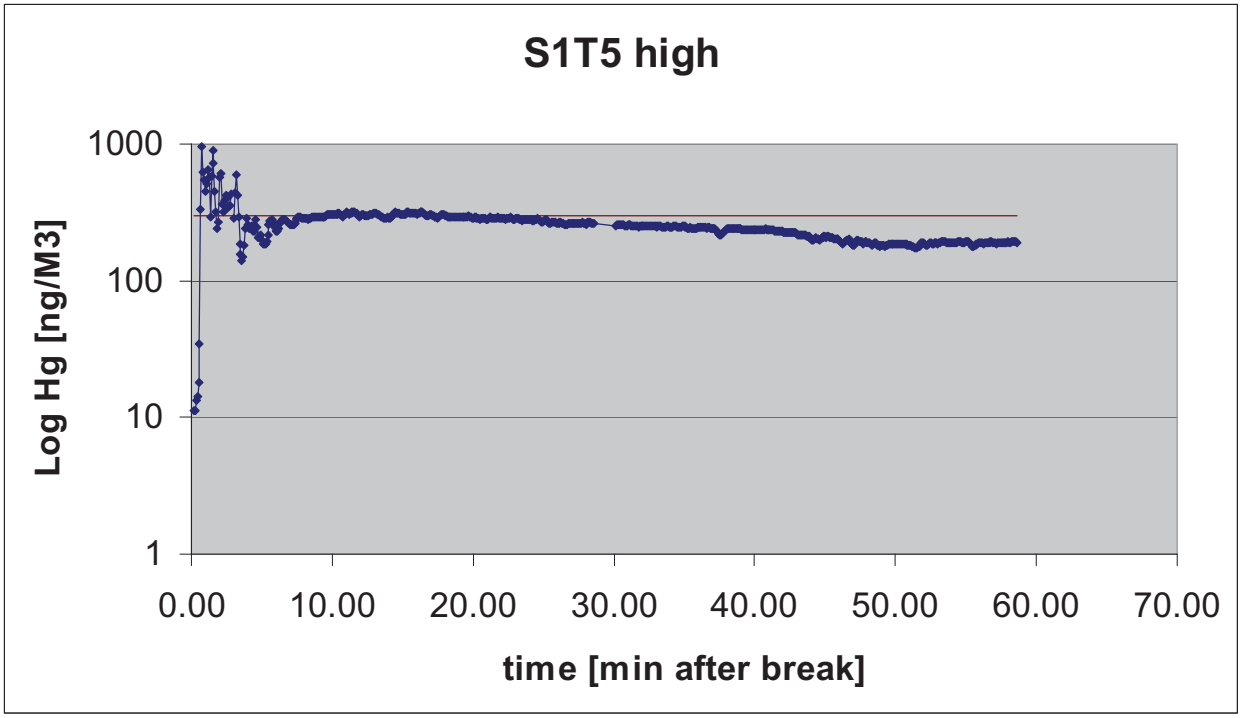


Figure A-1. Scenario 1, Trial 5 at Five-Foot Height (5/25/07)

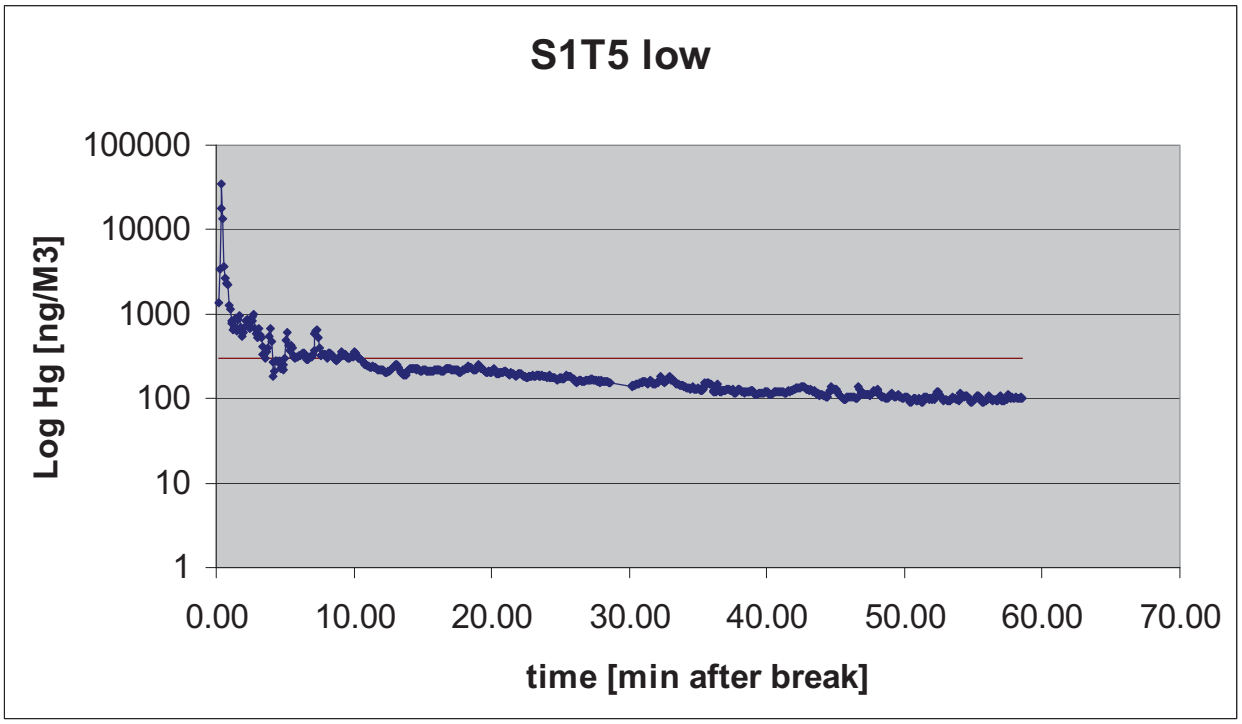


Figure A-2. Scenario 1, Trial 5 at One-Foot Height (5/25/07)

Appendix A

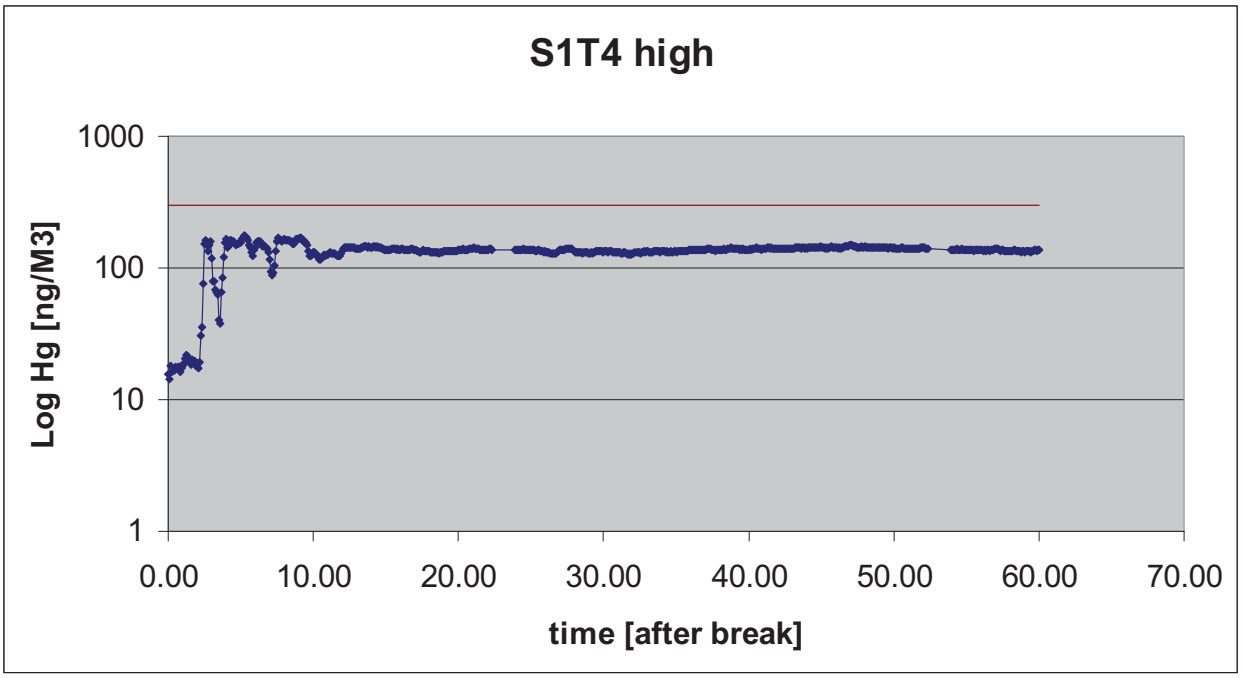


Figure A-3. Scenario 1, Trial 4 at Five-Foot Height, (5/25/07)

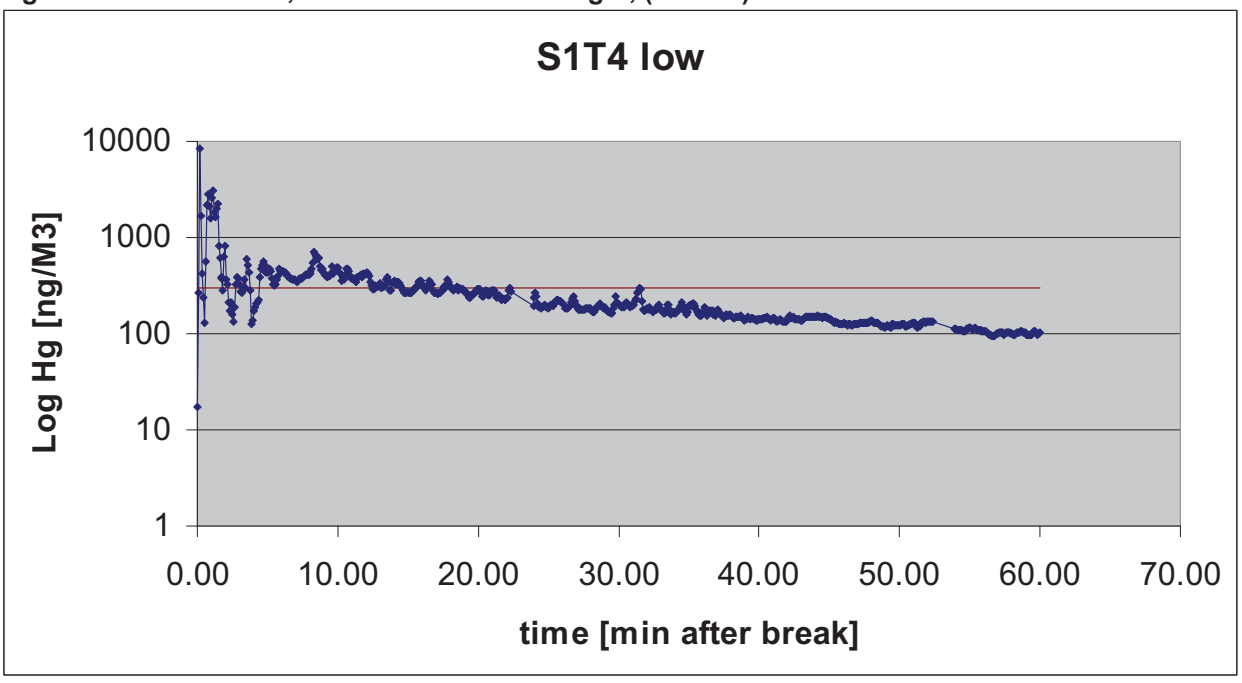


Figure A-4. Scenario 1, Trial 4 at One-Foot Height, (5/25/07)

Appendix A

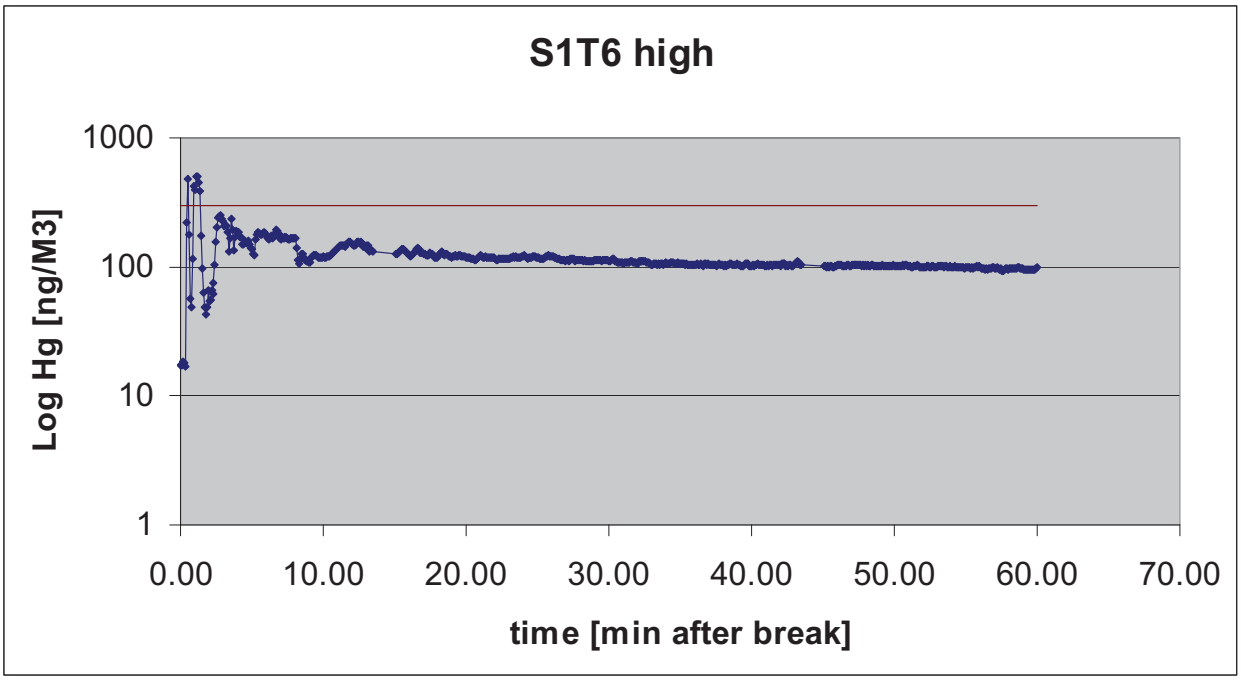


Figure A-5. Scenario 1, Trial 6 at Five-Foot Height, (5/25/07)

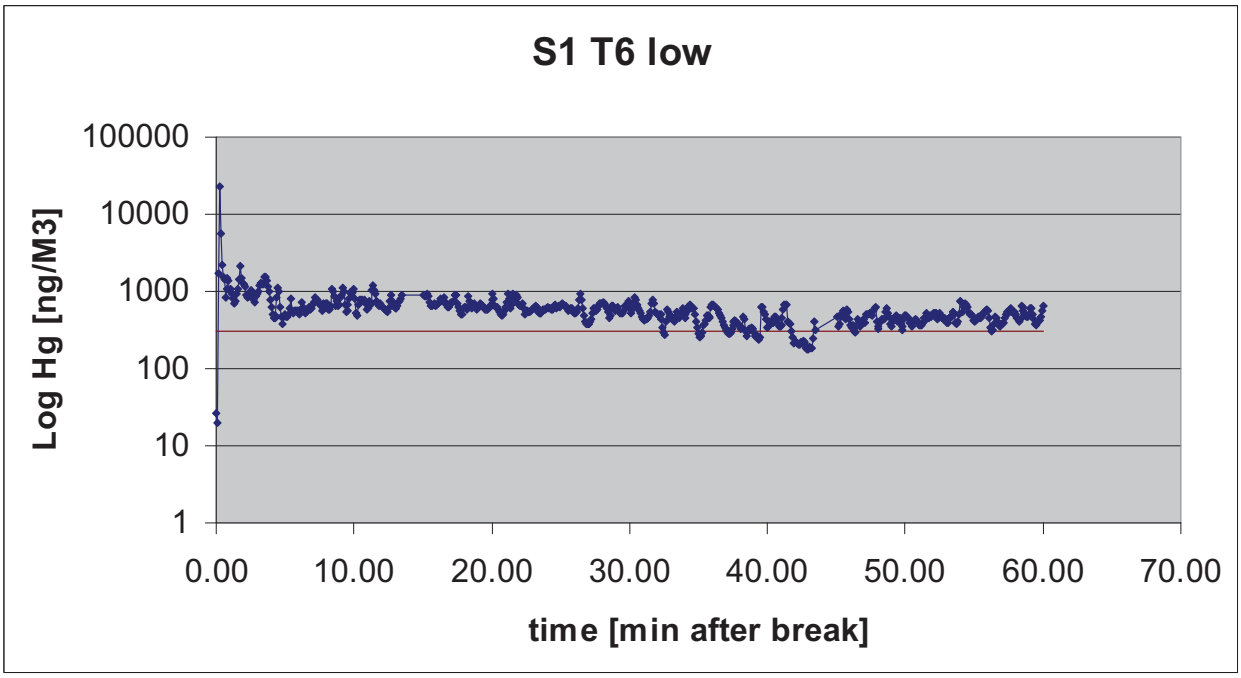


Figure A-6. Scenario 1, Trial 6 at One-Foot Height, (5/25/07)

Scenario 2: Wood Floor, Venting, Cleanup

A "Brand A" 60 watt equivalent lamp was thoroughly broken with a hammer on the hardwood floor, and was cleaned up using the pre-study cleanup guidance. (The window was opened, and the lamp was cleaned up with index cards, tape and a wet wipe. The waste was placed in a

re-sealable plastic bag.) The waste was removed from the room, the door was closed, and the waste was put in a hazardous waste drum. For Trial 3, on 5/29/07, mercury peaked at 489 ng/m^3 at the five foot height and peaked at 17,569 ng/m^3 at the one foot height. Concentrations of mercury in the room at both heights was less than 300 ng/m^3 after 4.0 minutes from breakage. All three trials for Scenario 2 looked similar.

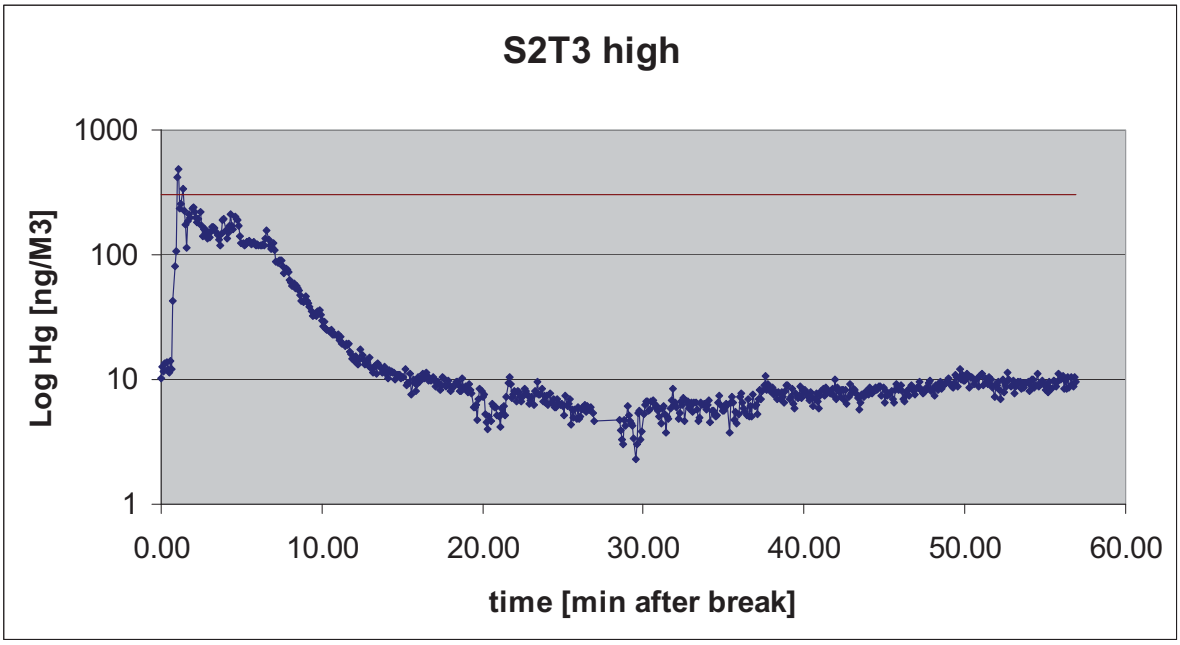


Figure A-7. Scenario 2, Trial 3 at Five-Foot Height (5/29/07)

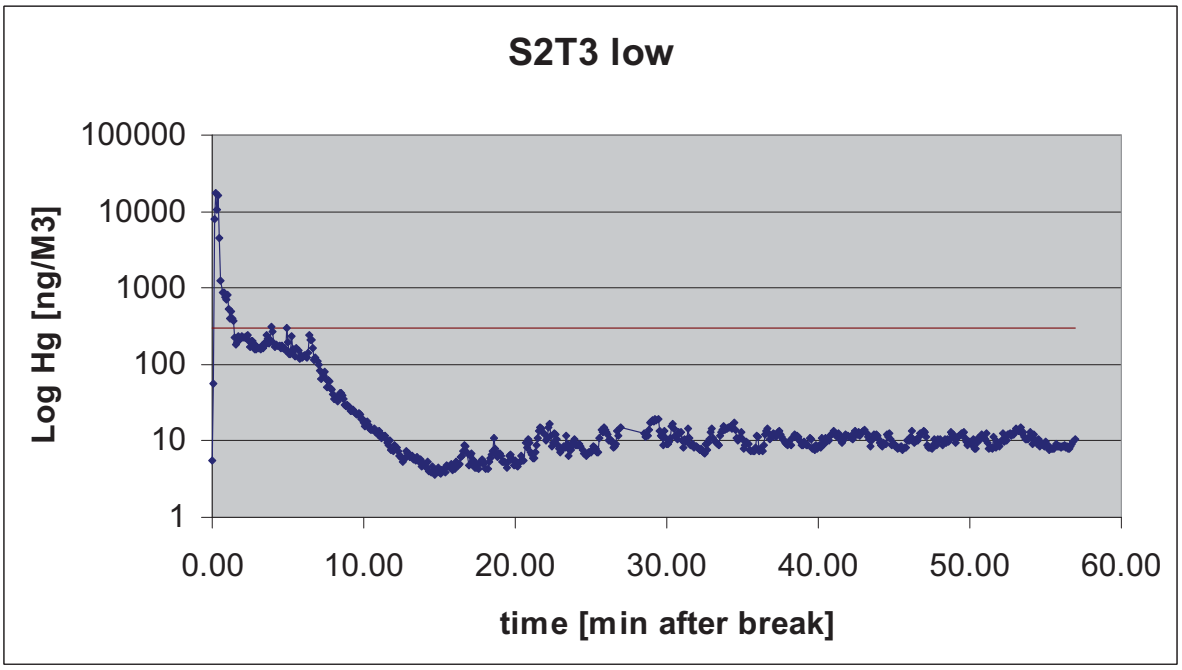


Figure A-8. Scenario 2, Trial 3 at One-Foot Height (5/29/07)

Appendix A

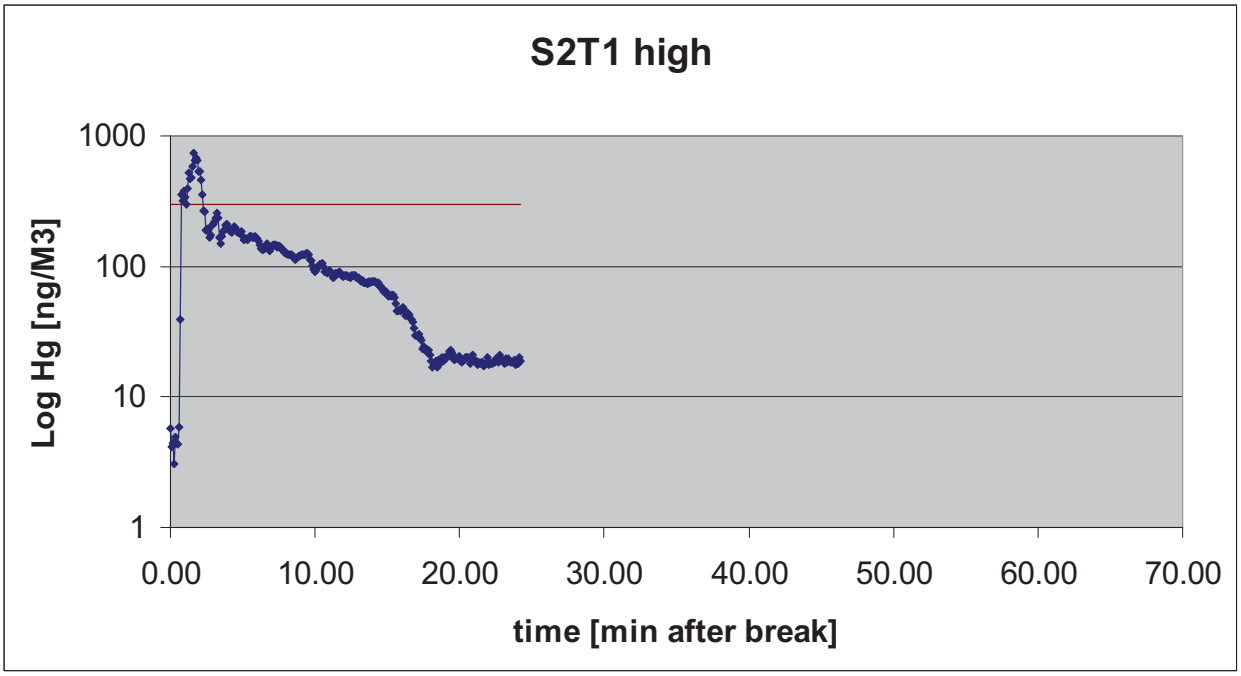


Figure A-9. Scenario 2, Trial 1 at Five-Foot Height, (5/29/07)

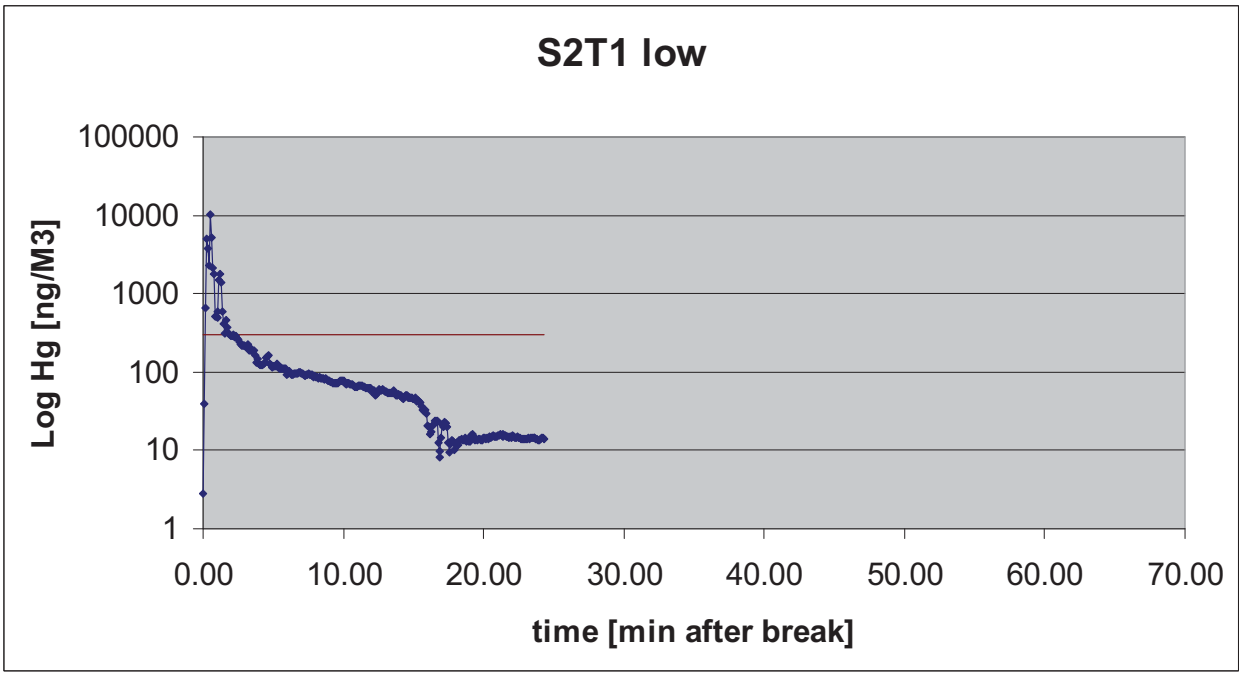


Figure A-10. Scenario 2, Trial 1 at One-Foot Height, (5/29/07)

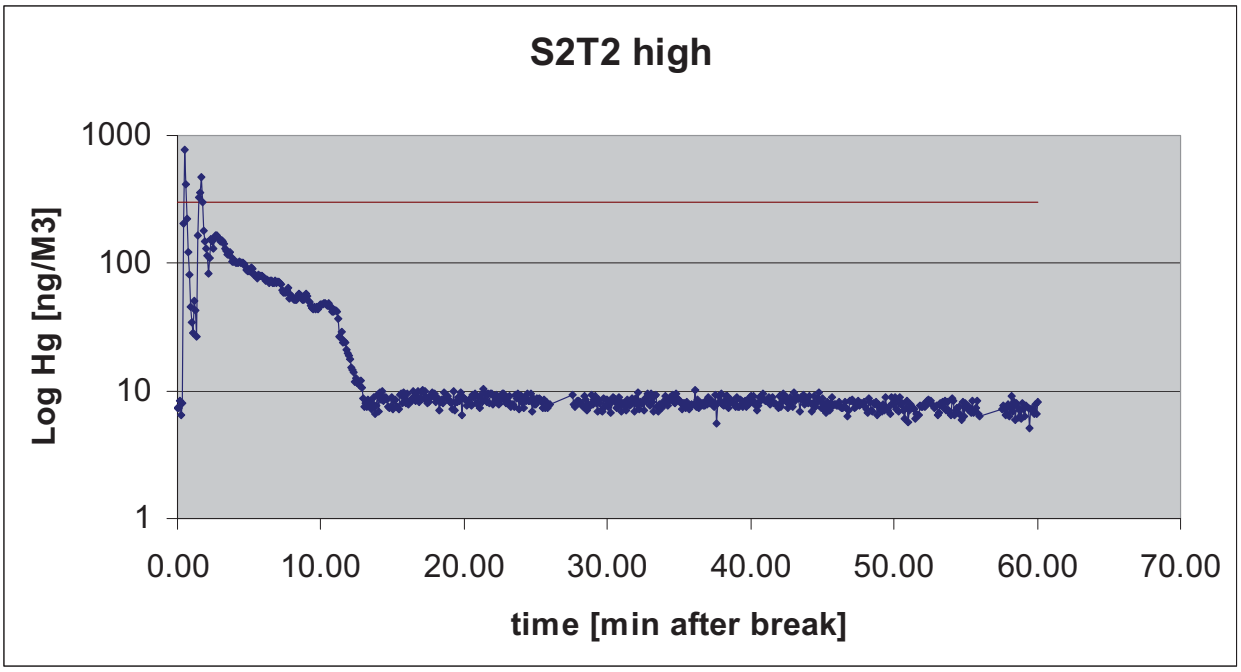


Figure A-11. Scenario 2, Trial 2 at Five-Foot Height (5/29/07)

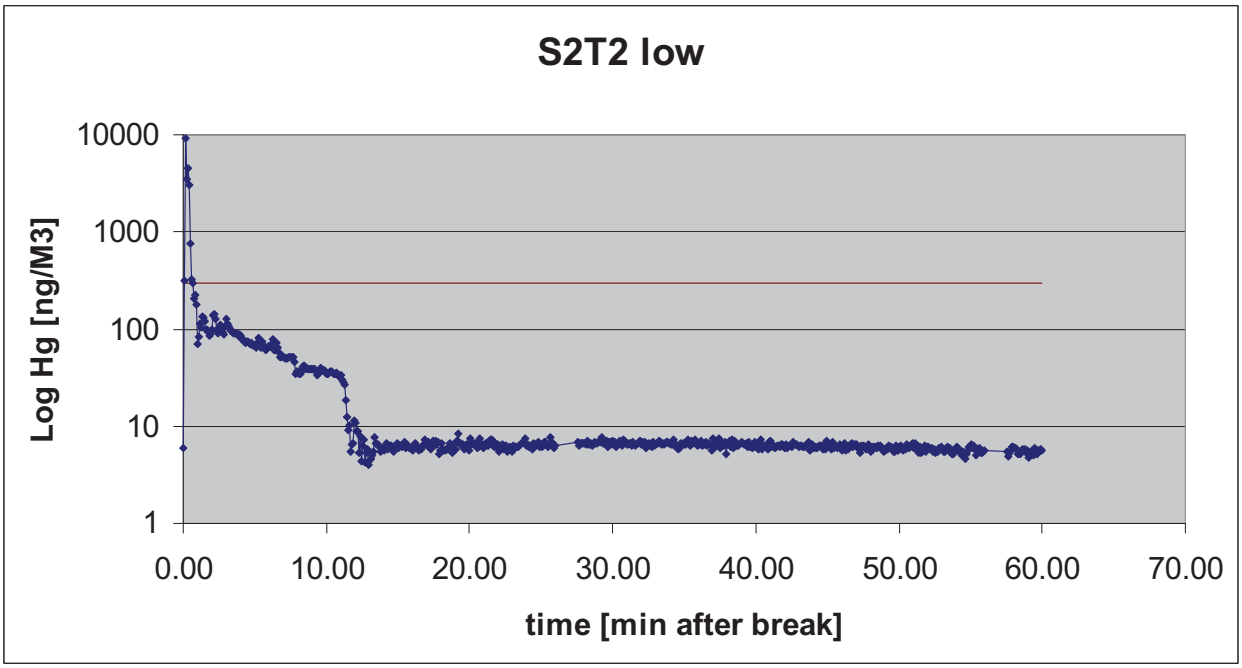


Figure A-12. Scenario 2, Trial 2 at One-Foot Height (5/29/07)

Scenario 3: Short Nap Carpet, Venting, Cleanup

A "Brand A" 60 watt equivalent lamp was thoroughly broken with a hammer on the short carpet, and was cleaned up using the pre-study cleanup guidance. (The window was opened, and the lamp was cleaned up with index cards, tape and a wet wipe. The waste was placed in a re-

sealable plastic bag.) The waste was removed from the room, the door was closed, and the waste was put in a hazardous waste drum.

All trials for this scenario had similar looking graphs. The trial with the highest peak of mercury is summarized at follows: mercury peaked at 1,200 ng/m^3 at the five-foot height and peaked at 10,788 ng/m^3 at the one-foot height. The high and low graphs appear below for this Trial 1 that occurred on 5/29/07.

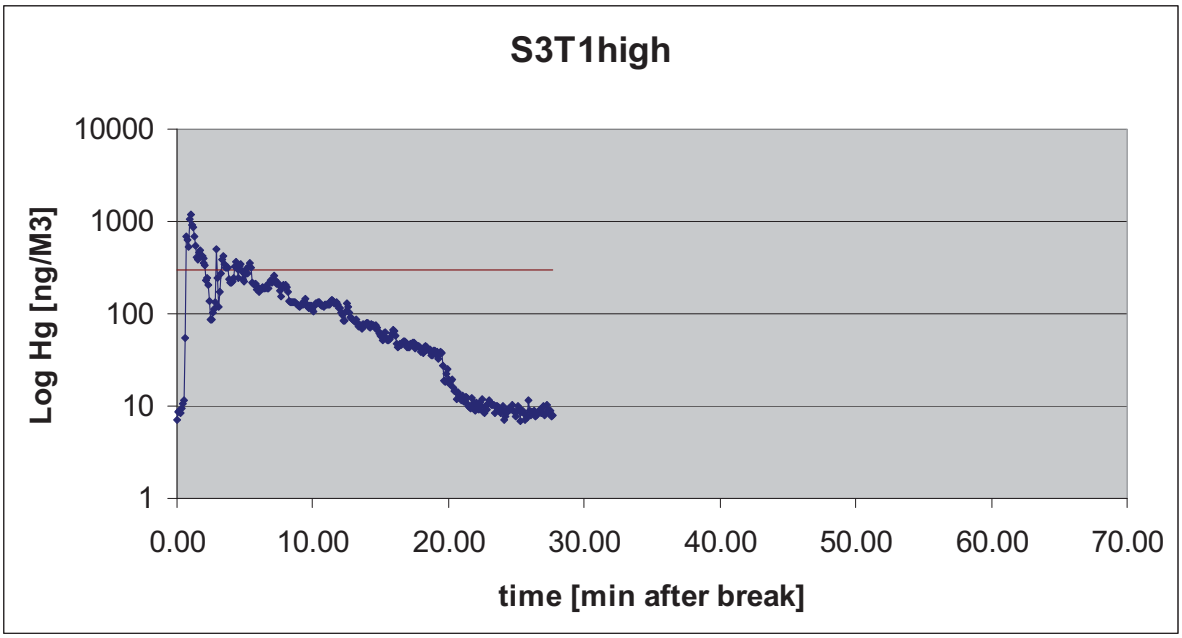


Figure A-13. Scenario 3, Trial 1 at Five-Foot Height (5/29/07)

Appendix A

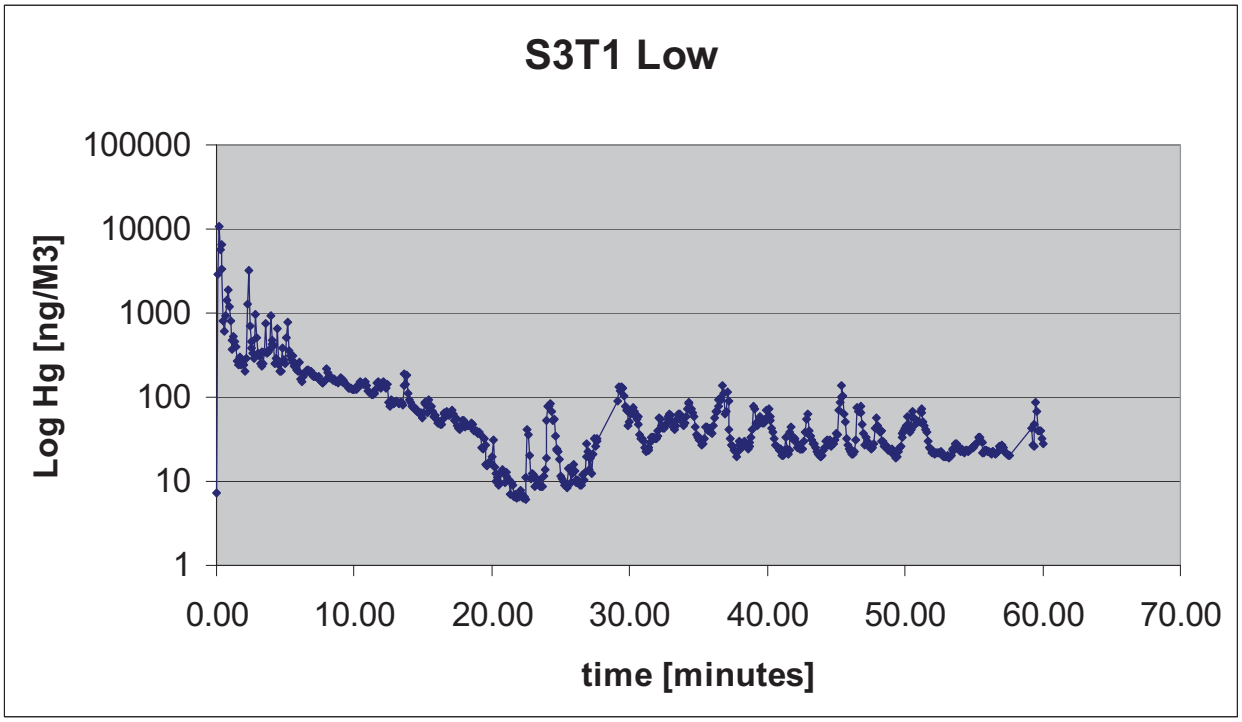


Figure A-14. Scenario 3, Trial 1 at One-Foot Height (5/29/07)

Scenario 3, trials 2 and 3 (S3T2 and S3T3) below were performed slightly different from S3T1 and S3T4 and S3T5. For S3T2 and S3T3, the lamp was broken, the window was opened, and cleanup was postponed five minutes. There was no five minute wait for S3T1, S3T4 and S3T5. (S3T4 appeared to be a "dud" lamp with very little mercury emissions and was ended early and accidentally not saved).

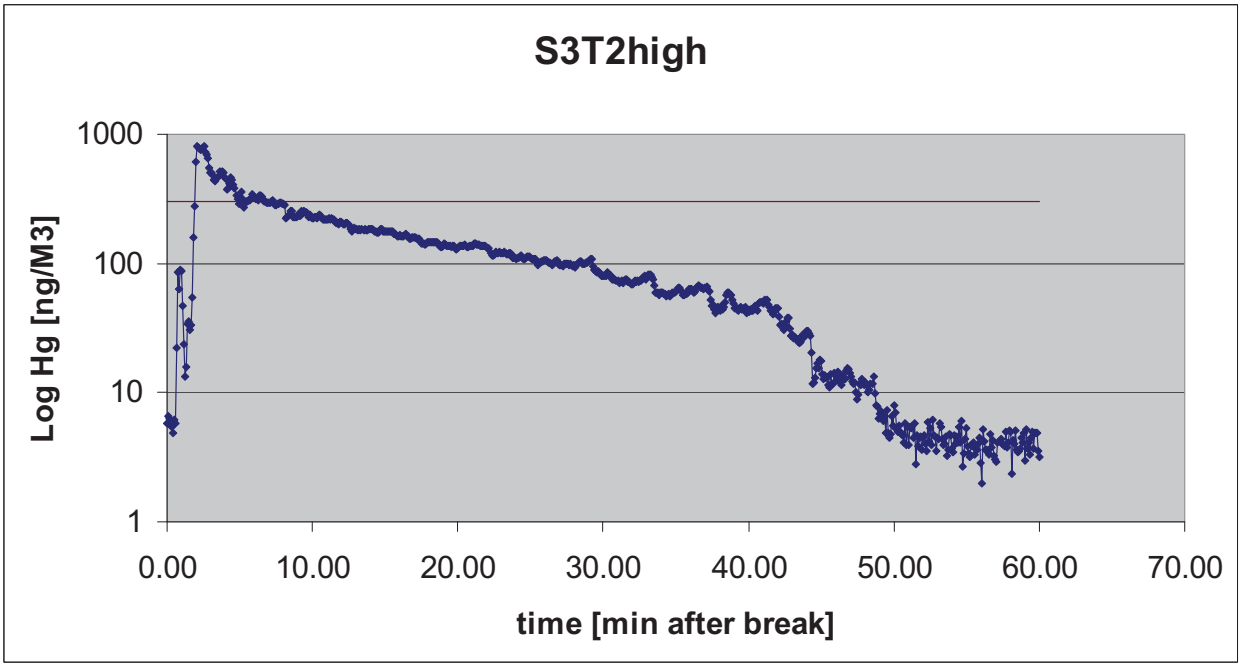


Figure A-15. Scenario 3, Trial 2 at Five-Foot Height (5/30/07)

Appendix A

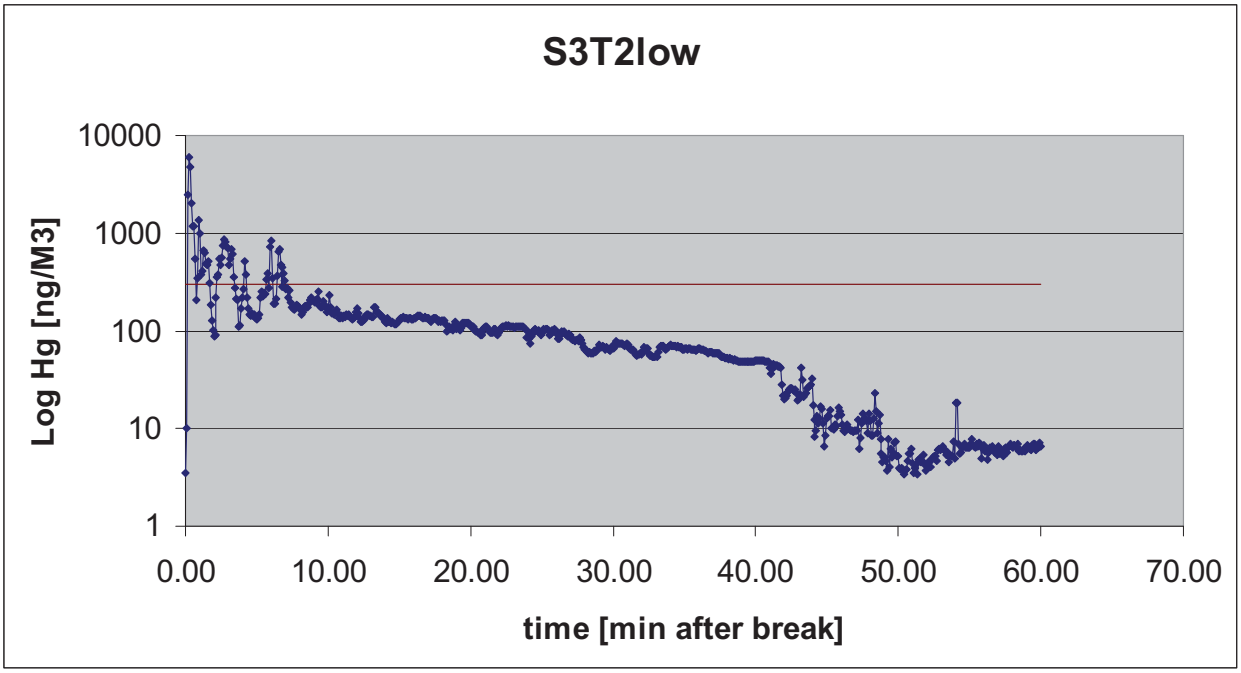


Figure A-16. Scenario 3, Trial 2 at One-Foot Height (5/30/07)

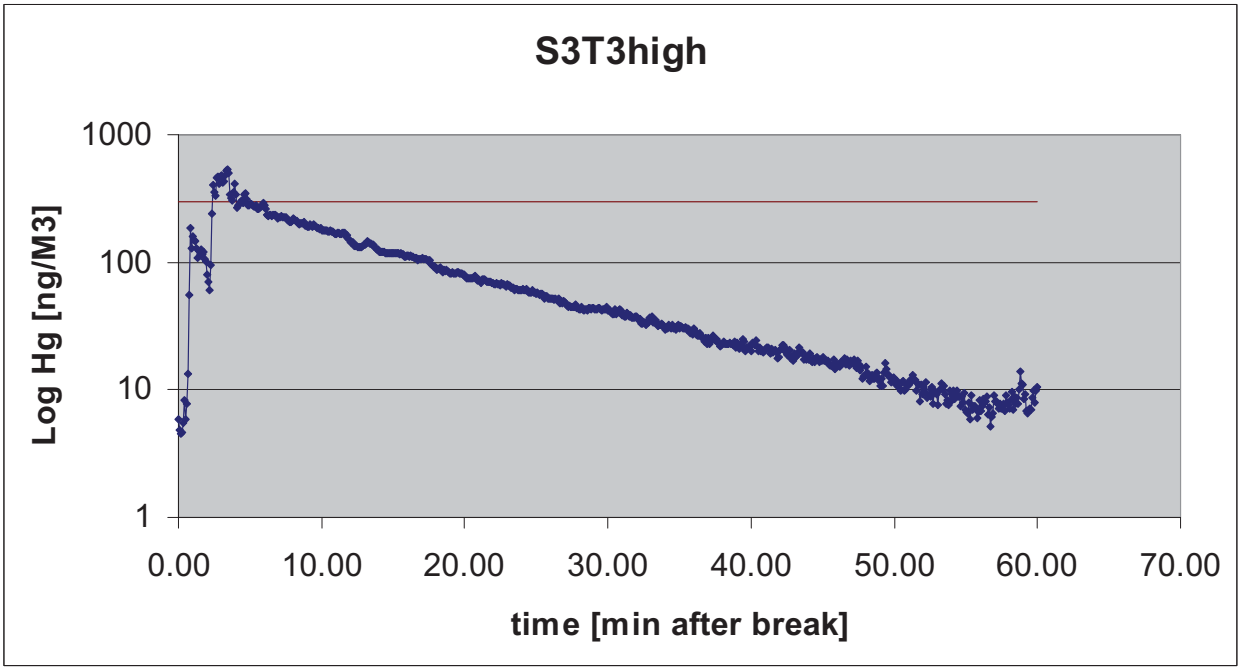


Figure A-17. Scenario 3, Trial 3 at Five-Foot Height (5/31/07)

Appendix A

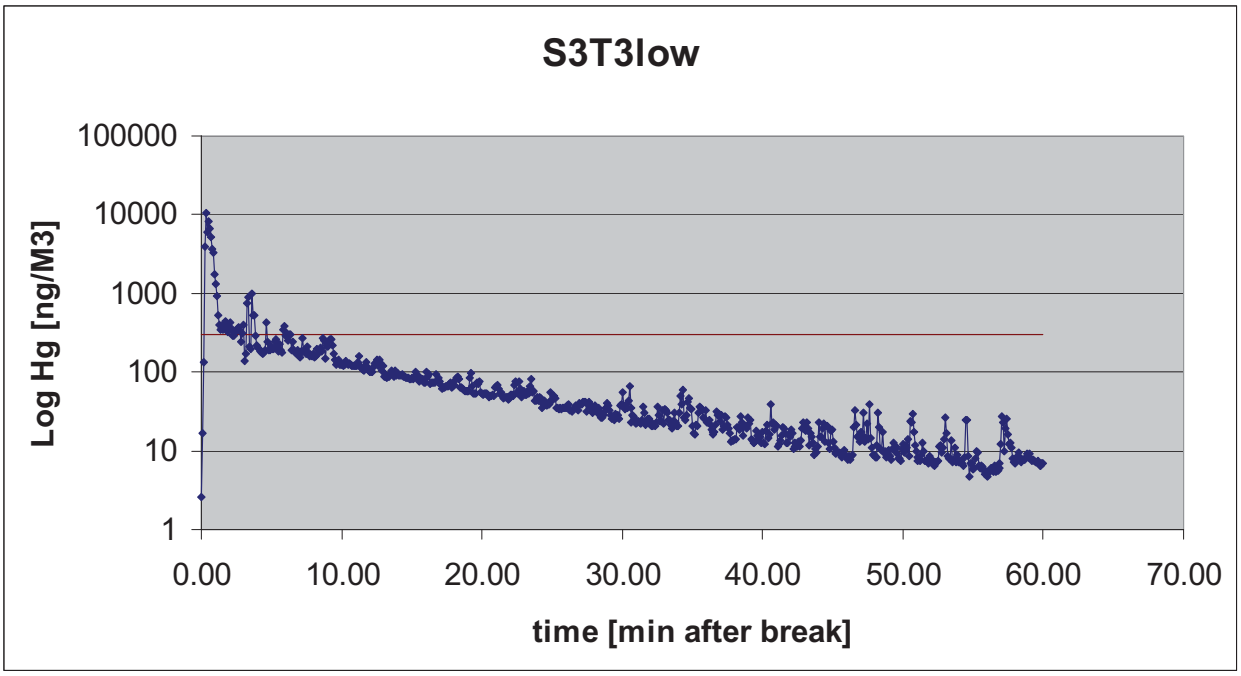


Figure A-18. Scenario 3, Trial 3 at One-Foot Height (5/31/07)

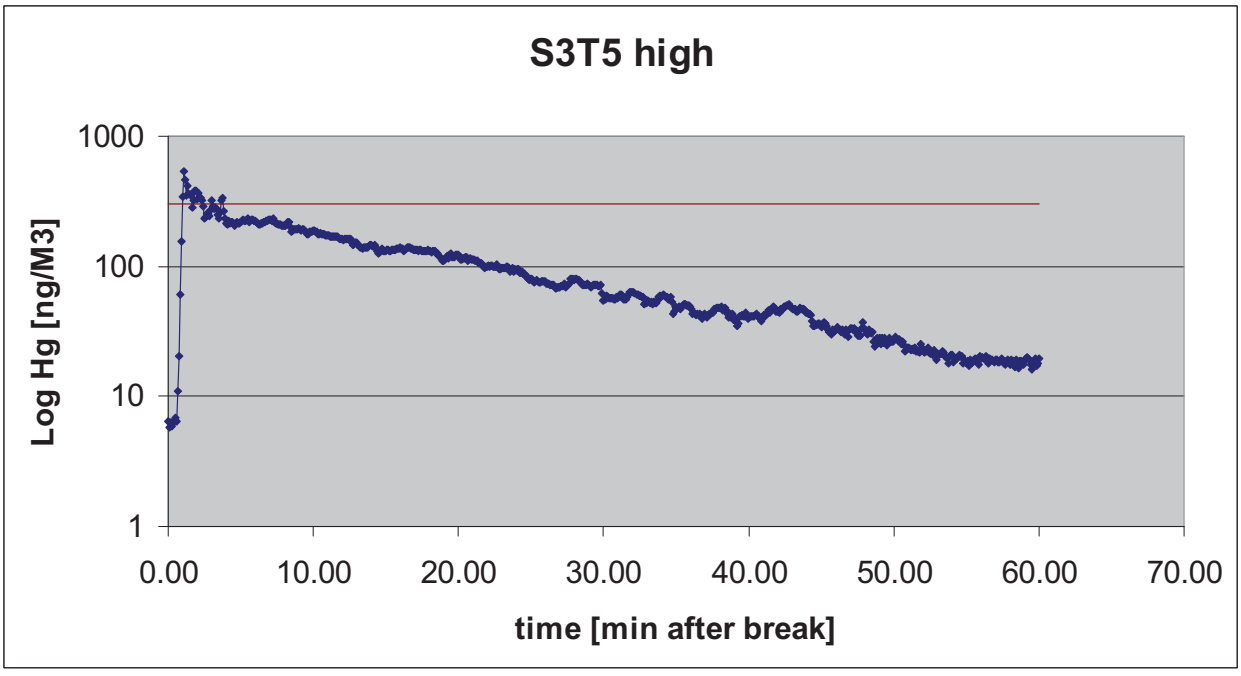


Figure A-19. Scenario 3, Trial 5 at Five-Foot Height (5/31/07)

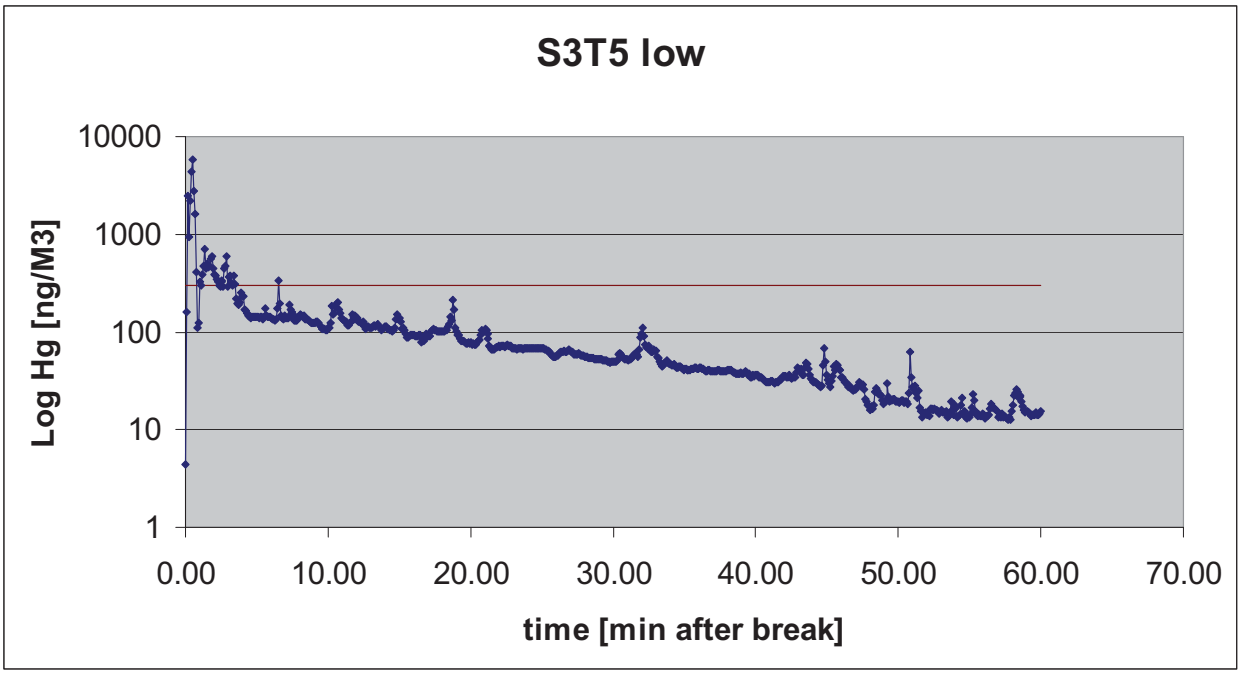


Figure A-20. Scenario 3, Trial 5 at One-Foot Height (5/31/07)

Scenario 4: Longer Carpet, Venting, Cleanup

A "Brand A" 60 watt equivalent lamp was thoroughly broken with a hammer on the shag carpet, and was cleaned up using the pre-study cleanup guidance. (The window was opened, and the lamp was cleaned up with index cards, tape and a wet wipe. The waste was placed in a re-sealable plastic bag.) The waste was removed from the room, the door was closed, and the waste was put in a hazardous waste drum.

For Trial 3, on 6/7/07, mercury peaked at 544 ng/m^3 at the five foot height and peaked at 8,262 ng/m^3 at the one foot height. Concentrations of mercury in the room at both heights was less than 300 ng/m^3 after 5.33 minutes. The other two trials for Scenario 4 looked similar.

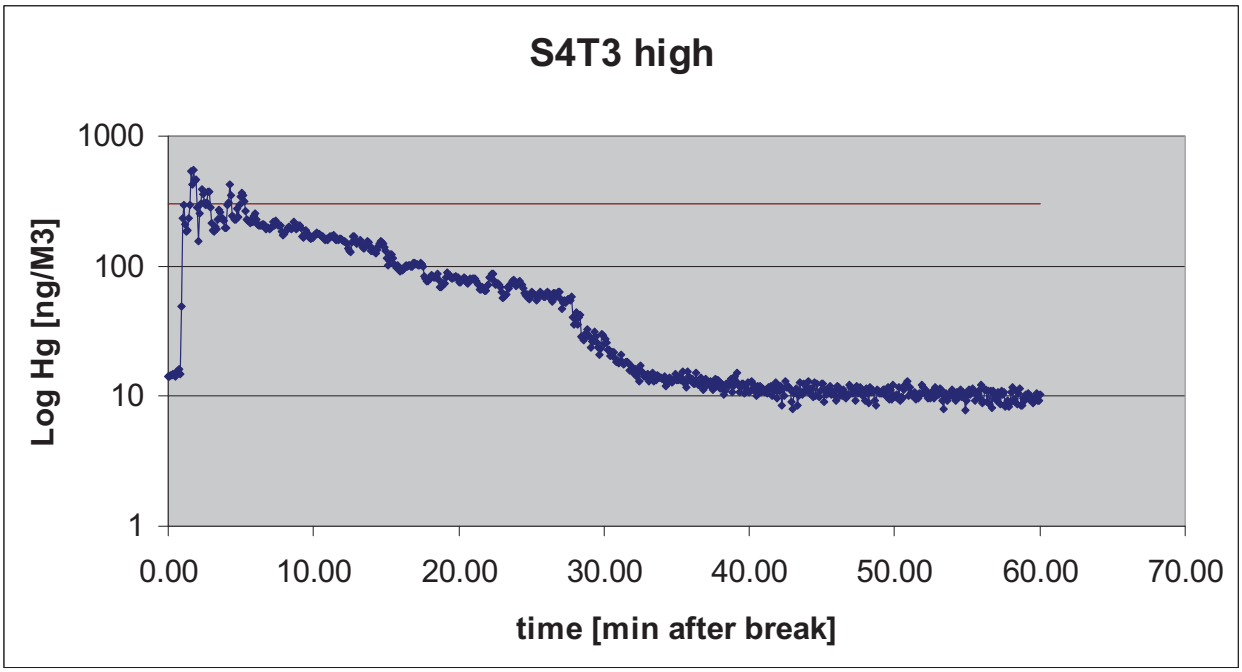


Figure A-21. Scenario 4, Trial 3 at Five-Foot Height (6/7/07)

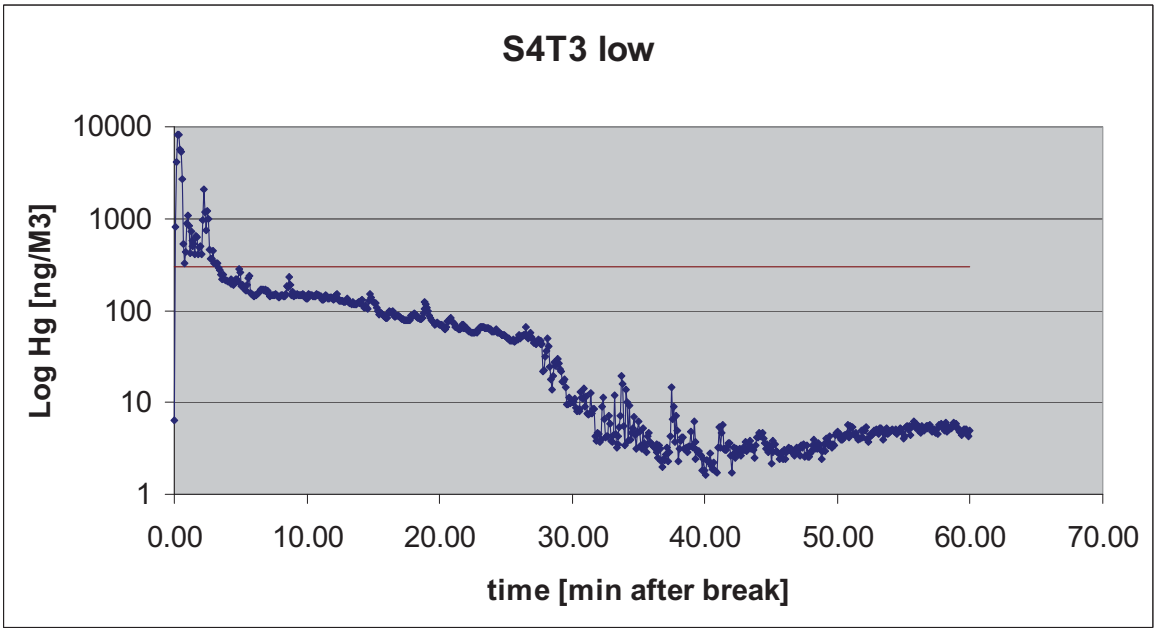


Figure A-22. Scenario 4, Tria1 3 at One-Foot Height (6/7/07)

As this study progressed, it was observed that the floorings, even after cleanup, often contained a source of mercury that the third Lumex could pick up when held close to the flooring, and that agitation made a significant difference in measured concentrations. On each floor type, the readings were variable depending on where the Lumex was located. For example, moving the Lumex over an inch or two on the flooring could dramatically increase or decrease the numbers.

Appendix A

Table A-1 lists results from Lumex scans of Scenario 4 flooring after a CFL had been broken and cleaned up. Results recorded are the highest concentrations of mercury observed while scanning flooring in ng/m^3.

Table A-1

Scenario	S4T2		S4T3	
Date of Breakage	6/7/2007		6/8/2007	
Floor Type	long carpet (shag)		long carpet (shag)	
Date Measured ↓	calm	agitated	calm	agitated
6/8/2007	<20	108	<20	99
6/11/2007	<20	413	<20	112
6/12/2007	<20	129	<20	55
6/13/2007	22	273	<20	190
6/14/2007	<20	303	<20	54
6/15/2007	<20	398		
6/19/2007	<20	511		
6/21/2007	25	512		
6/22/2007	28	1083		
6/25/2007	<20	1096		
6/26/2007	22	506		
6/27/2007	<20	1025		
6/28/2007	<20	618		
6/29/2007	<20	1640		
7/2/2007	<20	401		
7/3/2007	<20	307		
7/5/2007	61	1241		
7/6/2007	<20	392		
7/9/2007	<20	742		
7/10/2007	26	543		
7/11/2007	26	199		

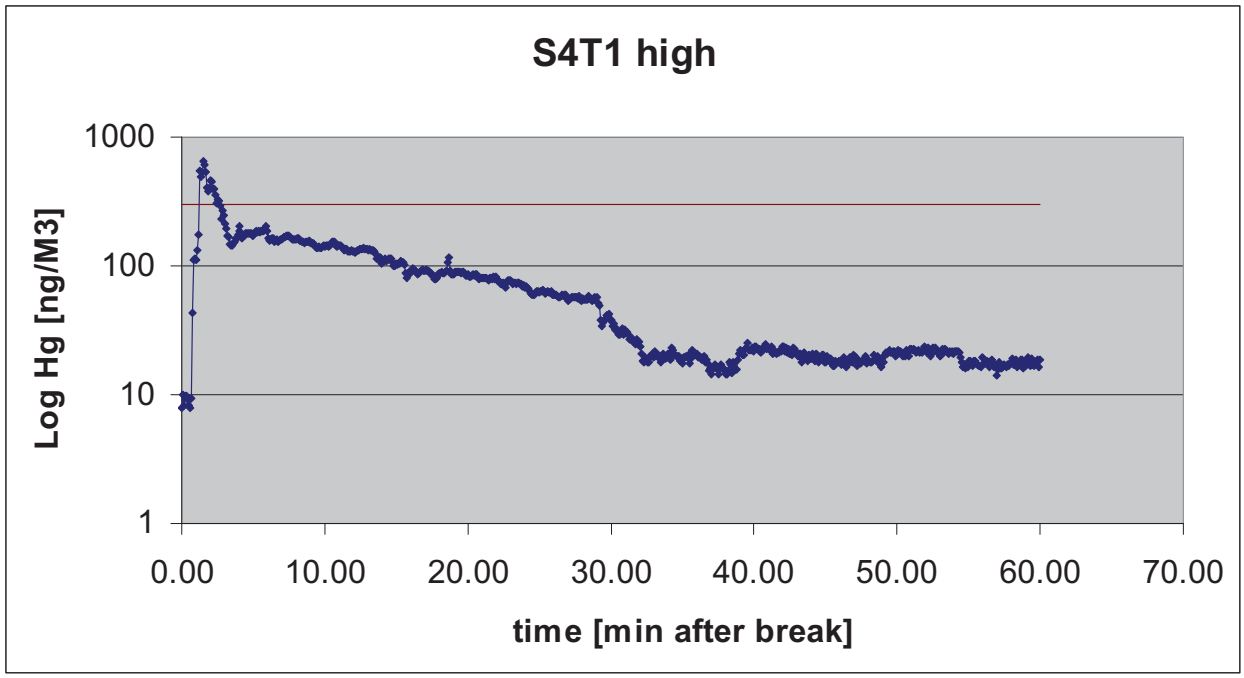


Figure A-23. Scenario 4, Trial 1 at Five-Foot Height (6/6/07)

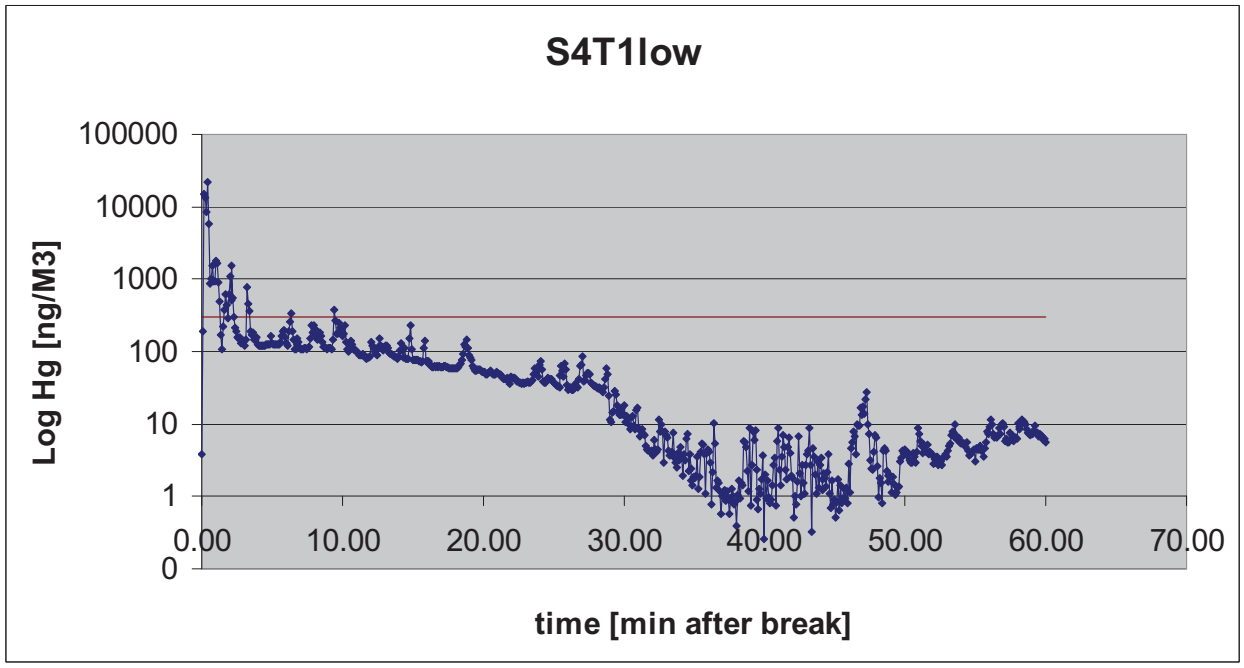


Figure A-24. Scenario 4, Trial 1 at One-Foot Height (6/6/07)

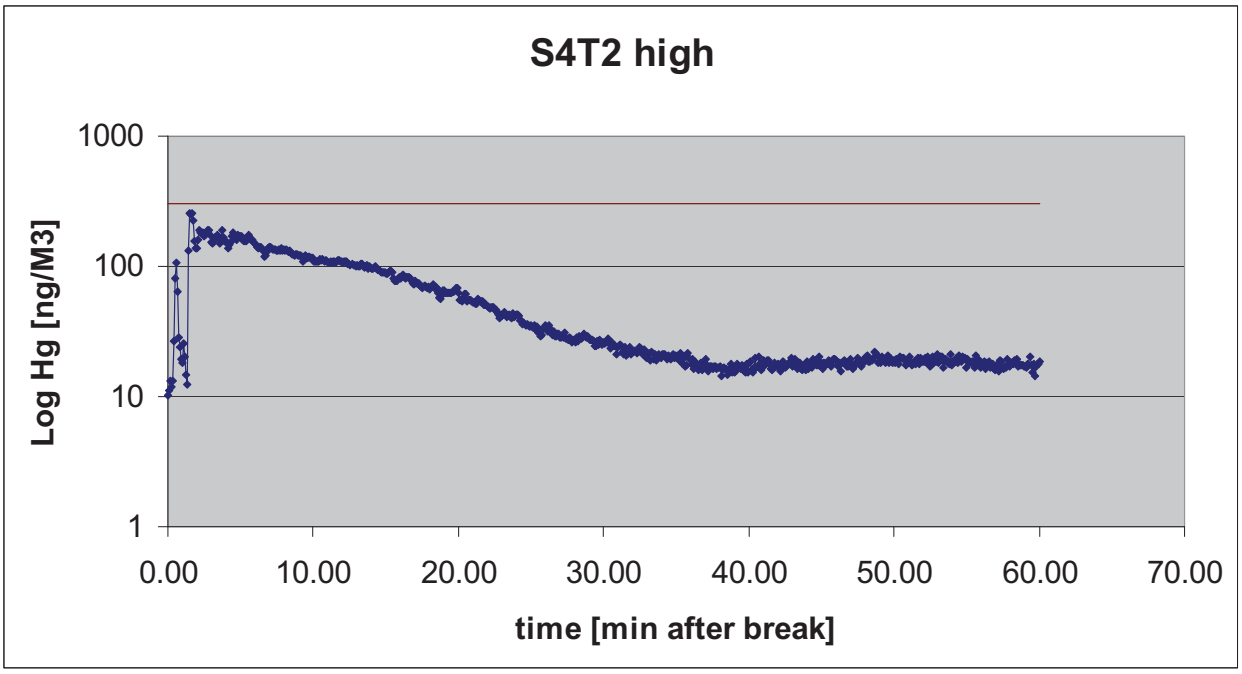


Figure A-25. Scenario 4, Trial 2 at Five-Foot Height (6/7/07)

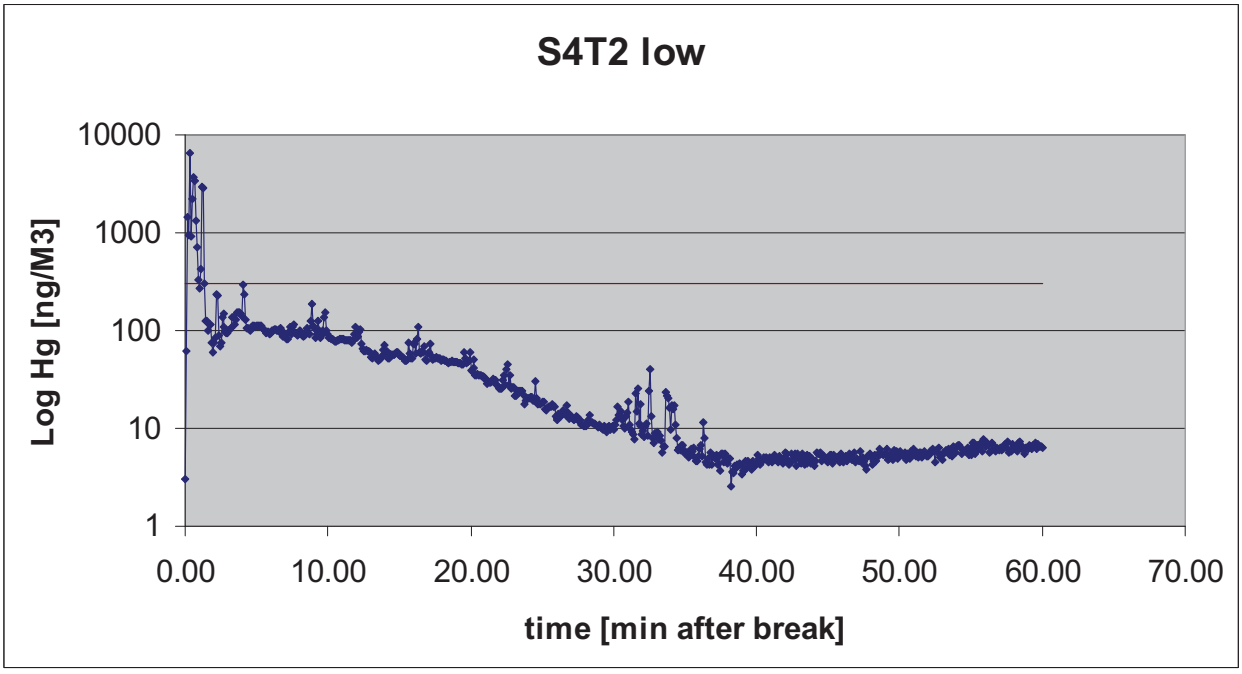


Figure A-26. Scenario 4, Trial 2 at One-Foot Height (6/7/07)

Scenario 5: Short Nap Carpet, Venting, Vacuuming

A "Brand A" 60 watt equivalent lamp was thoroughly broken with a hammer on the short nap carpet, the window was opened, and the larger pieces of broken lamp were put in a re-sealable bag. A Kenmore canister vacuum with beater floor attachment, filter and bag was used for the

smaller pieces of debris. The vacuum beater was then wiped down with a wet wipe. The waste and vacuum bag were taken out of the room, and disposed of in the hazardous waste drum.

For the first trial for Scenario 5, on 6/1/07, mercury peaked at 628 ng/m^3 at the five foot height and peaked at 18,578 ng/m^3 at the one foot height. Concentrations of mercury in the room, at both heights, were less than 300 ng/m^3 after about eight minutes.

The carpet for the third trial (S5T3) was used later in a vacuum scenario as part of the additional cleanup scenarios section. For S5T3 on 6/4/07, mercury peaked at 315 ng/m^3 at the five foot height and peaked at 3,953 ng/m^3 at the one foot height. Concentrations of mercury in the room, at both heights, were less than 300 ng/m^3 after 5.83 minutes. This carpet was vacuumed about four weeks later with a Hoover 400 Futura vacuum. See Figures A-78 and A-79.

Figure A-27. Kenmore Canister used in Scenario 5.

Appendix A

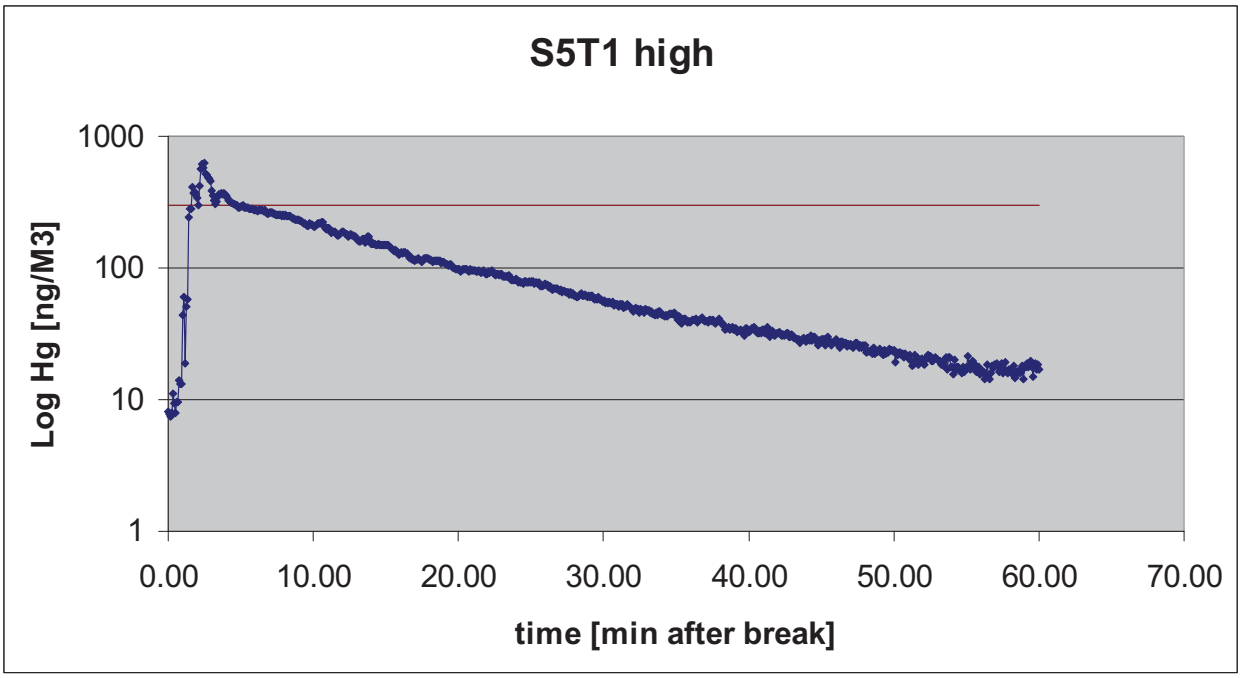


Figure A-28. Scenario 5, Trial 1 at Five-Foot Height (6/1/07)

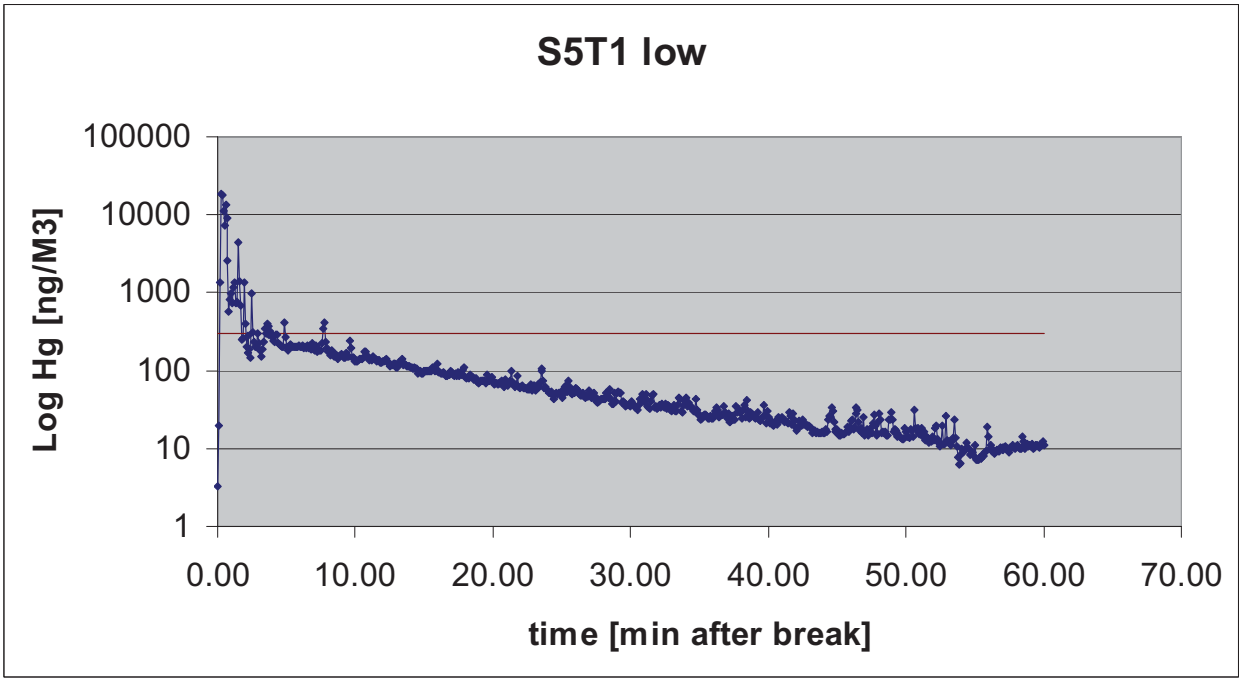


Figure A-29. Scenario 5, Trial 1 at One-Foot Height (6/1/07)

Appendix A

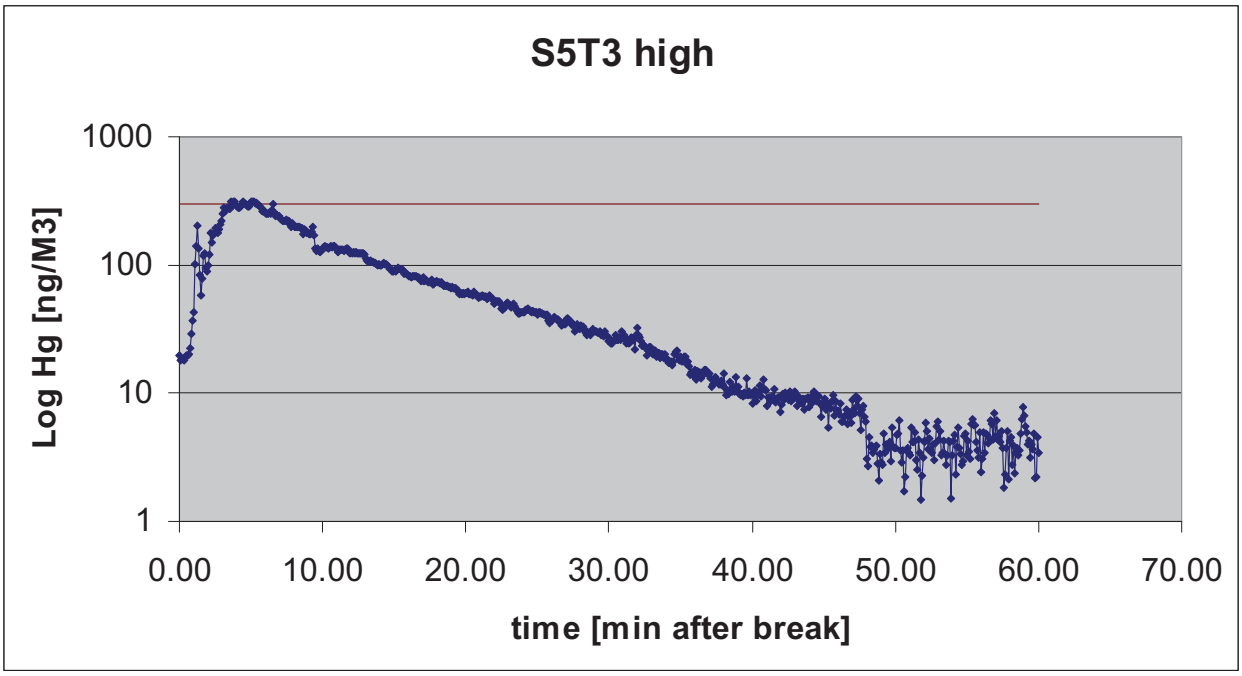


Figure A-30. Scenario 5, Trial 3 at Five-Foot Height (6/4/07)

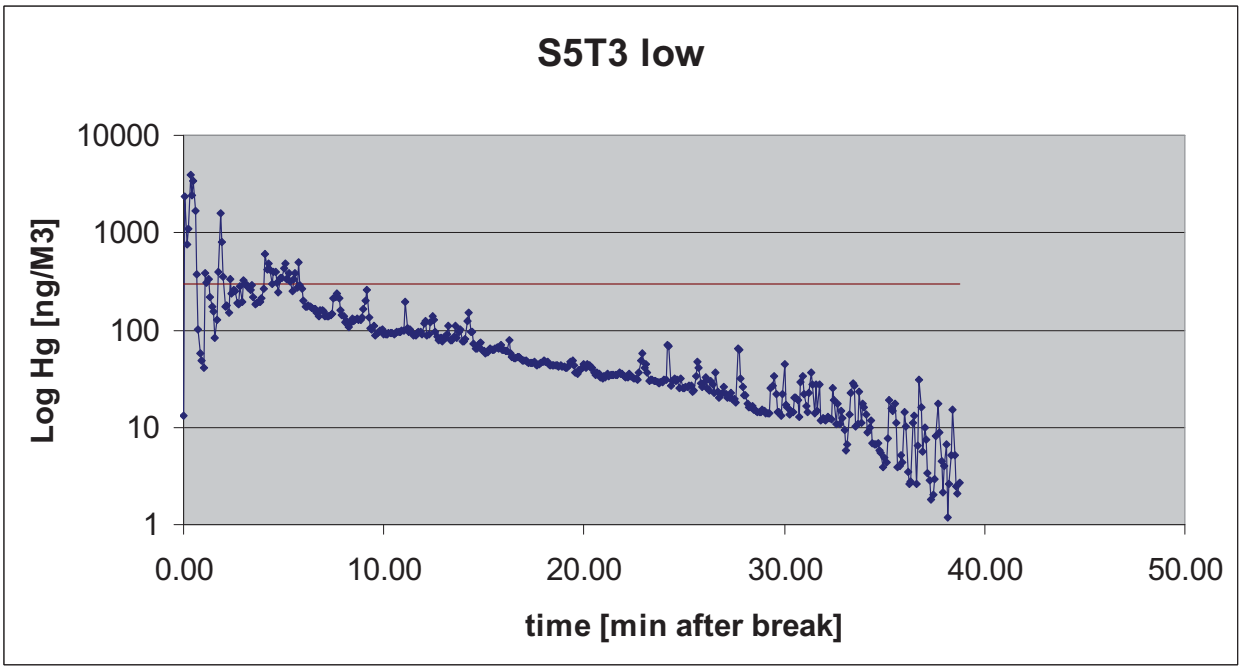


Figure A-31. Scenario 5, Trial 3 at One-Foot Height (6/4/07)

The third Lumex was used to take some readings up close to several of the Kenmore canister vacuum parts. See the Table A-2. below:

Appendix A

Table A-2.	Vacuum measurements with 3rd Lumex when room levels of mercury are low		
Kenmore	Vacuum ran for approx 10 min. to get warm vac or "hot" numbers		
canister	Measurements are in ng/m^3, recorded within approx. an inch of vac part surface		
	Wet wipes used on vacuum		

		Vacuum Cleaner Part													
		Beaters				Plastic hose		Inside vac		Metal wand		Filter			
Date of Vacuuming	Date of Measurement	hot	hot agitated	cold	cold agitated	hot	cold	hot	cold	hot	cold	hot	hot agitated	cold	cold agitated
6/1/07AM	6/1/2007AM (about 1hr. After 1st vacuuming)	46		67		114	146	63	57	137	103	37		<20	
6/1/2007PM	6/1/2007PM (about 1hr. After 2nd vacuuming)			148		70	355				83	39		33	
	6/4/2007 8:41AM before 3rd break			<20			52		40		41				
6/4/2007 9AM	6/4/2007 approx. 600 seconds into run for this 3rd vac	3,277				18,260		3,152		1,824		<room air			
	6/4/2007 approx. 10AM	330		357		858	608	170	240	428	109	75		<20	
	6/4/2007 approx. 1PM	163		383		578	654	43	56	256	615	32		<20	
	6/4/2007 4:20PM			179			305		22		48			<20	
	6/5/07 7:30AM	113		149		353	164	<20	20	201	184	<20		<20	
	6/5/07 5PM	92		87		476	488	50	51	878	171	60		20	
	6/6/2007	45		32		2,094	460	58	<20	608	472	42		<20	
	6/7/2007	291	444	<20	462	1,254	596	158	<20	282	120	35	91	<20	112
	6/8/2007	72	354	<20	520	247	184	84	<20	59	38	33	445	<20	251
	6/11/2007	32	136	26	263	372	511	68	<20	163	111	30	1,354	<20	454
	6/12/2007	36	725	39	105	1,709	759	60	23	122	200	26	899	<20	274
	6/13/2007	22	237	27	64	507	2009	51	30	52	55	33	82	<20	326
	6/14/2007	26	538	21	642	603	451	38	48	127	336	29	136	<20	180
	6/15/2007	27	1,050	<20	145	2,413	856	37	<20	82	53	34	168	<20	472

Table A-3 displays Lumex scans of Scenario 5 Trial 3 flooring after a CFL had been broken and cleaned up. Results recorded are the highest concentrations of mercury seen while scanning in ng/m^3. This piece of carpet was vacuumed again, with the Hoover 400, on 7/2/07, represented by the shaded boxes below.

Table A-3

Scenario	S5T3vac	
Date of Breakage	6/4/2007	
Floor Type	short carpet	
Date Measured ↓	calm	agitated
6/12/2007	<20	345
6/13/2007	<20	380
6/14/2007	<20	732
6/15/2007	<20	775
6/18/2007	<20	4,240
6/19/2007	21	1,714
6/21/2007	<20	1,940
6/22/2007	30	2,719
6/25/2007	22	739
6/26/2007	<20	914
6/27/2007	62	1,888
6/28/2007	<20	1,387
6/29/2007	<20	332
7/2/2007 (before vac)	<20	2,165
7/2/2007 (after vac)		4,330
7/5/2007	43	1,826
7/6/2007	89	1,061
7/9/2007	<20	2,032
7/10/2007	30	967
7/11/2007	<20	790
7/26/2007	24	173

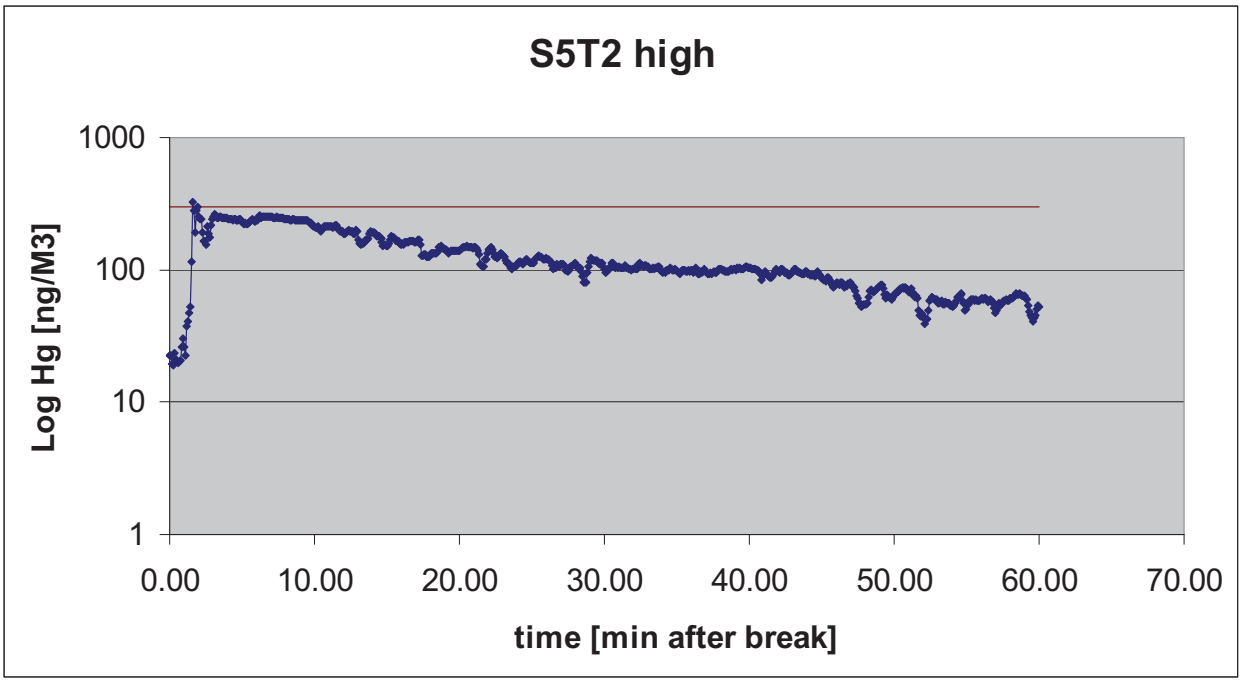


Figure A-32. Scenario 5, Trial 2 at Five-Foot Height (6/1/07)

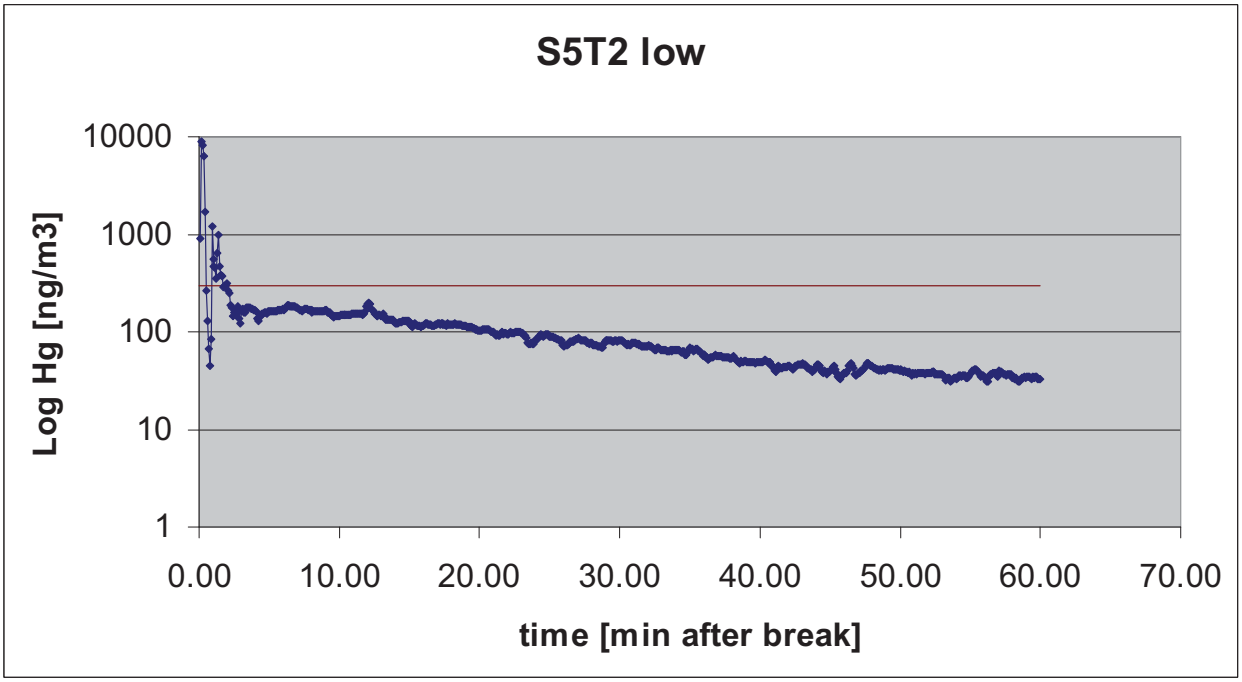


Figure A-33. Scenario 5, Trial 2 at One-Foot Height (6/1/07)

Scenario 6: Shag Carpet, Venting, Vacuuming with Lightweight Vacuum without Bag

For this scenario a “Brand A” 60 watt equivalent lamp was thoroughly broken with a hammer on the short carpet, the window was opened, and the larger pieces of broken lamp were put in a re-sealable plastic bag. The vacuum, a motorized Dirt Devil power sweeper, was used for the smaller pieces of debris. The vacuum surface that had touched the debris was wiped down with a wet wipe. The vacuum was left in the room, but the waste was taken out of the room, and placed in a hazardous waste drum.

On 6/5/07, mercury from Trial 2 peaked at 414 ng/m^3 at the five foot height and peaked at 16,942 ng/m^3 at the one foot height. Concentrations of mercury in the room at both heights were less than 300 ng/m^3 after 3.08 minutes.

Figure A-34. Dirt Devil motorized power sweeper used in Scenario 6

Figure A-35. Dirt Devil “beater”

Figure A-36. Dirt Devil detachable cup for emptying debris

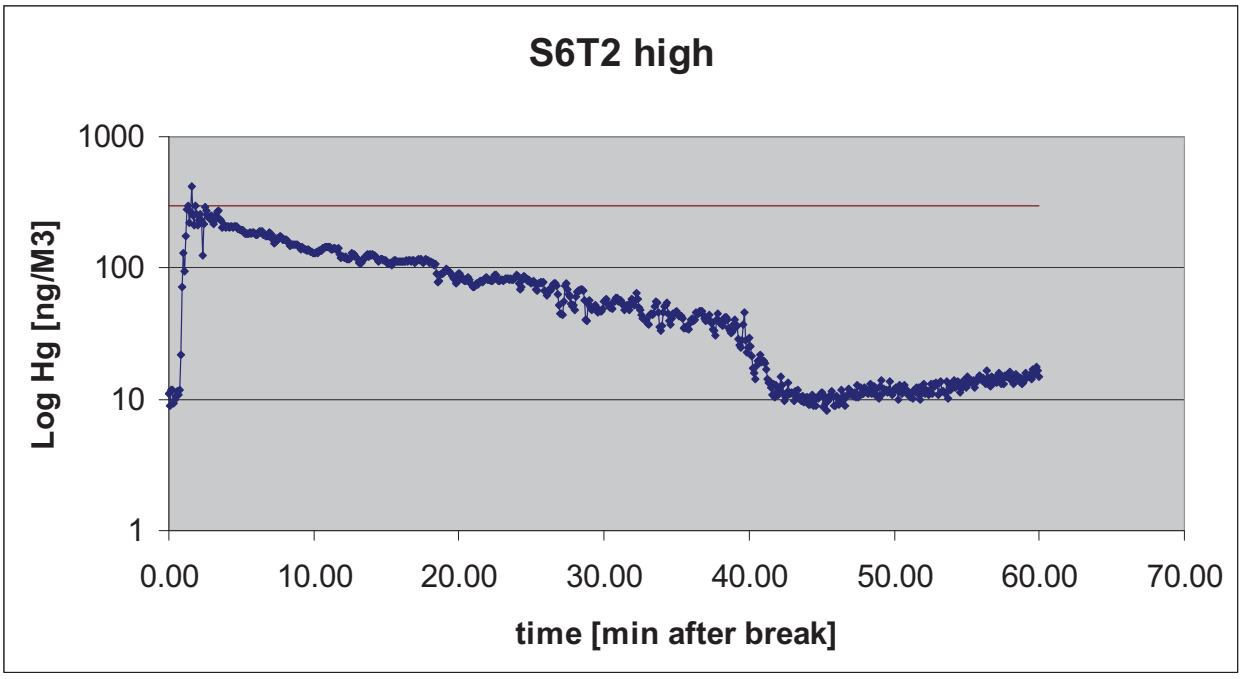


Figure A-37. Scenario 6, Trial 2 at Five-Foot Height (6/5/07)

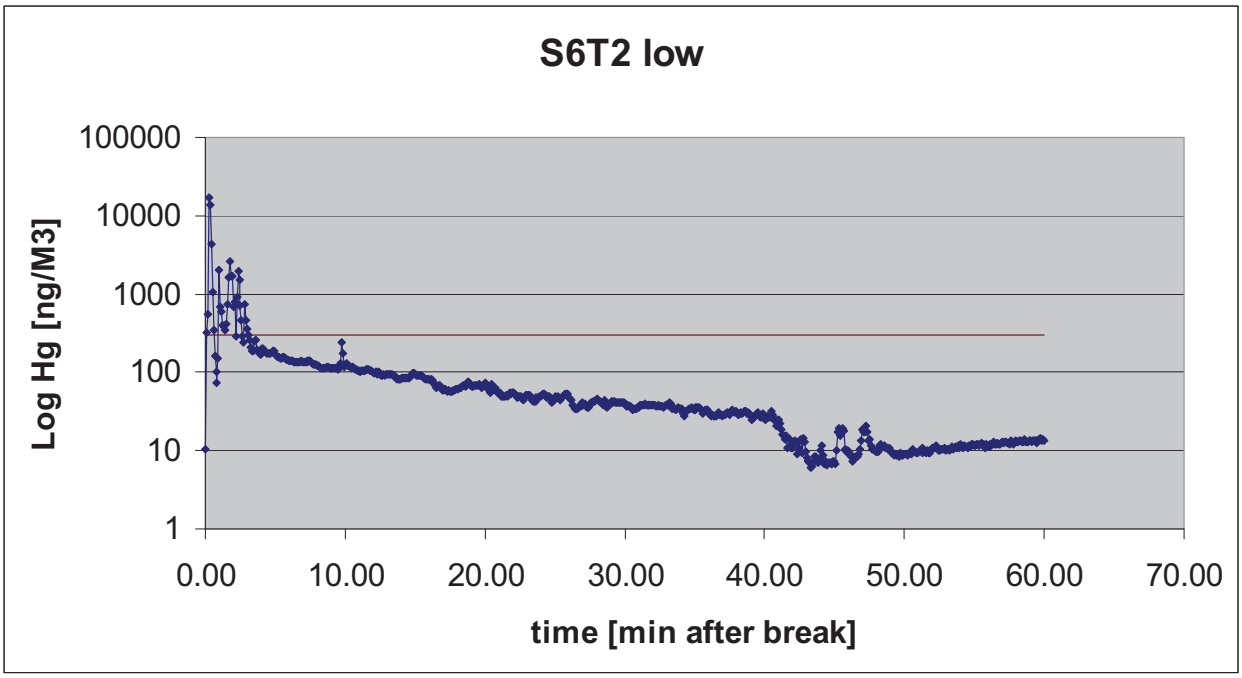


Figure A-38. Scenario 6, Trial 2 at One-Foot Height (6/5/07)

After about 15 minutes into the first trial of Scenario 6, the third Lumex was used to get some readings off the vacuum. Mercury in the air next to and within approximately an inch of the beaters equaled 370 ng/m^3. Room air at that time was about 130 ng/m^3. See table below for additional information:

Table A-4 shows mercury concentrations in ng/m^3 recorded within approx. an inch of vac part surface for a Dirt Devil Power Sweep, purchased new June 4, 2007. Wet wipes were used on vacuum surfaces before each set of readings below except first row of results.

Table A-4. . Dirt Devil Power Sweep

			Vacuum Cleaner Part		
Date of Lamp Breakage	**Date of Vacuuming**	**Date of Measurement**	**Beater**	**Handle**	**Cup**
6/5/2007AM	6/5/2007AM	6/5/2007AM (14.6 minutes into run)	370	220	249
		6/5/2007AM (about 1 hr. after vacuuming)	22	<20	21
6/5/2007PM	6/5/2007PM	6/5/2007PM (about 45 min. after 2nd vacuuming)	39	<20	20
6/6/2007	6/6/2007	6/6/2007	close to ambient air	close to ambient air	close to ambient air

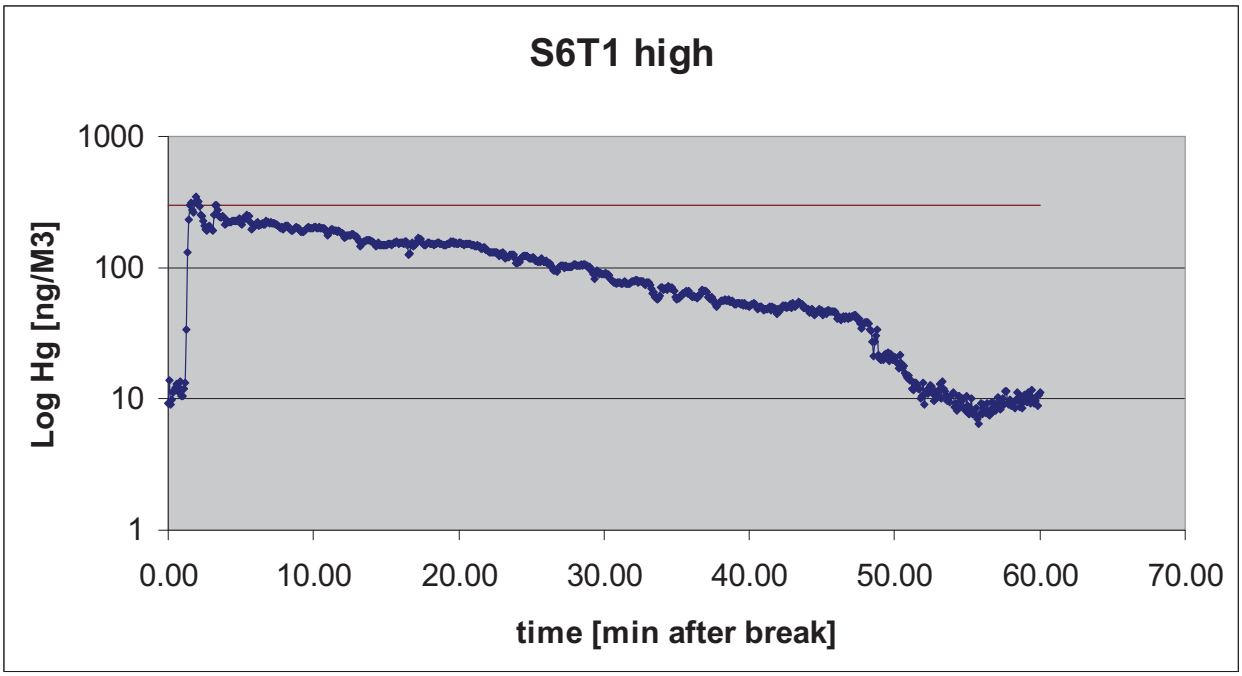


Figure A-39. Scenario 6, Trial 1 at Five-Foot Height (6/5/07)

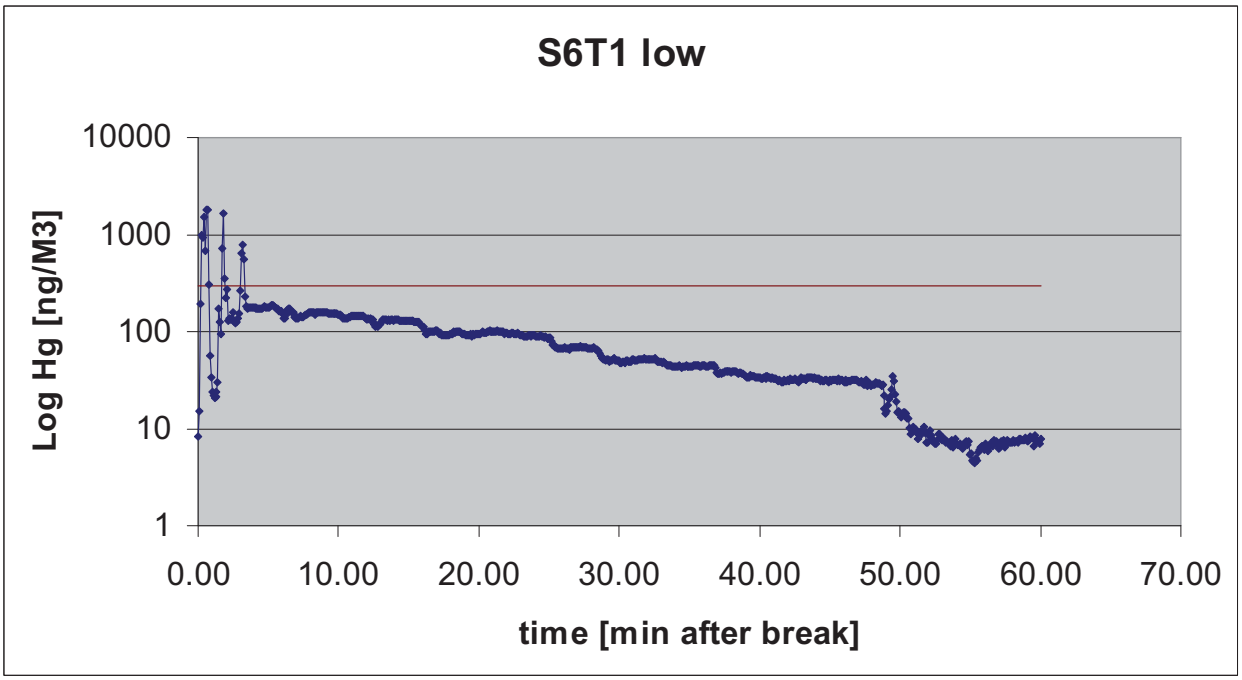


Figure A-40. Scenario 6, Trial 1 at One-Foot Height (6/5/07)

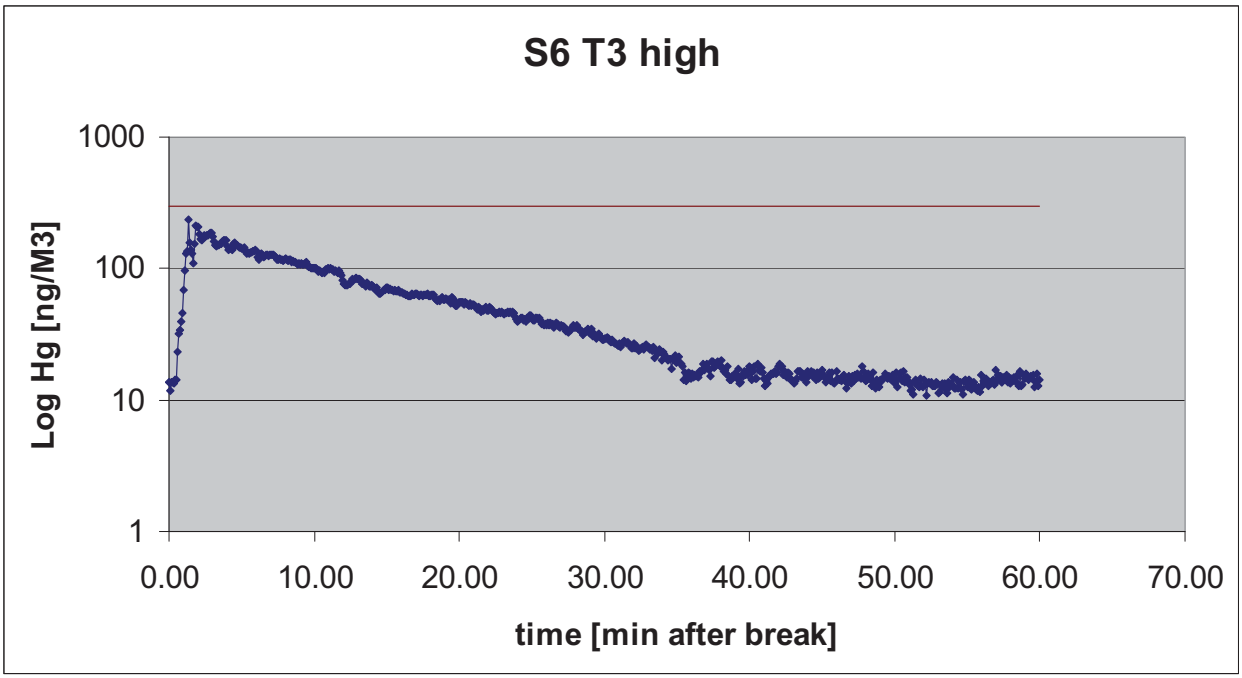


Figure A-41. Scenario 6, Trial 3 at Five-Foot Height (6/6/07)

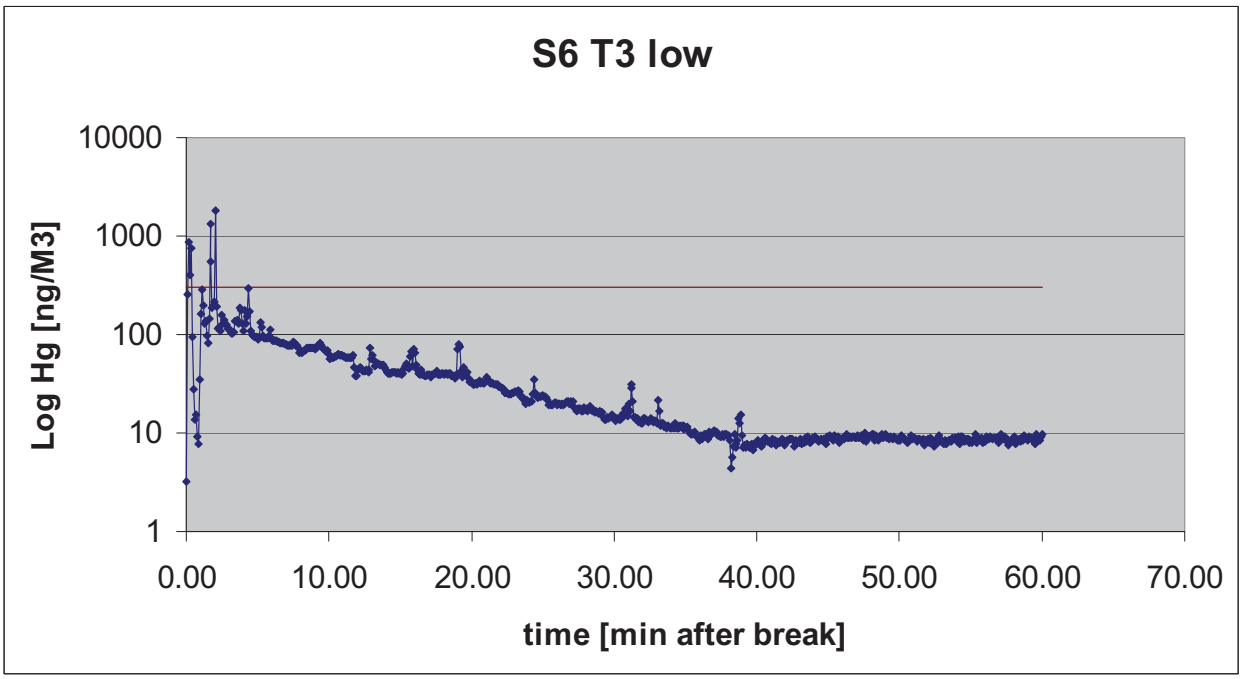


Figure A-42. Scenario 6, Trial 3 at One-Foot Height (6/6/07)

Additional Cleanup Scenarios

Scenario A: "Brand B" 90 Watt Equivalent, Wood, Venting, Cleanup. This was an older lamp donated from the Maine Public Utilities Commission. It was taller than the other lamps tested and consisted of four tall glass columns. Additional lamp information that is not listed in Table 2 is as follows: Product Order Code 21046, Description FLC26, RES.3719541, CG26-EC. Graphs for the first broken lamp and graphs for the duplicate are shown below because of the very different results.

For both trials of this scenario, the lamp was thoroughly broken on hardwood floor, the window was opened, the bigger pieces of debris were put into the re-sealable polyethylene bag. The smaller pieces were picked up with index cards, tape, and a wet wipe. The waste, in the re-sealable bag, was removed from the room, and put into the hazardous waste drum.

The first trial occurring 6/8/07, see Figures A-43 & A-44, showed mercury peaking at 1,640 ng/m^3 at the five foot height and peaking at 7,410 ng/m^3 at the one foot height. Mercury decreased to under 300 ng/m^3 after 15.5 minutes at the five foot height and after 10.41 minutes at the one foot height.

The second trial on 6/11/07, a duplicate to the first trial, showed a much higher concentration of mercury in the air after breakage. Mercury peaked at 9,893 ng/m^3 at the five foot height and peaked at 61,037 ng/m^3 at the one foot height. Mercury decreased to under 300 ng/m^3 at approximately 65 minutes for both the high and low levels, but spiked over 300 off and on for hours at the one foot height (see Figure A-47). For this trial, the third Lumex was used to measure mercury coming out of the room from under the door. At about 38 minutes from the start of the run, the third Lumex recorded mercury down the hall from the experiment room between 50-100 ng/m^3 with readings on the floor a little higher than at the five foot breathing zone. At the end of the hall, approximately 40 feet from the study room, concentrations of mercury decreased to between 20 and 30 ng/m^3. At about 47 minutes from the start of the run a camera with a tripod that was in the study room was removed from the study room. The third Lumex scanned the camera and noticed that the metal joints on the tripod legs appeared to be emitting some mercury. The joints on one tripod leg read 40 ng/m^3, the joints on another leg read 27 ng/m^3, and the joints on the other leg read <20 ng/m^3. The exhaust tube connected to the Lumex that was reading the mercury at the five foot height, that vented the air back into the study room slipped off around 90 minutes from the start of the run. It also slipped off both Lumex instruments a couple of times later in the run, and was put back each time. The filters at the air intake were changed at the end of this run.

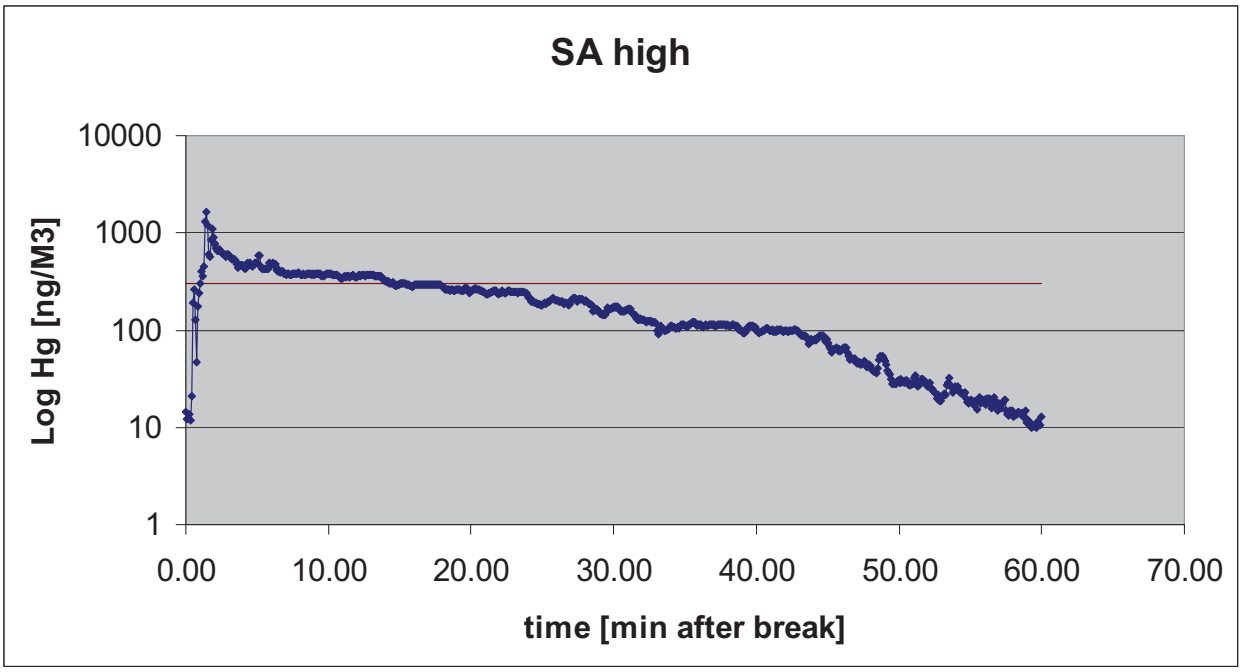


Figure A-43. Scenario A at Five-Foot Height (6/8/07)

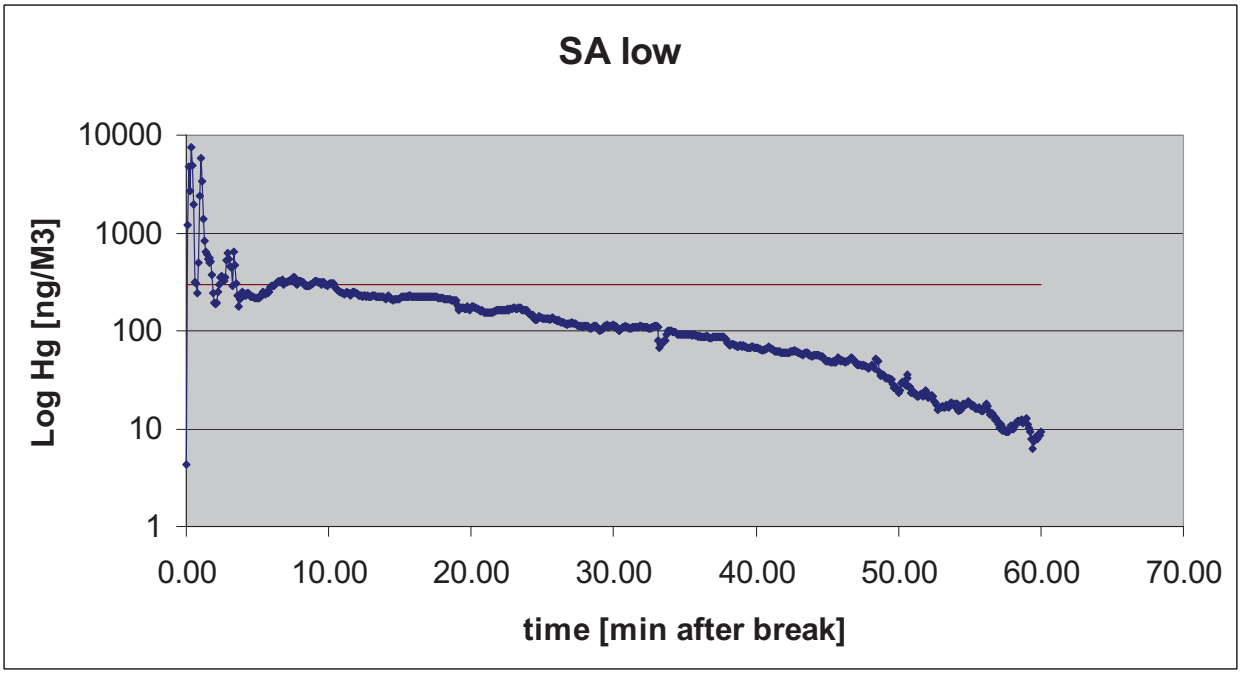


Figure A-44. Scenario A at One-Foot Height (6/8/07)

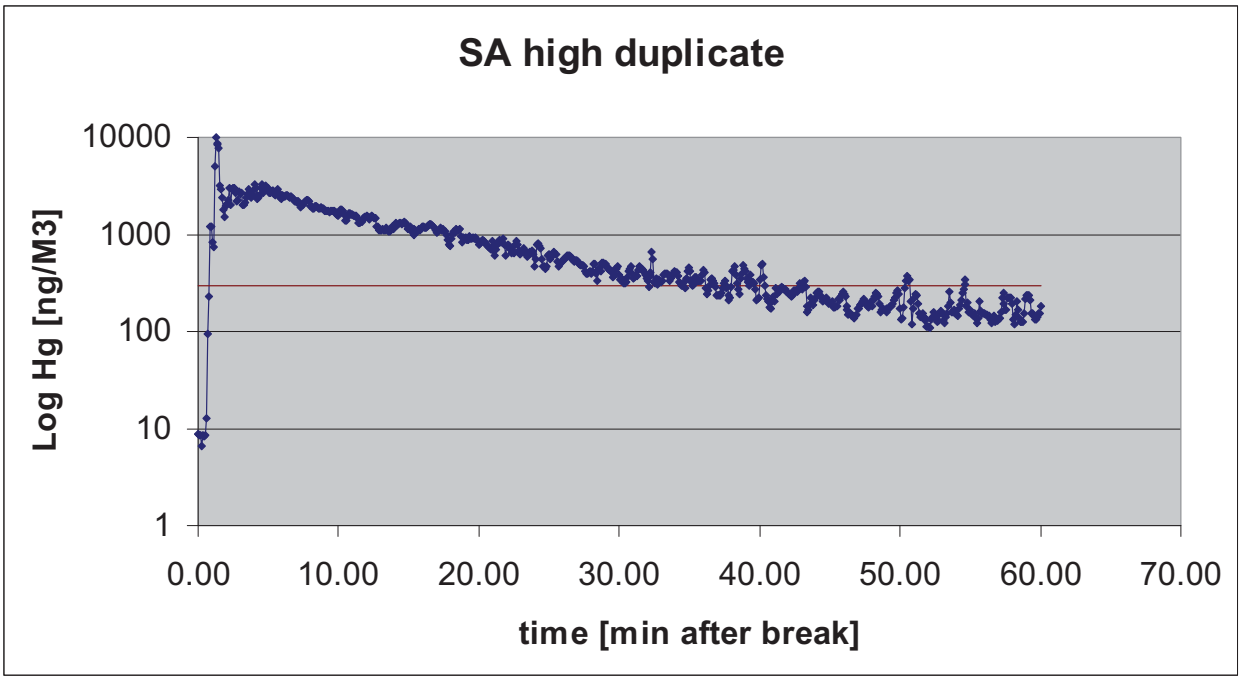


Figure A-45. Duplicate for Scenario A at Five-Foot Height (6/11/07)

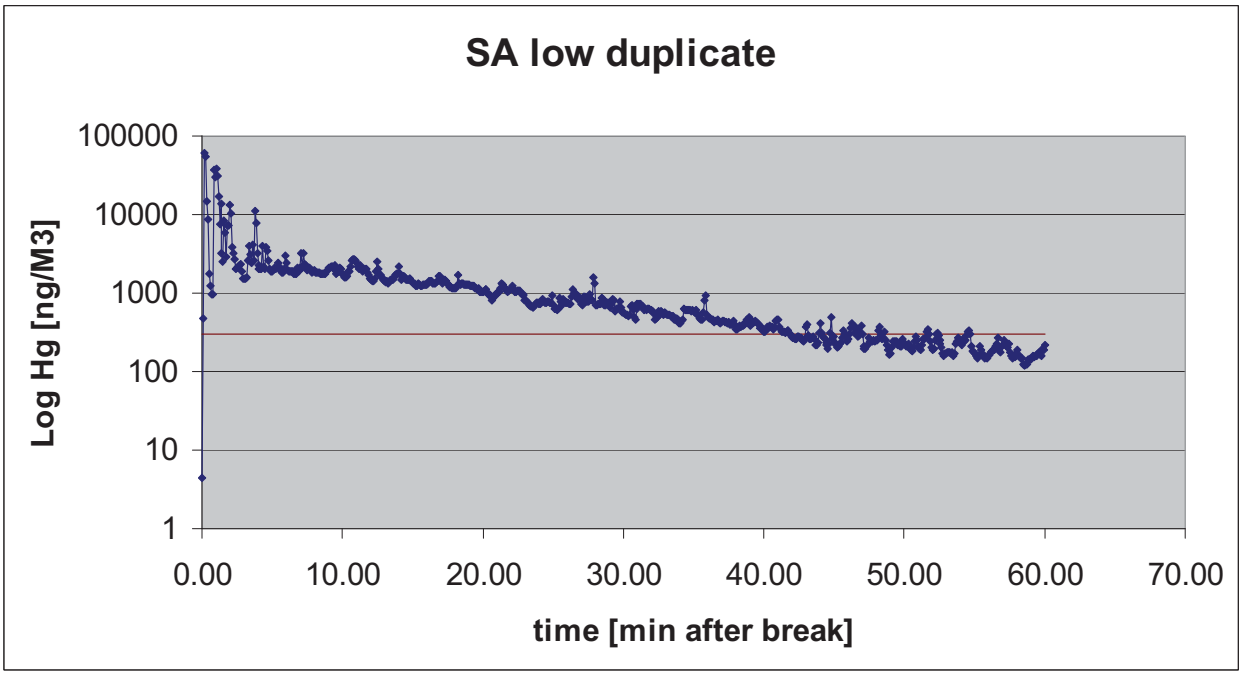


Figure A-46. Duplicate for Scenario A at One-Foot Height (6/11/07)

The following graph shows the concentration of mercury in the air one foot above the hardwood flooring AFTER the first hour since breakage had been recorded on the previous graph. The fifty minutes mark seen below, for example, represents an hour and fifty minutes from breakage.

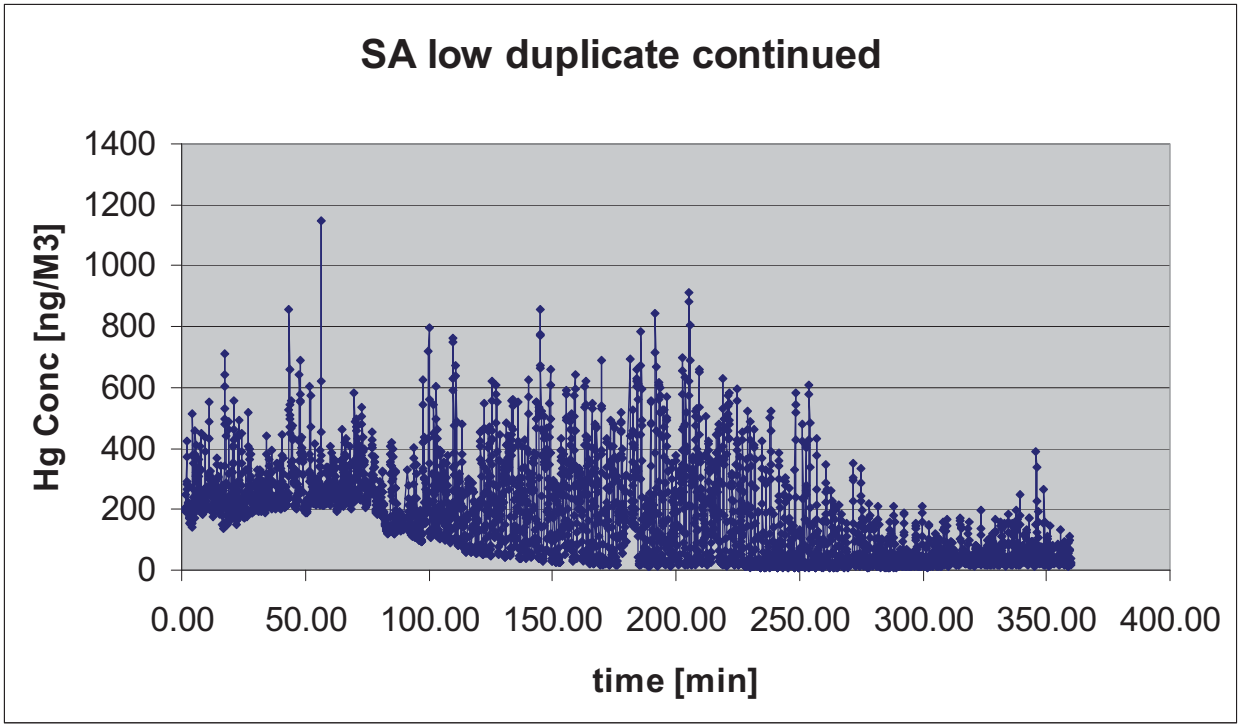


Figure A-47. Duplicate for Scenario A at One-Foot Height Continued (6/11/07)

Table A-5 displays Lumex scans of Scenario A flooring (duplicate) after a CFL had been broken and cleaned up. Results recorded are the highest concentrations of mercury seen while scanning in ng/m^3.

Table A-5.

Scenario	SA-"Brand B" 90D	
Date of Breakage	6/11/2007	
Floor Type	wood	
Date Measured ↓	calm	agitated
6/12/2007	254	797

Scenario B: "Brand C" 60 Watt Equivalent, Short Nap Carpet, Venting, Cleanup ("duplicate" broken on wood).

For this scenario a "Brand C" 60 watt equivalent lamp was thoroughly broken on short carpet, the room was vented, and the lamp was cleaned up with index cards, tape, a wet wipe, and the waste, in the re-sealable plastic bag, was removed from the room. The waste was disposed of in the hazardous waste drum.

After the mercury in the room was below detection limits of the Lumex, another "Brand C" 60 watt equivalent lamp was broken, with the same cleanup as the first only this time the break was on hardwood. Both breaks resulted in many spikes of mercury in the room. The third Lumex

was used to verify this spikiness. Figures A-48 & A-49 represent the break on short nap carpet, and the Figures A-50 & A-51 represent this lamp broken on hardwood.

For the break on short nap carpet, on 6/12/07, the mercury peaked at 1,777 ng/m^3 at the five foot height and peaked at 8,125 ng/m^3 at the one foot height. Mercury spiked above 300 ng/m^3 off and on for hours at the one foot height.

For the break on hardwood, on 6/13/07, mercury peaked at 1,139 ng/m^3 at the five foot height, and peaked at 9,523 ng/m^3 at the one foot height. Mercury appeared to decrease to under 300 ng/m^3 after 11.75 minutes at the low level (see Figure A-51).

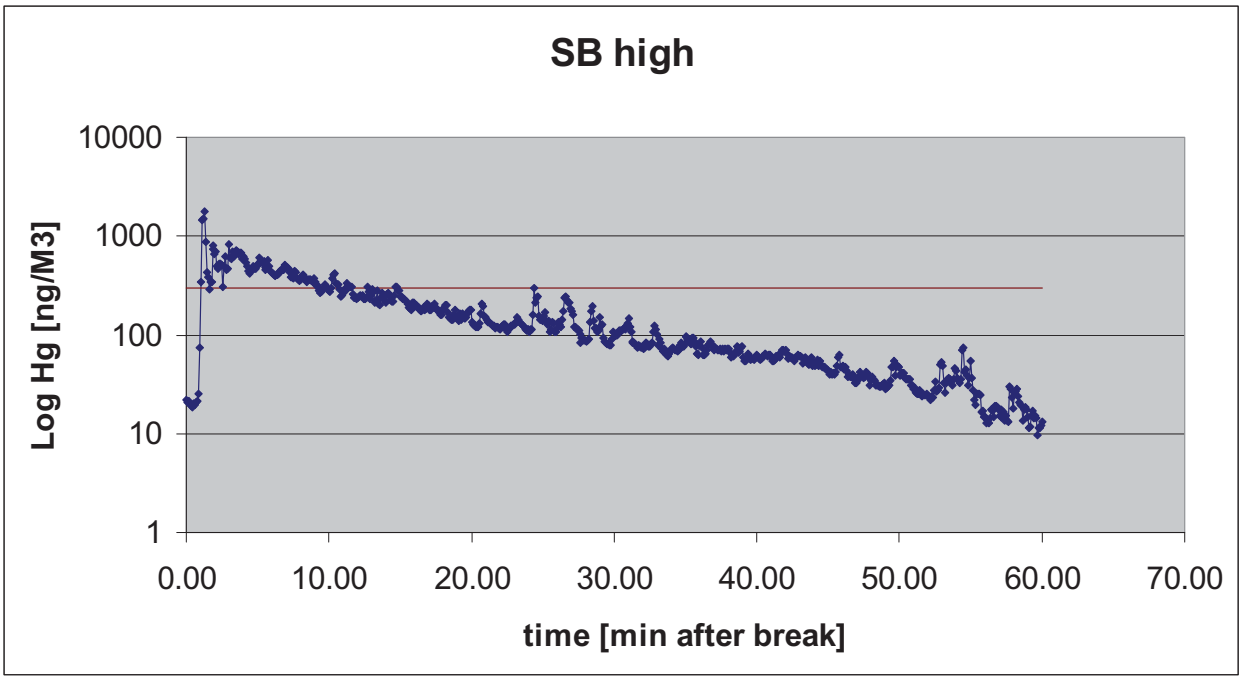


Figure A-48. Scenario B on Short Carpet at Five-Foot Height (6/12/07)

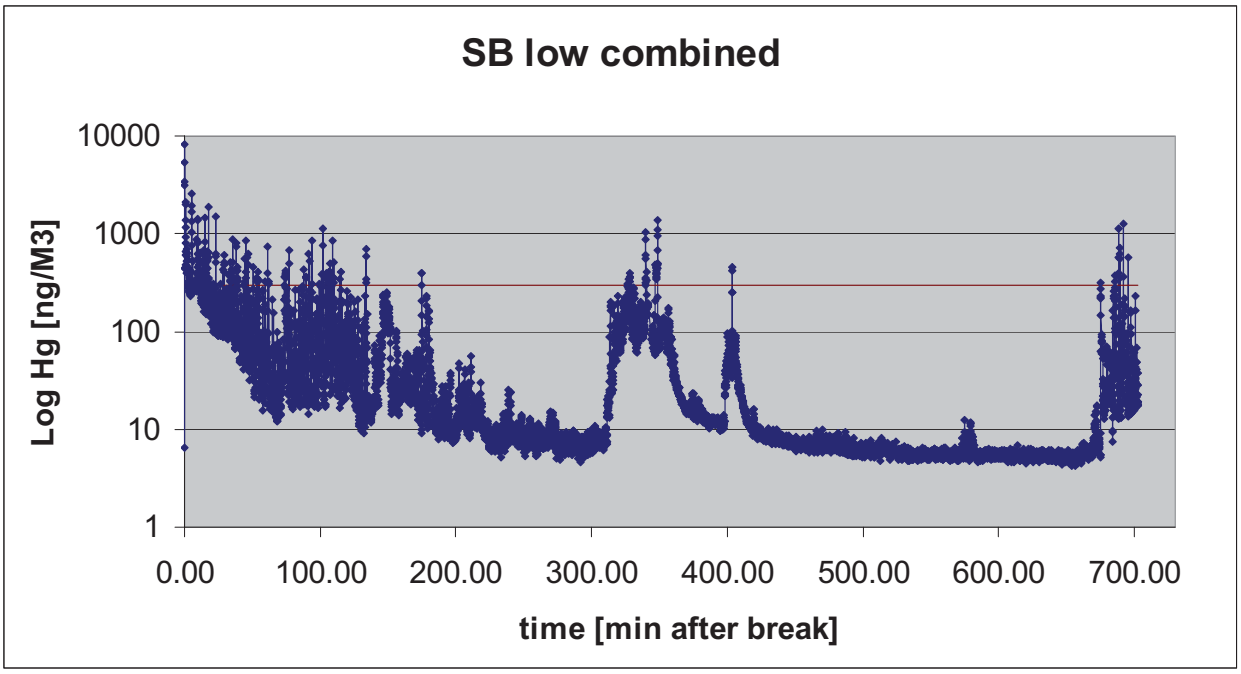


Figure A-49. Scenario B on Short Carpet at One-Foot Height (6/12/07)

The following two graphs are labeled “duplicate” but they represent a break on hardwood, and not the short nap carpet like the two graphs above.

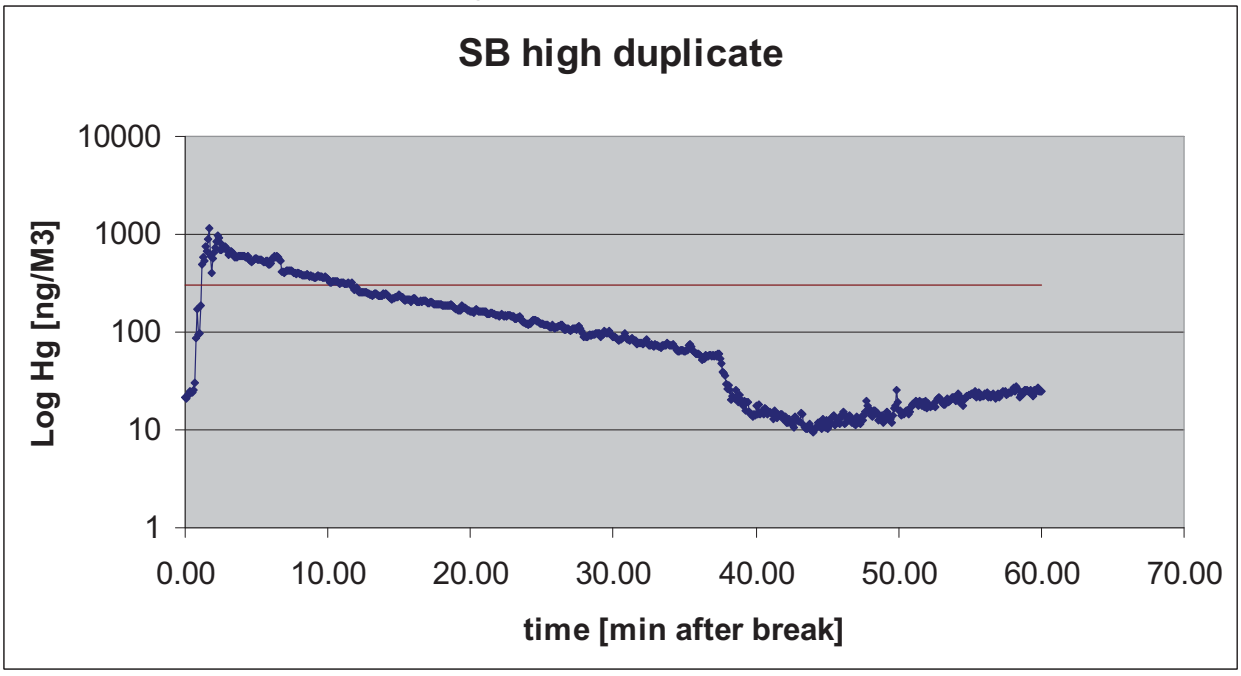


Figure A-50. Scenario B on Hardwood at Five-Foot Height (6/13/07)

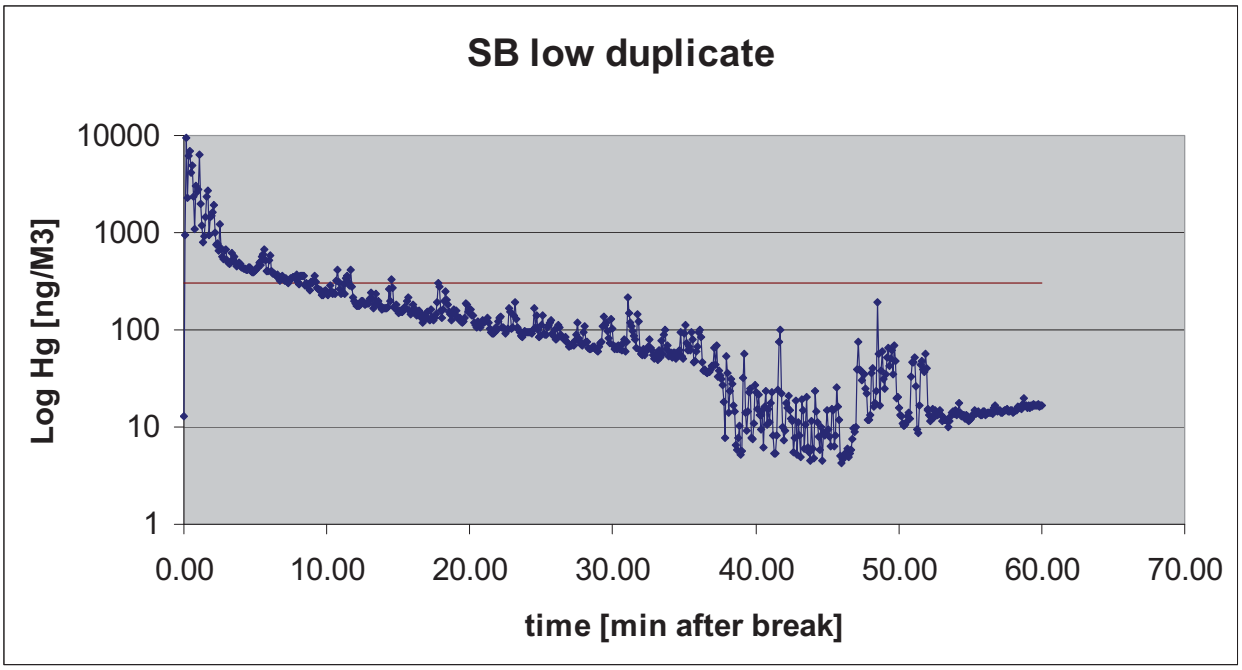


Figure A-51. Scenario B on Hardwood at One-Foot Height (6/13/07)

Table A-6 displays Lumex scans of Scenario B flooring after a CFL had been broken and cleaned up. Results recorded are the highest concentrations of mercury seen while scanning in ng/m^3. The shaded boxes below represent the dates of a vacuuming event.

Table A-6: Flooring readings for Scenario B

Scenario	SB-"Brand C" 60A		SB-"Brand C" 60A Dup	
Date of Breakage	6/12/2007		6/13/2007	
Floor Type	short carpet		wood	
Date Measured ↓	calm	agitated	calm	agitated
6/13/2007	532	1,418		
6/14/2007	<20	1,820	27	828
6/15/2007	190	6,197		
6/18/2007	233	5,102		
6/19/2007	195	2,129		
6/21/2007	<20	1,220		
6/22/2007	289	2,900		
6/25/2007	215	947		
6/26/2007	351	6,531		
6/27/2007	1,004	9,197		
6/28/2007	207	4,697		
6/29/2007	544	1,983		
7/2/2007	233	570		
7/3/2007	195	5,694		
7/5/2007	1803	13,010		
7/6/2007	1,686	12,750		
7/9/2007	253	2,317		
7/10/2007	2,077	3,717		
7/11/2007	959	2,297		
7/26/2007	141	2,275		
7/27/2007	265	4,593		
7/30/2007	160	2,652		
7/31/2007	102	3,301		
8/1/2007	75	6,019		
8/2/2007	226	1,876		
8/3/2007	1,202	1,696		
8/7/2007	318	540		
8/9/2007 (in sun)	524	13,030		
8/10/2007	49	456		

Scenario C: "Brand D" 60 Watt Equivalent, Wood, Venting, Cleanup. This type of "Brand D" lamp was thoroughly broken for each of two trials on hardwood flooring. Both the results and duplicate results are included below and show differences in initial peaks of mercury. Additional information for this lamp is as follows: SKU# 423-599.

For both breaks (both on 6/14/07), lamps were broken on hardwood flooring, the room was vented, and the lamps were cleaned up with index cards, tape, wet wipes, and the waste was removed from the room.
Figures A-52 & A-53 below for the first trial show mercury peaking to 4,257 ng/m^3 at the five foot height, and 27,224 ng/m^3 at the one foot height. Mercury was under 300 ng/m^3 after about 30 minutes for both heights. For the duplicate trial, mercury peaked to 5,927 ng/m^3 at the five foot

height, and 6,164 ng/m^3 at the one foot height. Mercury was under 300 ng/m^3 after about 26 minutes for both heights. The two trials had results that looked similar but the peak of mercury at the one foot height was more than four times higher for the first trial.

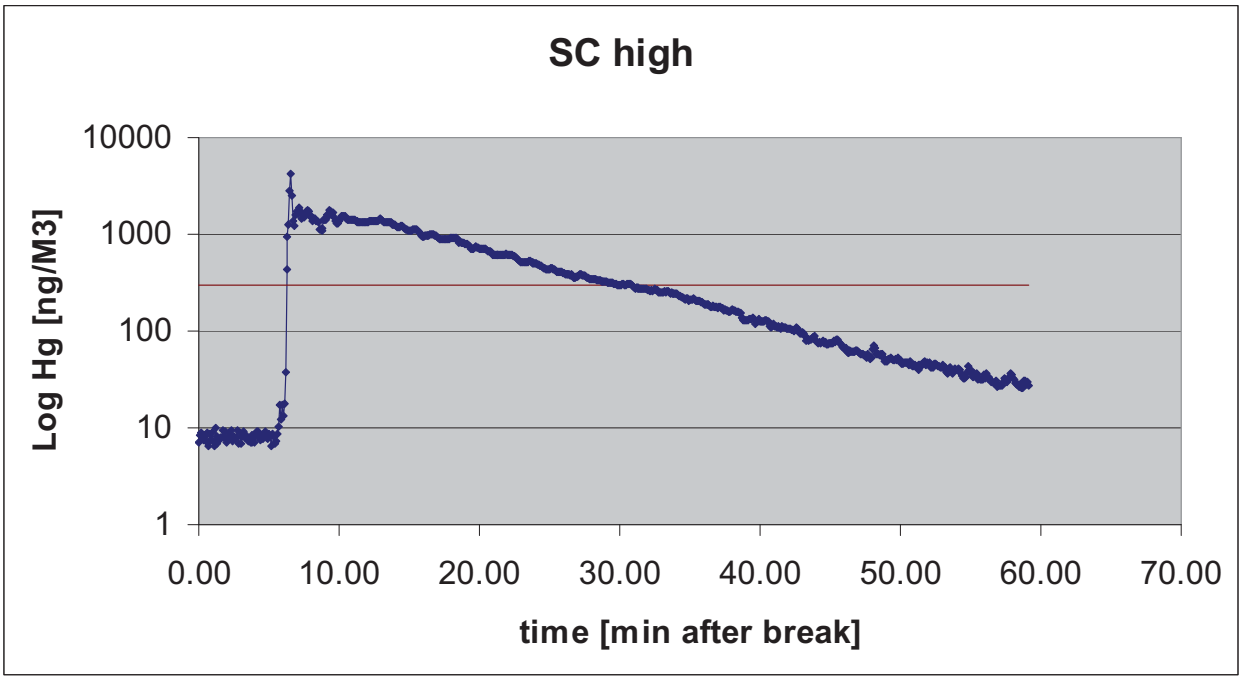


Figure A-52. Scenario C at Five-Foot Height (6/14/07)

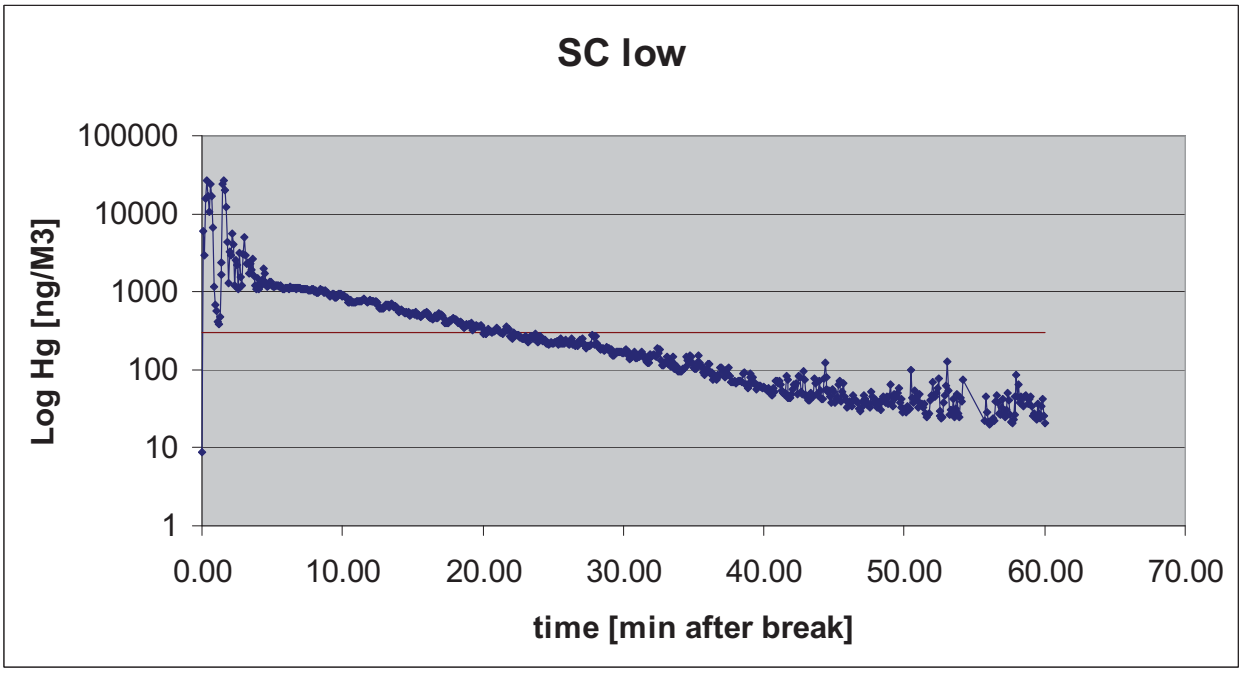


Figure A-53. Scenario C at One-Foot Height (6/14/07)

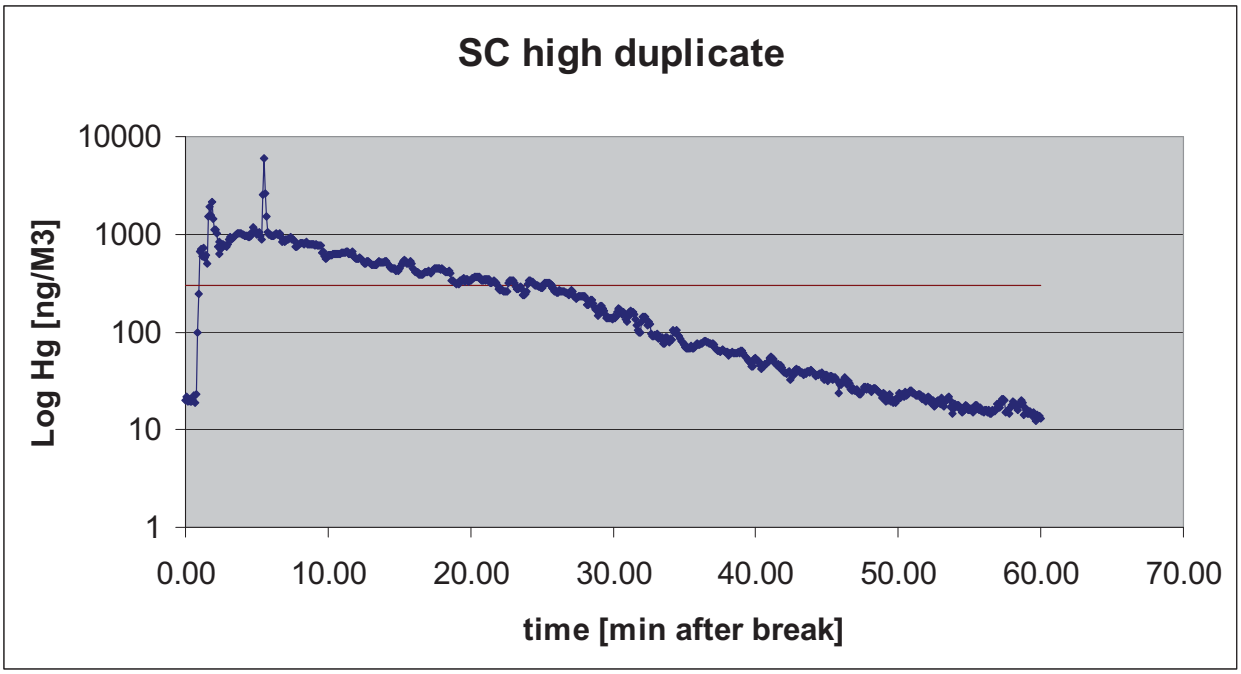


Figure A-54. Duplicate for Scenario C at Five-Foot Height (6/14/07)

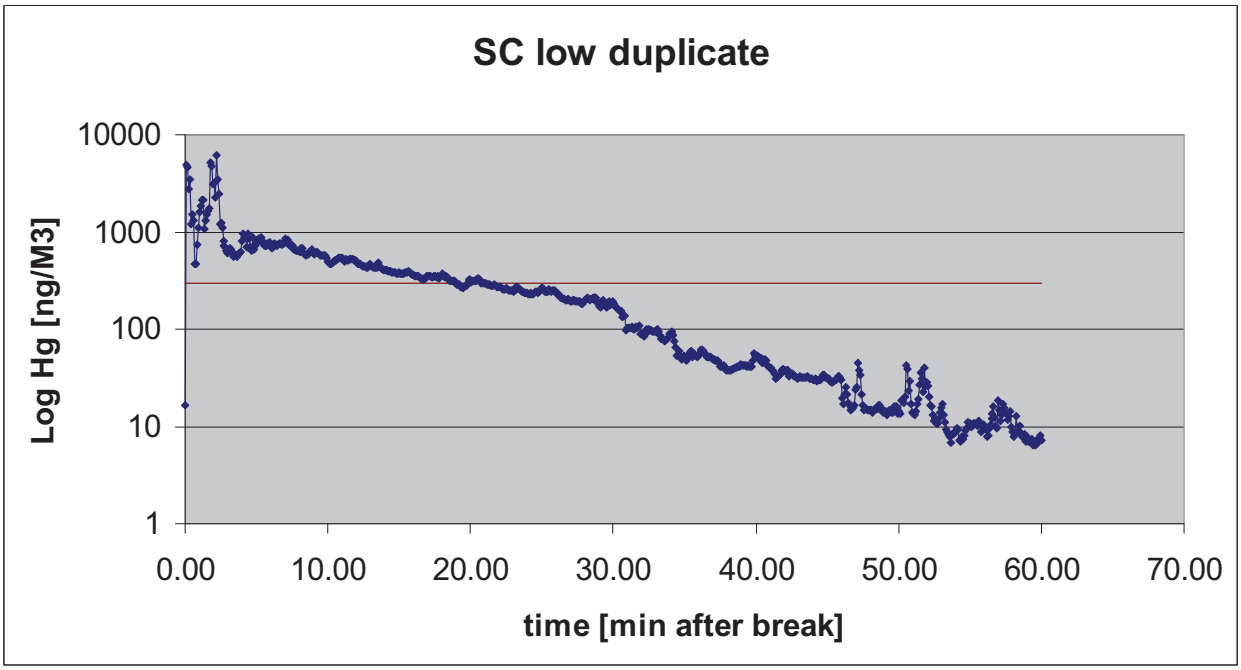


Figure A-55. Duplicate for Scenario C at One-Foot Height (6/14/07)

Table A-7 displays Lumex scans of Scenario C flooring after a CFL had been broken and cleaned up. Results recorded are the highest concentrations of mercury seen while scanning in ng/m^3.

Table A-7: Flooring Readings for Scenario C

Scenario	SC-"Brand D" 60		SC-"Brand D" 60dup	
Date of Breakage	6/14/2007		6/14/2007	
Floor Type	wood		woodFromSBdup	
Date Measured ↓	calm	agitated	calm	agitated
6/15/2007	446	342	<20	564
6/18/2007	203	800	68	680
6/19/2007	<20	526	<20	367
6/21/2007	22	319	72	943
6/22/2007	92	242	27	452
6/25/2007	55	551	<20	1060
6/26/2007	83	634	<20	673
6/27/2007	161	718	56	376
6/28/2007	36	366	<20	574
6/29/2007	34	253	<20	200
7/2/2007	20	360	81	552
7/3/2007	33	282	<20	717
7/5/2007	35	211	<20	564
7/6/2007			43	559
7/9/2007			<20	173

Scenario D: "Brand A" 60 Watt Equivalent, Hot Lamp, Wood, Venting, Cleanup.

This scenario was performed twice (two trials) with similar results, the first on 6/15/07, and the second on 6/18/07. For both breaks, lamps were turned on for an hour and then were thoroughly broken on hardwood flooring, the room was vented, and the lamps were cleaned up with index cards, tape, wet wipes, and the waste was removed from the room.

Figures A-56 & A-57 for the first trial show mercury peaking to 1,443 ng/m^3 at the five foot height, and 12,016 ng/m^3 at the one foot height. Mercury was under 300 ng/m^3 after 3.41 minutes at the five foot height and after 1.75 minutes at the one foot height.

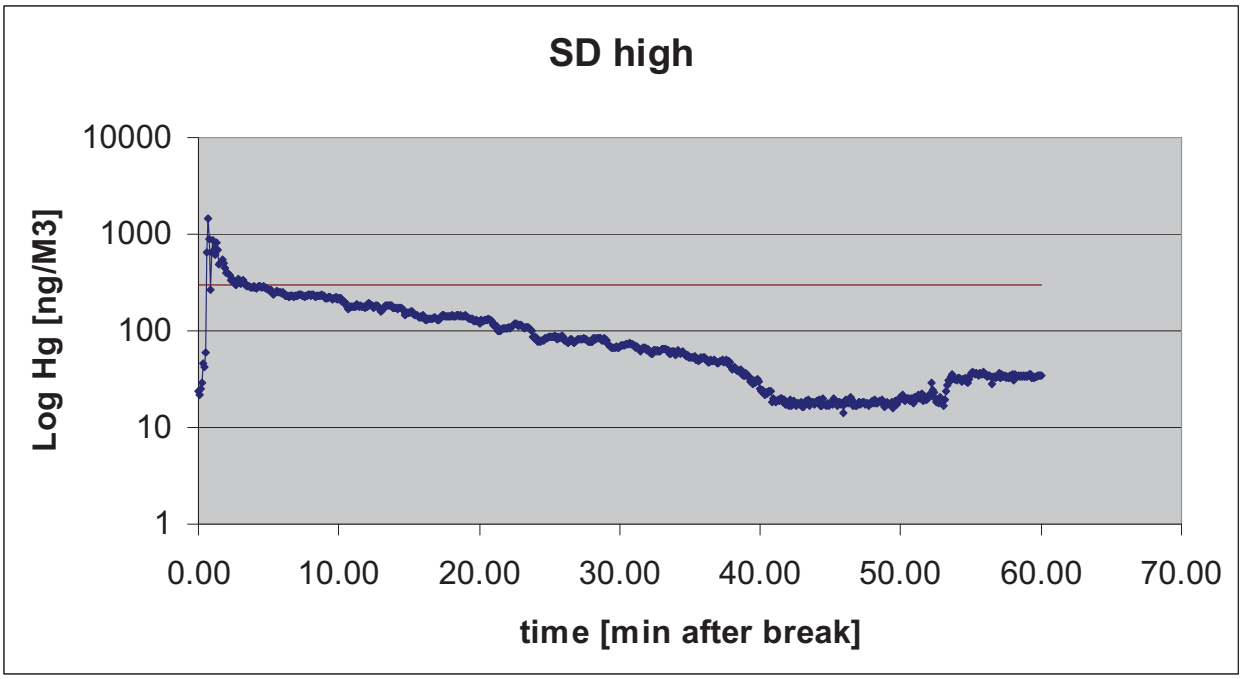


Figure A-56. Scenario D at Five-Foot Height (6/15/07)

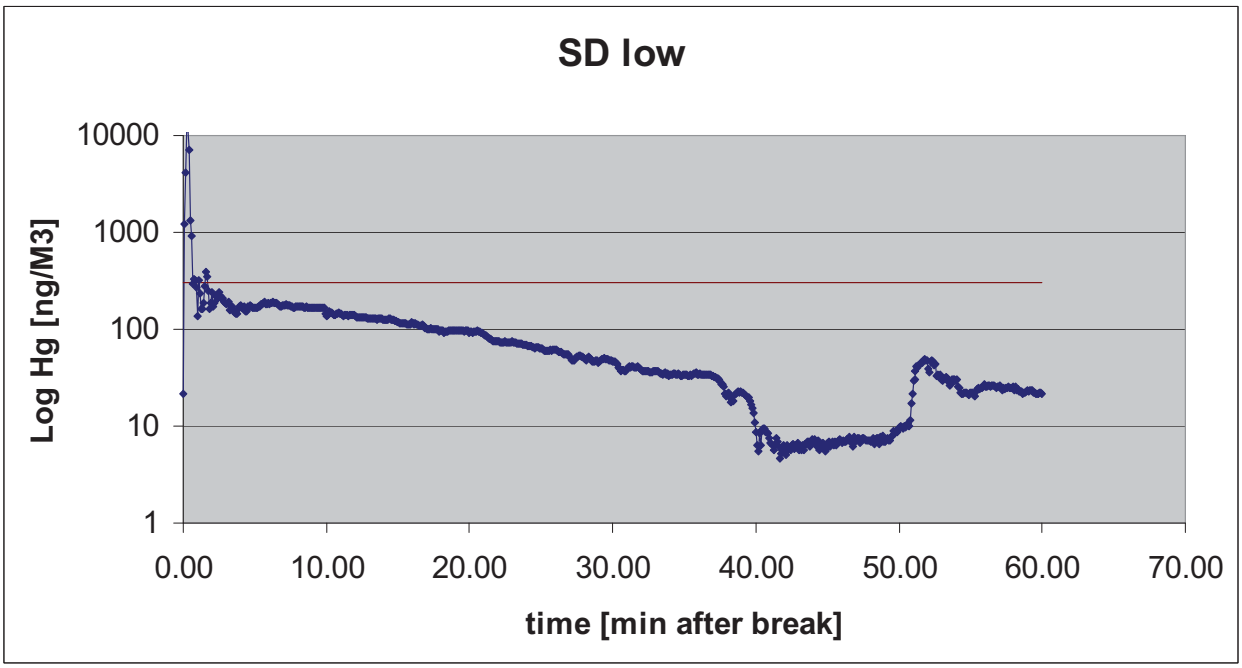


Figure A-57. Scenario D at One-Foot Height (6/15/07)

Table A-8 displays Lumex scans of Scenario D flooring after a CFL had been broken and cleaned up. Results recorded are the highest concentrations of mercury seen while scanning in ng/m^3.

Table A-8: Flooring readings for Scenario D

Scenario	SD-P60 hot		SD-P60 hot dup	
Date of Breakage	6/15/2007		6/18/2007	
Floor Type	wood		wood	
Date Measured ↓	calm	agitated	calm	agitated
6/18/2007	<20	<20		
6/19/2007			<20	<20

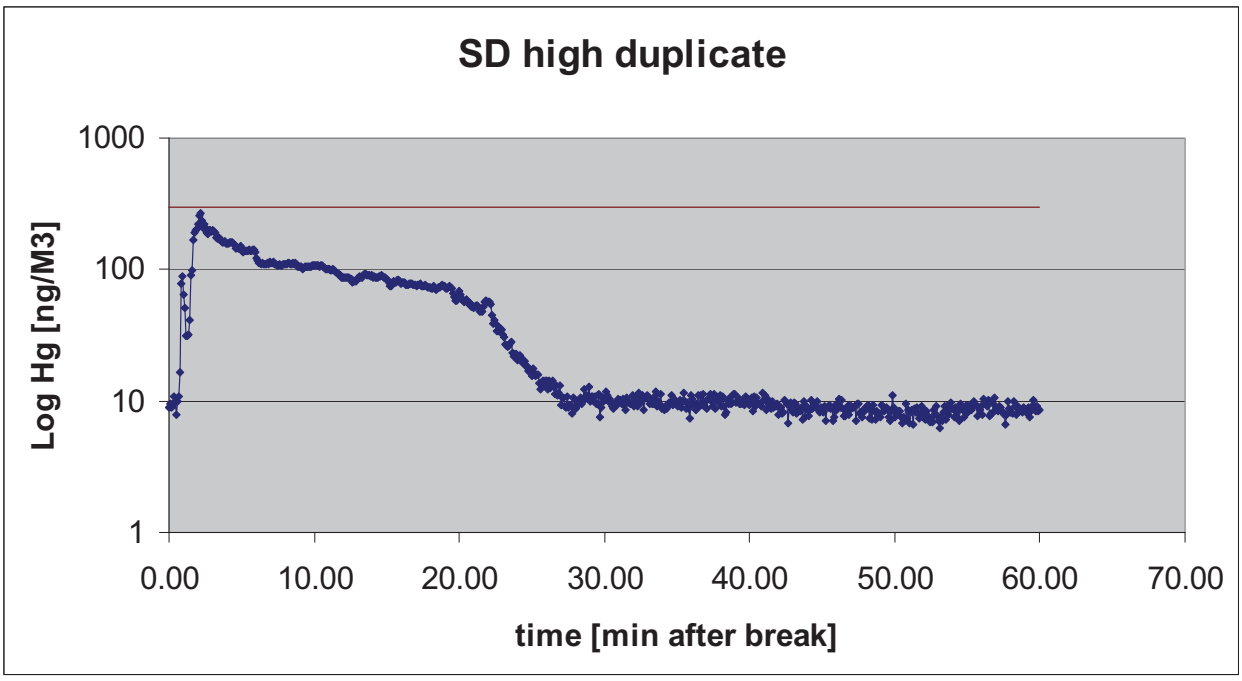


Figure A-58 Scenario D duplicate at five foot height (6/18/07)

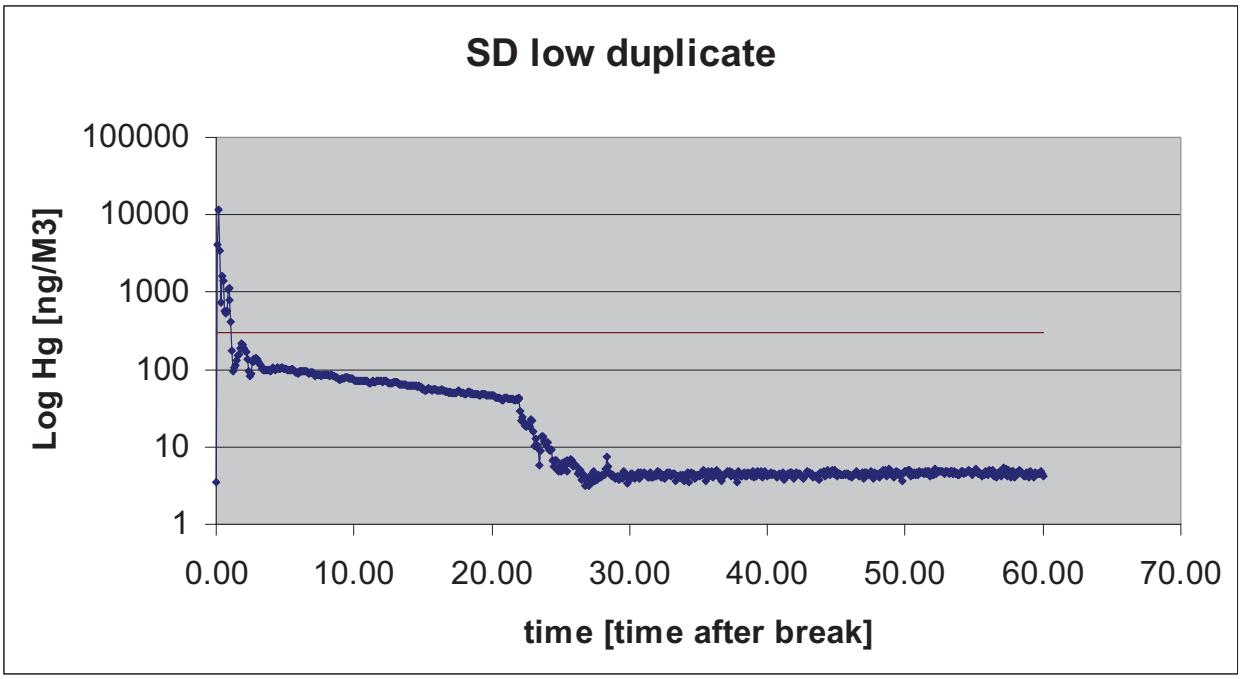


Figure A-59 Scenario D duplicate at one foot (6/18/07)

Scenario E: "Brand B" 100 Watt Equivalent, Wood, Venting, Cleanup. This "Brand B" 100 watt equivalent lamp was used here with a duplicate and also used in scenarios F and L. Additional information for this lamp that was not included in Table 2. is as follows: A Equiv, 120 VAC 60Hz 390mA, FLE26HT3/21 SW.

For both breaks for this scenario (the first on 6/18/07 and the second on 6/19/07), lamps were thoroughly broken on hardwood flooring, the room was vented, and the lamps were cleaned up with index cards, tape, wet wipes, and the waste was removed from the room.

Figures A-60 & A-61 for the first trial show mercury peaking to 7,288 ng/m^3 at the five foot height, and 65,094 ng/m^3 at the one foot height. Mercury was under 300 ng/m^3 after 23.67 minutes for the higher height, and after 40.5 minutes for the lower height. The graphs for the duplicate run looked similar, but the mercury peak at the one foot height in the duplicate run peaked at 25,399 ng/m^3.

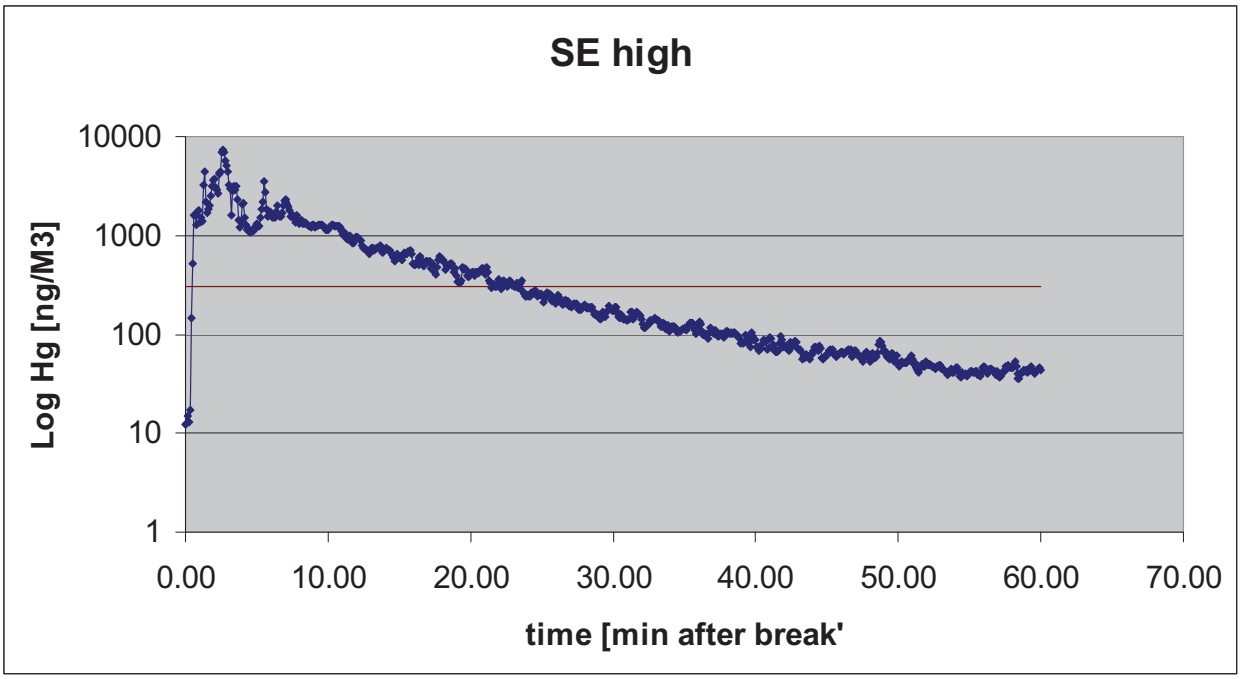


Figure A-60. Scenario E at Five-Foot Height (6/15/07)

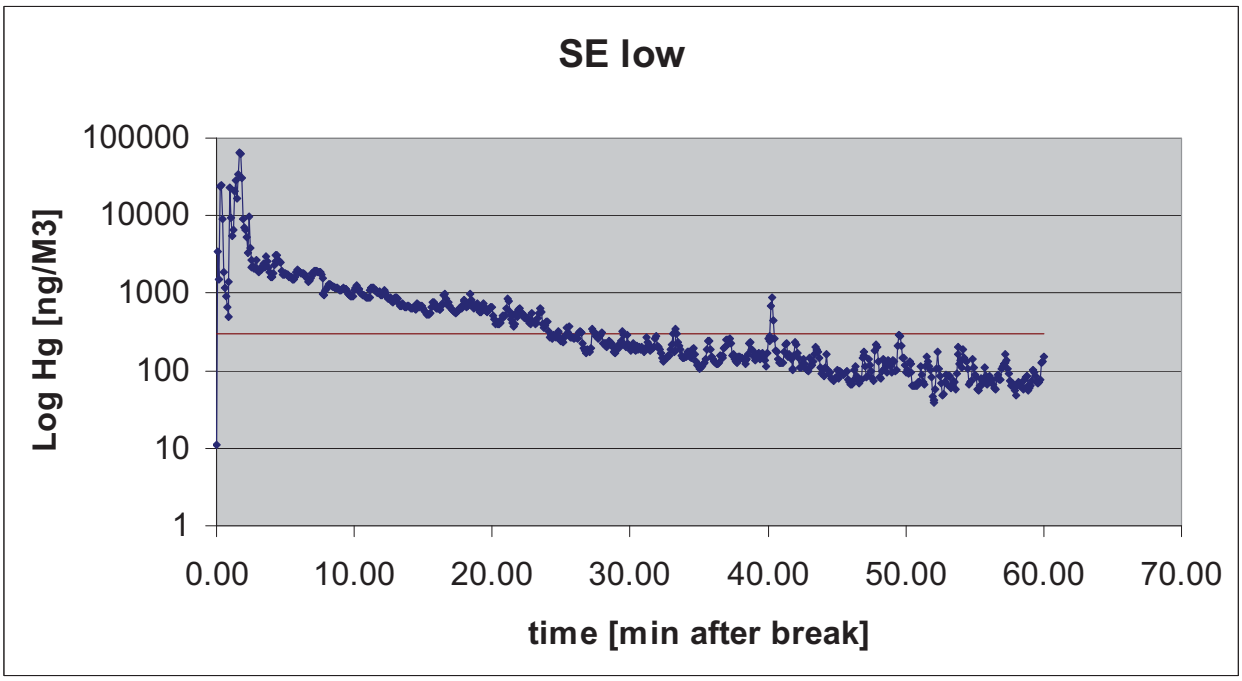


Figure A-61. Scenario E at One-Foot Height (6/15/07)

Table A-9 displays Lumex scans of Scenario E flooring after a CFL had been broken and cleaned up. Results recorded are the highest concentrations of mercury seen while scanning in ng/m^3.

Table A-9: Flooring Readings for Scenario E

Scenario	SE "Brand B" 100		SE "Brand B" 100 dup	
Date of Breakage	6/18/2007		6/19/2007	
Floor Type	wood		wood	
Date Measured ↓	calm	agitated	calm	agitated
6/19/2007	149	2,056		
6/21/2007	23	165	35	1,282
6/22/2007			26	360

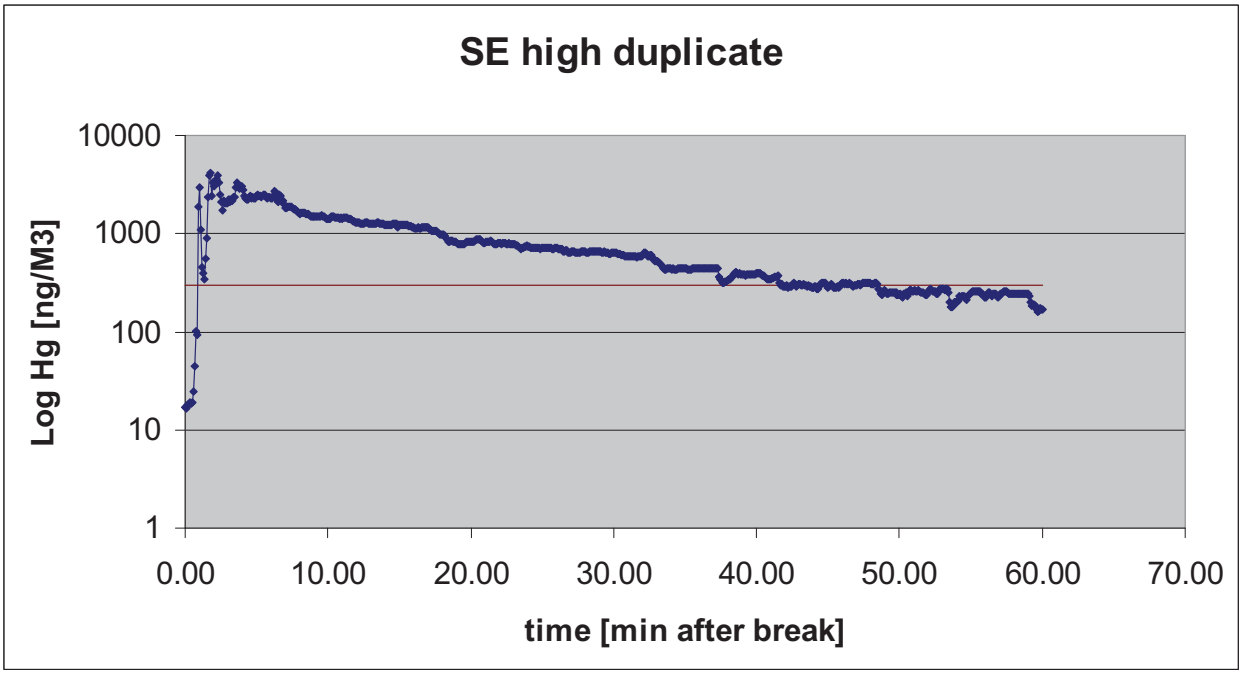


Figure A-62. Scenario E Duplicate at Five-Foot Height (6/19/07)

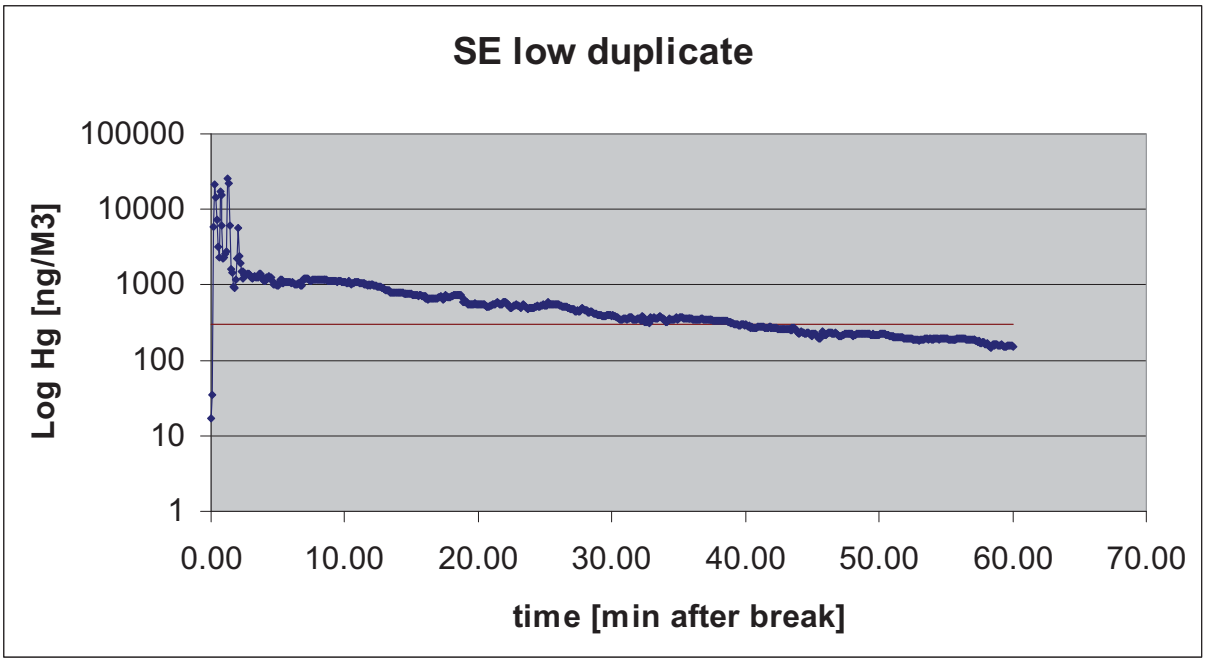


Figure A-63. Scenario E Duplicate at One-Foot Height (6/19/07)

Scenario F: "Brand B" 100 Watt Eq., Wood, Venting, Wait Before Cleanup

This scenario was only performed once. The lamp was thoroughly broken 6/19/07 on hardwood flooring, the room was vented, and 40 minutes later the lamp was cleaned up with index cards, tape, wet wipes, and the waste was removed from the room. Mercury peaked at to 8,285 ng/m^3 at the five foot height, and 54,142 ng/m^3 at the one foot height. Mercury was not under 300 ng/m^3 after 60 minutes for either height.

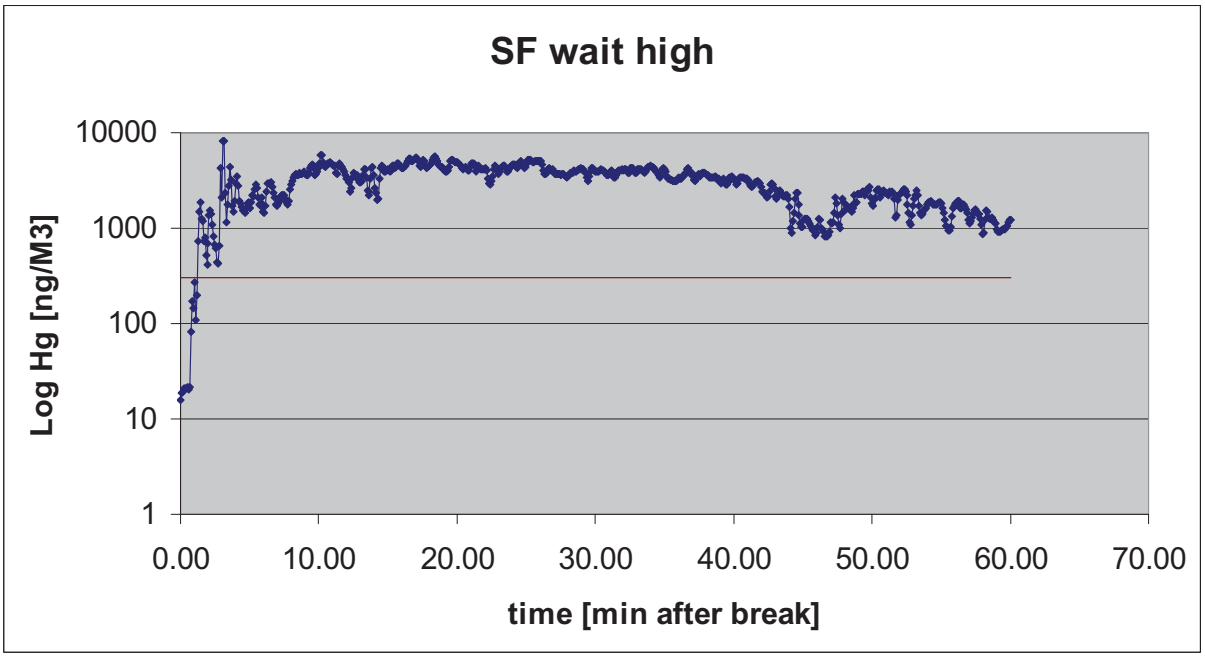


Figure A-64. Scenario F at Five-Foot Height (6/19/07)

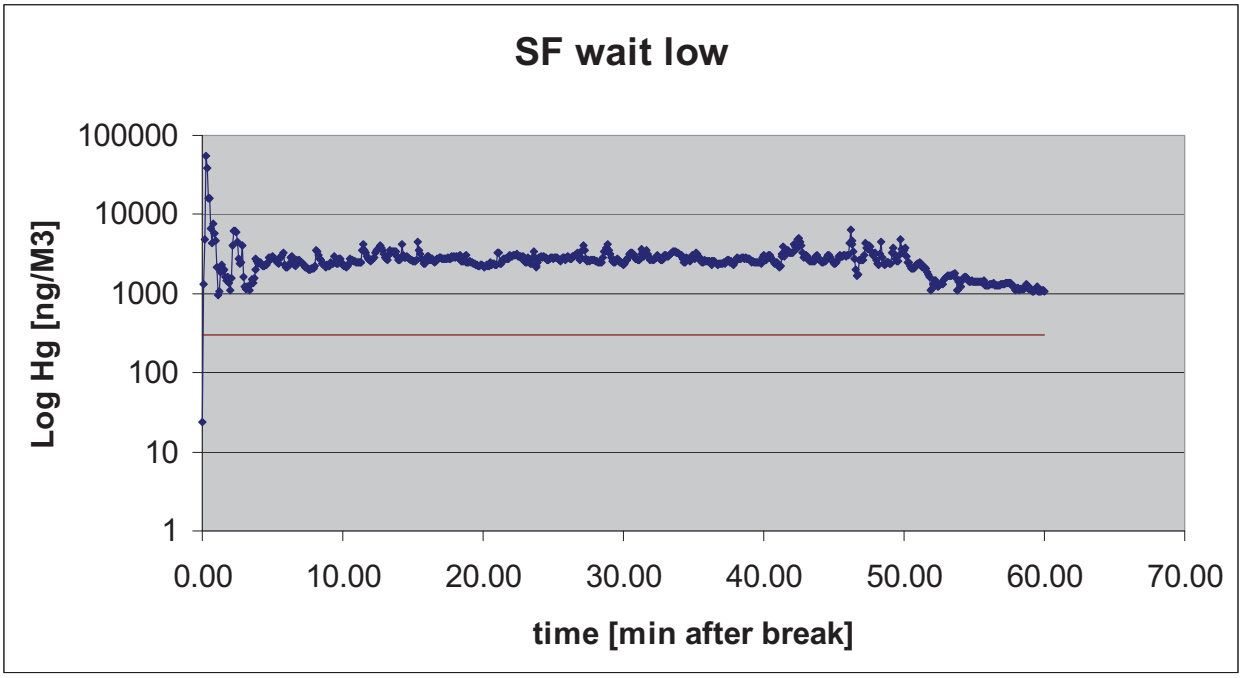


Figure A-65. Scenario F at One-Foot Height (6/19/07)

Table A-10: Flooring readings for Scenario F

Scenario	SF "Brand B" 100 wait	
Date of Breakage	6/19/2007	
Floor Type	wood	
Date Measured ↓	calm	agitated
6/21/2007	30	91

Results recorded are the highest concentrations of mercury seen while scanning in ng/m^3.

Scenario G: "Brand D" 100 Watt Eq., Wood, Venting, Wait Before Cleanup. Additional information for this "Brand D" lamp is as follows: 120 volts, 738-704, SM823.

This scenario was repeated twice. The lamps were thoroughly broken on hardwood flooring, the room was vented, and a short wait later the lamp was cleaned up with index cards, tape, wet wipes, and the waste was removed from the room. After the first break, on 6/19/07, the lamp was cleaned up after a 10 minute wait. The first results are shown in Figures A-66 & A-67. Mercury peaked at 956 ng/m^3 at the five foot height, and 8,603 ng/m^3 at the one foot height. Mercury was under 300 ng/m^3 after approximately 16 minutes for both heights.

The second trial for this scenario, which occurred on the morning of 6/21/07, was manually stopped after an hour, before an important instrument background check. The background check occurs periodically through a run and saves the previous data. Since the background check was not run, the data that were collected were lost. From the study notes it appears that this run looked similar to the first, and because of that, it was stopped early.

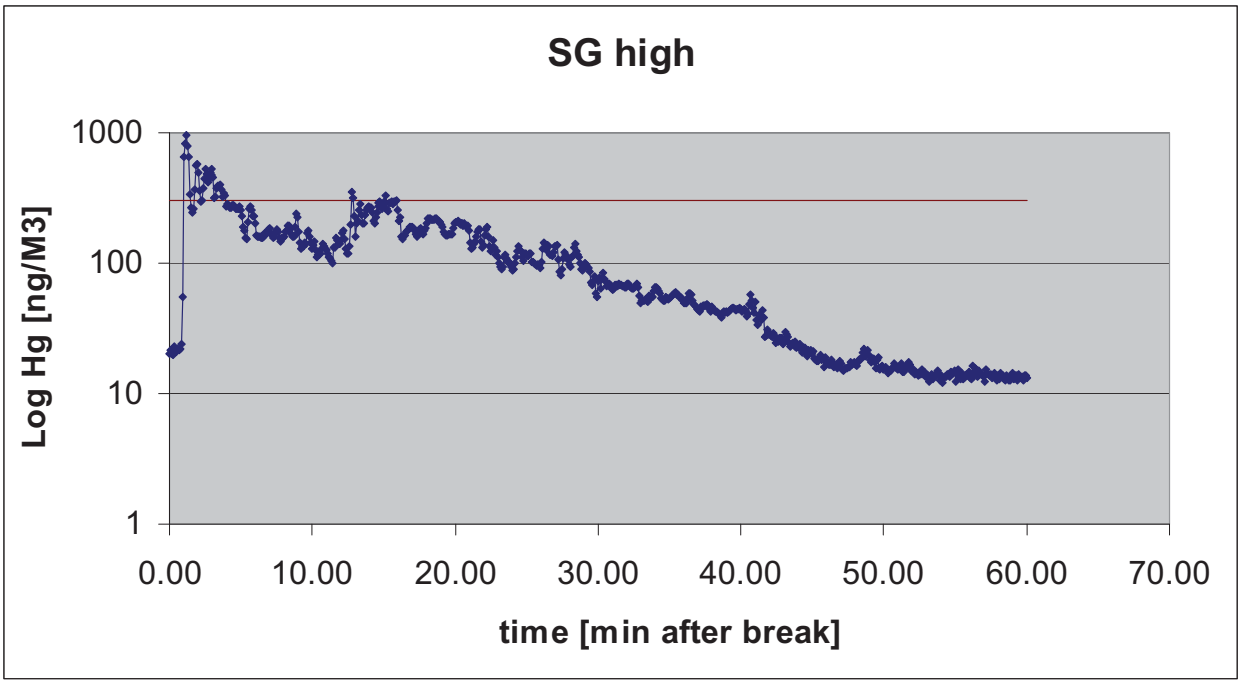


Figure A-66. Scenario G at Five-Foot Height (6/19/07)

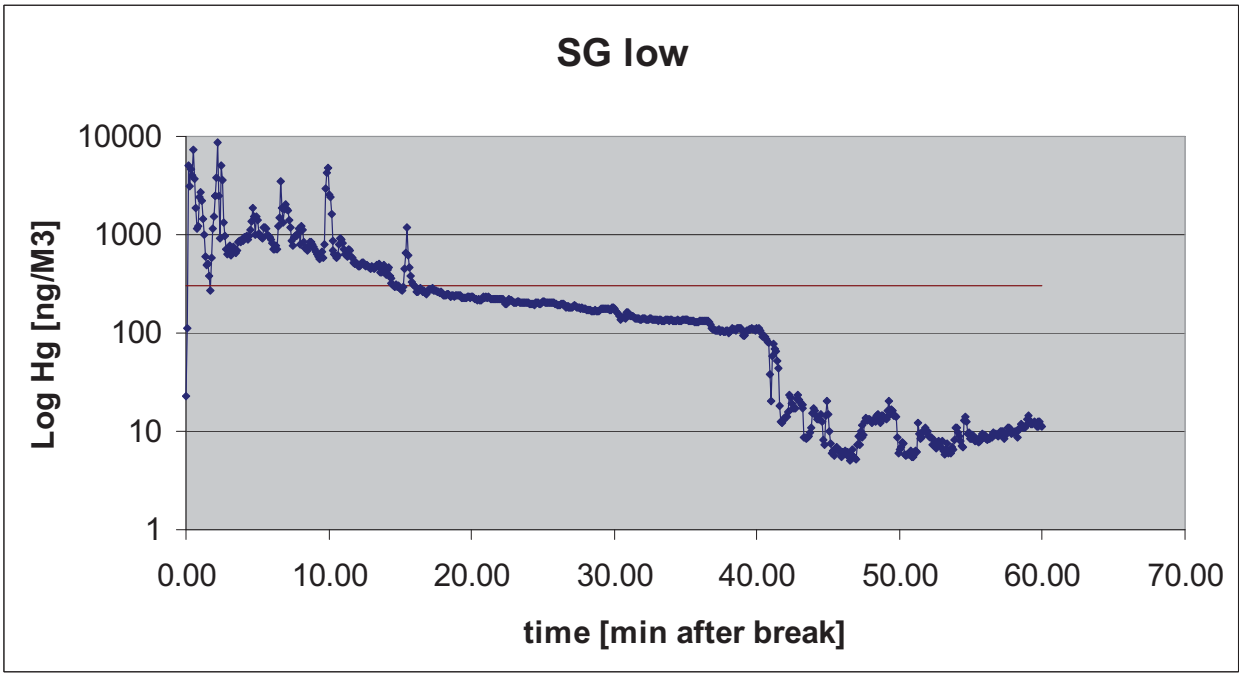


Figure A-67. Scenario G at One-Foot Height (6/19/07)

Table A-11. Flooring readings for Scenario G

Scenario	SG N Vis 100	
Date of Breakage	6/19/2007	
Floor Type	wood	
Date Measured ↓	calm	agitated
6/21/2007	<20	195

Results recorded are the highest concentration of mercury seen while scanning in ng/m^3.

Scenario H: "Brand E" 60 Watt Eq., Wood, Venting, Wait Before Cleanup

This scenario was only performed once. The lamp was thoroughly broken 6/21/07 on hardwood flooring, the same piece of flooring as the last lamp that was broken, the room was vented, and a short wait later the lamp was cleaned up with index cards, tape, wet wipes, and the waste was removed from the room. The results are shown in Figures A-68 & A-69. Mercury peaked at 4,543 ng/m^3 at the five foot height, and 17,178 ng/m^3 at the one foot height. Mercury was under 300 ng/m^3 after 15.5 minutes for the higher level and after 11.08 minutes at the lower height.

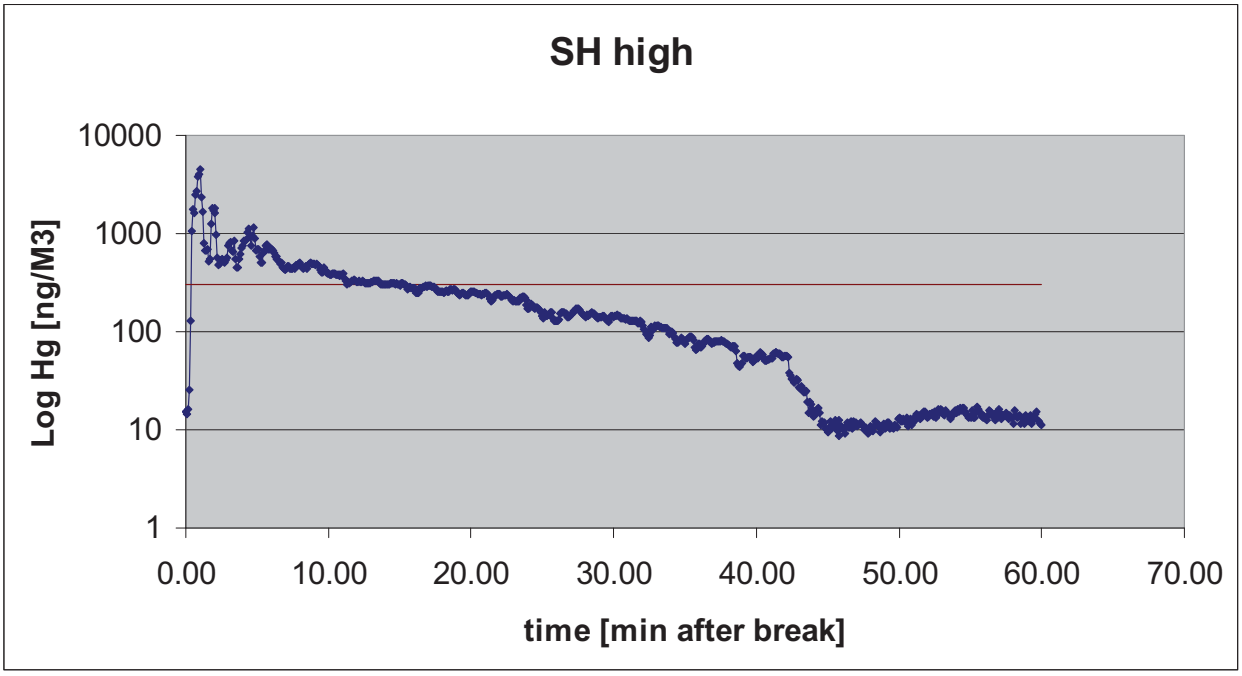


Figure A-68. Scenario H at Five-Foot Height (6/21/07)

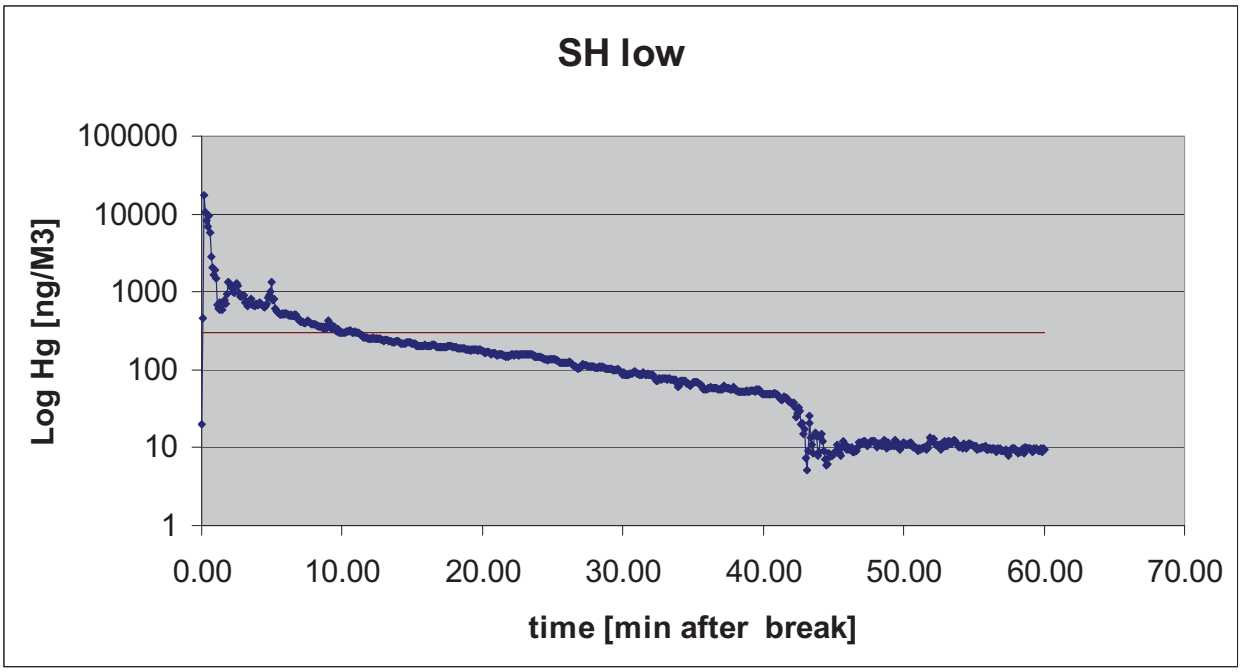


Figure A-69. Scenario H at One-Foot Height (6/21/07)

Table A-12. Flooring Readings for Scenario H

Scenario	SH "Brand E"	
Date of Breakage	6/21/2007	
Floor Type	wood from SG	
Date Measured ↓	calm	agitated
6/22/2007	39	199
6/25/2007	24	196

Results recorded are the highest concentration of mercury seen while scanning in ng/m^3.

Scenario I: "Brand F" 50 Watt Eq., Wood, Venting, Wait Before Cleanup.

This dimmable "soft start lamp," as it was labeled on the packaging, uses new amalgam technology. Only one trial was completed for this scenario. It was realized after the study that this may be the only amalgam lamp broken that was probably created by placing a stable amalgam source within a CFL positioned such that it controls mercury vapor within the lamp. This technology allows lamps to be used over a broader temperature range. It is more expensive, and is generally limited to special use lamps, such as dimmable CFLs and those used in enclosures where temperatures are higher than normal room temperature.

The "Brand F" 50 watt equivalent lamp was thoroughly broken 6/21/07 on hardwood flooring, the room was vented, and a short wait later (7 minutes from breakage) the lamp was cleaned up with index cards, tape, wet wipes, and the waste was removed from the room. The results are shown in Figures A-70 & A-71. Mercury peaked at 485 ng/m^3 at the five foot height, and 687 ng/m^3 at the one foot height. Mercury was under 300 ng/m^3 after 2.67 minutes for the higher level and after 5.5 minutes at the lower height.

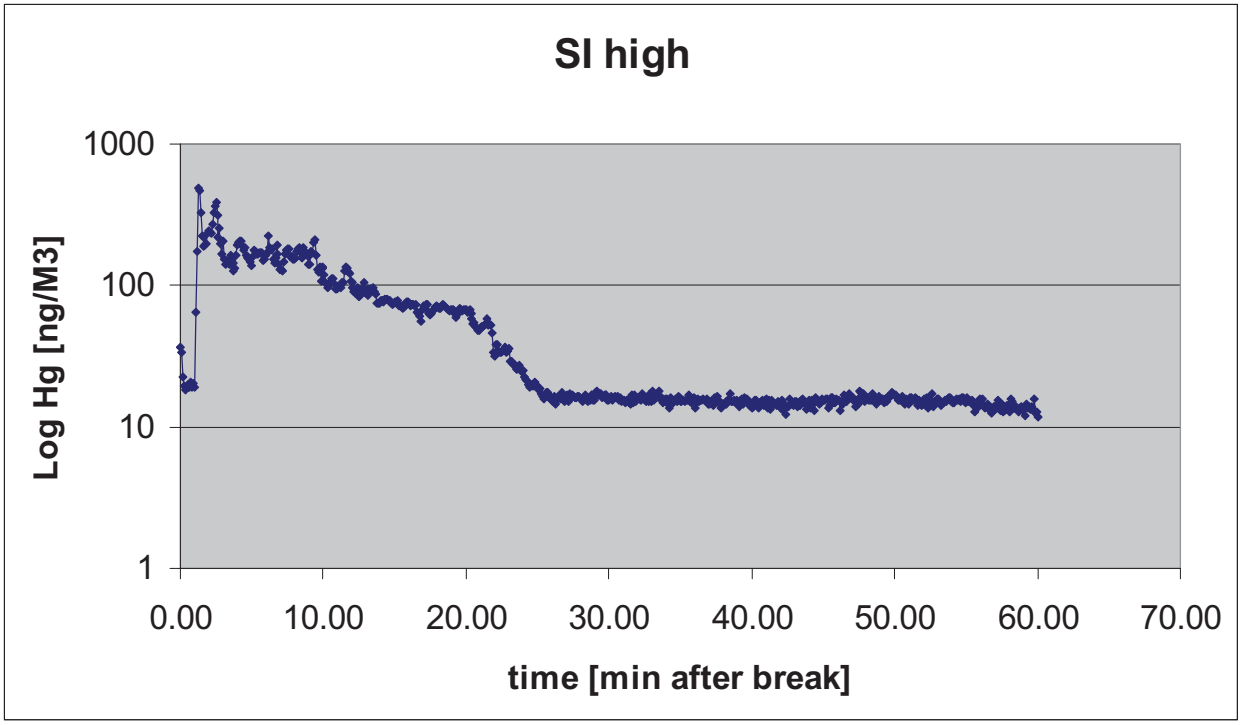


Figure A-70. Scenario I at Five-Foot Height (6/21/07)

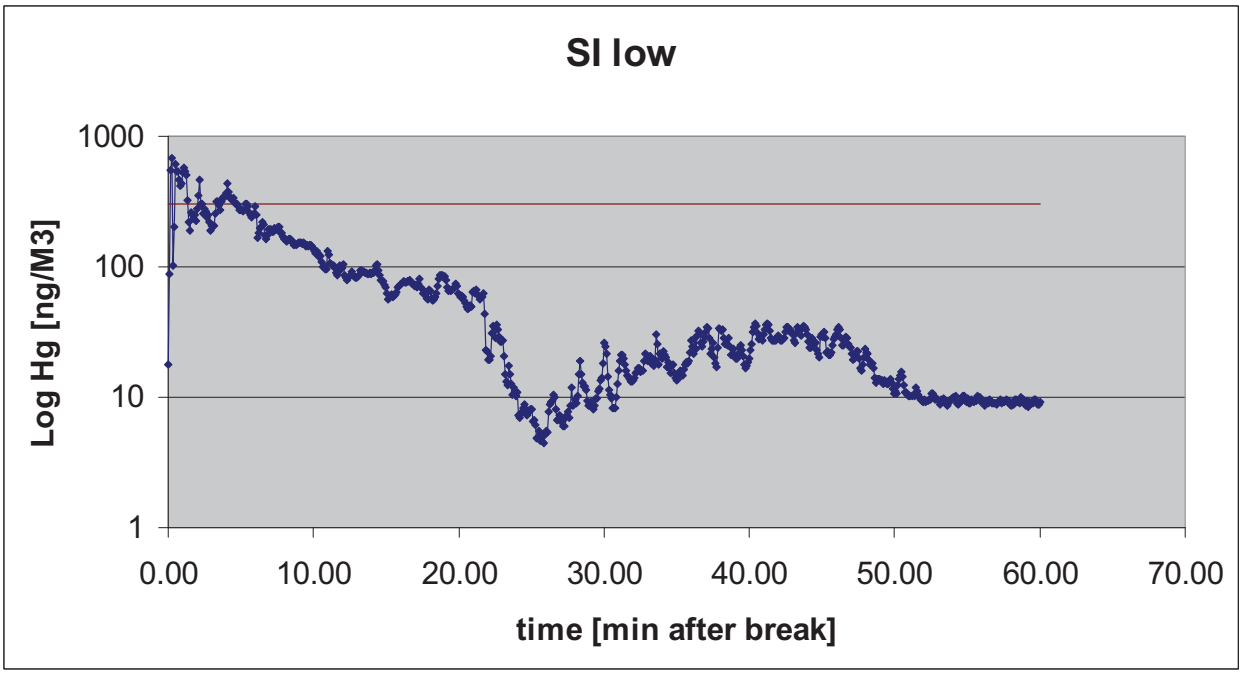


Figure A-71. Scenario I at One-Foot Height (6/21/07)

Table A-13. Flooring readings for Scenario I

Scenario	SI "Brand F" 50	
Date of Breakage	6/21/2007	
Floor Type	wood	
Date Measured ↓	calm	agitated
6/22/2007	44	744
6/25/2007	<20	77

Results recorded are the highest concentration of mercury seen while scanning in ng/m^3.

Scenario J: "Brand A" 60 Watt Eq., Cracked instead of Thoroughly Broken, Wood, Venting, Cleanup.

On 6/25/07 the lamp was cracked with the hammer instead of thoroughly broken. The flooring type was hardwood, the room was vented, and the lamp was cleaned up with index cards, tape, wet wipes, and the waste was removed from the room. The results are shown in Figures A-72 & A-73. Mercury peaked at 617 ng/m^3 at the five foot height, and 7,412 ng/m^3 at the one foot height. Mercury was under 300 ng/m^3 after approximately 3 minutes for both heights.

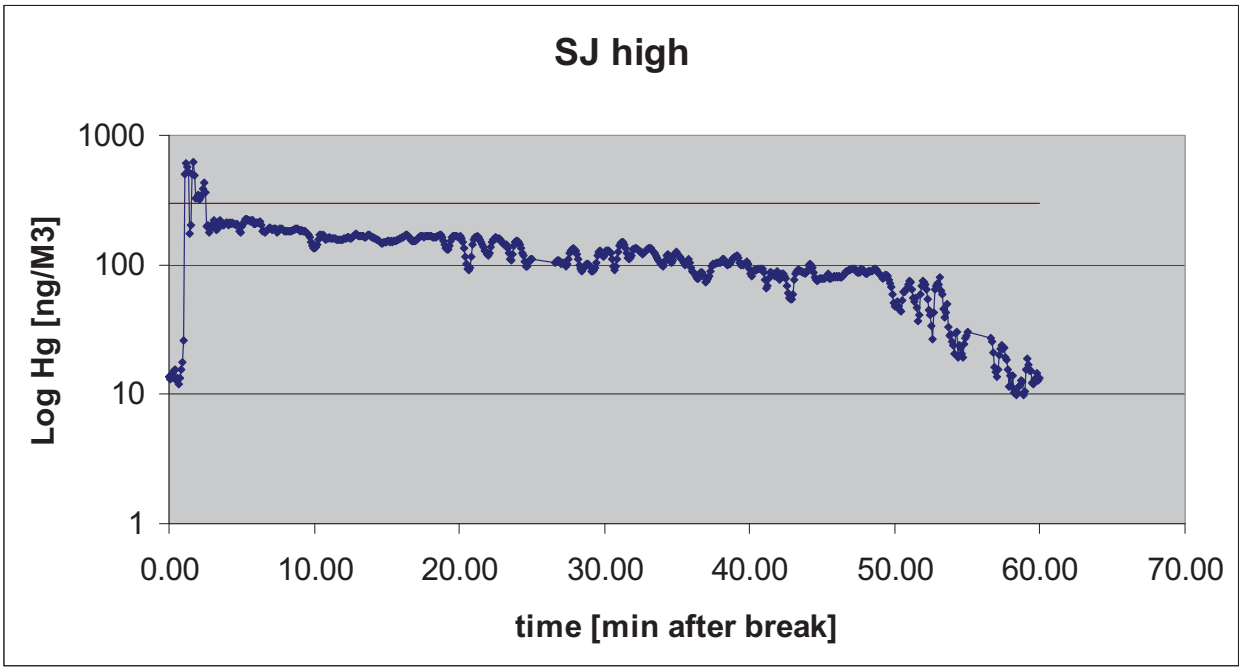


Figure A-72. Scenario J at Five-Foot Height (6/25/07)

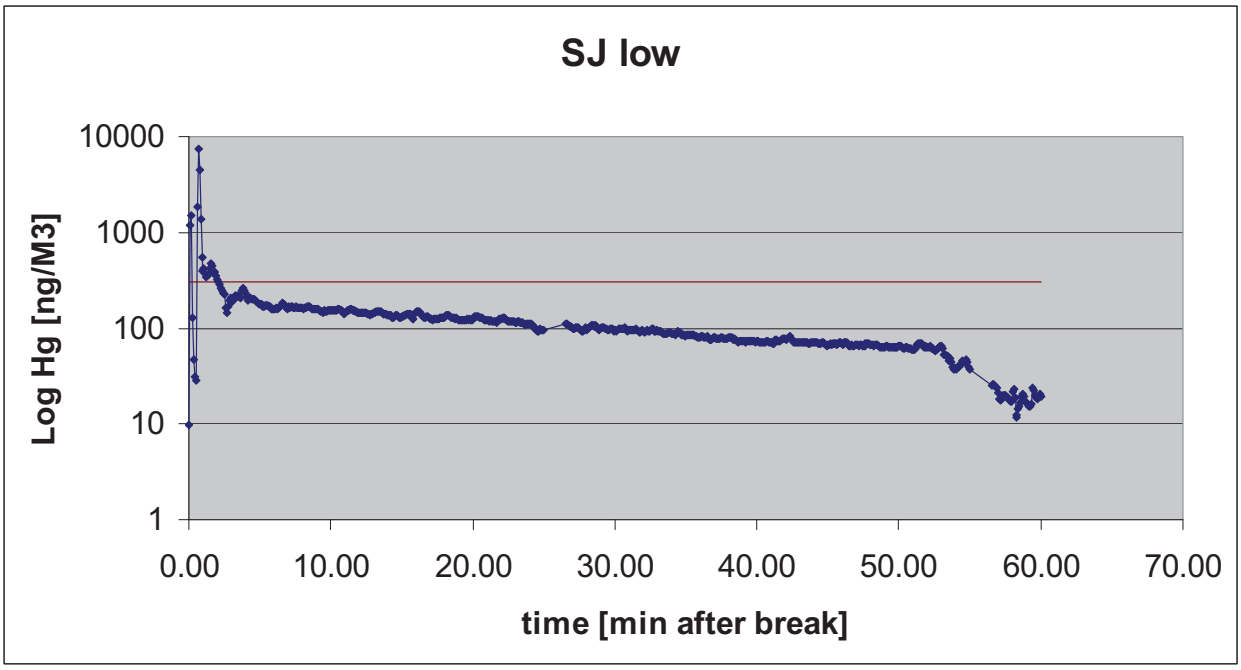


Figure A-73. Scenario J at One-Foot Height (6/25/07)

Table A-14. Flooring readings for Scenario J

Scenario	SJ P60 crack	
Date of Breakage	6/25/2007	
Floor Type	wood	
Date Measured ↓	calm	agitated
6/26/2007	<20	31

Results recorded are the highest concentration of mercury seen while scanning in ng/m^3.

Scenario K: "Brand B" 90 Watt Eq., Shag Carpet, Venting, Vacuuming.

On 6/25/07, the "Brand B" 90 watt equivalent lamp was thoroughly broken on shag carpet, the lamp was cleaned up with index cards, the room was vented, the rest of the debris was cleaned up with tape and wet wipes, and the waste was sealed into the plastic bag. A Hoover Quick-Broom Supreme, bagless, cyclonic action vacuum was then used over the carpet (see Figures A-74 & A-75). This was a used vacuum with model # 52535 and serial # 110000216769 that scanned clean with the third Lumex before use. The third Lumex was held over the vacuum during vacuuming at the vacuum exhaust area and the concentration of mercury appeared similar to room concentrations. After vacuuming, the vacuum cup was emptied into the plastic debris bag. The third Lumex read 5,526 ng/m^3 when scanning close to the vacuum cup after emptied. A wet wipe was used to wipe vacuum head, inside of vacuum, and inside of vacuum cup. The lamp debris and plastic bag were then removed from the room. The results are shown in the next two graphs. Mercury peaked at 2,034 ng/m^3 at the five foot height, and 2,392 ng/m^3 at the one foot height. Mercury was under 300 ng/m^3 after approximately 24 minutes for

the higher level and after approximately 34 minutes at the lower height, but had spikes over 300ng/m^3 at 193.84 minutes.

Figure A-74. Hoover Quick-Broom Supreme, bagless, cyclonic action vacuum

Figure A-75. Removable cup for emptying debris.

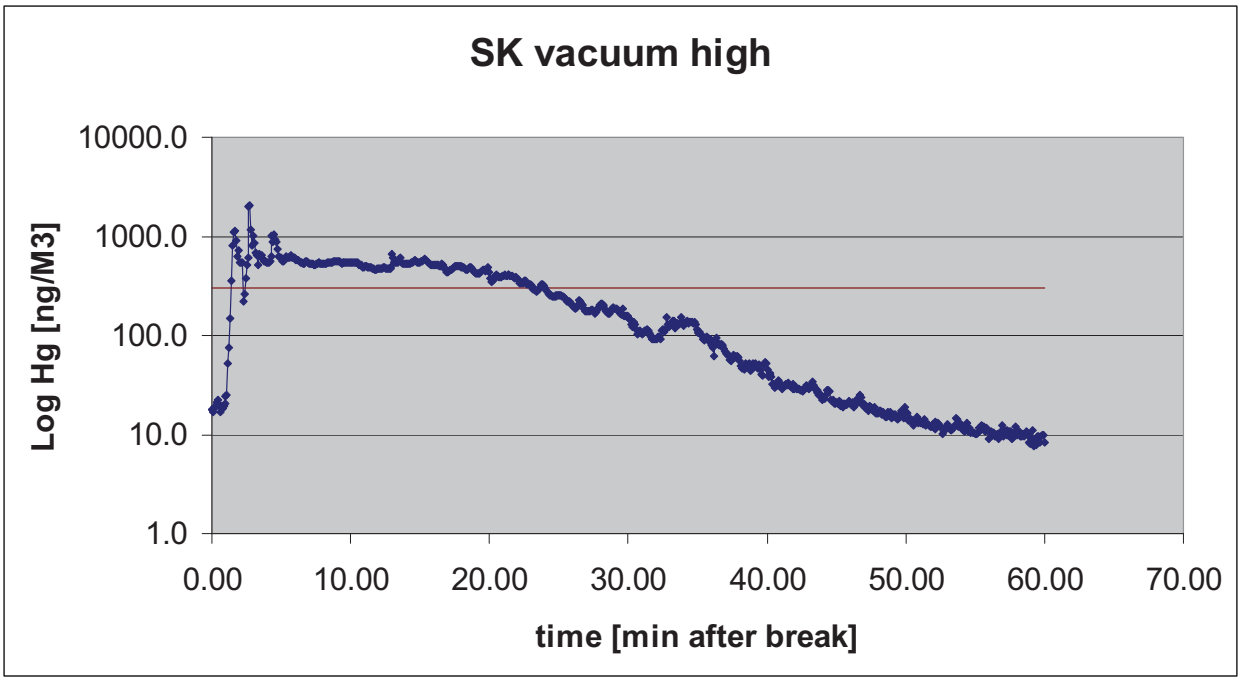


Figure A-76. Scenario K at Five-Foot Height (6/26/07)

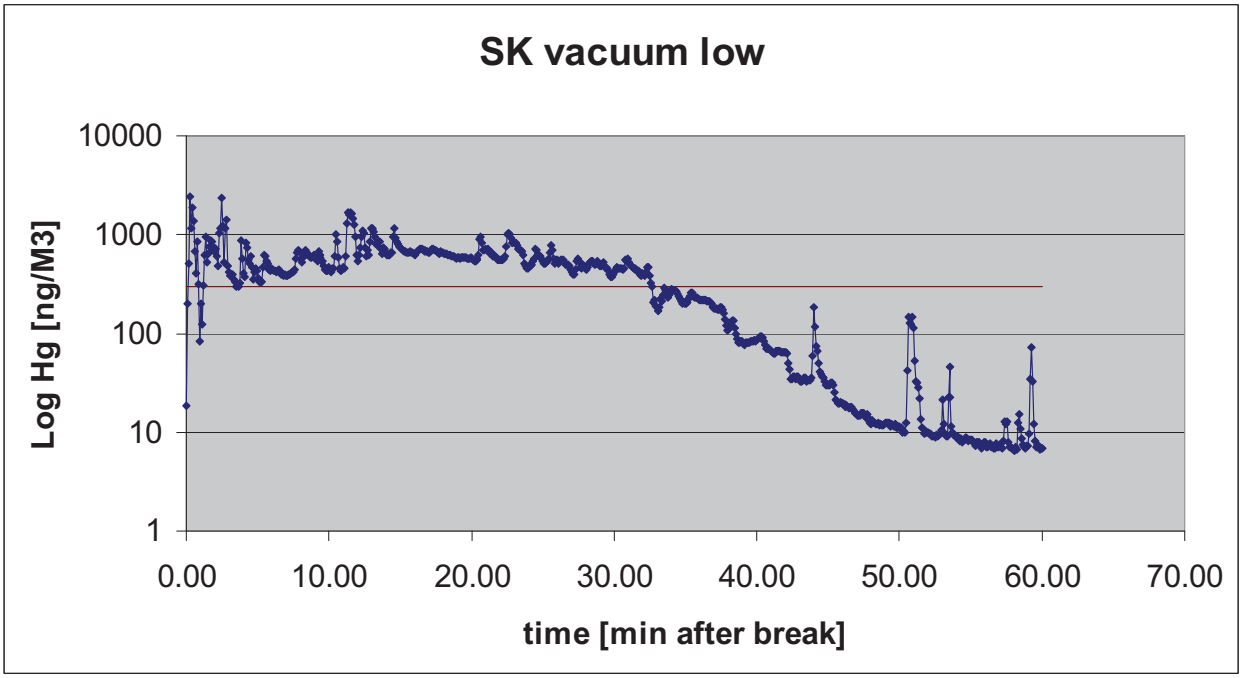


Figure A-77. Scenario K at One-Foot Height (6/26/07)

Table A-15. Flooring Readings for Scenario K

Scenario	SK-"Brand B" 90vac	
Date of Breakage	6/26/2007	
Floor Type	shag carpet	
Date Measured ↓	calm	agitated
6/26/2007	358	1,190
6/27/2007	551	3,623
6/28/2007	<20	2,197
6/29/2007	79	757
7/2/2007	<20	462
7/3/2007	34	1,574
7/5/2007	26	511
7/6/2007	27	417
7/9/2007	<20	406
7/10/2007	26	243
7/11/2007	23	278

Results recorded are the highest concentrations of mercury seen while scanning in ng/m^3.

The third Lumex was used to scan the vacuum when the vacuum had not been running for a while and was "cold." All readings were less and 100 ng/m^3. The vacuum was then turned on for approximately 10 minutes so that it was "hot." The readings were still less than 100 ng/m^3 at various places around the vacuum. See Table A-16:

Table A-16. Hoover Quick-Broom Supreme

		Vacuum measurements with 3rd Lumex when room levels of mercury are low												
		Vacuum ran for approx 10 min. to get "hot" numbers												
		Measurements are ng/m3												
Hoover Quick-Broom Supreme, bagless, "cyclonic action." Model # 52535, Serial # 10000216769														
			Floor attachment				**Cup**				**Near Motor**			
Date of Lamp Breakage	**Date of Vacuuming**	**Date of Measurement**	hot	hot agitated	cold	cold agitated	hot	hot agitated	cold	cold agitated	hot	hot agitated	cold	cold agitated
6/25/2007	6/25/2007	6/25/2007, after about 17 minutes into run					5,526							
		6/26/2007, after wet wipe used on vac parts	<20	46	27	59	21	88	35	74	<20	25	39	31

S5T3 Re-vacuum: Hoover 400 Futura on Carpet that had been Previously Vacuumed

No new lamp was broken as part of this scenario. The vacuum used in this scenario was a Hoover 400 Futura, canister style vacuum, serial # 129300101061. The vacuum was an older model and had a metal wand. The floor attachment did **not** have a power head with beater brushes. This vacuum was used on the S5T3 short nap carpet that had a "Brand A" lamp broken on it 28 days earlier and was vacuumed 28 days earlier (with a different Kenmore canister vacuum) as part of that scenario. Immediately before this scenario, the carpet showed <20 ng/m^3 of mercury un-agitated, and showed 2,165 ng/m^3 after being agitated. All measurements were taken with the third Lumex within an inch of the carpet surface. After vacuuming for this scenario with the Hoover 400 on 7/2/07, near carpet mercury concentrations were 4,330 ng/m^3 (see Table A-3).

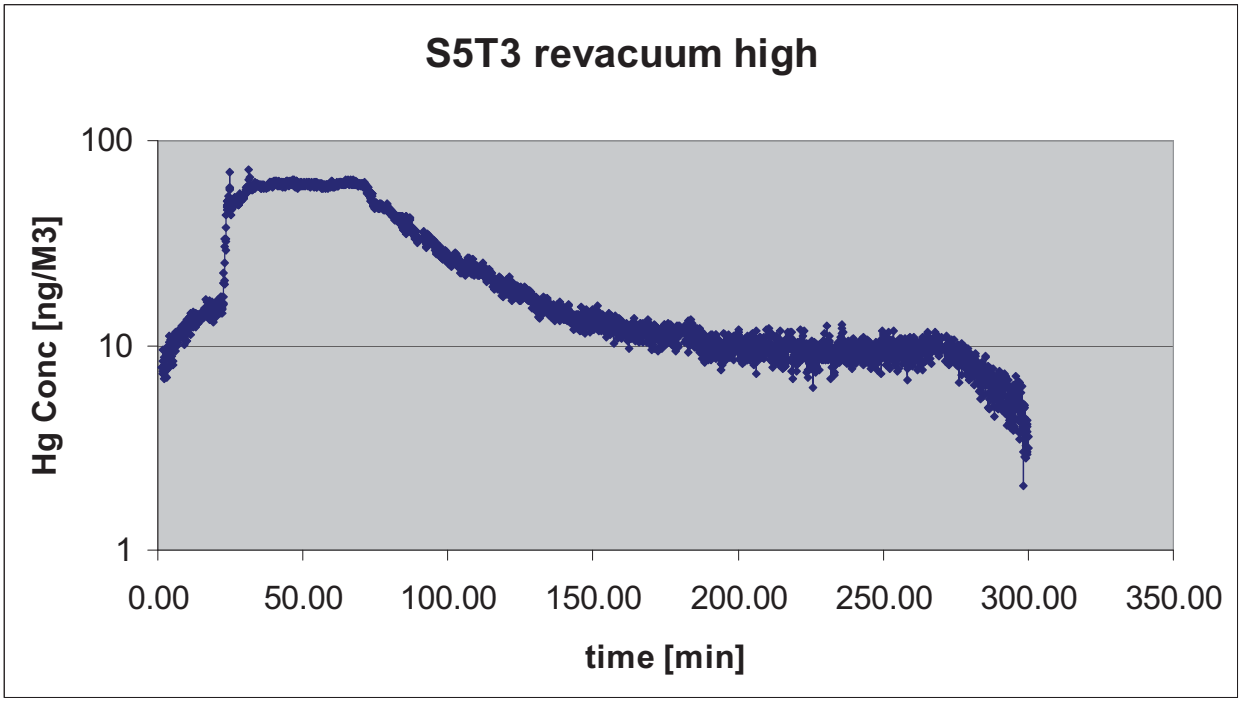


Figure A-78. Scenario "S5T3 Re-vacuum" at Five-Foot Height (7/2/07)

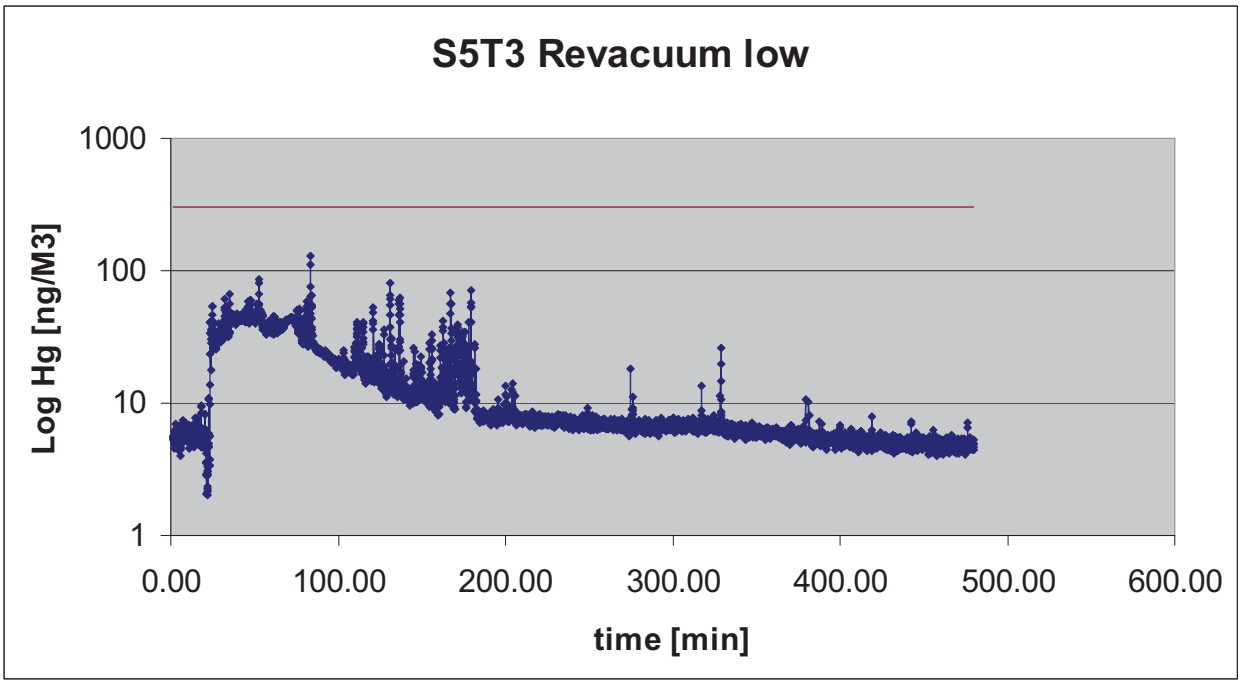


Figure A-79. Scenario "S5T3 Re-vacuum" at One-Foot Height (7/2/07)

On 7/2/07 directly after vacuuming, the Hoover 400 Futura vacuum had the following mercury readings: floor attachment 194 ng/m^3 (347 ng/m^3 agitated), hose connection to vacuum 172 ng/m^3, and inside vacuum and bag 184 ng/m^3. The floor attachment was cleaned. After this cleaning the third Lumex read 253 ng/m^3 for the floor attachment. These readings were taken within approximately an inch of the vacuum parts and inside the study room with the window closed. See Table A-17 for other measurements taken next to this vacuum after this run.

Table A-17. Hoover 400 Futura, mercury results in ng/m^3 recorded with Lumex within approx. an inch of vac part surface

			Vacuum Cleaner Part			
Hoover 400 Futura, Serial # 129300101061			**Beaters (floor attachment)**		**Plastic flexible hose**	**Inside vac**
Date of Lamp Breakage	**Date of Vacuuming**	**Date of Measurement**	cold	cold agitated	cold	cold
6/4/2007	6/4/07 (flooring vacuumed with Kenmore canister)					
	7/2/07 (same flooring as above vacuumed this time with Hoover 400)	7/2/2007	194	347	172	184
		7/2/07 (after cleaning)	253			
		7/3/2007	<20	45	<20	<20

5.3.13 SB Vacuum: A Hoover 850 on older Scenario B carpet – four vacuuming events

Before this vacuum was used for this scenario, the third Lumex showed 347 ng/m^3 of mercury near the beaters. The beaters were cleaned and then the third Lumex showed 22 ng/m^3 of mercury near the beaters. The other parts of the vacuum did not appear to be contaminated with mercury.

The carpet that was vacuumed for this scenario had not previously been vacuumed but a lamp had been broken on it 21 days earlier and cleaned up. No new lamp was broken. The previously cleaned short nap carpet was vacuumed four times during this scenario; 7/3/2007, 7/6/2007, 7/9/2007 and 7/10/2007 with the window closed.

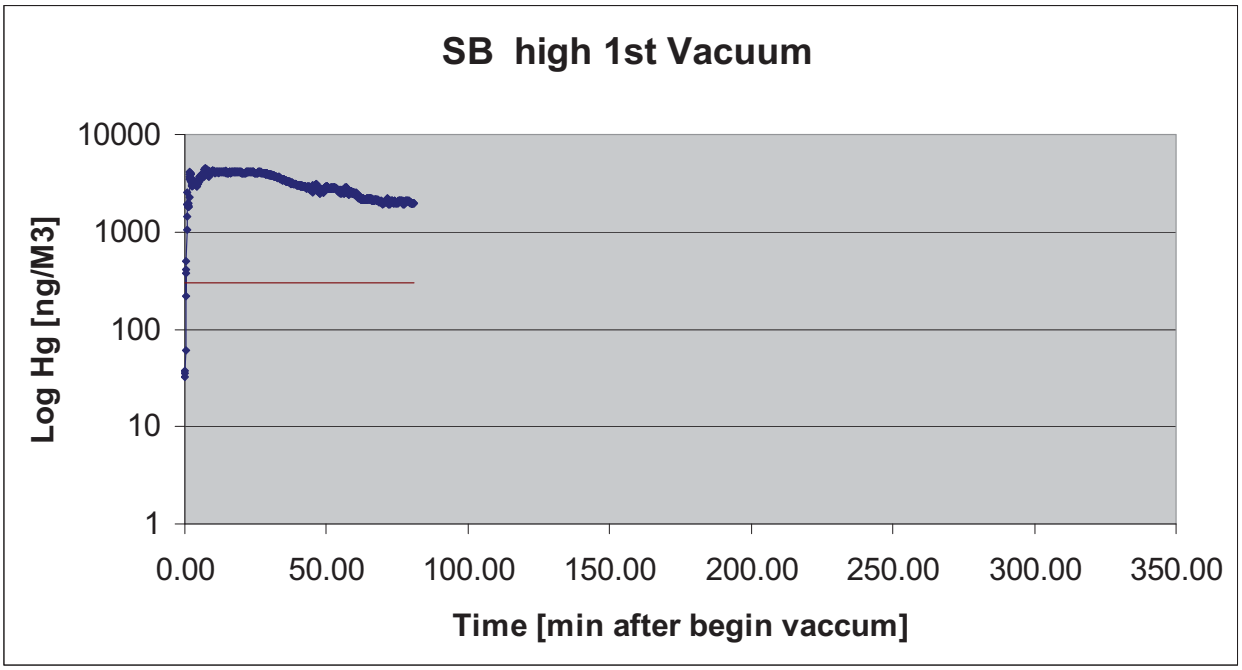


Figure A-80. Scenario "SB Vacuum" at Five-Foot Height (7/3/07)

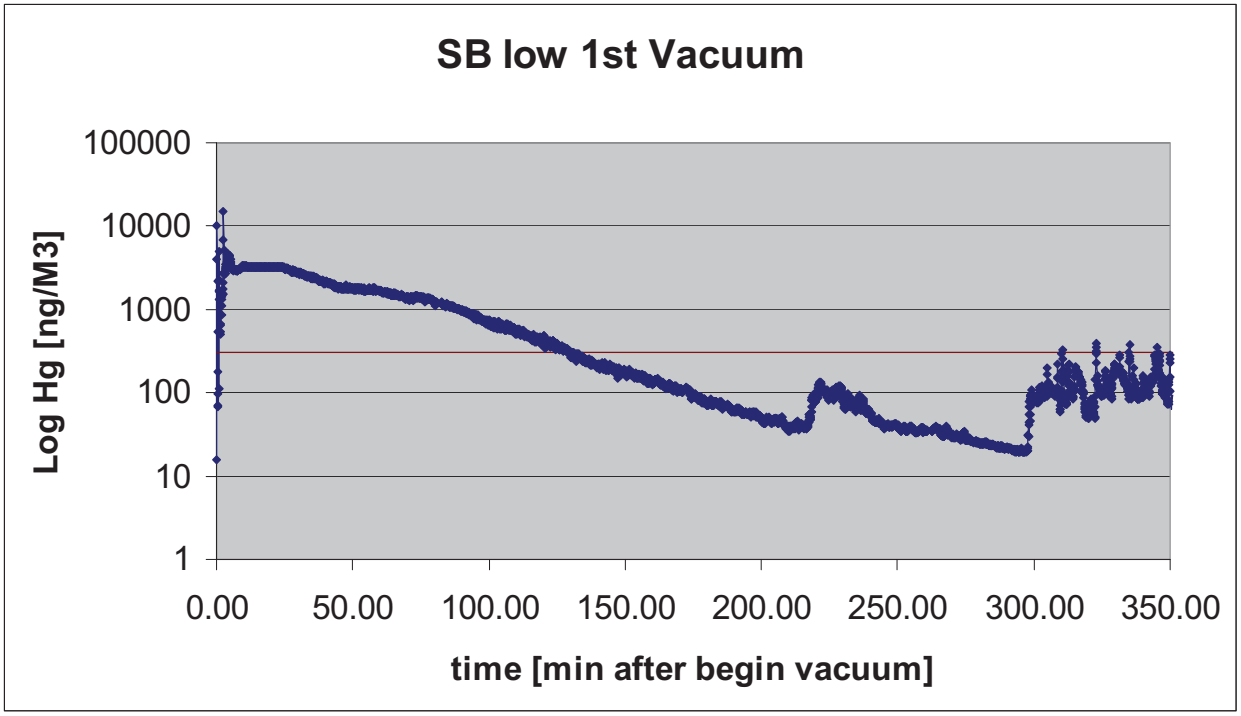


Figure A-81. Scenario "SB Vacuum" at One-Foot Height (7/3/07)

On 7/6/07 the carpet was vacuumed again with the same Hoover 850 vacuum.

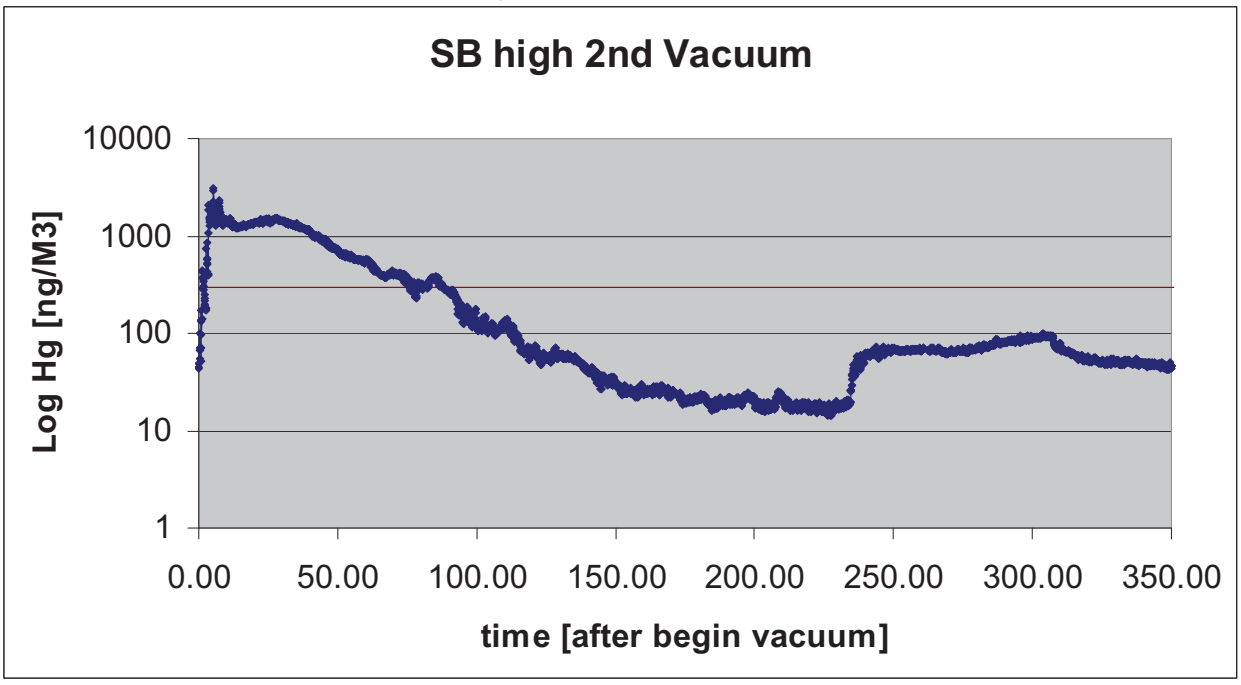


Figure A-82. Scenario "SB Vacuum" at Five-Foot Height (7/6/07)

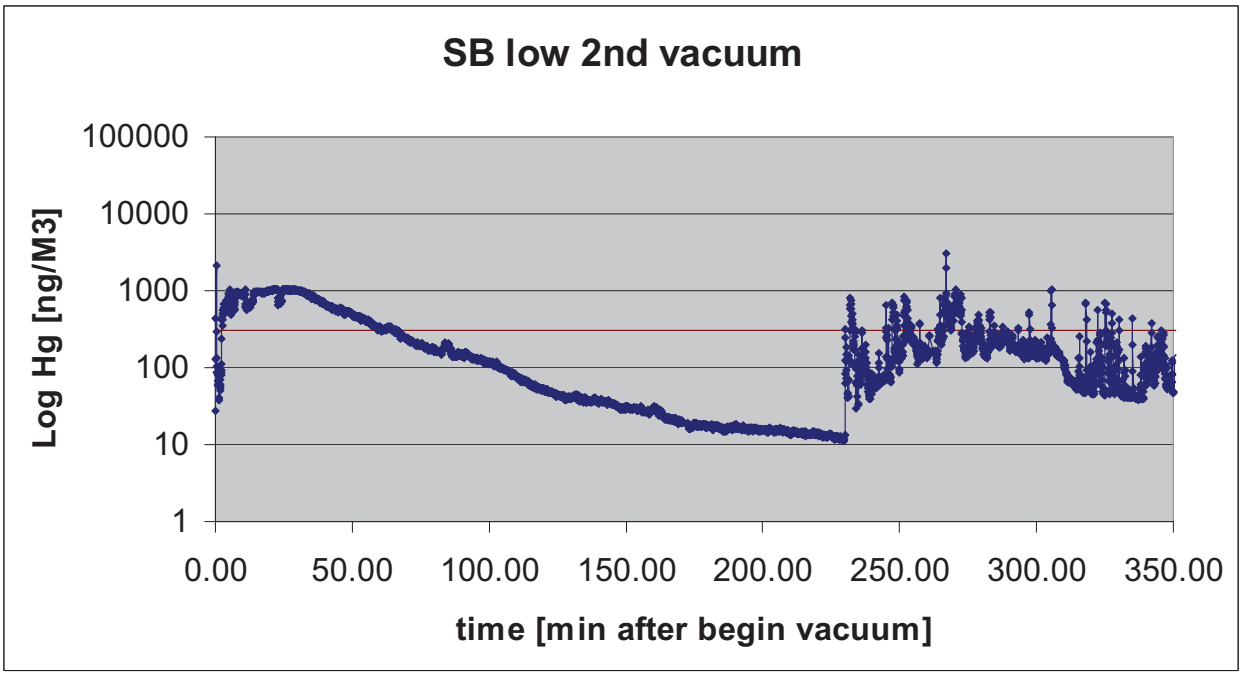


Figure A-83. Scenario "SB Vacuum" at One-Foot Height (7/6/07)

On 7/9/07 this carpet was vacuumed for a third time with a new bag in the vacuum.

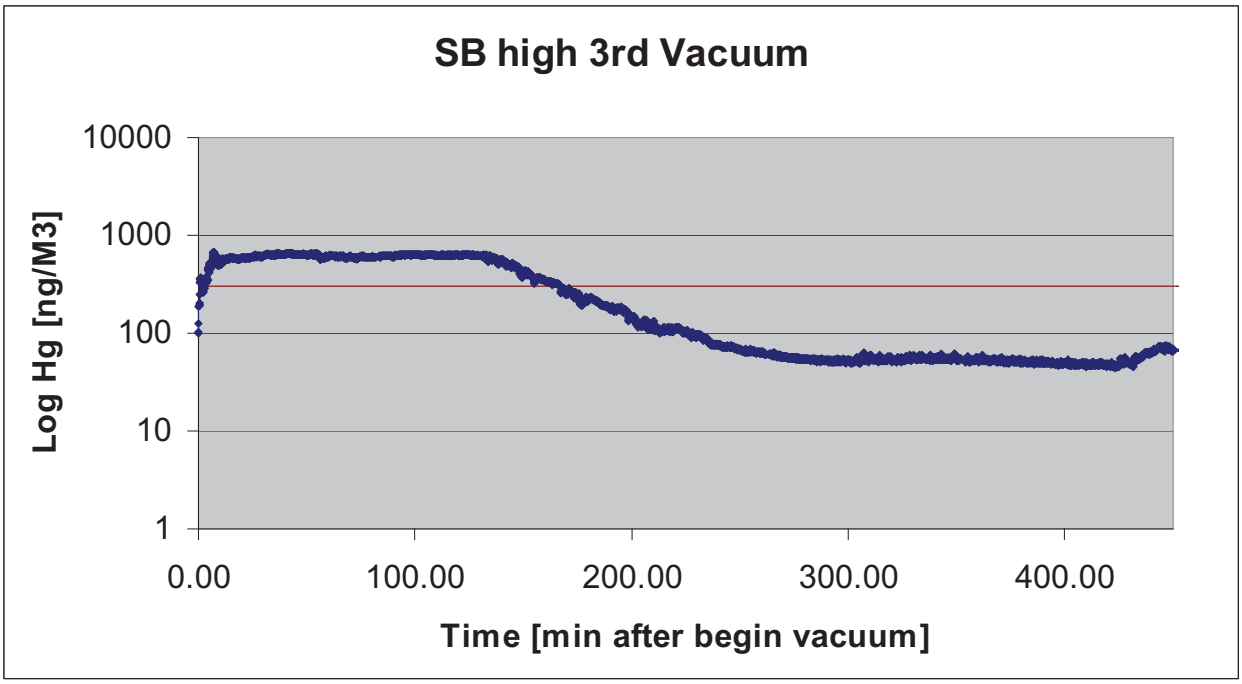


Figure A-84. Scenario "SB Vacuum" at Five-Foot Height (7/9/07)

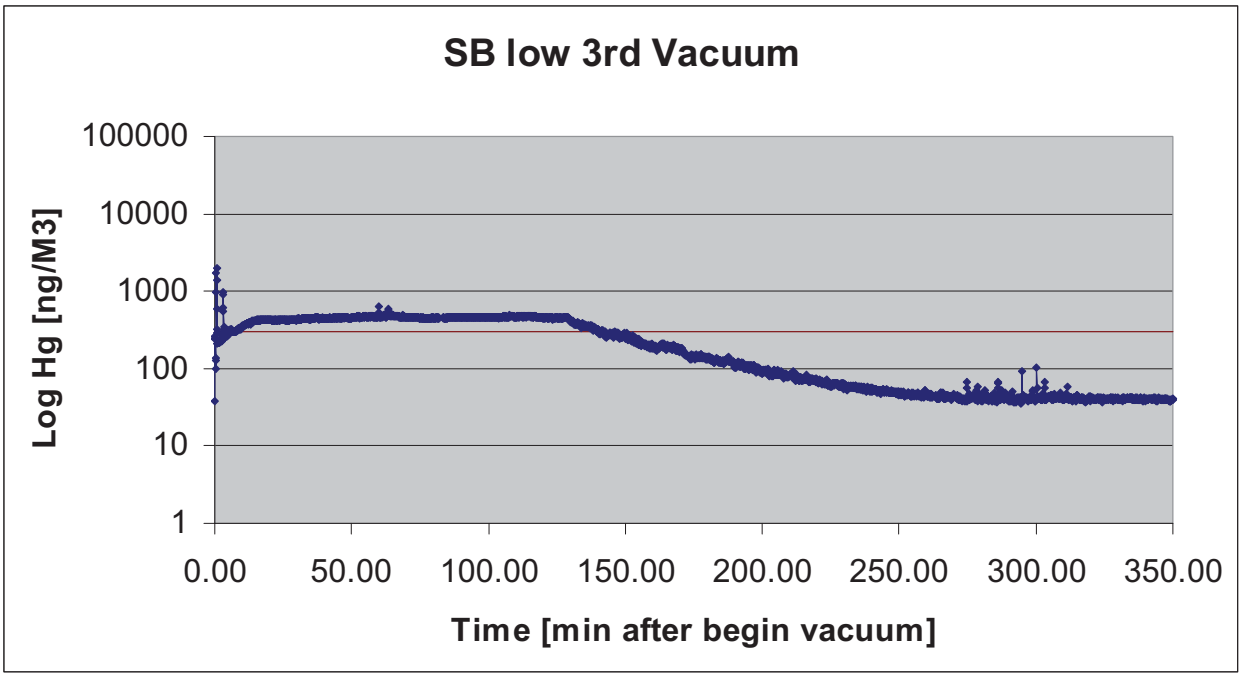


Figure A-85. Scenario "SB Vacuum" at One-Foot Height (7/9/07)

On 7/10/07 this carpet was vacuumed for a fourth time.

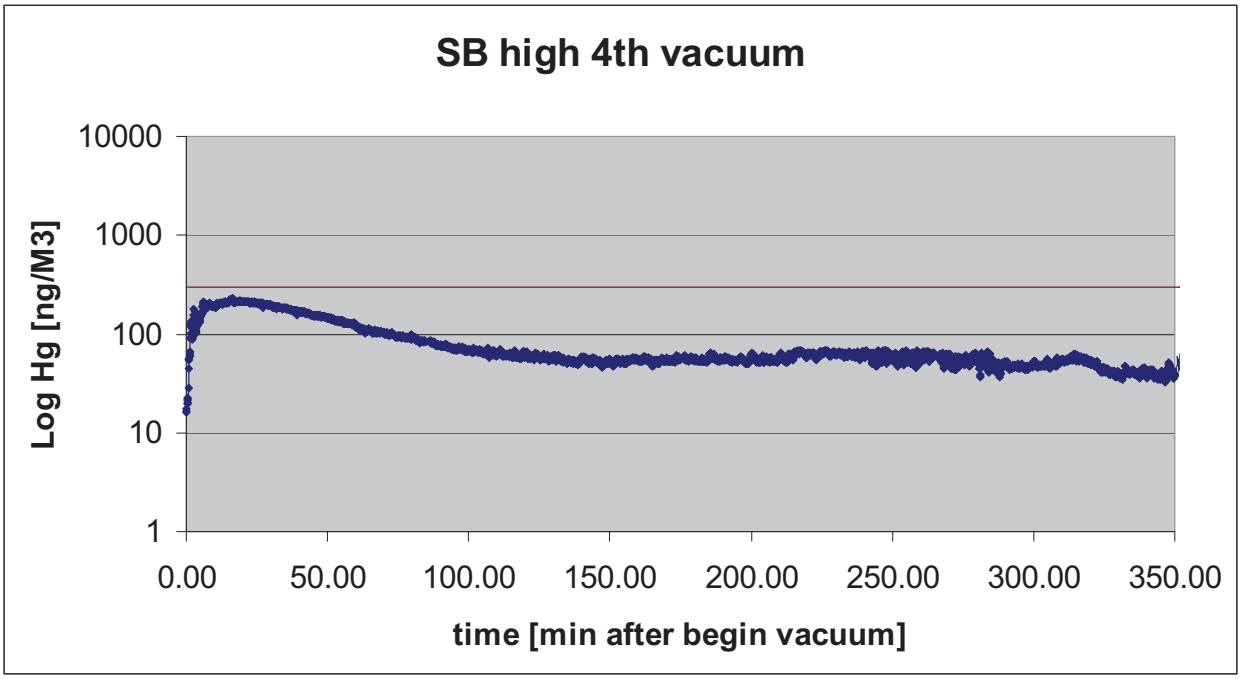


Figure A-86. Scenario "SB Vacuum" at Five-Foot Height (7/10/07)

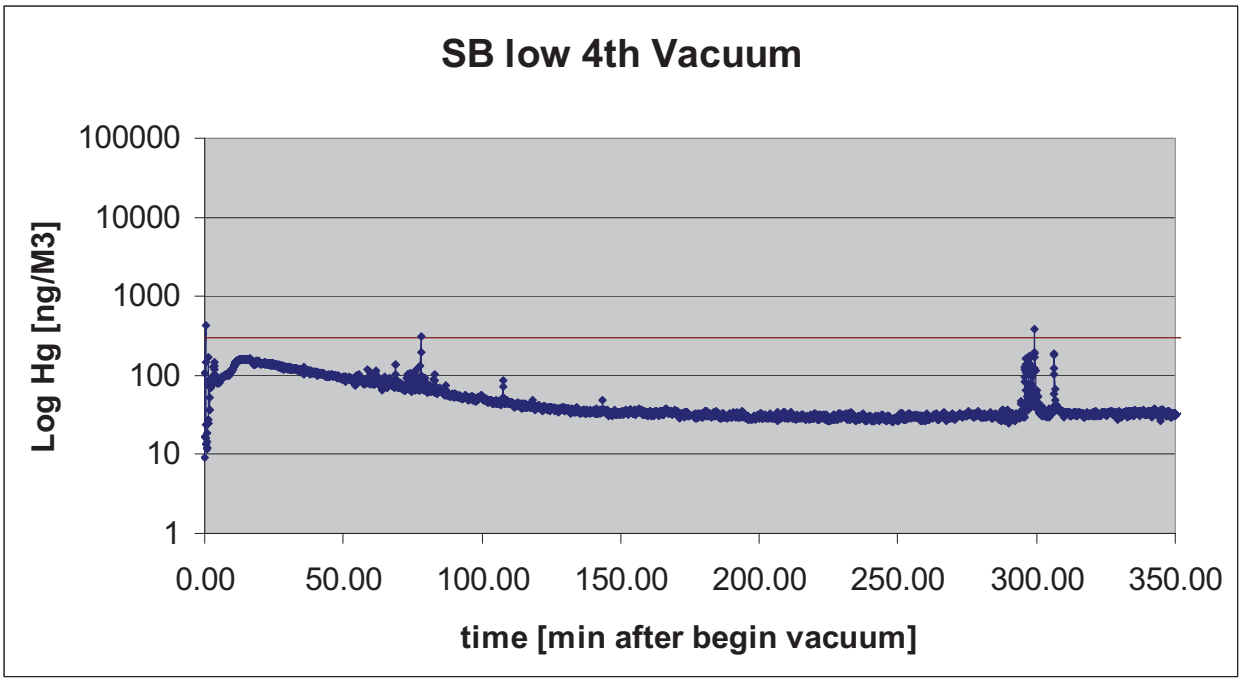


Figure A-87. Scenario "SB Vacuum" at One-Foot Height (7/10/07)

See Table A-18 below for measurements taken near the vacuum over time after this scenario.

Table A-18
Hoover Spectrum 850, canister style, Model #S3585, Serial # 089000014844, approx. 20 yrs. old

Date of Lamp Breakage	Date of Vacuuming	Date of Measurement	Vacuum Cleaner Part						
			Beaters			Plastic hose	Inside vac	Metal wand	Bag
			hot	cold	cold agitated	cold	cold	cold	cold
		6/28/2007	160	<20					
		7/2/2007		95	711				
		7/3/07 before cleaning		24	347	<20	<20		
		7/3/07 after cleaning		<20	22				
6/12/2007	7/3/2007	7/3/2007 Right after vacuuming	>50,000						
		7/3/07 after cleaning again		188	534	4,657		259	
		7/5/2007		75	990	17,540		142	
		7/6/2007 after cleaning again		<20	97	801		110	
	7/6/2007	7/6/07 after this vacuuming and before cleaning		137	537	14,670		943	972
		7/6/07 after cleaning		<20	296				
		7/6/07 PM		36	559	1,280	26	66	
		7/9/2007 after cleaning		64	125	550		<20	
	7/9/2007	7/9/07 after this vacuuming and before cleaning		75	81	666		1,553	417
		7/9/07 after cleaning again		81					
		7/10/2007		<20	22	528		26	<20
	7/10/2007	7/10/07 after 4th vacuum		87	74	1,319		193	188
		7/11/2007		20	43	214	29	25	

New vac bag before 3rd vac
Vacuum measurements with 3rd Lumex when room levels of mercury are low
Vacuum ran for approx 10 min. to get warm vac or "hot" numbers
Measurements are ng/m^3
Wet wipes used frequently on vacuum

Scenario L: "Brand B" 100 Watt Eq., Short Nap Carpet, No Venting, Vacuuming Four Different Times.

This was meant to be a worst case scenario. On 7/19/07 the "Brand B" lamp was thoroughly broken on short nap carpet, the big pieces of debris were picked up and put in an open trash can in the study room, and the rest of the debris was vacuumed with the Hoover 850. The window was left closed, and the vacuum bag was left in the vacuum and in the study room. The vacuum was not wiped down with a wet wipe.

The third Lumex was used to monitor the air outside of the study room that was contaminated from the mercury coming out from under the door. At about an hour after the first vacuuming, measurements were taken near the floor near the study room and at the five foot breathing zone. Along the floor two feet from the door the Lumex read 5,000 ng/m^3, fifteen feet from the door read approximately 1,150 ng/m^3 and 25 feet from the door read approximately 700 ng/m^3. In the five foot breathing zone the Lumex read over 2,000 ng/m^3 four feet from the door, approximately 1,000 ng/m^3 ten feet from the door, approximately 300 ng/m^3 twenty-five feet from the door, and approximately 40 ng/m^3 thirty feet from the door.

Figures A-88 & A-89 for the first vacuuming event for this scenario show mercury peaking to 23,720 ng/m^3 at the five foot height, and 133,955 ng/m^3 at the one foot height.[39] Mercury was still over 300 ng/m^3 after 1500 minutes at both heights.

During this scenario researchers observed that the overhead garage door located outside the study room had a direct effect on the concentrations of mercury in the study room depending on whether it was opened or closed. The more dramatic decreases of mercury on the graphs below are associated with the overhead door being closed. This had the effect of reducing mercury concentrations in the study room sooner, and venting into adjacent rooms.

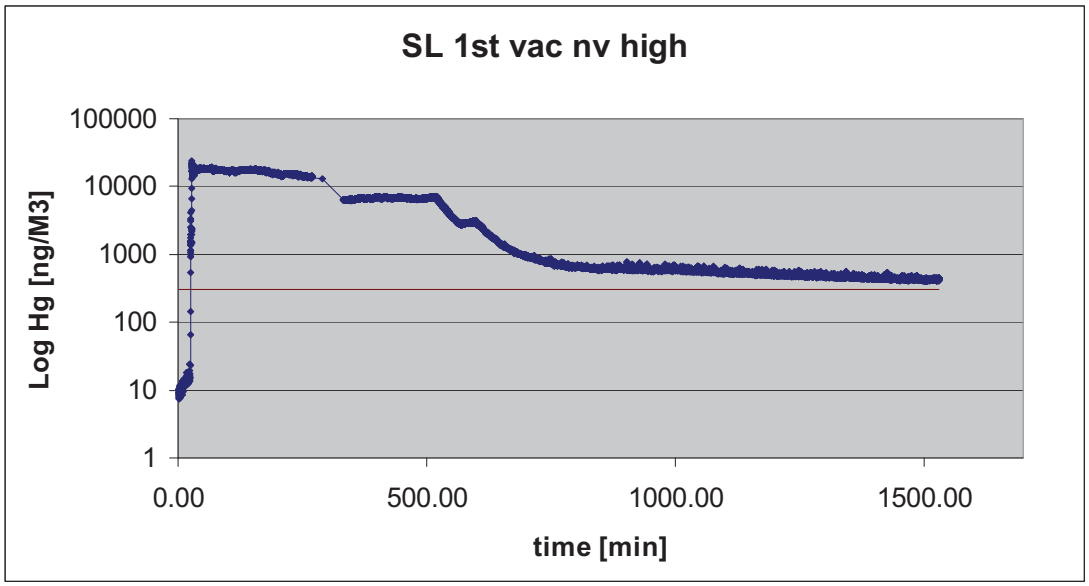


Figure A-88. Scenario L first vacuum at Five-Foot Height (7/19/07)

39 Lumex RA-915+ calibration is out of range above 50,000 ng/m^3. This number is therefore a relative number.

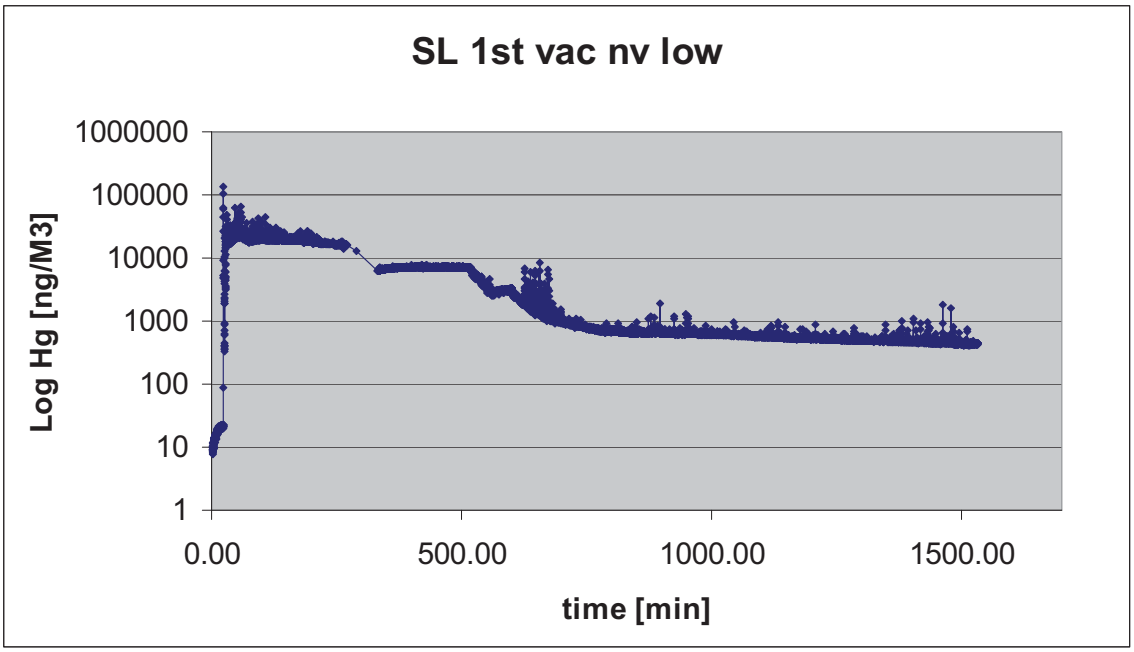


Figure A-89. Scenario L first vacuum at One-Foot Height (7/19/07)

On 7/23/2007, without trying to decontaminate the vacuum, the carpet was vacuumed again, with the window closed. The overhead garage door outside the study room had been closed over the weekend. Before this second vacuuming, the room had approximately 300-400 ng/m^3 of mercury in the air. The garage door was opened for the first eight hours of this run (approximately 480 minutes).

The graphs for the second vacuuming event for this scenario below show mercury peaking to 3,135 ng/m^3 at the five foot height, and 36,397 ng/m^3 at the one foot height. Mercury was less than 300 ng/m^3 after 530.75 minutes at the five foot height and was still over 300 ng/m^3 after 1200 minutes at the one foot height.

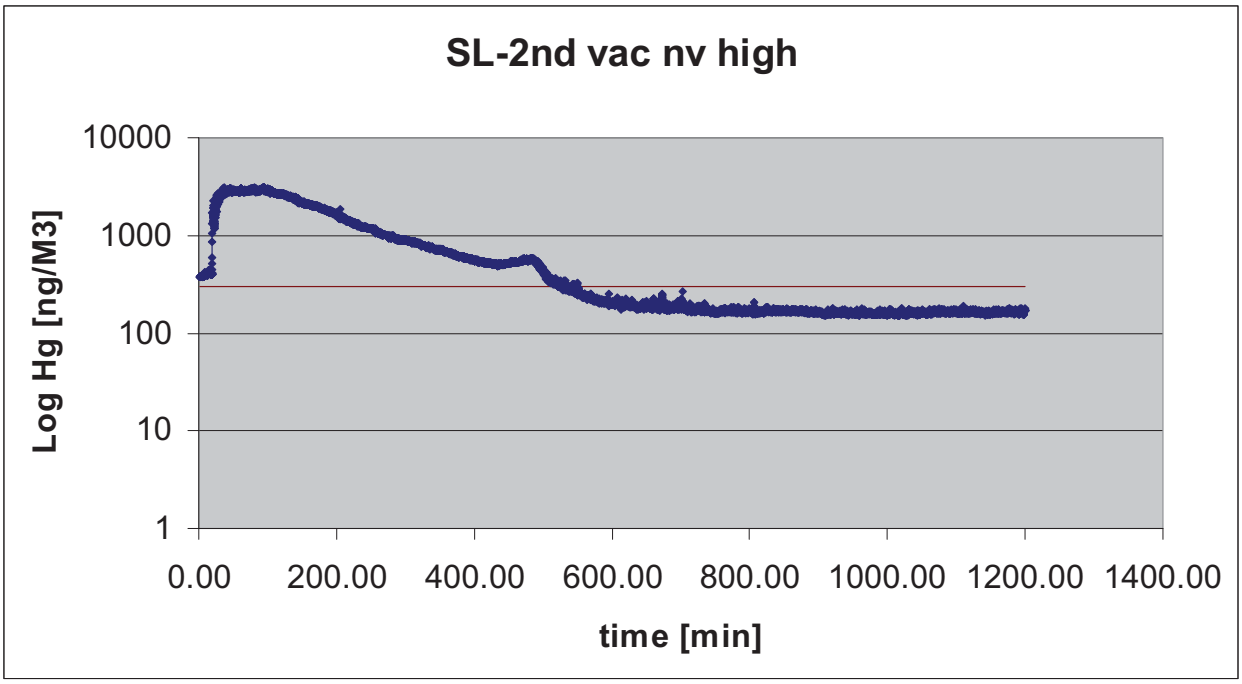


Figure A-90. Scenario L second vacuum at Five-Foot Height (7/23/07)

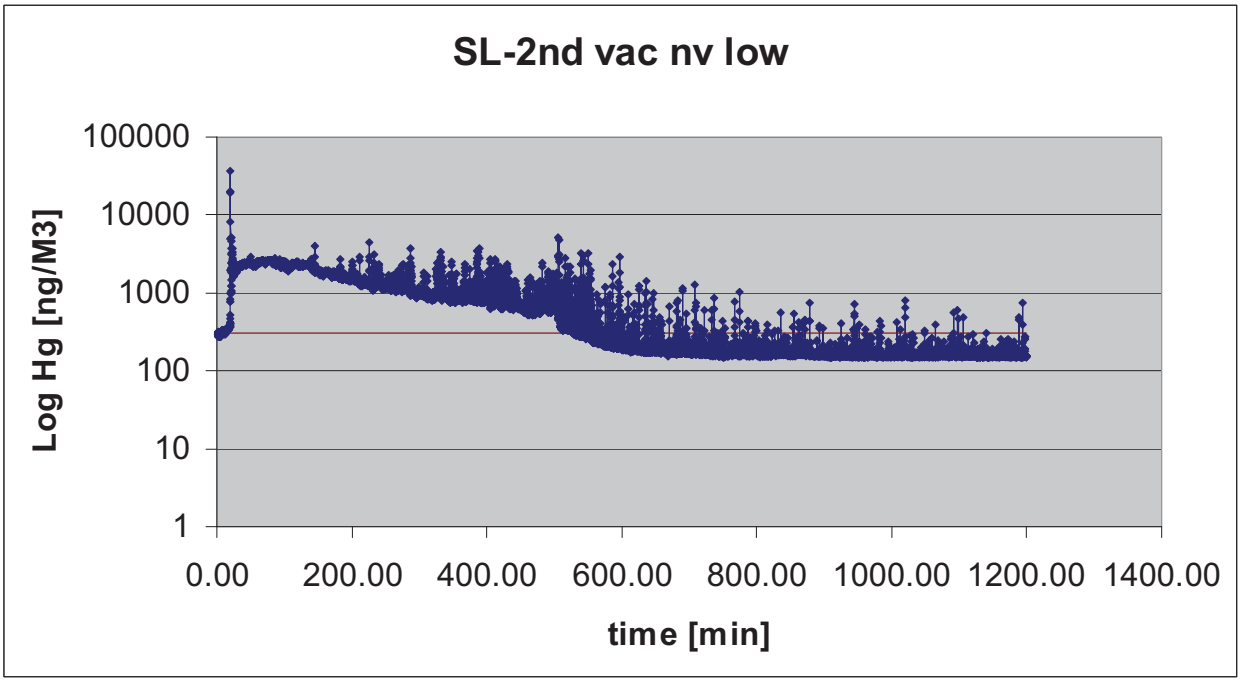


Figure A-91. Scenario L second vacuum at One-Foot Height (7/23/07)

On 7/24/2007 the garage door was opened again at 7:15 AM. Mercury concentrations in the study room were in the range of approximately 200 to 600 ng/m^3. This carpet was vacuumed for a third time. After about eight hours and 20 minutes, the garage door was closed again for the night (approx. 500 minutes). The concentration of mercury in the air decreased much more rapidly when the garage door was closed as can be seen in Figures A-92 & A-93.

The graphs in Figures A-92 and A-93 show mercury peaking at 3,708 ng/m^3 at the five foot height, and 19,270 ng/m^3 at the one foot height. Mercury was less than 300 ng/m^3 after 539.33 minutes at the five foot height and was still over 300 ng/m^3 after 1200 minutes at the one foot height.

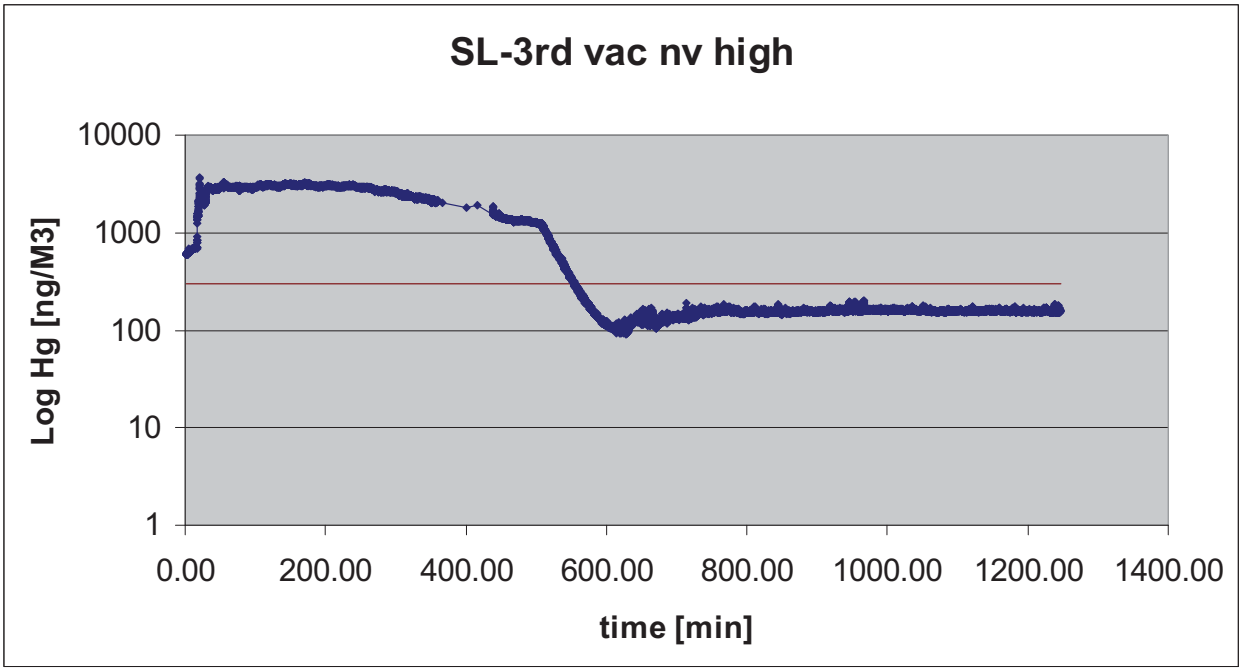


Figure A-92. Scenario L third vacuum at Five-Foot Height (7/24/07)

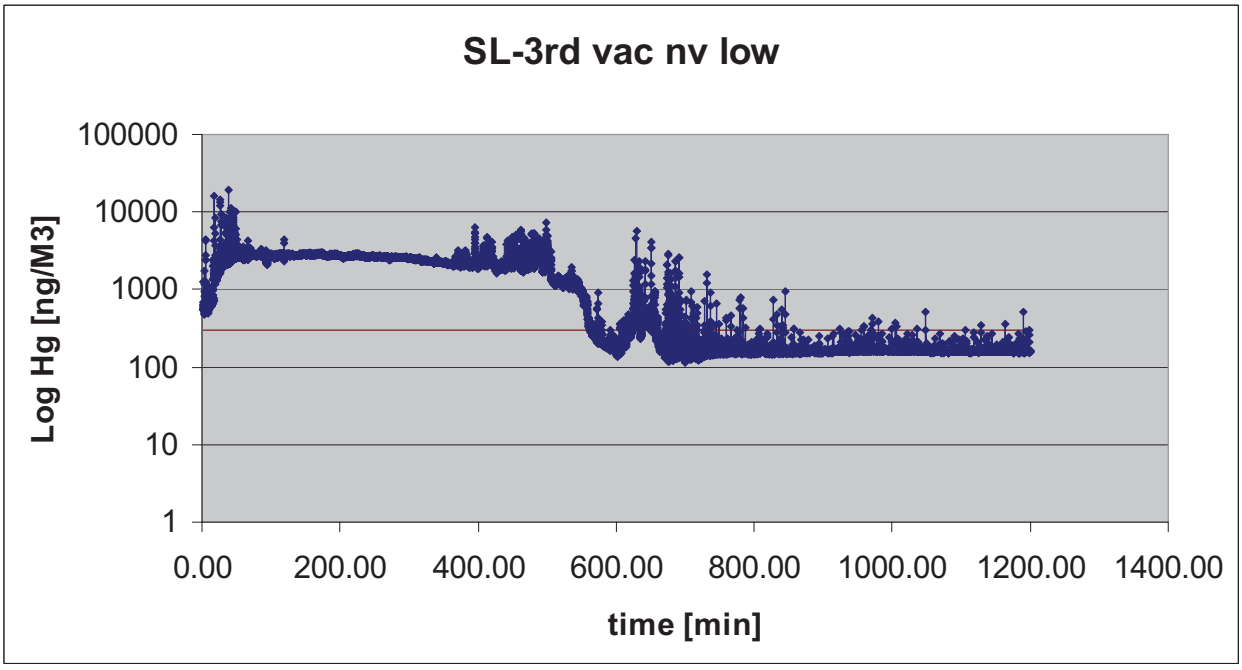


Figure A-93. Scenario L third vacuum at One-Foot Height (7/24/07)

The fourth vacuuming event for this scenario occurred 7/25/07. The graphs for the fourth vacuuming event below show mercury peaking at 3,288 ng/m^3 at the five foot height, and

12,367 ng/m^3 at the one foot height. Mercury was less than 300 ng/m^3 after 523.75 minutes at the five foot height and continued to spike above 300 ng/m^3 after 1200 minutes for the one foot height.

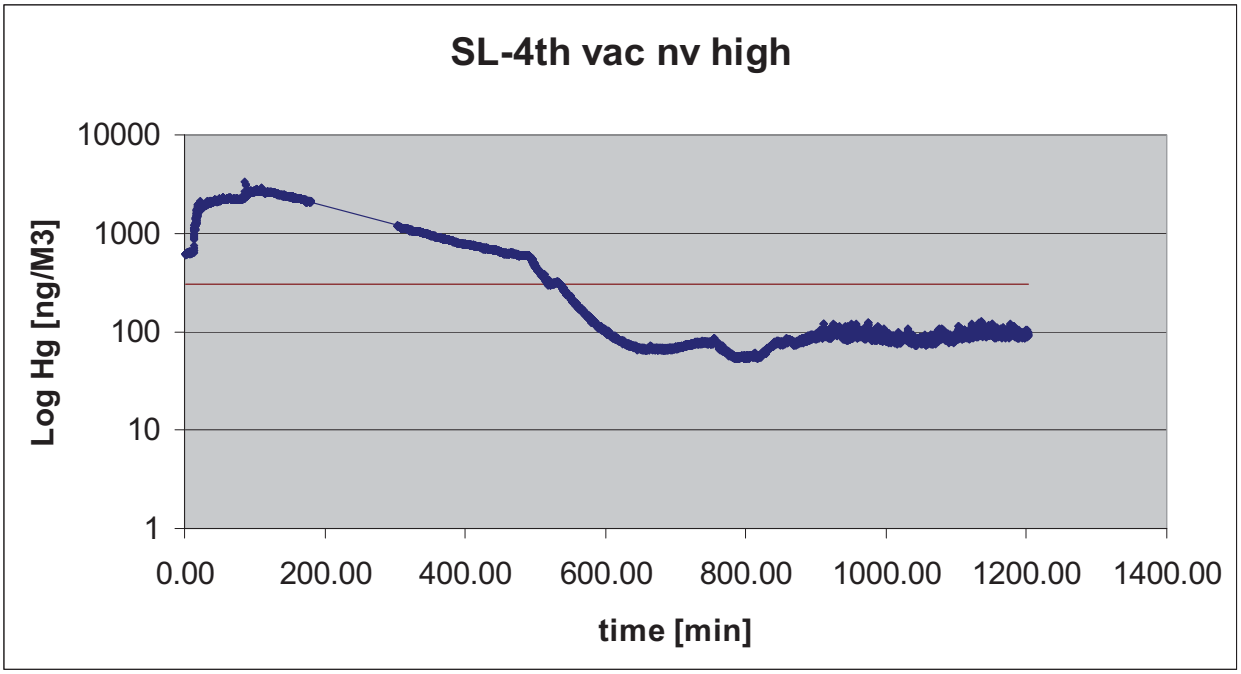


Figure A-94. Scenario L for the vacuum at Five-Foot Height (7/25/07)

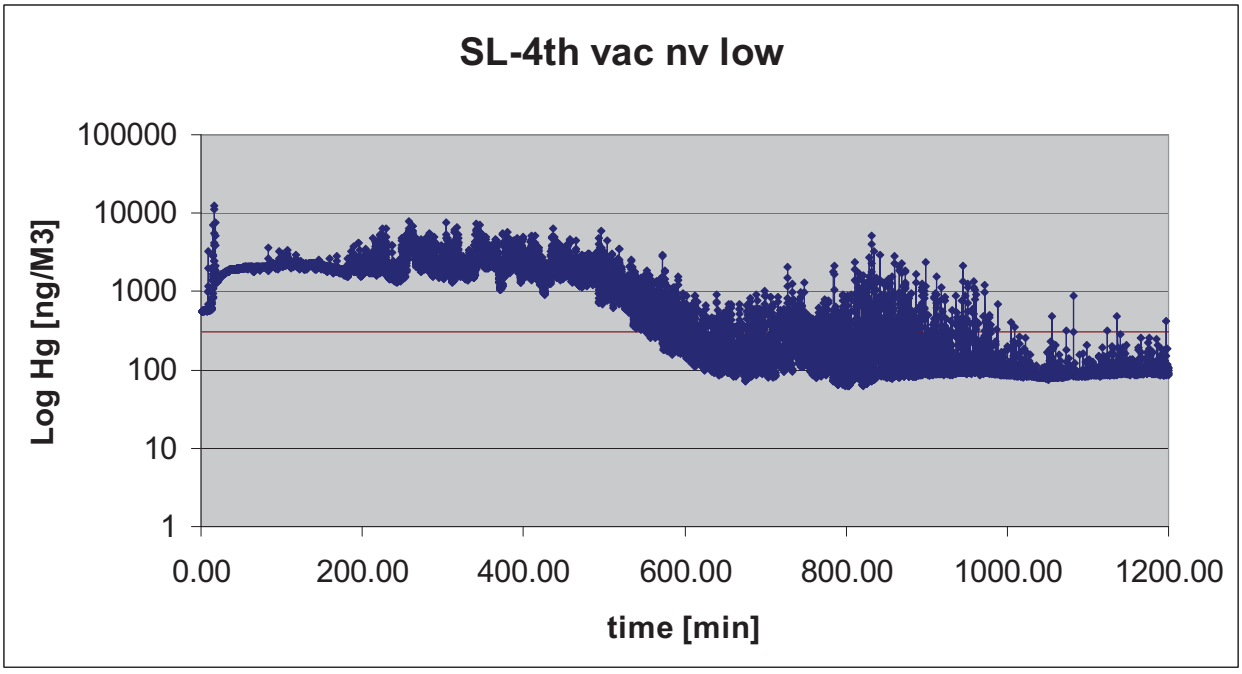


Figure A-95. Scenario L forth vacuum at One-Foot Height (7/25/07)

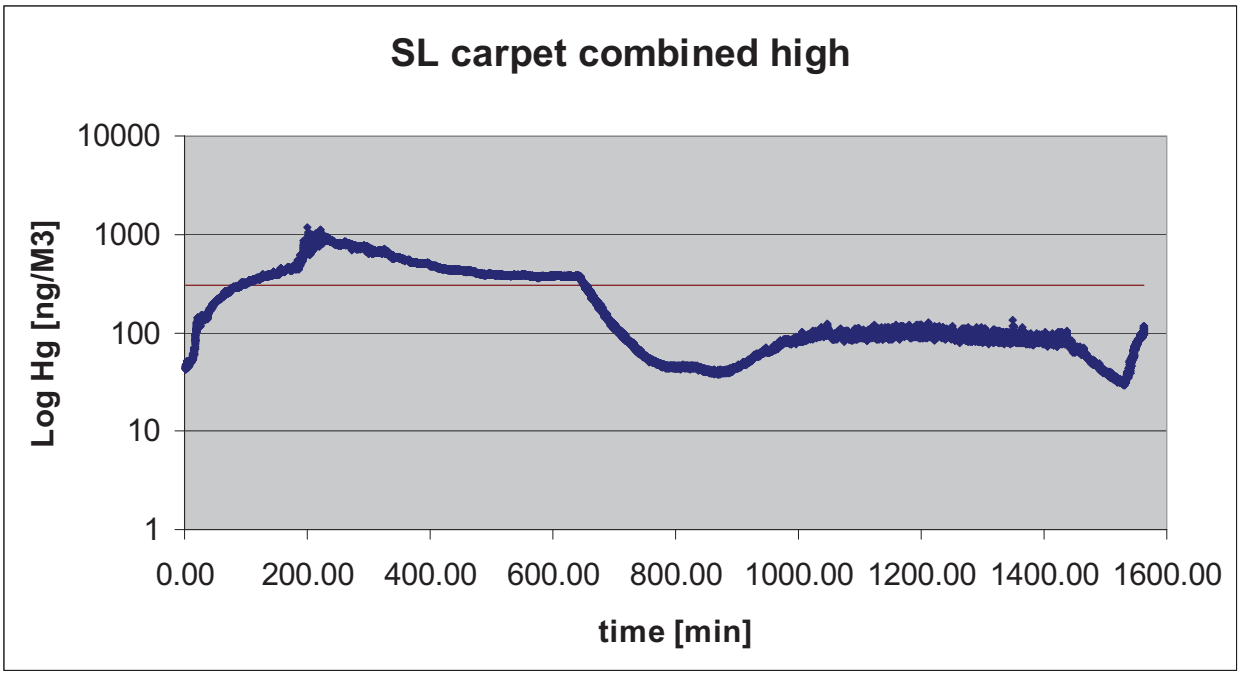


Figure A-96. Scenario L carpet only at Five-Foot Height on 7/26/07

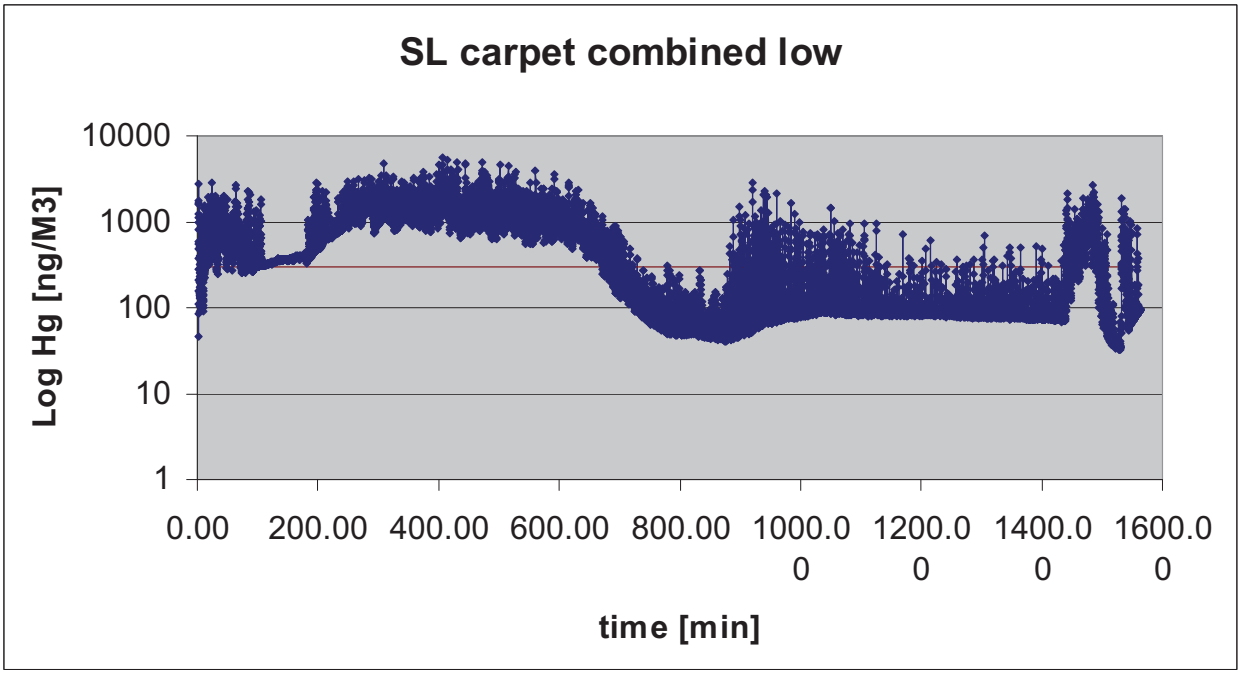


Figure A-97. Scenario L carpet only at One-Foot Height on 7/26/07

Table A-19. Flooring readings for Scenario L

Scenario	SL-"Brand B" 100vacnv	
Date of Breakage	7/19/2007	
Floor Type	short carpet	
Date Measured ↓	unagitated	agitated
7/19/2007 (vacuumed)		
7/23/2007 (vacuumed)		
7/24/2007 (vacuumed)	862	>50,000
7/25/2007 (vacuumed)	690	37,000
7/26/2007	990	13,200
7/27/2007	10,505	29,000
7/30/2007	392	7,795
7/31/2007	912	21,070
8/1/2007	310	16708
8/2/2007	2,116	12,170
8/3/2007	2,691	7,382
8/7/2007	2,033	14,536
8/9/2007	433	4,183
8/10/2007	551	7,456

Results recorded are the highest concentrations of mercury seen while scanning in ng/m^3. Readings for vacuuming days were recorded before the vacuuming.

Table A-20. Vacuum parts readings with Lumex

Hoover Spectrum 850, canister style, Model #S3585, Serial # 089000014844, approx. 20 yrs. old								
			Vacuum Cleaner Parts					
			Beaters		Plastic hose	Inside vac	Metal wand	Bag
Date of Lamp Breakage	Date of Vacuuming	Date of Measurement	cold	cold agitated	cold	cold	cold	cold
7/19/2007	7/19/2007							
	7/23/2007							
		7/24/2007 (ambient air = approx. 600)	1,043	1,755	>50,000			4,288
	7/24/2007							
		7/25/2007 before vac	763	1,421				
	7/25/2007							
		7/26/2007	419		38,600		2,524	1,750
		7/26/07 after wiping down with wet wipes	4,941	13,400	5,968	280	84	
		7/27/2007	87	567	3,807			
		7/30/2007	576	2,403	1,059			
		7/31/07(just removed from a container)	1,153	2,397	13,410			
		7/31/07 (after being out of container for 5 min.)	153	1,580	5,671			
		8/1/2007	42	563	4,739			
		8/2/2007	55	4,043	5,566			
		8/3/2007	254	1,793	16,009			
		8/7/2007	597	544	3,328			
		8/9/2007	3,144	3,138	886			
		8/10/2007	848	3,198	804			

This vacuum was used earlier in study
Vacuum measurements with 3rd Lumex when room levels of mercury are low
Measurements are ng/m^3
Vacuum not cleaned with wet wipes between vacuuming events on this table

Container Study Additional Results

All mercury debris for the original study was contained in single re-sealable polyethylene storage bags and placed in 55 gallon hazardous waste drums. Mercury air concentration near the hazardous waste drums was measured while bags were deposited. After debris from the third CFL was placed in the drum, mercury concentrations were observed to be quite high (>50,000 ng/m^3) near the open drum. This observation led researchers to consider whether or not re-sealable bags were appropriate for containing mercury contaminated debris.

Microsoft® Excel graphs with regression lines, graphing mercury vapor readings taken in phase one of the container study, are presented below.

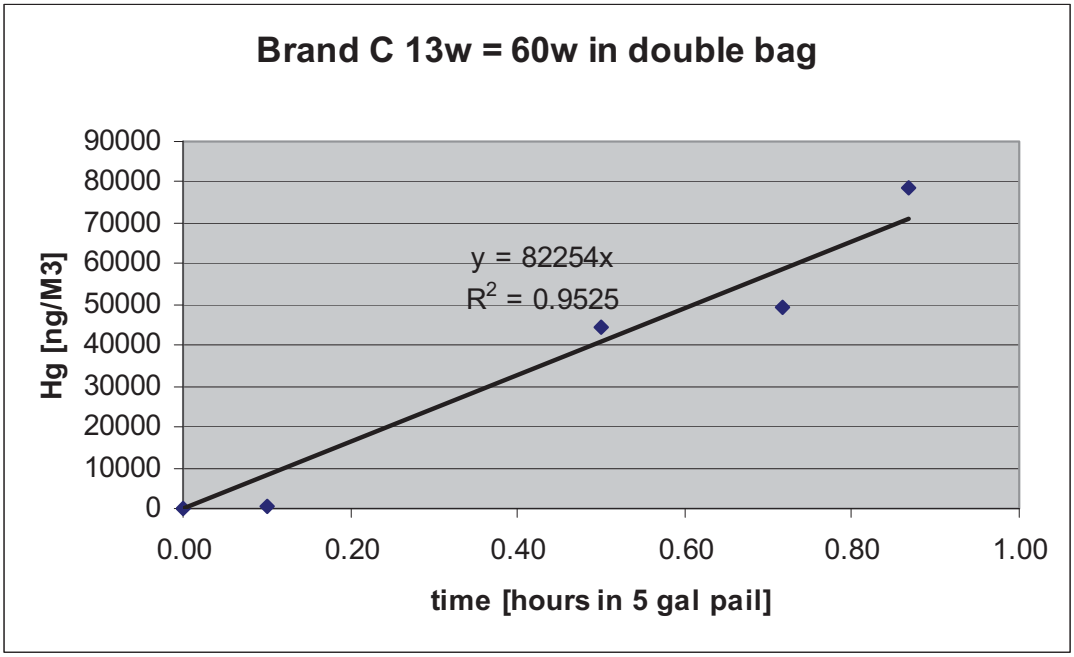


Figure A-98. Regression graph for "Brand C" 60 watt replacement CFL in double re-sealable plastic bags.

Glass jars with metal "gum seal" lids such as canning jars performed the best in waste pail trials. See Figure A-99.

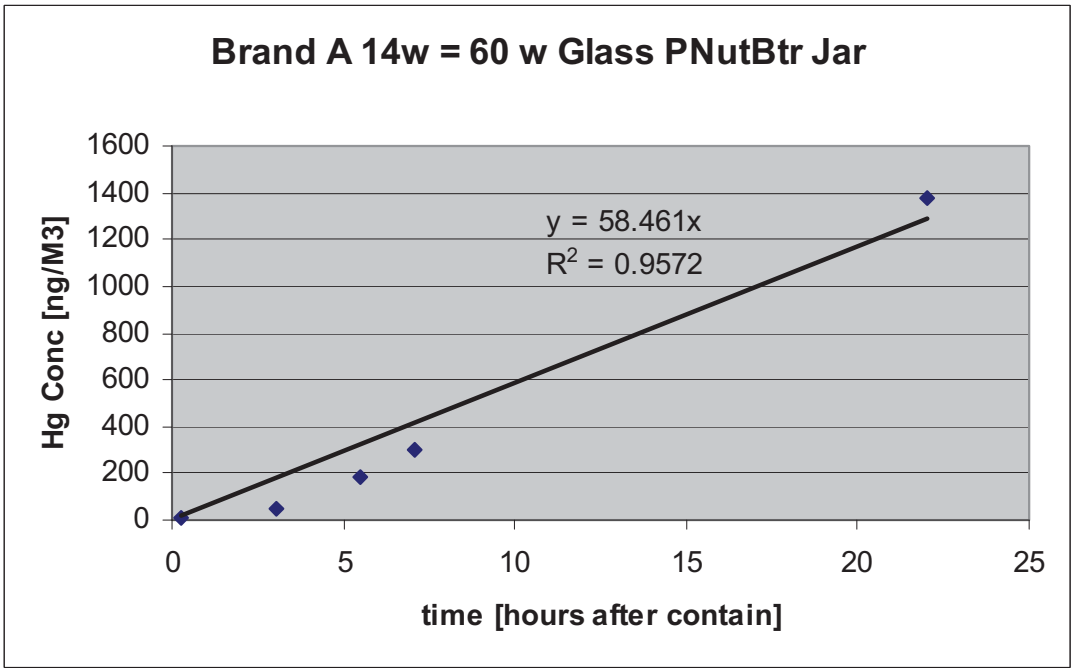


Figure A-99. Regression graph for "Brand A" 60 watt replacement CFL in glass jar/ metal lid.

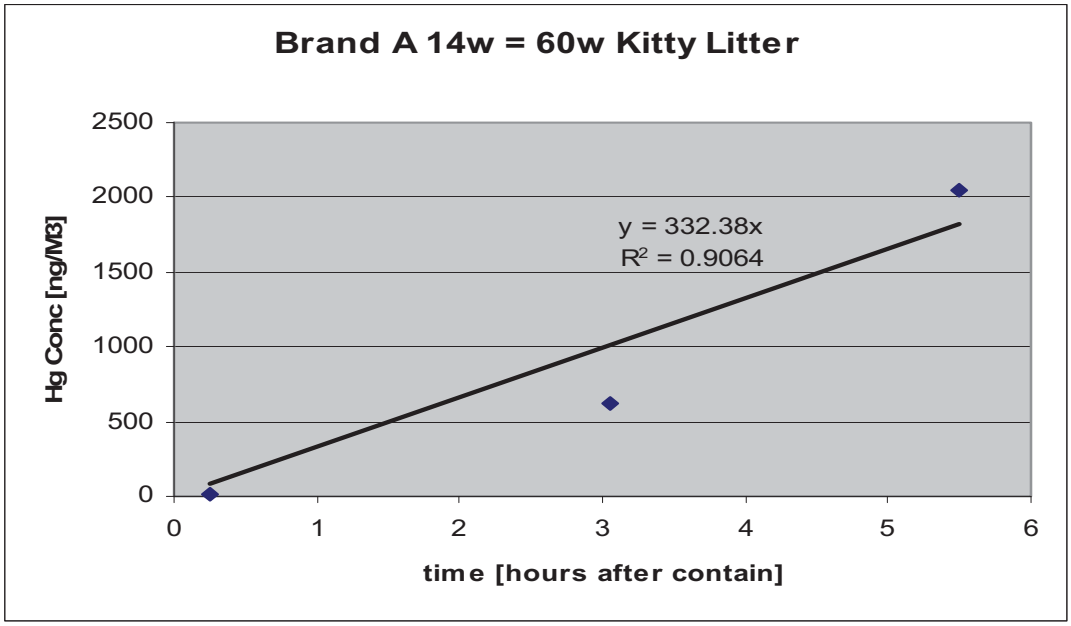


Figure A-100. Regression graph for "Brand A" 60 watt replacement CFL in HPDE Kitty Litter Jug.

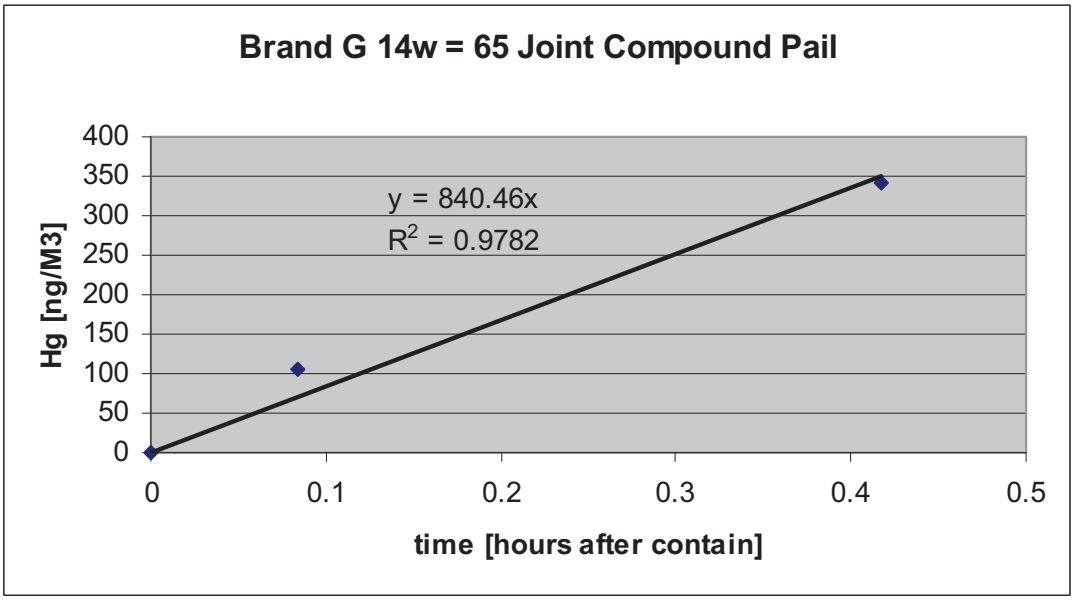


Figure A-101. Regression graph for Commercial Electric 65 watt replacement CFL in HPDE joint compound bucket.

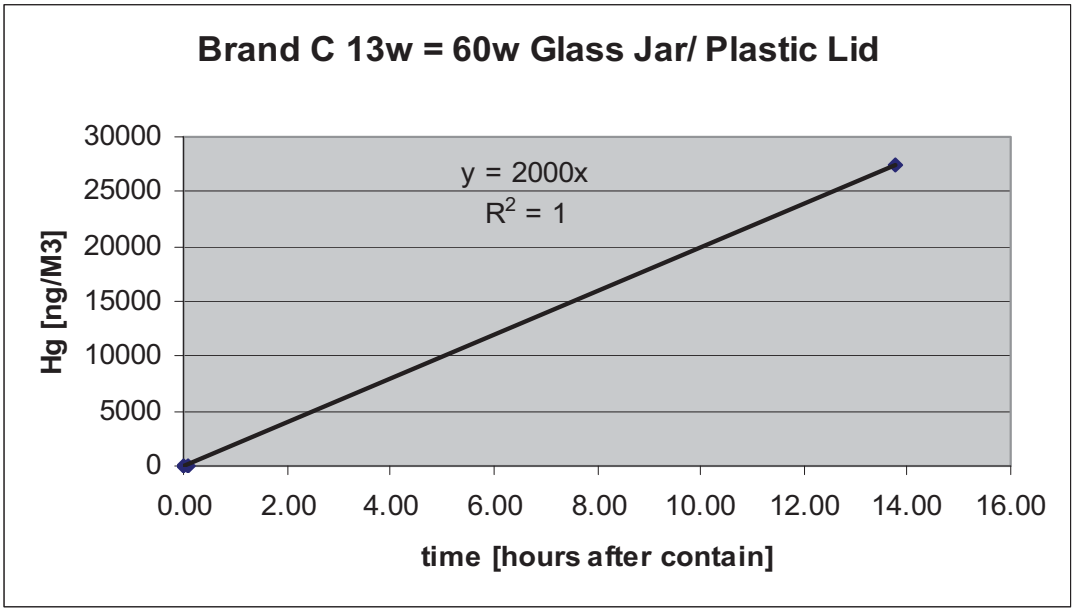


Figure A-102. Regression graph for "Brand C" 60 watt replacement CFL in glass with plastic lid.

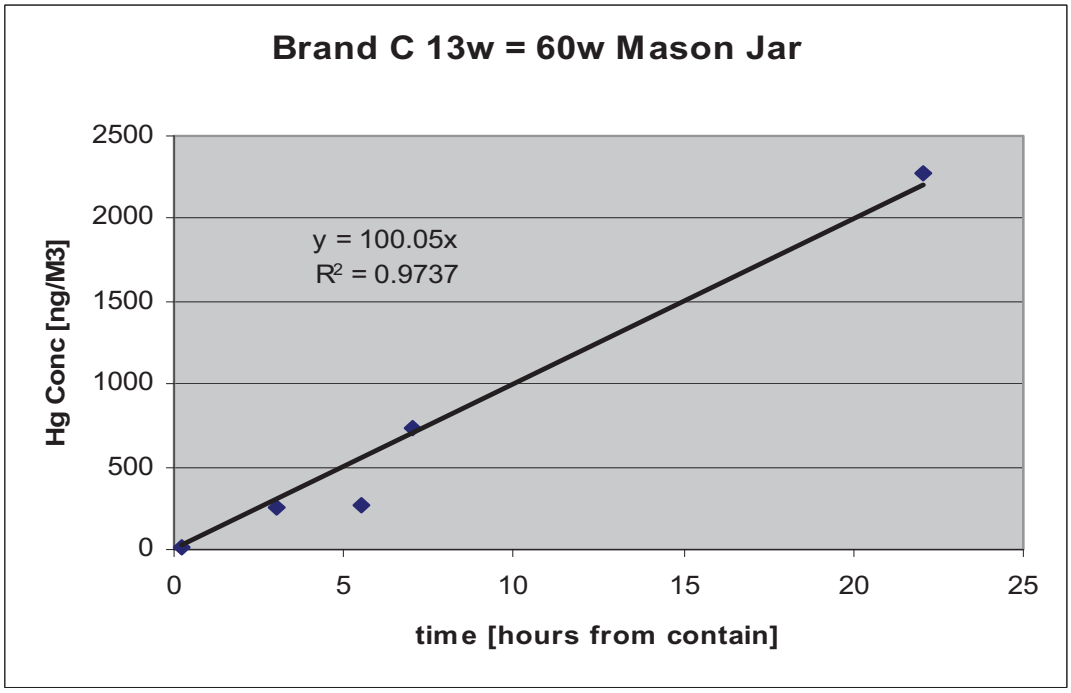


Figure A-103. Regression graph for "Brand C" 60 watt replacement CFL in glass jar/ metal lid.

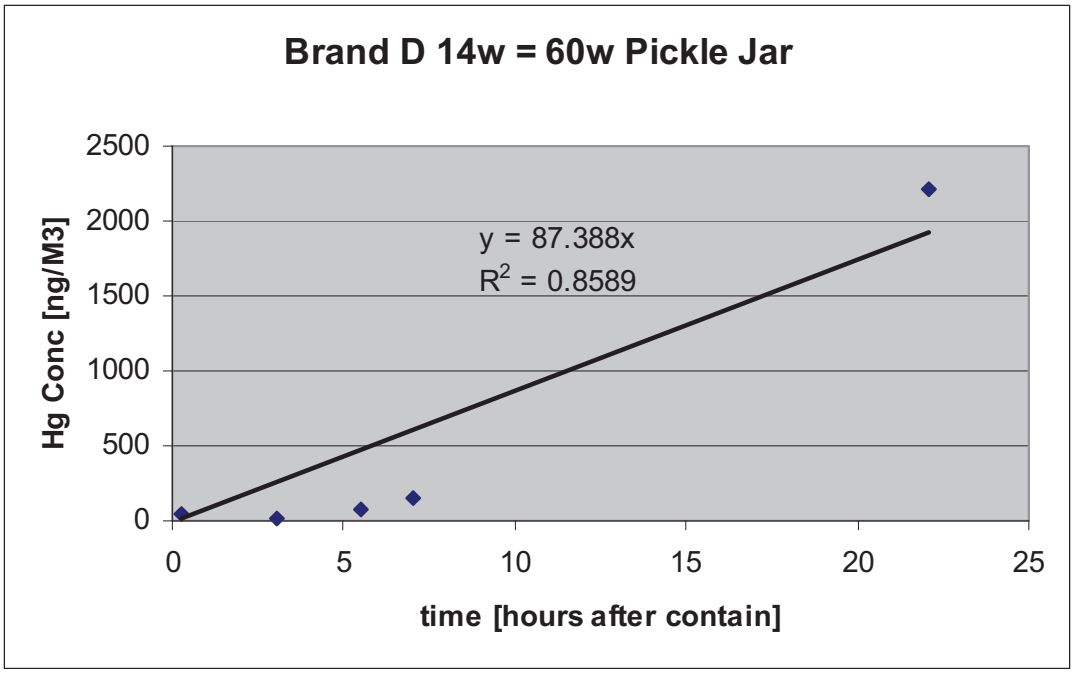


Figure A-104. Regression graph for "Brand D" 60 watt replacement CFL in glass jar/ metal lid.

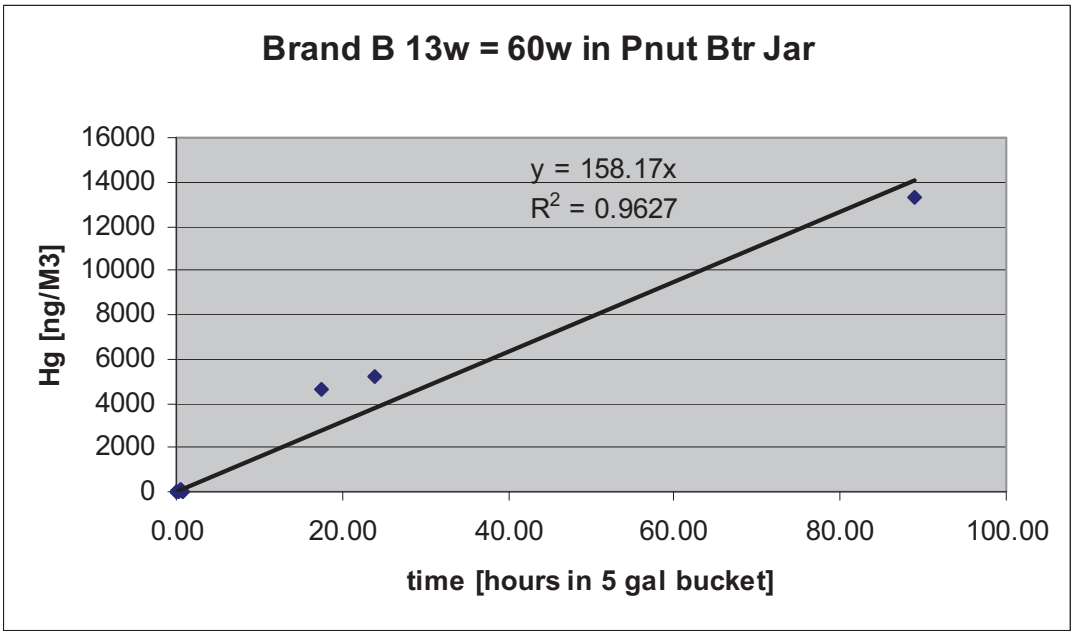


Figure A-105. Regression graph for "Brand B" 60 watt replacement CFL in glass jar/ metal lid.

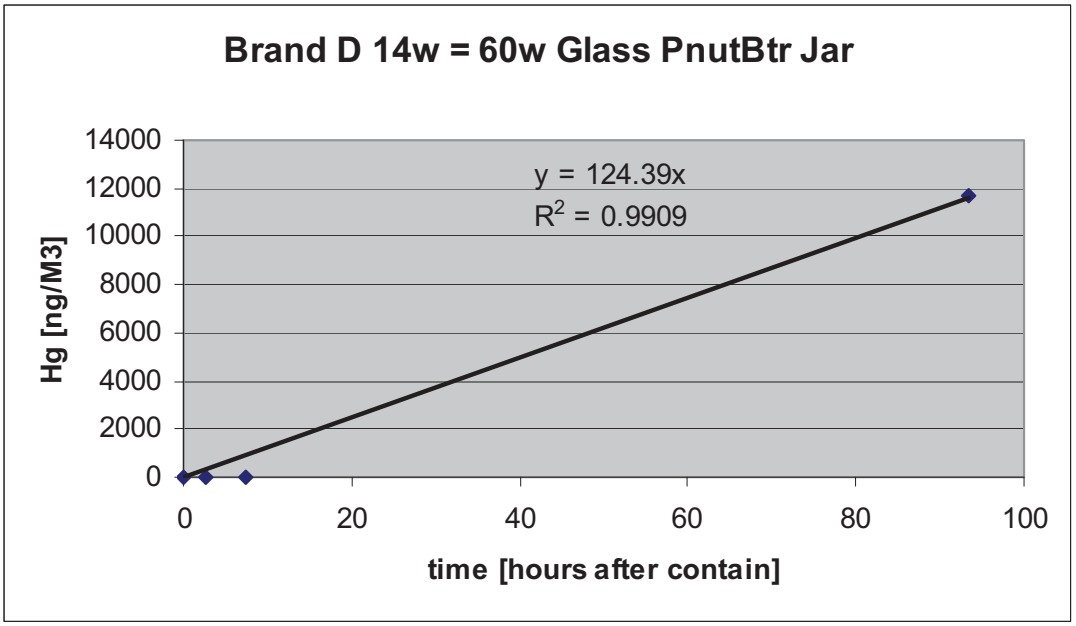


Figure A-106. Regression graph for "Brand D" 60 watt replacement CFL in glass jar/ metal lid.

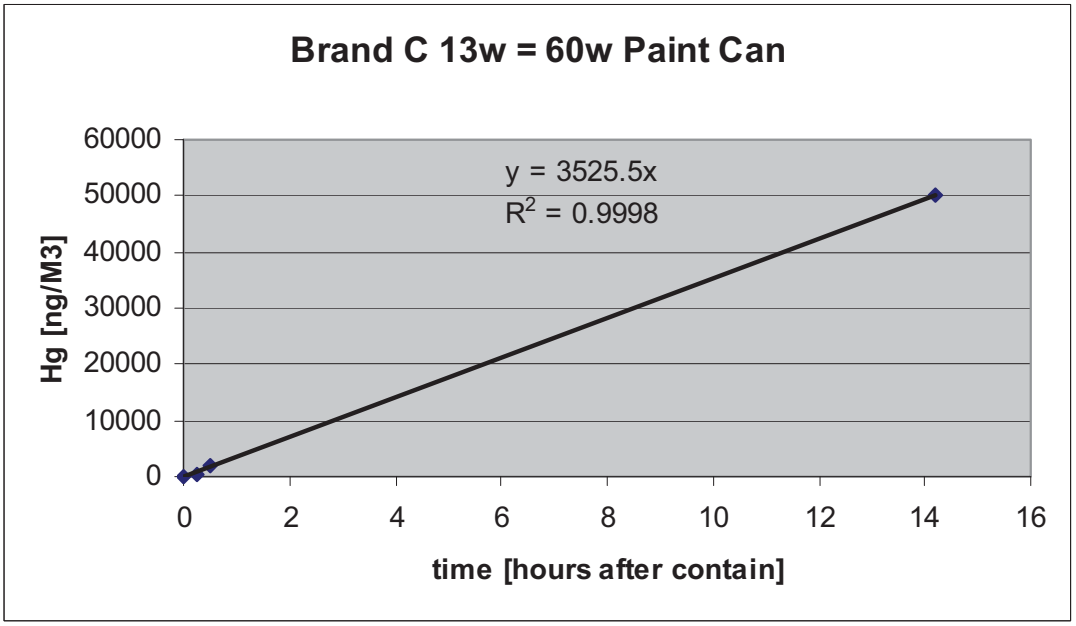


Figure A-107. Regression graph for "Brand C" 60 watt replacement CFL in paint can.

Data for the above graphs were originally recorded in study notebooks, and have been consolidated into the Excel file Containers.xls, available on request.

The four scenarios set up inside the study room were monitored to confirm previous findings in waste pail trials. Performance criterion for study room trials was whether or not study room mercury vapor concentrations exceeded the Maine Ambient Air Guideline (MAAG) of 300 ng/m^3. Room door and window were closed for these trials. Study room air did not exceed the MAAG for scenarios where lamp debris was contained in glass jars. One scenario, with broken "Brand D" 60 lamp contained in a glass peanut butter jar was monitored for one week with the following results as listed in Table A-21.

Table A-21 "Brand D" 60 in Glass Peanut Butter Jar

Date	Time (military)	Hg (ng/M3)
7/11//07	10:05	35
7/11//07	10:15	20.3
7/11//07	12:10	<20
7/11//07	15:05	20.7
7/12/2007	16:00	<20
7/13/2007	10:30	<20
7/16/2007	6:30	<20
7/16/2007	15:00	<20
7/17/2007	8:00	<20
7/17/2007	9:10	<20
7/18/2007	6:30	<20

Mercury measurements taken from Study Room 5' intake.

An additional glass jar scenario was monitored using Lumex Air Monitoring software saving mercury air concentrations every 5 seconds. Study room trial graphs not included in the results section of the report are presented in figures A-108 & A-109). Six hour monitoring runs for study room scenarios with broken lamps contained in double re-sealable polyethylene storage bags exceed the MAAG in approximately one hour.

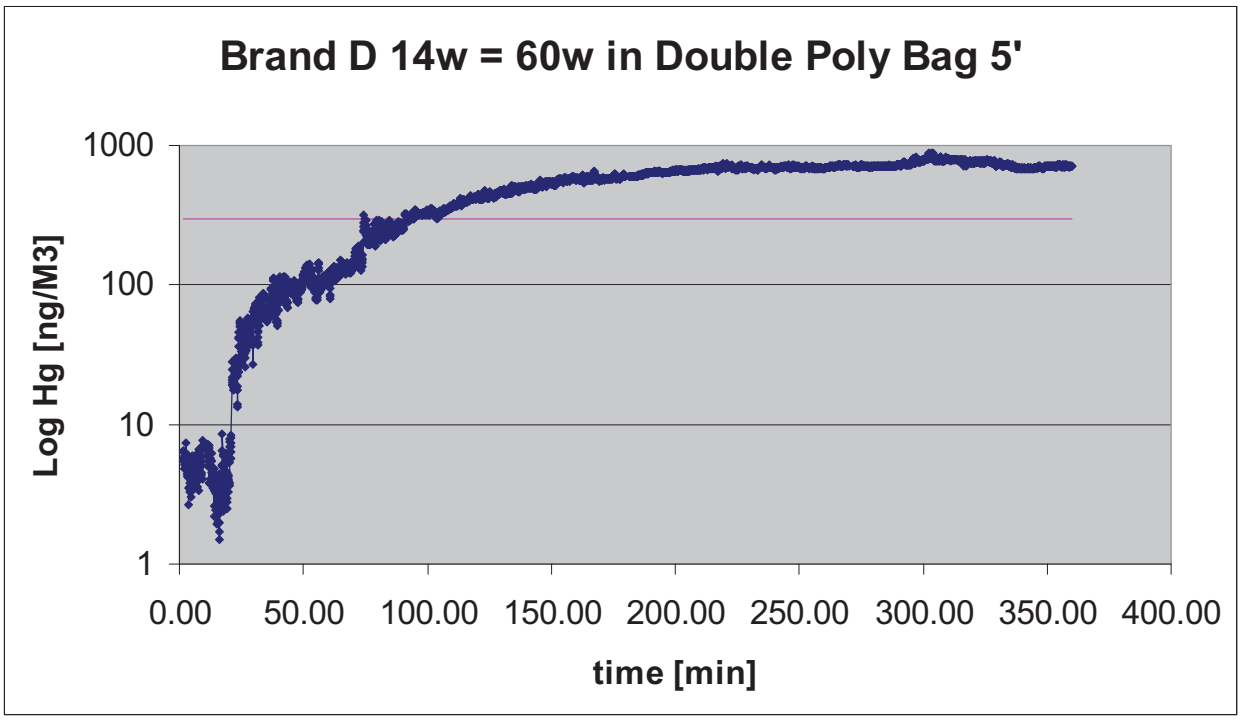


Figure A-108. Broken "Brand D" 60 watt replacement CFL in double re-sealable plastic bag at 5' (9/24/07)

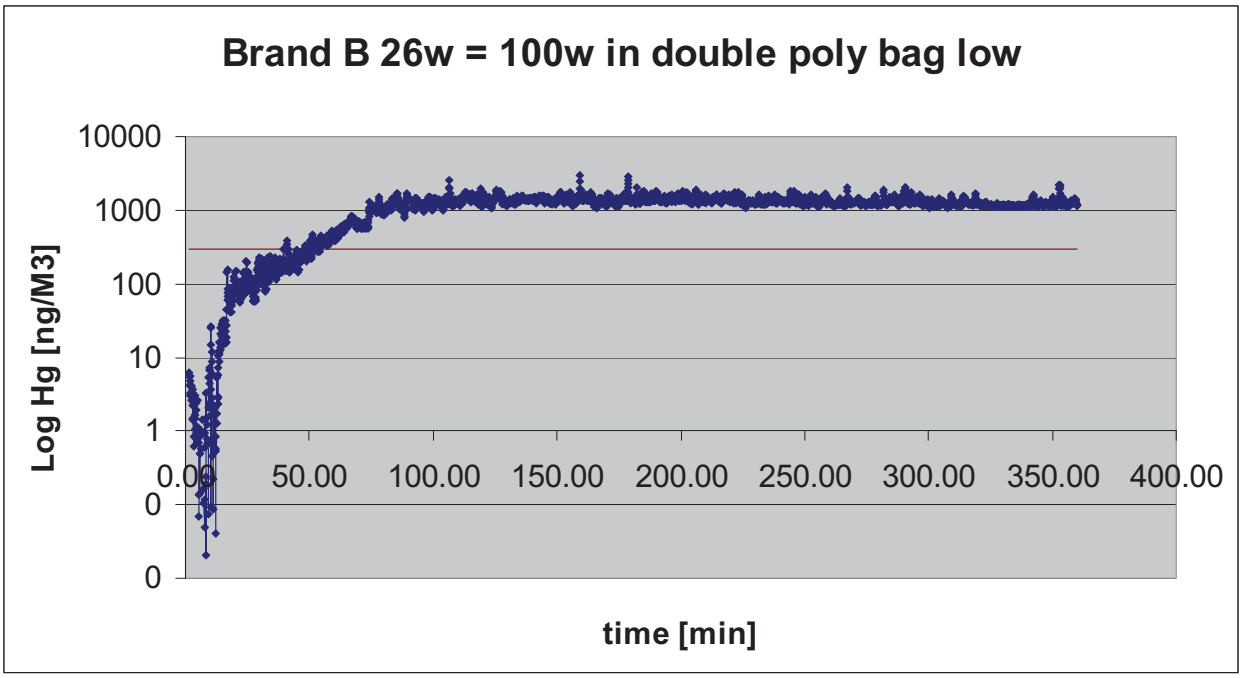


Figure A-111. Broken "Brand B" 100 watt replacement CFL in double re-sealable plastic bag at 1' (7/30/07)

Figure A-112.
Containers

Re-sealable Plastic Bags

Canning Jar

APPENDIX B.

Additional Photos

Figure B-1. Study room with window open to vent room.

Figure B-2. Breaking a CFL.

Figure B-3. Taking near-surface mercury measurements.

APPENDIX C. Temperature Log

Date	Time	Inside Temp. °C	Inside Temp. °F	Outside Temp. °F	Outside Temp °C
5/23/2007	8AM	17.4	63.3	55	12.8
	Noon	19.4	66.9	60	15.6
	2:15PM	19.6	67.3	62	16.7
5/24/2007	8AM	17.7	63.9	55	12.8
	Noon	18.8	65.8	60	15.6
	3PM	21.2	70.2	74	23.3
5/25/2007	8AM	19.9	67.8	60	15.6
	11AM	22.3	72.1	75	23.9
	1PM	23.2	73.8	80	26.7
5/29/2007	8AM	22.5	72.5	59	15.0
	10:15AM	22.5	72.5	62	16.7
	1PM	22.8	73.0	61	16.1
	2:45PM	23.0	73.4	65	18.3
	3:30PM			66	18.9
5/30/2007	9:30AM	22.2	72.0	62	16.7
	10:30AM		32.0	70	21.1
	3PM	22.6	72.7		
	4PM			61	16.1
5/31/2007	8AM	20.9	69.6	58	14.4
	9:15AM	21.5	70.7		
	1:45PM	22.5	72.5	64	17.8
	3PM			64	17.8
6/1/2007	8AM	20.2	68.4	52	11.1
	1PM	21.5	70.7	66	18.9
	4PM	22.0	71.6	68	20.0
6/4/2007	8AM	17.2	63.0	45	7.2
	Noon	17.2	63.0	48	8.9
	4:15PM			50	10.0
6/5/2007	8AM	17.6	63.7	56	13.3
	11:45AM	19.8	67.6	64	17.8
	4:30PM			64	17.8
	4:45PM	20.3	68.5		
6/6/2007	8AM	19.3	66.7	58	14.4
	1:30PM	21.3	70.3	60	15.6
	3:15PM	20.6	69.1	58	14.4
6/7/2007	8AM	19.8	67.6	52	11.1
	1:30PM	20.3	68.5	60	15.6
6/8/2007	8AM	20.7	69.3	60	15.6
6/11/2007	8AM	22.0	71.6	62	16.7
	10AM			68	20.0
	2PM	24.3	75.7	72	22.2
6/12/2007	8AM	22.3	72.1	60	15.6
	9:45AM	23.2	73.8		

Date	Time	Inside Temp. °C	Inside Temp. ºF	Outside Temp. ºF	Outside Temp ºC
	11:30AM	23.1	73.6	62	16.7
	3:15PM	23.7	74.7	70	21.1
6/13/2007	8AM	21.3	70.3	52	11.1
	3PM	20.9	69.6	55	12.8
6/14/2007	8AM	19.3	66.7	50	10.0
	Noon	21.0	69.8	60	15.6
	4PM	21.1	70.0	62	16.7
6/15/2007	8AM	20.3	68.5	58	14.4
	4:30PM	22.5	72.5	68	20.0
6/18/2007	7:30AM (sun)			76	24.4
	7:45AM (shade)			66	18.9
	8AM	24.3	75.7		
	Noon	24.9	76.8	68	20.0
6/19/2007	8AM	23.7	74.7	57	13.9
	10:15AM	24.7	76.5	68	20.0
	Noon	25.0	77.0	70	21.1
	3:15PM	25.6	78.1	71	21.7
6/21/2007	8AM	22.7	72.9	64	17.8
	10AM	23.9	75.0	64	17.8
	Noon	24.2	75.6	66	18.9
	4PM	24.9	76.8	70	21.1
6/25/2007	8AM	22.7	72.9	64	17.8
	Noon	23.6	74.5	70	21.1
	4PM	24.4	75.9	72	22.2
6/26/2007	6AM	22.8	73.0	60	15.6
	1:30PM	25.5	77.9	80	26.7
	4:30PM	28.4	83.1	80	26.7
6/27/2007	7AM	25.3	77.5	75	23.9
	8AM	27.1	80.8	77	25.0
	Noon	29.7	85.5	85	29.4
	2:45PM	30.2	86.4	87	30.6
	4PM	30.3	86.5	82	27.8
6/28/2007	7AM	27.6	81.7	70	21.1
	11AM	27.4	81.3	73	22.8
	4PM	28.2	82.8	79	26.1
6/29/2007	Noon	25.6	78.1	62	16.7
7/2/2007	8AM	23.9	75.0	58	14.4
	2:45PM	24.9	76.8	62	16.7
7/3/2007	8AM	22.3	72.1	60	15.6
	1:45PM	24.0	75.2	65	18.3
	3PM	24.0	75.2	64	17.8
7/5/07 (no run)	1:30PM	24.0	75.2		
	1:45PM			70	21.1
7/6/2007	8AM			60	15.6
	10AM	24.2	75.6	68	20.0

Date	Time	Inside Temp. °C	Inside Temp. ºF	Outside Temp. ºF	Outside Temp ºC
	2:45PM			69	20.6
	4:30PM	24.8	76.6		
7/9/2007	6:30AM	20.0	68.0	54	12.2
	10:30AM	20.6	69.1	57	13.9
	4:30PM		69.3	56	
	4:45PM	20.7			13.3
7/10/2007	8AM			53	11.7
	8:30AM	19.4	66.9		18.9
	1:15PM			66	
	2PM	21.1	70.0		
	3PM	21.3	70.3	70	21.1
7/16/2007	6AM	23.0	73.4		
	3PM	25.4	77.7		
7/17/2007	8AM	25.7	78.3	60	15.6
7/18/2007	6:30AM	23.6	74.5	55	12.8
7/19/2007	7:15AM	22.3	72.1		
	7:30AM			60	15.6
	11:15AM			61	16.1
	3:30PM			62	16.7
	4:45PM			63	17.2
7/20/2007	9:30AM	21.8	71.2	60	15.6
7/23/2007	8:15AM			61	16.1
	9AM	24.9	76.8		
	Noon			68	20.0
	3:30PM			66	18.9
	4:30PM			63	17.2
7/24/2007	8AM	22.9	73.2		
	8:15AM			59	15.0
	10AM			61	16.1
	1:15PM	24.2	75.6		
	3:15PM	24.2	75.6	71	21.7
7/25/2007	11AM	25.7	78.3	73	22.8
	3PM	26.0	78.8	77	25.0
7/26/2007	7AM (shade)	25.3	77.5	60	15.6
	7AM (sun)			80	26.7
	8AM	26.5	79.7	70	21.1
	Noon	27.3	81.1	78	25.6
	2:30PM	27.5	81.5	80	26.7
7/27/2007	8AM	28.1	82.6		
	8:30AM			74	23.3
	1:30PM	28.8	83.8	82	27.8
7/30/2007	9:45AM	27.5	81.5		
	10:15AM			69	20.6
	Noon	28.3	82.9	74	23.3
	4PM			73	22.8
7/31/2007	6:30AM	25.4	77.7		
	6:45AM			64	17.8

Date	Time	Inside Temp. °C	Inside Temp. ºF	Outside Temp. ºF	Outside Temp ºC
8/1/2007	1:30PM	28.3	82.9		
8/2/2007	4PM	29.8	85.6		
8/3/2007	2:30PM	31.3	88.3		
8/7/2007	4:30PM	25.3	77.5		
8/9/2007	10AM	24.2	75.6		
8/10/2007	7:30AM	20.9	69.6		
8/14/2007	7:45AM	22.9	73.2		
	Noon	23.8	74.8		

Appendix D: Work Plan/QAPP with Pre-Study Broken CFL Cleanup Guidance

Title: Study Plan, Mercury exposure minimization during cleanup of broken compact fluorescent lamps

Project Personnel:

Maine DEP: Heather Jackson, Stacy Ladner, Deb Stahler
Maine CDC: Erik Frohmberg, Dr. Deb Rice, Dr. Andrew Smith

Project Organization: MDEP, BRWM

This study has been developed by the Hazardous/ Universal Waste Unit within the Bureau of Remediation and Waste Management of the Department of Environmental Protection. Stacy Ladner is the project manager for the study. Stacy Ladner, Deb Stahler and Heather Jackson will be performing cleanup scenarios as listed in the Sampling/ Analysis section of this study plan. Deb Stahler, project Chemist, will provide guidance regarding mercury analyzer operation and data analysis. Eric Frohmberg, DHHS toxicologist, provided review comments for study plan and Maine CDC will provide review and evaluation of the study results. All have direct contact with each other and are responsible to know and follow this work plan. The final report will be the responsibility of Heather Jackson in collaboration with the project team.

Introduction:

Goals:

The goal of this study is to collect data to support mercury cleanup guidance when a single compact fluorescent lamp is broken. We will collect data to support guidance for the following questions:

1. Will breaking one compact fluorescent light bulb cause the air in a small-moderate sized room to have mercury concentrations above the Maine Ambient Air Guidelines (AAG) of 300 ng/m^3 in the breathing zone for both adults and crawling infants?
2. How long do you need to vent the room before concentrations remain below the AAG even when the room is no longer vented?
3. How does the type of floor surface affect cleanup efficiency, and if the surface is a rug, does it need to be removed?
4. How does vacuuming affect the air mercury concentrations?
5. Do vacuum cleaners become irreversibly contaminated with mercury if they are used to clean up broken lamps, or are there any simple steps to decontaminate them?

Appendix D: Work Plan/QAPP with Pre-Study Broken CFL Cleanup Guidance

End Use of Data:

Regulators and public health officials may use data to create guidance for the general public. Data will be available to public.

Background:

Compact fluorescent lamps (CFL) are an energy efficient source of light. However, these lamps contain mercury and may need special handling if broken. Recently the issue of what guidance to give when someone breaks a lamp in a home with children has been highlighted in several news stories. Differences in the guidance given by state agencies has been confusing and worrisome to the public.
The Bureau of Remediation and Waste Management at the Department of Environmental Protection (DEP) has been tasked with writing a guidance document that can be used by state agencies. While there are some limited data about release of mercury from fluorescent lamps, more data are needed to support this guidance. The Department currently has a cleanup guidance which may be revised based upon the results of this study.

Study Design:

The basic plan includes measuring mercury air concentrations continuously over time up to one week for six scenarios where one CFL is broken on different surfaces and cleaned up with and without venting, and with and without vacuuming. Three Lumex RA 915+ mercury analyzers, with a quantitation limit of 20 ng/M3, will be used to measure mercury concentrations as described in the attached standard operating procedures. Two analyzers will be connected to lap-top computers using RA-915+ software version 3.17.4 to continuously monitor mercury concentrations during the initial lamp break and periods of time throughout the experiment. The third analyzer will be used to measure mercury concentrations near vacuum surfaces initially, during and right after vacuum operations, and later after decontamination both when the vacuum is turned off, and after 10 minutes of operation when the vacuum is warm. Discrete mercury concentrations will also be measured 1” from vacuum surfaces before and after vacuuming broken lamp residuals, and after simple decontamination procedures. Lumex mercury analyzer data are considered screening level data. Lumex data are being employed in this study to collect high volume continuous data, and because the Lumex mercury analyzers are what DEP uses to screen mercury air concentration data in homes where mercury thermometers and fluorescent lamps are broken.

All scenarios will be carried out in a room with dimensions 11’4” x 12’1” with 10’ ceilings. A window opening to the outside of the building with dimensions, 30” x 38” will be closed during the non-vented trial, and will be opened for discrete lengths of time as determined to be effective in the vented trials. Heat is delivered to the room via ceiling duct during the heating season. Heat is not expected to be operating during the time frame of the experimental trials. There is no room air conditioning or air-out vent, the only air exchange is through doors and windows. Inside and outside temperature will be recorded at 8AM, noon and 4PM of each day. Each scenario will be repeated three times and the combined mercury concentration data will be evaluated in the study report. New CFL, with known amounts of liquid mercury dosing will be used in this study since it is generally understood that the amount of

elemental/ liquid mercury will be highest in new, rather than spent lamps. We plan to use one model from one manufacturer, and if at all possible, one lot number to eliminate variability in the amount of mercury spilled in each trial. Manufacturer information will be documented for the selected CFL.

Table A, below, describes the six different experimental scenarios.

Floor Treatment	Cleanup	Hg Measurements
Scenario 1: Wood	No lamp cleanup/ no ventilation	Measure air concentrations continuously until highest concentration is reached
Scenario 2: Wood	Ventilate room and clean up glass over ⅜" (hardware cloth), clean remainder according to current guidance*	Measure continuously
Scenario 3: Short pile rug	Ventilate room and clean up glass over ⅜" (hardware cloth), clean remainder according to current guidance	Measure continuously
Scenario 4: Long pile "shag" rug	Ventilate room and clean up glass over ⅜" (hardware cloth), clean remainder according to current guidance	Measure continuously
Scenario 5: Short pile rug	Ventilate room and clean up glass over ⅜" (hardware cloth), vacuum	Measure continuously/ take discrete measurements at vacuum locations
Scenario 6: Long pile "shag" rug	Ventilate room and clean up glass over ⅜" (hardware cloth), vacuum	Measure continuously/ take discrete measurements at vacuum locations

* Current cleanup guidance is specified in Attachment 2 of this work plan.

In addition, two different types of vacuum cleaners will be used, one will have an internal vacuum bag, and the other will be a motorized sweeper with no internal bag. Both vacuum cleaners will be emptied after the lamp cleanup, outside surfaces wiped with a wet-wipe and stored for a period of time to determine whether or not the vacuum remains a mercury "source" for a period of time up to two weeks after use.

Lumex RA 915+ mercury analyzer serial numbers:

1. Augusta Lumex: Serial Number 329
2. Bangor Lumex: Serial Number 254
3. Portland Lumex: Serial Number 215

Vacuum Cleaner Model information:

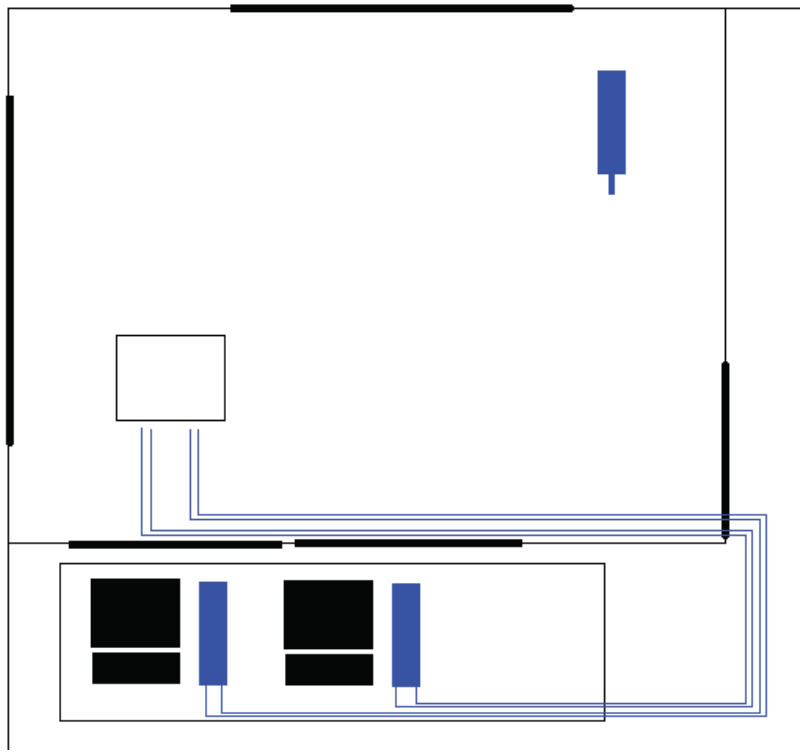
1. Kenmore Canister Model 116, Serial D81401163 using vacuum bag [20] 5033
2. Dirt Devil Power Sweep, purchased new June 4, 2007

Both vacuum cleaners were tested for mercury emission before cleanup scenarios, and results for all testing was < 20 ng/M3 emissions.

Compact Fluorescent Lamps: Philips Soft White Energy Saver 60; 800 Lumens light output, 14 watts, 8000 hours life.

Sampling/ Analysis Plan:

Room set up is given in Figure 1, below:



Room dimensions: 12'1" X 11'4" with 10' ceilings.

Lamp will be broken inside cardboard box with dimensions: 14½" x 23" x 3½" height lined with vinyl plastic and equipped with scenario floor covering. A painted hardware cloth with ¼" square grid for easy glass cleanup will be placed on top of floor surface.

Opening window on east side of building (top of drawing] with dimensions 30" x 38" opens to the outside of building and will be used for ventilation.

Door in lower right will only be opened to allow access on a limited basis, and access will be documented.

Sampling lines and instrument exhaust lines run under the door, which is not sealed. There is a ⅝" space under the door.

Air mercury concentrations will be measured at two heights, 1' from floor and 5' from floor and placed adjacent to the lamp breakage location. Fixed sampling lines are ½" ID lines with a 12' lineal run for a total volume of approximately 1 Liter. Since the Lumex pump operates at 15 L/ min, there is less than 5 seconds delay between mercury air concentrations entering the sampling tube, and concentrations measured by the analyzer. Discrete mercury concentrations will be measured outside room under door and in breathing zone outside room door.

Appendix D: Work Plan/QAPP with Pre-Study Broken CFL Cleanup Guidance

Scenario 1: Procedure for non-vented trial on hardwood with no cleanup:

1. Set up room with cardboard box and Lumex analyzers positioned as in Figure 1.
2. Windows and door should be closed. Record room temperature on the Project Daily Temperature Record each day.
3. Line cardboard box with vinyl plastic and place first hardwood flooring, then painted hardware cloth in bottom.
4. Place CFL on hardware cloth and cover with vinyl plastic coverlet.
5. Follow Lumex SOP (Attachment 1 of this QAPP) for initial start-up, and begin recording mercury air concentrations.
6. Don appropriate PPE.
7. Break CFL by striking plastic covered CFL with hammer & move cover plastic to one side of box.
8. Exit room and allow Lumex analyzers to record up to 24 hours after breakage.
9. Review Lumex analyzer data. Continue monitoring until all results stabilize under 300 ng/M3.
10. Repeat step 9 until room mercury levels stabilize.
11. Measure and record mercury vapor concentrations outside door during study to confirm that levels do not exceed ambient air guidelines (300 ng/M3).
12. Vent room, don appropriate PPE and clean up broken lamp.
13. Bag and properly dispose of all broken lamp debris and decontaminate room by venting overnight. Other decontamination procedures will be employed if room mercury concentrations do not stabilized under 50 ng/M3.

Scenario 2: Procedure for vented trial on hardwood with current guidance cleanup:

1. Set up room with cardboard box and Lumex analyzers positioned as in Figure 1.
2. Windows and door should be closed. Record room temperature on the Project Daily Temperature Record each day.
3. Line cardboard box with vinyl plastic and place first hardwood flooring, then painted hardware cloth in bottom.
4. Place CFL on hardware cloth and cover with vinyl plastic coverlet.
5. Follow Lumex SOP (Attachment 1 of this QAPP) for initial start-up, and begin recording mercury air concentrations.
6. Don protective clothing and respirator as described in PPE.
7. Break CFL by striking plastic covered CFL with hammer & move cover plastic to one side of box.
8. Vent room.
9. Clean up lamp using current DEP cleanup guidance as described in Attachment 2.
10. Record mercury concentrations until measurements stabilize under 20 ng/M3.
11. Close outside window and let mercury concentrations equilibrate to check for rebound.
12. Measure and record mercury vapor concentrations outside door during study to confirm that levels do not exceed ambient air guidelines.
13. Bag and properly dispose of any remaining mercury contaminated materials and decontaminate room by venting overnight. Other decontamination procedures will be employed if room mercury concentrations do not stabilized under 50 ng/M3.

Scenario 3: Procedure for vented trial with short pile rug/ current guidance cleanup:

1. Set up room with cardboard box and Lumex analyzers positioned as in Figure 1.

2. Windows and door should be closed. Record room temperature on the Project Daily Temperature Record each day.
3. Line cardboard box with vinyl plastic, place short pile rug on top of plastic, and place painted hardware cloth on top of rug.
4. Place CFL on hardware cloth and cover with vinyl plastic coverlet.
5. Follow Lumex SOP (Attachment 1 of this QAPP) for initial start-up, and begin recording mercury air concentrations.
6. Don protective clothing and respirator as described in PPE.
7. Break CFL by striking plastic covered CFL with hammer & move cover plastic to one side of box.
8. Vent room.
9. Clean up lamp using current DEP cleanup guidance as described in Attachment 2.
10. Record mercury concentrations until measurements stabilize under 20 ng/M3.
11. Close outside window and let mercury concentrations equilibrate to check for rebound.
12. Measure and record mercury vapor concentrations outside door during study to confirm that levels do not exceed ambient air guidelines.
13. Bag and properly dispose of any remaining mercury contaminated materials and decontaminate room by venting overnight. Other decontamination procedures will be employed if room mercury concentrations do not stabilized under 50 ng/M3.

Scenario 4: Procedure for vented trial with long pile rug/ current guidance cleanup:

1. Set up room with cardboard box and Lumex analyzers positioned as in Figure 1.
2. Windows and door should be closed. Record room temperature on the Project Daily Temperature Record each day.
3. Line cardboard box with vinyl plastic, place long pile rug on top of plastic, and place painted hardware cloth on top of rug.
4. Place CFL on hardware cloth and cover with vinyl plastic coverlet.
5. Follow Lumex SOP for initial start-up, and begin recording mercury air concentrations.
6. Don protective clothing and respirator as described in PPE.
7. Break CFL by striking plastic covered CFL with hammer & move cover plastic to one side of box.
8. Vent room.
9. Clean up lamp using current DEP cleanup guidance as described in Attachment 2.
10. Record mercury concentrations until measurements stabilize under 20 ng/M3.
11. Close outside window and let mercury concentrations equilibrate to check for rebound.
12. Measure and record mercury vapor concentrations outside door during study to confirm that levels do not exceed ambient air guidelines.
13. Bag and properly dispose of any remaining mercury contaminated materials and decontaminate room by venting overnight. Other decontamination procedures will be employed if room mercury concentrations do not stabilized under 50 ng/M3.

Scenario 5: Procedure for vented trial with short pile rug/ vacuum cleanup:

1. Set up room with cardboard box and Lumex analyzers positioned as in Figure 1.
2. Windows and door should be closed. Record room temperature on the Project Daily Temperature Record each day.
3. Line cardboard box with vinyl plastic, place short pile rug on top of plastic, and place painted hardware cloth on top of rug.

4. Place CFL on hardware cloth and cover with vinyl plastic coverlet.
5. Follow Lumex SOP (Attachment 1 of this QAPP) for initial start-up, and begin recording mercury air concentrations.
6. Don protective clothing and respirator as described in PPE.
7. Break CFL by striking plastic covered CFL with hammer & move cover plastic to one side of box.
8. Clean up lamp:
   - Open outside window,
   - Pick up cover plastic and place inside plastic trash bag.
   - Carefully pick up hardware cloth, dump contents into trash bag and
   - vacuum small pieces of glass and powder residue with canister vacuum.
   - Carefully remove vacuum bag and place it in the lamp trash bag.
   - Wipe outside contact surfaces of vacuum with wet wipe and place used wipes in trash bag.
   - Close lamp trash bag.
   - Scan the vacuum with Lumex analyzer to determine areas of highest measurement (keep Lumex sampling tube 1" from vacuum surfaces).
   - Record 10 second average measurements at all areas of the vacuum where levels exceed 300 ng/M3.
   - Exit room and place lamp trash bag in hazardous waste container.
9. After one hour, record 10 second average measurements at all areas of the vacuum where levels exceed 300 ng/M3.
10. Turn on vacuum, allow to run continuously for 10 minutes and repeat step 9.
11. After three hours repeat step 9 & 10.
12. Repeat steps 9 & 10 periodically until all readings on the vacuum are below 300 ng/M3.
13. Record room air mercury concentrations until room air measurements stabilize under 20 ng/M3.
14. Close outside window and let mercury concentrations equilibrate to check for rebound.
15. Measure and record mercury vapor concentrations outside door during study to confirm that levels do not exceed ambient air guidelines.
16. Bag and properly dispose of carpet and decontaminate room by venting overnight. Other decontamination procedures will be employed if room mercury concentrations do not stabilized under 50 ng/M3.

Scenario 6: Procedure for vented trial with long pile rug/ vacuum cleanup:

1. Set up room with cardboard box and Lumex analyzers positioned as in Figure 1.
2. Windows and door should be closed. Record room temperature on the Project Daily Temperature Record each day.
3. Line cardboard box with vinyl plastic, place long pile rug on top of plastic, and place painted hardware cloth on top of rug.
4. Place CFL on hardware cloth and cover with vinyl plastic coverlet.
5. Follow Lumex SOP (Attachment 1 of this QAPP) for initial start-up, and begin recording mercury air concentrations.
6. Don protective clothing and respirator as described in PPE.
7. Break CFL by striking plastic covered CFL with hammer & move cover plastic to one side of box.
8. Clean up lamp:

- Open outside window,
- pick up cover plastic and place inside plastic trash bag.
- Carefully pick up hardware cloth, dump contents into trash bag and
- vacuum small pieces of glass and powder residue with motorized sweeper.
- Wipe contact surfaces of vacuum with wet wipe and place used wipes in trash bag.
- Close lamp trash bag.
- Scan the vacuum with Lumex analyzer to determine areas of highest measurement (keep Lumex sampling tube 1" from vacuum surfaces).
- Record 10 second average measurements at all areas of the vacuum where levels exceed 300 ng/M3.
- Exit room and place lamp trash bag into hazardous waste container.

8. After one hour, record 10 second average measurements at all areas of the vacuum where levels exceed 300 ng/M3.
9. Turn on vacuum, allow to run continuously for 10 minutes and repeat step 9.
10. After three hours repeat step 9 & 10.
11. Repeat steps 9 & 10 periodically until all readings on the vacuum are below 300 ng/M3.
12. Record room air mercury concentrations until room air measurements stabilize under 20 ng/M3.
13. Close outside window and let mercury concentrations equilibrate to check for rebound.
14. Measure and record mercury vapor concentrations outside door during study to confirm that levels do not exceed ambient air guidelines.
15. Bag and properly dispose of carpet and decontaminate room by venting overnight. Other decontamination procedures will be employed if room mercury concentrations do not stabilized under 50 ng/M3.

Safety:

Hazard Analysis:

Mercury exposure: Mercury air concentrations within the test room are expected to exceed the Maine ambient air guideline for periods of time, and will be monitored. Only personnel with 40 hour safety training who are in the DEP respirator program will be allowed inside the test room during the test period. In addition to air concentrations, mercury and other heavy metals may be present on plastic, wood or rug surfaces. PVC plastic will be worn during experimental operations. PVC plastic gloves, along with any other contaminated media will be bagged and placed in a drum labeled for hazardous waste disposal. Mercury air concentrations will be monitored during all experimental trials.

Broken glass: Lamps will be broken during experimental trials, and glass fragments will be handled during cleanup. A piece of painted hardware cloth will be placed directly under the CFL prior to breakage to collect glass fragments over ⅜" in width to minimize cuts and punctures. Cut resistant gloves in conjunction with PVC plastic will be worn during cleanup operations.

PPE:

1. Gloves:
   - Ansell HyFlex coated cut-resistant
   - Disposable PVC plastic
2. Tyvek coverall
3. Full face respirator with dust and mercury cartridges attached

Quality Assurance/ Quality Control:

Sampling/ Analysis:

1. One manufacturer, make/ model CFL were purchased for this study on the same date, May 16, 2007 from the same store. All lamps are Philips Soft White, 800 lumens, 14 watts, 120 volts, 0.2 amps; stamped 815790 on each package; and inventory item 15274.
2. Calibration verification and background air/ blank contamination will be determined for each mercury analyzer for each day of use.
3. All procedures contained in this work plan, including attached standard operating procedures must be followed unless a modification is approved by the project team and documented.
4. All scenarios will be repeated three times, and precision evaluated.

Data Evaluation:

All data will be reviewed by the project chemist and state toxicologist and discussed in the study report.

Reporting:

A report of data collected during this study will include:

- manufacturer, make/ model and lot number for CFL used in this study,
- recorded temperatures,
- tables of Lumex results generated by Lumex RA 915+ software,
- discrete Lumex measurements taken from vacuum cleaner locations,
- copies of any notes generated during the study,
- documentation of any changes to standard protocols,
- documentation of Lumex calibration verification,
- any data evaluation procedures and
- discussion of results/ revised cleanup guidance.

Pre-Study Cleanup Guidance

What if I break a fluorescent bulb in my home?

The most important thing to remember is to ***never* use a vacuum**. A standard vacuum will spread mercury-containing dust throughout the area as well as potentially contaminating the vacuum. What you should do is:

- Keep people and pets away from the breakage area so that the mercury in the powder inside the bulb is not accidentally tracked into other areas.
- Ventilate the area by opening windows.
- If possible, reduce the temperature.
- Wear appropriate personal protective equipment, such as rubber gloves, safety glasses, old clothing or coveralls, and a dust mask (if you have one) to keep bulb dust and glass from being inhaled.
- Carefully remove the larger pieces and place them in a secure closed container or airtight plastic bag.
- Next, begin collecting the smaller pieces and dust. You can do this using a disposable broom and dustpan or two stiff pieces of paper to scoop up the pieces.
- Put all material into the container or airtight plastic bag. Pat the area with the sticky side of duct, packing or masking tape. Wipe the area with a damp cloth or paper towels to pick up fine particles.
- Put all waste and materials used to clean up the bulb in the secure closed container or airtight plastic bag and label it "Universal Waste - broken lamp".
- Take the container for recycling as universal waste. To determine where your town has made arrangements for recycling of this type of waste, call your town office or check out the Maine Department of Environmental Protection website at http://www.maine.gov/dep/rwm/hazardouswaste/uwmuniciplemaster.xls

The next time you replace a bulb, consider putting a drop cloth on the floor so that any accidental breakage can be easily cleaned up.

Appendix E: Revised Cleanup Guidance

What if I accidentally break a fluorescent lamp in my home?

The lamp contains a small amount of mercury, but you can clean this up yourself if you do the following:

- Do not use a vacuum cleaner to clean up the breakage. This will spread the mercury vapor and dust throughout the area and could potentially contaminate the vacuum.
- Keep people and pets away from the breakage area until the cleanup is complete.
- Ventilate the area by opening windows, and leave the area for 15 minutes before returning to begin the cleanup. Mercury vapor levels will be lower by then.
- For maximum protection and if you have them, wear rubber gloves to protect your hands from the sharp glass.
- Carefully remove the larger pieces and place them in a secure closed container, preferably a glass container with a metal screw top lid and seal like a canning jar.[40] A glass jar with a good seal works best to contain any mercury vapors inside.[41]
- Next, begin collecting the smaller pieces and dust. You can use two stiff pieces of paper such as index cards or playing cards to scoop up pieces.
- Pat the area with the sticky side of duct tape, packing tape or masking tape to pick up fine particles. Wipe the area with a wet wipe or damp paper towel to pick up even finer particles.
- Put all waste and materials into the glass container, including all material used in the cleanup that may have been contaminated with mercury. Label the container as "Universal Waste - broken lamp."
- Remove the container with the breakage and cleanup materials from your home. This is particularly important if you do not have a glass container.
- Continue ventilating the room for several hours.
- Wash your hands and face.
- Take the glass container with the waste material to a facility that accepts "universal waste" for recycling. To determine where your municipality has made arrangements for recycling of this type of waste, call your municipal office or go to MaineDEP.com, click on "Fluorescent Light Bulb Information" and look for the link to municipal collection sites.
- When a break happens on carpeting, homeowners may consider removing throw rugs or the area of carpet where the breakage occurred as a precaution, particularly if the rug is in an area frequented by infants, small children or pregnant women.
- Finally, if the carpet is not removed, open the window to the room during the next several times you vacuum the carpet to provide good ventilation.

The next time you replace a lamp, consider putting a drop cloth on the floor so that any accidental breakage can be easily cleaned up. If consumers remain concerned regarding safety, they may consider not utilizing fluorescent lamps in situations where they could easily be broken. Consumers may also consider avoiding CFL usage in bedrooms or carpeted areas frequented by infants, small children, or pregnant women. Finally, consider not storing too many used/spent lamps before recycling as that may increase your chances of breakage. Don't forget to properly recycle your used fluorescent bulbs so they don't break and put mercury into our environment.

[40] Other jars that can be made of glass and also work are pickle, peanut butter and applesauce jars. Not ideal but also a good choice for containing breakage is a heavy duty #2 plastic container with either a screw lid or push-on lid such as a joint compound bucket or certain kitty litter-type containers.

[41] If the only suitable jar available has food in it, you may need to empty it into another container before using it.

Appendix F

Maine Department of Environmental Protection

Standard Operating Procedure

PROTOCOL FOR COLLECTING AND ANALYZING MERCURY VAPOR IN AIR WITH A LUMEX RA-915+ MERCURY ANALYZER

PROTOCOL FOR COLLECTING AND ANALYZING MERCURY VAPOR IN AIR WITH A LUMEX RA-915+ MERCURY ANALYZER

Maine Department of Environmental Protection
Bureau of Remediation and Waste Management

Standard Operating Procedure: **BRWMHg01**
Revision: **1**
Effective Date: **February 1, 2003**
Revision Date: **January 15, 2003**
Written by: **Deb Stahler**
Reviewed by: **Mary Corr**

Approval:

M. C Burn 1/21/03
Malcolm Burson, MDEP Quality Assurance Manager — date

David Lennett 2/11/03
David Lennett, Bureau Director — date

1.0 APPLICABILITY

This standard operating procedure (SOP) is designed to be a guideline for operating the Lumex RA-915 for mercury vapor analysis. The Lumex RA-915 is applicable for ambient air testing of mercury vapor in the range of 20 ng/M^3 to 50,000 ng/M^3. (50,000ng/M^3 = .05 mg/M^3) For areas of higher concentration, a Jerome meter should be used. Do not directly expose the RA-915 to elemental mercury as this may permanently contaminate the instrument.

The ambient air guideline for mercury is 300 ng/M^3.

2.0 PURPOSE

The purpose of this document is to describe the Maine Department of Environmental Protection, Bureau of Remediation and Waste Management (MDEP/BRWM) procedure for collecting and analyzing air samples for mercury vapor analysis.

3.0 RESPONSIBILITIES

All Bureau Staff must follow this procedure when using the Lumex RA-915 for mercury vapor analysis. All managers and supervisors within MDEP/BRWM are responsible for ensuring that their staff is familiar with and adhere to this procedure. This instrument is not intrinsically safe and must not be used in confined spaces without proper training, monitoring, and permits required in the Department's Confined Space Policy. Any mercury reading above 300 ng/ M^3 (the ambient air guideline) will require pregnant or potentially pregnant staff to leave the area or use appropriate respiratory protection. MDEP/BRWM staff should not work for extended periods of time (over 30 minutes) where mercury reading are above 12,500 ng/M^3 (1/2 of the ACGIH TLV of 25,000 ng/M^3) without appropriate respiratory protection. Mercury reading above 25,000 ng/M^3 require MDEP/BRWM staff to leave the area or use appropriate respiratory protection. Any exposures over 25,000 ng/M^3 should be reported on a safety exposure report form.

4.0 DEFINITIONS:

4.1 MDEP: Maine Department of Environmental Protection
4.2 BRWM: Bureau of Remediation and Waste Management
4.3 Hg: Mercury
4.4 SOP: Standard Operating Procedure
4.5 ACGIH: American Conference of Industrial Hygienists
4.6 TLV: Threshold Limit Value

5.0 PROCEDURES

5.1 Starting the instrument:

- The instrument can be powered by either 120-v AC line current (with adapter cord), a battery pack in the instrument, or vehicle cigarette lighter adapter. The battery pack is intended for a maximum of 4 hours continuous use, and should be recharged using the included cord plugged into120 v AC line current. The instrument may be used with batteries if the battery indicator is flashing red. A steady red indicates the battery needs to be charged and AC power must be used

to run the instrument. A supplemental battery pack is stored in the side pocket and can be plugged into the AC adapter cord port. The supplemental battery will provide an additional 2 hours use.

- Pre-operational procedures:
  1. Before operating the RA-915, conduct a visual inspection of the analyzer's component parts. The instrument may be used while in the carrying case.
  2. Place the RA-915 in a horizontal position with the Palm monitor (controls and display screen) on top. The power switch will be the front end. (see photo 1)
  3. Set the test cell control handle (on the side of instrument) to the **OFF** position. This can be accessed inside the side pocket of the carrying case.
  4. Check to make sure Palm monitor is securely connected to the base unit.
  5. The handle for optical bridge switch at the back and opposite the power switch should be pre-set to position III.
- Turn on the power switch on front of the instrument. The Palm monitor will then show the Lumex version screen (see photo 2).
- Press the "Ent" button on the Palm monitor. The MAIN MENU display will appear. There will be an * next to the words MAIN MENU.
- Press (3-5 sec) and release the Lamp Ignition button on front of the machine. When the lamp lights the * next to the words MAIN MENU will disappear. Repeat this step as necessary to light the lamp.
- Allow the instrument to warm up for 5 minutes prior to testing.

5.2 Menu Screens:

The MAIN MENU will have the following options:

- Parameter ⇒ Used to change parameter settings (see below).
- On Stream ⇒ Used to analyze background and environmental samples.
- On Time ⇒ Not used for air analysis.
- Test ⇒ Used to verify instrument calibration.
- Settings ⇒ Used to save new parameter settings or restore factory settings. This should not normally be used.

To select an option, highlight the option and push the ***Ent*** button.
To return to the main menu, push the ***Esc*** button.

Parameter settings for air analysis should generally follow preset values. The following settings have been stored:

Parameter	Value	Units
Average time	1	sec
Baseline Cor time	20	sec
Frame time	10	sec
Integr. time	120	sec
Low limit	20	ng/M^3
High limit	300	ng/M^3

5.3 Background air analysis:

- Prior to taking the instrument to a potentially contaminated site, a background air sample should be analyzed to demonstrate that the instrument reading is below the reporting limit for this instrument, 20 ng/M^3.
- A background sample must be taken at the beginning and end of each analysis day. All results must be below 20 ng/M^3. Do not proceed until this condition has been met.

- For this analysis the Lumex RA-915 should be operated in the ON STREAM mode as described below:

Operation in ON STREAM (AIR ANALYSIS) mode

1. The optical bridge handle should already be in the III position as described in the starting instructions above (section 4.1).
2. Use the arrow buttons, on the Palm monitor indication unit to select the ON STREAM mode and press the Ent button. This will switch the compressor on, and the zero signal will be measured. The following will occur on the display (see photo 3):
   - The current S value which corresponds to the mercury concentration in the pumped air in ng/M^3 is displayed in the upper right of the palm monitor
   - The Si level is also displ ayed below the S value. This result (Si) corresponds to the value S averaged over a given time range.
   - The bottom right displays a countdown (in seconds) of the time over which S values were averaged. The current setting is for values to be averaged over 10 seconds.
   - An **Alarm!!** Message is displayed across the top of the screen if the mercury concentration exceeds the ambient air guideline. Any mercury reading above the ambient air guideline (300 ng/ M^3) will require pregnant or potentially pregnant staff to leave the area or use appropriate respiratory protection.
3. If the ***Ent*** button is pressed a second time, the following changes occur on the display
   - Three Si readings and S_c (the average of these three Si readings) are displayed. In this mode three 10 second average readings are repeated, averaged, and displayed with the corresponding relative deviation (R) in the measurements.
   - The average, S_c = (S1+S2+S3)/3.
   - The relative deviation of three measured concentrations is displayed as R R = 100*(max(S1,S2,S3) - min(S1,S2,S3))/S_{ave}, %.
   - If S_c is less than the parameter "Low limit" (20 ng/M^3), "< 20" is displayed.
4. Record the three Si readings, S_c and R for the background sample in a field notebook and any analysis record developed for the current sampling event.
5. If the background reading does not fall below 20 ng/M^3, remove the intake hose and repeat the procedure to determine whether the intake hose is contaminated.
6. To quit the On Stream mode, press the ***ESC*** button, which causes the air pump to switch off. The device switches over to the standby mode waiting for the next command. The message MAIN MENU appears on the Palm display.

5.4 Calibration verification:

- The instrument calibration must be verified on each analysis day prior to analyzing samples, and again at the end of the day.
- The calibration is considered verified if the relative deviation (designated with R on the instrument) is below 20%.
- Calibration verification is measured in the TEST mode as described below:

Operation in the TEST mode (serviceability check)

1. Use arrow buttons, on the indication unit to select the (TEST) mode and press the ***Ent*** button. After the instrument measures the zero signal the display will show the message *Enter Test Cell*.
2. Set the test cell handle on the side of the instrument to the ON position, and wait for 20 seconds before pressing the ***Ent*** button. The following will be displayed:

- The current S value which represents the measured mercury concentration in the test cell in ng/M^3;
- the Sk value, which represents the mercury concentration which should be measured based on the test cell temperature; (see table on page 21 of the RA-915+ Operation Manual for reference)
- the average measured mercury concentration (Si);
- the relative deviation (R) of the measured value average (Si) from the theoretical value is automatically calculated by: R= 100*|(Si- Sk)/Sk|; and
- a countdown (in seconds) of the time over which Si values were averaged. The current setting is for values to be averaged over 10 seconds.
- The message "*Temperature*" is displayed across the top, if the temperature of the test cell is beyond the admissible temperature range for proper operation of the analyzer.

3. Record the Si, Sk, and R values associated with the calibration check in a field notebook and any analysis record developed for the current sampling event.
4. If the relative deviation (R) of the measured values Si from its table value is below 20%, the RA-915+ analyzer is ready for operating, otherwise see "Maintenance" in the Operation Manual.
5. To quit the TEST mode, press the ESC button whereupon the analyzer switches over to the standby mode for the removal of the test cell. The display will show the message Remove Test Cell. Remove test cells and press the ESC button again and the analyzer switches over to the standby mode waiting for the next command. The message appearing on the display reads MAIN MENU.

5.5 Analysis:

- Allow the Lumex RA-915 to equilibrate to site temperature.
- Sample locations should be selected according to a site plan designed for the specific site. It is important to note that environments with high levels of mercury are not suitable for the Lumex RA-915. Several precautions should be taken at possibly contaminated sites:
  1. Use a Jerome meter to delineate areas possibly contaminated above 0.05 mg/M^3.
  2. If a Jerome meter is not available, start the investigation outside the possibly contaminated areas and work toward the contaminated areas stopping when the mercury readings exceed the calibration range of the instrument (0.05 mg/M^3).
  3. Do not place the instrument on any potentially contaminated area, including floors or surfaces where mercury has been spilled.
  4. Do not place the inlet sample tube on any potentially contaminated surface.
- Air temperature should also be measured and recorded concurrently with the mercury sample results. A digital thermometer is included in the travel case with the mercury analyzer for this use.
- For this analysis the Lumex RA-915 should be operated in the ON STREAM mode as described in section 4.3, making sure to record the three Si values, Sc, and R in a field notebook and any analysis record developed for the current sampling event.
- Check a (low) background sample and calibration verification at the end of the sampling day.
- To turn the instrument off press the Esc key to go to the main menu. Then turn the power toggle switch off. If the instrument was operated on battery power, the battery

must be recharged prior to storing the instrument. Storing the instrument with an uncharged battery may cause damage to the battery.

5.6 Instrument Maintenance and Storage:

- The instrument should be stored in a low mercury (<20 ng/M^3) atmosphere at temperatures between 40°F and 100°F with relative humidity less than 80%. If it is inadvertently stored below 32°F, it should be taken to and kept at a temperature of 60°F or higher for up to 24 hours (temperature dependent) prior to use.
- When the analyzer is used with battery power, the battery must be recharged before returning the instrument to storage. Storage of a discharged battery for 3 days may permanently damage the battery.
- Maintenance procedures for the analyzer include:
  1. daily (when in use) visual inspection;
  2. periodic preventive maintenance;
- All the maintenance operations should be duly recorded in the analyzer log.
- Daily (when in use) inspection is performed in the work place and involves visual inspection of the analyzer and serviceability check. The serviceability check consists of a background air check for contamination and a calibration verification check.
- Periodic prevention maintenance is performed in the work place and involves:
  1. Quarterly:
     - checking the fastening of the body covers;
     - checking the connectors for cleanness;
     - checking the state of the cables;
  2. Checking the dust filter: A small dust filter is located inside the intake hose attachment port. This filter should be checked on a quarterly basis (sooner if used in high dust areas) and replaced if the dust filter has turned color from white to brown & appears to be clogged. To remove the filter for inspection/ replacement, use a pair of tweezers.
  3. The built-in absorption filter (located in the left-hand inlet on the front wall of the base unit) should be replaced as needed. Typically this will be once or twice per year. If the instrument is used often, or in a mercury environment above 10,000ng/M^3 for a period of time the filter should be replaced more often.
- Annual preventive maintenance is recommended. It is performed by OhioLumex and involves recalibration and checking the RA-915+ for conformity to the technical specifications.
- For further information refer to the Operation Manual and Lumex RA-915+ Mercury Analyzer Maintenance Schedule and Procedure OL-110.

5.7 Documentation

All sampling activities must be documented according to a site-specific plan, either in a field notebook or on pre-printed sampling worksheets. At a minimum the following items must be documented:

- Project name
- Date and time of sample
- Background air results
- Calibration verification results

- Sample location
- Name of person(s) performing air sampling/ analysis
- Temperature
- Mercury result
- Any special considerations or sampling conditions

5.8 Quality Assurance/Quality Control

5.8.1 QA Sample Collection: Collection and analysis of the following QA samples is mandatory:

- Background sample: A background air sample should be taken outside of the site and in a location where there is no (low) mercury contamination. Results must be below 20 ng/ M^3. This sample is taken to ensure that the instrument is free of contamination. At a minimum, background samples should be taken at the beginning an end of each sampling day. If the instrument is taken into an environment where mercury vapor concentrations exceed the calibration range of the instrument (50,000 ng/ M^3) a background sample must be re-analyzed before continuing with the sampling event.
- Calibration verification: The instrument calibration must be verified at the beginning and end of each sampling day. The calibration is considered verified if the relative deviation (designated with R on the instrument) is below 20%. The instrument must be returned to the factory for calibration yearly, and when calibration falls outside the designated range.
- Duplicate samples: Each time a sample is analyzed the instrument automatically takes three 10 second average readings (Si) and averages the three readings to arrive at a result (Sc). A relative deviation (displayed as R) is also calculated by the instrument by the following formula:

  $R = 100*(\max(S1,S2,S3) - \min(S1,S2,S3))/S_{ave}$
  $S_{ave} = (\max(S1,S2,S3) + \min(S1,S2,S3))/2$

5.8.2 Deviations from SOPs: All deviations from the procedures outlined in this or in any other SOP must be documented in field notes.

6.0 REFERENCES:

1. **Multifunctional Mercury Analyzer RA-915+ Operation Manual**, OhioLumex Co, Inc. Analytical Equipment, Cleveland, Ohio, 2001.
2. **Quality Assurance Plan** for Maine Department of Environmental Protection's Division of Site Remediation, Revision 2, April 30, 1999
3. **Standard Operating Procedure Development, Format, Approval and Distribution,** Maine Department of Environmental Protection SOP OC-PR-0001, 6/15/01.

Lap-top Computer Connection for Continuous Mercury Vapor Concentrations Monitoring

Follow manufacturer directions below to use the Lumex in continuous monitoring mode. This will generate a data file that can be evaluated in Lumex computer software and can be imported into an Excel file.

RA 915+ Mercury Analyzer Monitoring Software

1. Turn POWER on RA 915 to ON. Connect to computer.
2. Turn LAMP to ON, warm up the instrument for 20 minutes.
3. Click on RA 915 icon on the computer and click on AIR in main menu. **Click on MONITORING icon in the PROGRAM bar** (The MONITORING window will appear. Minimize screen).
4. On the bar GRAPH click on PARAMETERS.
5. Click on COMMON tab and type name (name of the site) in FILE NAME field. Should you forget to name file the default untitled.dat will be set for you by the software. You may rename it later.
6. Axis X is a timeframe for auto zero in seconds. Set it four times shorter as your total monitoring time (set in minutes), (i.e. for 10 minutes run duration set X for 150 seconds). In this case ZERO will be taken automatically, at the beginning, at the end and in between totaling six auto ZERO measurements. This setting is a must.
7. If you are planning to visually monitor measurement line on the screen set Axis Y per the concentration range you expect to find. The preliminary data will be known to you by direct measurement with the Lumex. This setting will not affect the print out graph at the end (Print out graph will be auto scaled).

8. Set INTERVAL in GRAPH to the resolution you need. This is frequency of sample data logging. Maximum interval is 5 seconds, minimum is 1 second. One second is recommended for maximum accuracy
9. Click on Tab LIQUID. In window BASELINE set T zero aver. = 30 sec.
10. Ref. Points =1, and disregard all other settings in this Tab window.
11 Click on Tab Monitor. In window Measure, set DURATION to the time in minutes for how long you would like to monitor this particular site.
12. Set DELAY to 20 seconds (must not exceed T zero aver.). This is time after auto ZERO measurements are taken needed to fill measurement cell. Analytical signal line will change color from red (baseline color) to dark red (Hg concentration color).
13. Click on SAVE (floppy disc in the middle) and APPLY (checkmark). Restore MONITORING window on the screen and type the description of your test site, etc.
In Window GRAPH click on RUN and MONITORING window becomes active with File name in the File name box, pump will start automatically

and a 30 second Zero test will be performed. You could do Zero baseline test any time manually during the run by clicking on BLANK in MONITORING window (however, the instrument will do this automatically as set in 6.).
You may terminate the run manually by clicking on TERMINATION button.
When run is completed or terminated, instrument will perform the last ZERO check and will report the AVEREGED concentration throughout the run. ZERO points measured during the run will not affect averaging the concentration result. After that the instrument will shut off the pump and will remain on stand by with LAMP ON.

If your printer is connected (recommended) you may print this as an original file by clicking on PRINT at FILE bar.
To acquire new data click on NEW in GRAPH bar and change FILE NAME in PARAMETER, SAVE and APPLY.
You may save this file to floppy disc or open the file in Excel by starting the Excel program and look for the file in Program Files, Lumex, RA915, All files, open.

Appendix G. Compact Fluorescent Lamps Used in Study

Pictures missing for older GE 26w, 90w replacement lamp used in Scenario A and Commercial Electric 14w, 65w replacement lamp used in container study.

Brand A = Philips
Brand B = General Electric
Brand C = Sylvania
Brand D = N:Vision
Brand E = Lightwiz
Brand F = Greenlite
Brand G = Commercial Electric

Appendix H

Vacuum Results

Vacuum Scenario Results

Table H-1: Initial Vacuum Results where vacuum was used to clean up broken lamp.

Scenario	Lamp type	Maximum concentration of mercury (ng/m3)	Time above 300 ng/m3 in minutes	Average mercury concentration for 1 hour (ng/m3)	Average mercury concentration for 8 hours (ng/m3)	Average mercury concentration for 24 hours (ng/m3)	Average mercury concentration for 24+ hours (ng/m3)
S5 Three trials at two heights • Short pile rug. Ventilate room. Clean up glass over 3/8" by hand, vacuum with Kenmore canister vacuum with beater, and remove waste pieces and vacuum bag from room. • Measure continuously/ take discrete measurements at vacuum locations.	"Brand A" 14watt, 60 watt equivalent	**At 5 feet**: 628 328 315 **At 1 foot:** 18,578 8,815 3,953	**At 5 feet**: 5.25 1.66 5.5 **At 1 foot:** 7.83 2.08 5.83	**At 5 feet**: 97 123 61 **At 1 foot:** 202 128 77			
S6 Three trials at two heights • Long pile "shag" rug. Vacuumed with Dirt Devil Power Sweeper. Otherwise same as S5.	"Brand A" 14watt, 60 watt equivalent	**At 5 feet**: 350 414 236 **At 1 foot:** 1,811 16,942 1,811	**At 5 feet**: 2.16 1.67 0 **At 1 foot:** 3.33 3.08 2.16	**At 5 feet**: 99 72 48 **At 1 foot:** 86 133 41			

Scenario	Lamp type	Maximum concentration of mercury (ng/m3)	Time above 300 ng/m3 in minutes	Average mercury concentration for 1 hour (ng/m3)	Average mercury concentration for 8 hours (ng/m3)	Average mercury concentration for 24 hours (ng/m3)	Average mercury concentration for 24+ hours (ng/m3)
SK One trial at two heights • Break on long pile "shag" rug. After traditional cleanup was vacuumed using a Hoover Quick-Broom bag less vacuum. Otherwise same as S2.	"Brand B" 26w, 90watt equivalent	**At 5 feet**: 2,034 **At 1 foot:** 2,392	**At 5 feet**: 24.0 **At 1 foot:** 32.67 Spike at 193.84	**At 5 feet**: 241 **At 1 foot:** 368			
SL One trial at two heights • Break on short pile rug. • No ventilation, clean up only big pieces and put in trash in room, vacuum rest of debris with Hoover 850 vacuum with beater. • Measure continuously.	"Brand B" 26w, 100 watt equivalent	**At 5 feet**: 23,720 **At 1 foot:** 133,955	**At 5 feet**: >1,500 **At 1 foot:** >1,500	**At 5 feet**: 16,814 **At 1 foot:** 21,262	**At 5 feet**: 12,364 **At 1 foot:** 14,384	**At 5 feet**: 4,490 **At 1 foot:** 5,130	**At 5 feet**: 4,302 (25 hour average) **At 1 foot:** 4,913 (25 hour average)

Table H-2 Vacuum Results where carpet was vacuumed where a lamp had previously been broken and cleaned up but where the vacuum in these trials was not used to clean up the initial breakage. These trials were vacuuming the residual source left in the carpets.

Scenario	Lamp type	Maximum concentration of mercury (ng/m3)	Time above 300 ng/m3 in minutes	Average mercury concentration for 1 hour (ng/m3)	Average mercury concentration for 8 hours (ng/m3)	Average mercury concentration for 24 hours (ng/m3)	Average mercury concentration for 24+ hours (ng/m3)
S5T3 Revacuum: One trial at two heights • No new bulbs were broken as part of this scenario. This was a revacuum of S5T3 short nap carpet. It was vacuumed by a Kenmore beater vacuum as part of S5T3. • During this scenario, a non beater Hoover 400 wand vacuum was used and the room was not ventilated[42]. • Measure continuously.	"Brand A" 14watt, 60 watt equivalent Broken and cleaned up 28 days earlier.	**At 5 feet**: 72 **At 1 foot:** 130	**At 5 feet**: 0 **At 1 foot:** 0	**At 5 feet**: 57 **At 1 foot:** 40	**At 5 feet:** <20 **At 1 foot:** 13		

[42] For the purposes of this table, references to "no ventilation" mean that no deliberate ventilation occurred such as with an open window in the study room or open door to the study room. It does not refer to unintentional ventilation from the closure of the overhead door in the area adjacent to the study room.

Scenario	Lamp type	Maximum concentration of mercury (ng/m3)	Time above 300 ng/m3 in minutes	Average mercury concentration for 1 hour (ng/m3)	Average mercury concentration for 8 hours (ng/m3)	Average mercury concentration for 24 hours (ng/m3)	Average mercury concentration for 24+ hours (ng/m3)
SBvac1 One trial at two heights • No new bulbs were broken as a part of this scenario. This was a vacuum of SB short nap carpet. This carpet had not been previously vacuumed but a lamp had been broken and cleaned up with traditional cleanup techniques 21 days earlier. It was vacuumed with a Hoover 850 beater vacuum. • This is the first vacuum of the carpet. No ventilation of room. • Measure continuously.	"Brand C" 13w, 60watt equivalent Broken and cleaned up 21 days earlier.	**At 5 feet**: 4,529 **At 1 foot:** 14,779	**At 5 feet**: >81 **At 1 foot:** >350spikes	**At 5 feet**: 3,406 **At 1 foot:** 2,554	**At 5 feet**: No data **At 1 foot:** 677(6 hour average)		
SBvac2 One trial at two heights • This is the second vacuum of the carpet. The bulb was cleaned up 24 days earlier. • Otherwise same as SBvac1.	"Brand C" 13w, 60watt equivalent Broken and cleaned up 24 days earlier.	**At 5 feet**: 3,090 **At 1 foot:** 3,077	**At 5 feet**: 88.08 **At 1 foot:** >350spikes	**At 5 feet**: 1,207 **At 1 foot:** 714	**At 5 feet**: 266 (6 hour average) **At 1 foot:** 223 (6 hour average)		

Scenario	Lamp type	Maximum concentration of mercury (ng/m3)	Time above 300 ng/m3 in minutes	Average mercury concentration for 1 hour (ng/m3)	Average mercury concentration for 8 hours (ng/m3)	Average mercury concentration for 24 hours (ng/m3)	Average mercury concentration for 24+ hours (ng/m3)
SBvac3 One trial at two heights • This is the third vacuum of the carpet. The bulb was cleaned up 27 days earlier • Otherwise same as SBvac1.	"Brand C" 13w, 60watt equivalent Broken and cleaned up 27 days earlier.	**At 5 feet**: 680 **At 1 foot:** 2,001	**At 5 feet**: 167.08 **At 1 foot:** 146.33	**At 5 feet**: 584 **At 1 foot:** 422	**At 5 feet**: 253 **At 1 foot:** 180		
SBvac4 One trial at two heights • This is the fourth vacuum of the carpet. The bulb was cleaned up 28 days earlier. • Otherwise same as SBvac1.	"Brand C" 13w, 60watt equivalent Broken and cleaned up 28 days earlier.	**At 5 feet**: 228 **At 1 foot:** 427	**At 5 feet**: 0 **At 1 foot:** 0[43]	**At 5 feet**: 172 **At 1 foot:** 113	**At 5 feet**: 79 (6 hour average) **At 1 foot:** 52 (6 hour average)		

[43] Spikes at 0.25, 77.92, & 299.17

Scenario	Lamp type	Maximum concentration of mercury (ng/m3)	Time above 300 ng/m3 in minutes	Average mercury concentration for 1 hour (ng/m3)	Average mercury concentration for 8 hours (ng/m3)	Average mercury concentration for 24 hours (ng/m3)	Average mercury concentration for 24+ hours (ng/m3)
SLvac2 One trial at two heights • No new bulbs were broken as a part of this scenario. This was a revacuum of SL short nap carpet. This carpet had been previously vacuumed as a means of cleaning up a lamp breakage 4 days earlier. It was vacuumed with a Hoover 850 beater vacuum. • This is the second vacuum of the carpet. • Otherwise same as SL.	"Brand B" 26w, 100 watt equivalent Broken and cleaned up 4 days earlier.	**At 5 feet**: 3,135 **At 1 foot:** 36,397	**At 5 feet**: 530.75 **At 1 foot:** >1,200 spikes[44]	**At 5 feet**: 2,623 **At 1 foot:** 2,444	**At 5 feet**: 1,429 **At 1 foot:** 1,471	**At 5 feet**: 691 (20 hour average) **At 1 foot:** 729 (20 hour average)	
SLvac3 One trial at two heights • This carpet had been previously vacuumed as a means of cleaning up a lamp breakage 5 days earlier. • This is the third vacuum of the carpet. • Otherwise same as SL.	"Brand B" 26w, 100 watt equivalent Broken and cleaned up 5 days earlier	**At 5 feet**: 3,708 **At 1 foot:** 19,270	**At 5 feet**: 539.33 **At 1 foot:** >1,200 spikes[45]	**At 5 feet**: 2,671 **At 1 foot:** 2,768	**At 5 feet**: 2,590 **At 1 foot:** 2,587	**At 5 feet**: 1,038 (20.5 hour average) **At 1 foot:** 1,236 (20 hour average)	

[44] Still spiking over 1,000 ng/m3.
[45] Still spiking above 1,000 ng/m3.

Scenario	Lamp type	Maximum concentration of mercury (ng/m3)	Time above 300 ng/m3 in minutes	Average mercury concentration for 1 hour (ng/m3)	Average mercury concentration for 8 hours (ng/m3)	Average mercury concentration for 24 hours (ng/m3)	Average mercury concentration for 24+ hours (ng/m3)
SLvac4 One trial at two heights • This carpet had been previously vacuumed as a means of cleaning up a lamp breakage 6 days earlier. • This is the fourth vacuum of the carpet. • Otherwise same as SL.	"Brand B" 26w, 100 watt equivalent Broken and cleaned up 6 days earlier.	**At 5 feet**: 3,288 **At 1 foot:** 12,367	**At 5 feet**: 523.75 **At 1 foot:** >1,200 spikes[46]	**At 5 feet**: 1,986 **At 1 foot:** 1,871	**At 5 feet**: 1,502 **At 1 foot:** 2,244	**At 5 feet**: 574 (20 hour average) **At 1 foot:** 1,085 (20 hour average)	

Table H-3 Results in room from off-gassing of carpet after vacuuming.

Scenario carpet	Lamp type	Maximum concentration of mercury (ng/m3)	Time above 300 ng/m3 in minutes	Average mercury concentration for 1 hour (ng/m3)	Average mercury concentration for 8 hours (ng/m3)	Average mercury concentration for 24 hours (ng/m3)	Average mercury concentration for 24+ hours (ng/m3)
SLcarpet One trial at two heights • Carpet alone in room after SLvac4. Room ventilated prior to placing carpet square in room. • Measure Continuously.	"Brand B" 26w, 100 watt equivalent Broken and cleaned up 7 days earlier.	**At 5 feet**: 1,186 **At 1 foot:** 5,679	**At 5 feet**: 652.42 **At 1 foot:** >1,600 spikes[47]	**At 5 feet**: 135 **At 1 foot:** 699	**At 5 feet**: 491 **At 1 foot:** 1,056	**At 5 feet**: 255 **At 1 foot:** 561	**At 5 feet**: 239 (26 hour average) **At 1 foot:** 548 (26 hour average)

[46] Still spiking over 400 ng/m^3.
[47] Still Spiking over 800 ng/m^3.

Table H-4. Lumex readings of carpet in ng/m^3 within an inch of surface

Scenario	S5T3vac		S4T2		S4T3		SB-"Brand C" 60A		SK-"BrandB"90vac		SL-"BrandB"100vacnv	
Date of Breakage	6/4/2007		6/7/2007		6/8/2007		6/12/2007		6/26/2007		7/19/2007	
Floor Type	short carpet		long carpet (shag)		long carpet (shag)		short carpet		long carpet (shag)		short carpet	
Days after break	calm	agitated	calm	agitated	calm	agitated	calm	agitated	calm	agitated	calm	agitated
1			<20	108			532	1,418	551	3,623		
2							<20	1,820	<20	2,197		
3					<20	112	190	6,197	79	757		
4			<20	413	<20	55					vac	23-Jul
5			<20	129	<20	190					862	>50,000
6			22	273	<20	54	233	5,102	<20	462	690	37,000
7			<20	303			195	2,129	34	1,574	990	13,200
8	<20	345	<20	398							10,505	29,000
9	<20	380					<20	1,220	26	511		
10	<20	732					289	2,900	27	417		
11	<20	775									392	7,795
12			<20	511							912	21,070
13							215	947	<20	406	310	16,708
14	<20	4,240	25	512			351	6,531	26	243	2,116	12,170
15	21	1,714	28	1,083			1,004	9,197	23	278	2,691	7,382
16							207	4,697				
17	<20	1,940					544	1,983				
18	30	2,719	<20	1,096								
19			22	506							2,033	14,536
20			<20	1,025			233	570				
21	22	739	<20	618			195	5,694			433	4,183
22	<20	914	<20	1,640							551	7,456
Scenario	S5T3vac		S4T2		S4T3		SB-"Brand C" 60A		SK-"BrandB"90vac		SL-"BrandB"100vacnv	

Days after break	calm	agitated	calm	agitated	calm	agitated	calm	agitated	calm	agitated	calm	agitated
23	62	1,888					1,803	13,010				
24	<20	1,387					1,686	12,750				
25	<20	332	<20	401								
26			<20	307								
27							253	2,317				
28	<20	2,165	61	1241			2,077	3,717				
29	<20	748	<20	392			959	2,297				
31	43	1,826										
32	89	1,061	<20	742								
33			26	543								
34			26	199								
35	<20	2,032										
36	30	967										
37	<20	790										
44							141	2,275				
45							265	4,593				
48							160	2,652				
49							102	3,301				
50							75	6,019				
51							226	1,876				
52	24	173					1,202	1,696				
56							318	540				
58							524	13,030				
59							49	456				
	Vacuumed 6/4/07 with Kenmore beater style canister											
	Vacuumed 7/2/07 with Hoover 400 non-beater canister											
	Vacuumed 7/3/007, 7/6/07, 7/9/07 and 7/10/07 with Hoover 850 beater style canister											
	Vacuumed 6/26/07 with Dirt Devil motorized sweeper											
	Vacuumed 7/19/07, 7/23/07, 7/24/07 and 7/25/07 with Hoover 850 beater style canister											

Table H-5 Hoover Spectrum 850 (canister style), First Vacuum Scenario

	New vac bag before 3rd vacuuming								
	Vacuum ran for approx 10 min. to get warm vac ("hot") numbers								
	Measurements are ng/m^3, within approx. an inch of vac part								
			Vacuum Cleaner Part						
			Beaters			Plastic flexible hose	Inside vac	Metal wand	Bag
Date of Lamp Breakage	**Date of Vacuuming**	**Date of Measurement**	hot	cold	cold agitated	cold	cold	cold	Cold
		6/28/2007	160	<20					
		7/2/2007		95	711				
		7/3/07 before cleaning		24	347	<20	<20		
		7/3/07 after cleaning		<20	22				
6/12/2007	7/3/2007	7/3/2007 Right after vacuuming	>50000						
		7/3/07 after cleaning again		188	534	4,657		259	
		7/5/2007		75	990	17,540		142	
		7/6/2007 after cleaning again		<20	97	801		110	
	7/6/2007	7/6/07 after this vacuuming and before cleaning		137	537	14,670		943	972
		7/6/07 after cleaning		<20	296				
		7/6/07 PM		36	559	1,280	26	66	
		7/9/2007 after cleaning		64	125	550		<20	
	7/9/2007	7/9/07 after this vacuuming and before cleaning		75	81	666		1,553	417
		7/9/07 after cleaning again		81					
		7/10/2007		<20	22	528		26	<20
	7/10/2007	7/10/07 after 4th vacuum		87	74	1,319		193	188
		7/11/2007		20	43	214	29	25	

Wet wipes used frequently on vacuum
Vacuum Model #S3585, Serial # 089000014844, approx. 20 yrs. old

Table H-6 Hoover Spectrum 850 (canister style), Second Vacuum Scenario

	This vacuum was used earlier in study							
	Measurements are ng/m^3, within approx. an inch of vac part							
			Vacuum Cleaner Part					
			Beaters		**Plastic hose**	**Inside vac**	**Metal wand**	**Bag**
Date of Lamp Breakage	**Date of Vacuuming**	**Date of Measurement**	cold	cold agitated	cold	cold	cold	cold
7/19/2007	7/19/2007							
	7/23/2007							
		7/24/2007 (ambient air = approx. 600)	1,043	1,755	>50,000			4,288
	7/24/2007							
		7/25/2007 before vac	763	1421				
	7/25/2007							
		7/26/2007	419		38,600		2,524	1,750
		7/26/07 after wiping down with wet wipes	4,941	13,400	5,968	280	84	
		7/27/2007	87	567	3807			
		7/30/2007	576	2,403	1,059			
		7/31/07(just removed from a container)	1,153	2,397	13,410			
		7/31/07 (after being out of container for 5 min.)	153	1,580	5,671			
		8/1/2007	42	563	4,739			
		8/2/2007	55	4043	5,566			
		8/3/2007	254	1,793	16,009			
		8/7/2007	597	544	3,328			
		8/9/2007	3,144	3,138	886			
		8/10/2007	848	3,198	804			

Vacuum not cleaned with wet wipes between vacuuming events on this table

Table H-7: Kenmore Canister Model 116, Serial D81401163, using vacuum bag 20 5033

Date			Beaters				Plastic hose		Inside vacuum		Metal wand		Filter			
Lamp Break	Vacuuming	Measurement	hot	hot agitate	cold	cold agitate	hot	cold	hot	cold	hot	cold	hot	hot agitate	cold	cold agitate
6/1/2007AM	6/1/07AM	6/1/2007AM (about 1hr. After 1st vacuuming and after wet wipe)	46		67		114	146	63	57	137	103	37		<20	
		6/1/2007 PM just before 2nd vacuuming			39			57		20		29			<20	
6/1/2007PM	6/1/2007PM	6/1/2007PM (about 1hr. After 2nd vacuuming and after wet wipe - same wet wipe as mentioned in 2nd note at bottom of this table)			148		70	355				83	39		33	
		6/4/2007 8:41AM before 3rd break			<20			52		40		41				
6/4/2007 9AM	6/4/2007 9AM	6/4/2007 approx. 600 sec. into run for this 3rd vac and after a wet wipe of beaters	3,277				18,260		3,152		1,824		<room air			
		6/4/2007 approx. 10AM	330		357		858	608	170	240	428	109	75		<20	
		6/4/2007 approx. 1PM	163		383		578	654	43	56	256	615	32		<20	
		6/4/2007 4:20PM			179			305		22		48			<20	
		6/5/07 7:30AM	113		149		353	164	<20	20	201	184	<20		<20	
		6/5/07 5PM	92		87		476	488	50	51	878	171	60		20	
		6/6/2007	45		32		2,094	460	58	<20	608	472	42		<20	
		6/7/2007	291	444	<20	462	1,254	596	158	<20	282	120	35	91	<20	112
		6/8/2007	72	354	<20	520	247	184	84	<20	59	38	33	445	<20	251

Date			Beaters				Plastic hose		Inside vacuum		Metal wand		Filter			
Lamp Break	Vacuuming	Measurement	hot	hot agitate	cold	cold agitate	hot	cold	hot	cold	hot	cold	hot	hot agitate	cold	cold agitate
		6/11/2007	32	136	26	263	372	511	68	<20	163	111	30	1,354	<20	454
		6/12/2007	36	725	39	105	1,709	759	60	23	122	200	26	899	<20	274
		6/13/2007	22	237	27	64	507	2,009	51	30	52	55	33	82	<20	326
		6/14/2007	26	538	21	642	603	451	38	48	127	336	29	136	<20	180
		6/15/2007	27	1,050	<20	145	2,413	856	37	<20	82	53	34	168	<20	472

lamps = Brand A 14w = 60w
Vacuum measurements with 3rd Lumex when room levels of mercury are low
Vacuum ran for approx 10 min. to get "hot" numbers
Measurements are ng/m3
Wet wipes used on vacuum

Table H-8: Hoover Quick-Broom Supreme, bagless, "cyclonic action." Model # 52535, Serial # 10000216769

Date			Floor attachment				Cup				Near Motor			
Lamp Breakage	Vacuuming	Measurement	hot	hot agitated	cold	cold agitated	hot	hot agitated	cold	cold agitated	hot	hot agitated	cold	cold agitated
6/25/2007	6/25/2007	6/25/2007, about 17 min. into run					5,526							
		6/26/2007, after wet wipe used on vac parts	<20	46	27	59	21	88	35	74	<20	25	39	31

Table H-9: Hoover 400 Futura, Serial # 129300101061

Date			Beaters (floor attachment)		Plastic flexible hose	Inside vac
Lamp Breakage	**Vacuuming**	**Measurement**	cold	cold agitated	cold	cold
6/4/2007	6/4/07 (flooring vacuumed with Kenmore canister)					
	7/2/07 (same flooring as above vacuumed this time with Hoover 400)	7/2/2007	194	347	172	184
		7/2/07 (after cleaning)	253			
		7/3/2007	<20	45	<20	<20

lamp=Brand B 26w = 90w
Vacuum measurements with 3rd Lumex when room levels of mercury are low
Vacuum ran for approx 10 min. to get "hot" numbers
Measurements are ng/m3

Table H-10: Dirt Devil Power Sweep, purchased new June 4, 2007, wet wipes used on vac surfaces before each set of readings below except first row of results (results in ng/m3)

Date of Lamp Breakage	Date of Vacuuming	Date of Measurement	Beater	Handle	Cup
6/5/2007AM	6/5/2007AM	6/5/2007AM (14.6 minutes into run)	370	220	249
		6/5/2007AM (about 1 hr. after vacuuming)	22	<20	21
6/5/2007PM	6/5/2007PM	6/5/2007PM (about 45 min. after 2nd vacuuming)	39	<20	20
6/6/2007	6/6/2007	6/6/2007	close to ambient air	close to ambient air	close to ambient air

Vacuum measurements with 3rd Lumex when room levels of mercury are low
lamps=Brand A 14w = 60w

Appendix I

Lumex Calibration Verification and Background Instrument Contamination Check

Lumex Serial Number: 254 Instrument Used for study room one foot intake
Factory Calibration Date April 4, 2007

Date	Time	S_k[a]	S_i[b]	%R[c]	Background
5/23/07	9 AM	1675	1657	<1	<20
5/23/07	4 PM	2975	2712	8	<20
5/24/07	8 AM	1625	1652	<1	<20
5/24/07	3 PM	3125	2880	7	<20
5/25/07	8:19 AM	1910	1907	1	<20
5/25/07	3:35 AM	4710	4047	14	<20
5/29/07	8:30 AM	2255	2181	3	<20
5/30/07	7:30 AM	2880	2719	5	<20
5/30/07	3:13 AM	3750	3409	9	<20
5/30/07	7:40 AM	2145	2076	3	<20
6/1/07	8 AM	2975	2772	6	<20
6/1/07	4 PM	3690	3292	9	<20
6/4/07	8 AM	2040	2001	1	<20
6/4/07	4:30 PM	2485	2405	3	<20
6/5/07	7:30 AM	1625	1633	0	<20
6/6/07	7:45 AM	2485	2376	6	<20
6/7/07	7:30 AM	2215	2165	2	<20
6/8/07	7:30 AM	2445	2372	3	<20
6/8/07	3:20 PM	3340	3074	7	<20
6/11/07	7:45 AM	2145	2067	3	<20
6/12/07	AM	3125	2891	7	<20
6/13/07	AM	2975	2773	7	<20
6/13/07	PM	3125	2917	8	<20
6/14/07	AM	1880	1853	2	<20
6/15/07	AM	2570	2452	4	<20
6/15/07	PM	3510	3215	9	<20
6/18/07	AM	2445	2293	7	<20
6/19/07	AM	3075	2847	7	<20
6/19/07	PM	4710	4007	14	<20
6/21/07	AM	2290	2190	4	<20
6/21/07	PM	4200	3699	11	<20
6/22/07	AM	2445	2332	4	<20
6/25/07	AM	2330	2243	3	<20
6/26/07	AM	3340	3045	8	<20
6/28/07	AM	3285	2976	9	<20
7/2/07	AM	2405	2291	4	<20
7/3/07	AM	2835	2651	6	<20
7/3/07	PM	4070	3588	11	<20
7/5/07	AM	2655	2485	6	<20
7/6/07	AM	2745	2558	6	<20

Appendix I

Date	Time	S_k[a]	S_i[b]	%R[c]	Background
7/6/07	4:40 PM	4710	4018	13	25/ <20
7/9/07	AM	2145	2063	3	<20
7/10/07	AM	2700	2558	5	<20
7/10/07	PM	3630	3247	10	<20
7/19/07	AM	2525	2439	3	<20
7/25/07	AM	2445	2335	4	<20
7/26/07	AM	2675	2500	5	<20
7/30/07	AM	2950	2733	6	<20
7/31/07	AM	3025	2790	7	<20
8/2/07	PM	3125	2875	7	<20
8/3/07	PM	3285	2941	10	20

a Sk = Mercury concentration (theoretical) calculated based on internal instrument temperature.
b Si = 10 second mercury concentration measured by the instrument
c %R = relative percent difference between the theoretical and actual mercury concentration. %R must be below 20%

Lumex Serial Number: 329 Instrument Used for study room five foot intake
Factory Calibration Date October 28, 2005

Date	Time	S_k[a]	S_i[b]	%R[c]	Background
5/23/07	9 AM	2290	2601	11	<20
5/23/07	3 PM	4070	4446	9	<20
5/24/07	8 AM	2290	2511	9	<20
5/24/07	3 PM	4640	4810	3	<20
5/25/07	8:19 AM	2655	2923	8	<20
5/25/07	3:35 PM	6870	6688	2	<20
5/29/07	8:30 AM	3075	3382	10	<20
5/29/07	3:27 PM	5640	5759	1	<20
5/30/07	7:40 AM	2930	3192	8	<20
5/30/07	3:80 PM	5830	5839	1	<20
5/31/07	7:40 AM	2975	3199	9	<20
6/1/07	8 AM	4496	4689	4	<20
6/1/07	4 PM	5640	5649	<1	<20
6/4/07	8 AM	2790	3077	10	<20
6/4/07	4:30 PM	3930	4178	6	27/ <20
6/5/07	7:30 AM	2290	2487	10	<20
6/6/07	7:45 AM	3816	4071	8	<20
6/7/07	7:30 AM	3516	3738	6	<20
6/8/07	7:30 AM	3630	3867	6	<20
6/8/07	3:00 PM	5030	4999	0	<20
6/11/07	7:45 AM	2975	3064	3	<20
6/12/07	AM	4648	4790	1	<20
6/12/07	PM	6130	6002	2	<20
6/13/07	AM	3075	3289	5	<20
6/13/07	PM	4870	4933	1	<20
6/14/07	AM	2655	2793	5	<20

Appendix I

Date	Time	S_k[a]	S_i[b]	%R[c]	Background
6/15/07	AM	3930	4104	6	<20
6/15/07	PM	5550	5460	1	<20
6/18/07	AM	3395	3425	1	<20
6/19/07	AM	4710	4790	3	<20
6/19/07	PM	7100	6733	3	<20
6/21/07	AM	3125	3295	5	<20
6/21/07	PM	6330	6141	4	<20
6/25/07	AM	3125	3295	5	<20
6/26/07	AM	4950	4990	<1	<20
6/28/07	AM	4560	4573	<1	<20
7/2/07	AM	3340	3498	3	<20
7/3/07	AM	4270	4374	4	<20
7/3/07	PM	6130	5954	4	<20
7/5/07	1:30 PM	3690	3741	1	<20
7/6/07	AM	3930	4000	1	29/ <20
7/6/07	4:40 PM	6870	6570	4	<20
7/9/07	AM	2975	3154	6	<20
7/10/07	AM	4130	4320	2	<20
7/10/07	PM	5370	5363	<1	<20
7/11/07	AM	3075	3158	4	<20
7/12/07	AM	3510	3650	3	<20
7/13/07	AM	3570	3684	3	<20
7/16/07	AM	3395	3617	8	<20
7/17/07	AM	3395	3640	7	<20
7/18/07	AM	3450	3721	7	<20
7/19/07	AM	3180	3442	6	<20
7/20/07	AM	5370	5377	<1	<20
7/23/07	AM	3285	3506	4	<20
7/24/07	AM	5120	5155	<1	<20
7/25/07	AM	5800	5683	2	<20
7/26/07	AM	6540	6269	5	<20
7/30/07	AM	4340	4437	2	<20
7/30/07	PM	9230	8249	12	<20
8/1/07	PM	3075	2867	8	<20
8/2/07	PM	3125	2875	7	<20
8/3/07	PM	3285	2941	10	<20
8/70/7	PM	2930	2721	7	<20
8/9/07	PM	2700	2559	5	<20
8/10/07	PM	3570	3721	4	<20
8/14/07	AM	3630	3789	6	<20

a Sk = Mercury concentration (theoretical) calculated based on internal instrument temperature.
b Si = 10 second mercury concentration measured by the instrument
c %R = relative percent difference between the theoretical and actual mercury concentration. %R must be below 20%

Appendix I

Lumex Serial Number: 215 3rd Instrument
Factory Calibration Date April 4, 2007

Date	Time	S_k [a]	S_i [b]	%R [c]	Background
5/24/07	AM	2145	2185	2	<20
5/25/07	AM	2145	2197	2	<20
5/31/07	AM	2290	2378	3	<20
5/31/07	PM	2745	2715	1	<20
6/1/07	AM	2330	2339	<1	<20
6/4/07	AM	2110	2119	<1	<20
6/5/07	AM	2075	2189	5	<20
6/6/07	AM	2110	2135	1	<20
6/7/07	AM	2040	2101	3	<20
6/8/07	AM	2145	2133	1	<20
6/11/07	AM	2365	2384	<1	<20
6/12/07	AM	2330	2326	1	<20
6/13/07	AM	2330	2294	1	<20
6/14/07	AM	2255	2285	1	<20
6/15/07	AM	2255	2274	<1	<20
6/18/07	AM	2445	2406	<1	<20
6/19/07	AM	2445	2466	<1	<20
6/21/07	AM	2485	2474	1	<20
6/25/07	AM	2330	2314	<1	<20
6/26/07	AM	2525	2540	<1	<20
6/26/07	PM	2655	2640	1	<20
6/27/07	AM	2655	2634	<1	<20
6/27/07	PM	3340	3213	3	<20
6/28/07	AM	2880	2772	2	<20
6/29/07	AM	2790	2706	4	<20
7/2/07	AM	2525	2567	1	<20
7/3/07	AM	2525	2540	<1	<20
7/5/07	AM	2700	2650	1	<20
7/6/07	AM	2610	2592	2	<20
7/9/07	AM	2485	2467	<1	<20
7/10/07	AM	2445	2439	<1	<20
7/20/07	AM	4130	3952	2	<20
7/23/07	AM	2525	2487	1	<20
7/24/07	AM	3750	3682	3	<20
7/30/07	AM	3230	3035	5	<20

a Sk = Mercury concentration (theoretical) calculated based on internal instrument temperature.
b Si = 10 second mercury concentration measured by the instrument
c %R = relative percent difference between the theoretical and actual mercury concentration. %R must be below 20%

Appendix J

Temperature Corrected One Hour Average Mercury Concentrations

Trial	intake	Run time [minutes]	Room Temperature During Trial	1 Hour average	1 hr ave at 23 C	1 hr ave at 32 C
S1T4	H	83.4	19.9	133	170	**355**
S1T5	H	119.9	22.3	254	275	**574**
S1T6	H	105.0	23.2	120	120	251
S2T2	H	117.6	22.5	26	28	59
S3T2	H	350.6	22.2	115	124	260
S3T3	H	267.5	21.5	78	84	176
S3T5	H	357.5	22.5	94	102	212
S4T1	H	359.6	20.6	72	85	177
S4T2	H	260.7	19.8	53	68	142
S4T3	H	592.2	20.3	73	93	195
S5T1	H	174.4	20.2	97	124	259
S5T2	H	86.1	21.5	123	133	278
S5T3	H	357.9	17.2	61	100	209
S5T3Revac	H	481.4	24.9	57	48	101
S6T1	H	82.8	17.6	99	149	310
S6T2	H	355.7	19.8	72	92	192
S6T3	H	254.7	19.3	48	67	139
SA	H	340.4	20.7	199	234	**490**
SA D	H	677.9	22.0	**815**	**881**	**1,841**
SB	H	343.1	23.2	161	161	**336**
SB D	H	345.8	21.3	155	183	**382**
SBRevac1	H	91.0	22.3	**3,406**	**3,682**	**7,693**
SBRevac2	H	361.0	24.2	**1,114**	**1,026**	**2,144**
SBRevac3	H	481.4	20.6	**584**	**688**	**1,438**
SBRevac4	H	361.0	19.4	172	239	**499**
SC	H	235.5	19.3	**424**	**589**	**1,230**
SC D	H	357.0	21.1	298	**351**	**734**
SD	H	408.2	20.3	110	141	294
SD D	H	259.8	24.3	43	40	83
SE	H	267.7	24.9	**527**	**447**	**934**
SE D	H	85.5	23.7	**806**	**742**	**1,551**
SF	H	81.8	24.7	**2,992**	**2,537**	**5,302**
SG	H	87.0	25.0	111	87	181
SH	H	136.8	23.9	232	214	**446**
SI	H	133.4	24.2	54	50	104
SJ	H	117.1	23.6	122	112	235
SK	H	471.3	24.4	241	222	**464**
SL Carpet	H	1,563.3	25.3	135	106	221
SLVac1	H	1,507.4	22.3	**16,814**	**18,176**	**37,980**
SLVac2	H	1,181.3	24.9	**2,623**	**2,416**	**5,048**
SLVac3	H	1,231.2	24.2	**2,671**	**2,460**	**5,140**
SLVac4	H	1,190.7	25.7	**1,986**	**1,553**	**3,245**
S1T4	L	83.4	19.9	269	**344**	**719**
S1T5	L	119.9	22.3	**319**	**345**	**721**

Appendix J

Temperature Corrected One Hour Average Mercury Concentrations

Trial	intake	Run time [minutes]	Room Temperature During Trial	1 Hour average	1 hr ave at 23 C	1 hr ave at 32 C
S1T6	L	105.0	23.2	**624**	**624**	**1,304**
S2T2	L	117.6	22.5	50	54	113
S2T3	L	58.2	22.8	126	126	263
S3T1	L	28.9	23.0	140	140	293
S3T2	L	350.6	22.2	127	137	287
S3T3	L	267.5	21.5	142	154	**321**
S3T5	L	357.5	22.5	108	117	244
S4T1	L	359.6	20.6	159	187	**391**
S4T2	L	260.7	19.8	72	92	192
S4T3	L	592.2	20.3	126	161	**337**
S5T1	L	174.4	20.2	202	258	**540**
S5T2	L	86.1	21.5	128	138	289
S5T3	L	357.9	17.2	77	126	263
S5T3Revac	L	481.4	24.9	40	34	71
S6T1	L	82.8	17.6	86	129	270
S6T2	L	355.7	19.8	133	170	**355**
S6T3	L	254.7	19.3	41	57	119
SA	L	340.4	20.7	185	218	**455**
SA D	L	677.9	22.0	**1,398**	**1,511**	**3,158**
SB	L	343.1	23.2	264	264	**552**
SB D	L	345.8	21.3	220	259	**542**
SBRevac1	L	91.0	22.3	**2,554**	**2,761**	**5,769**
SBRevac2	L	361.0	24.2	**714**	**658**	**1,374**
SBRevac3	L	481.4	20.6	**422**	**497**	**1,039**
SBRevac4	L	361.0	19.4	113	157	**328**
SC	L	235.5	19.3	**684**	**949**	**1,984**
SC D	L	357.0	21.1	**310**	**365**	**763**
SD	L	408.2	20.3	123	157	**329**
SD D	L	259.8	24.3	68	63	131
SE	L	267.7	24.9	**1,048**	**889**	**1,857**
SE D	L	85.5	23.7	**738**	**680**	**1,420**
SF	L	81.8	24.7	**2,745**	**2,328**	**4,864**
SG	L	87.0	25.0	**377**	295	**616**
SH	L	136.8	23.9	263	242	**506**
SI	L	133.4	24.2	70	64	135
SJ	L	117.1	23.6	133	122	256
SK	L	471.3	24.4	**368**	**339**	**708**
SL Carpet	L	1,563.3	25.3	**699**	**547**	**1,142**
SLVac1	L	1,507.4	22.3	**21,262**	**22,984**	**48,027**
SLVac2	L	1,181.3	24.9	**2,444**	**2,251**	**4,703**
SLVac3	L	1,231.2	24.2	**2,768**	**2,549**	**5,327**
SLVac4	L	1,190.7	25.7	**1,871**	**1,463**	**3,057**

Bolded averages are over 300 ng/m3

Appendix K:
Wood Floor Mercury Contamination Measurements

Appendix K:
Wood Floor Mercury Contamination Measurements

Trial	SA		SB dup		SC		SC dup		SD hot		SD-hot dup		SE	
Date of Breakage	6/11/2007		6/13/2007		6/14/2007		6/14/2007		6/15/2007		6/18/2007		6/18/2007	
Floor Type	wood		wood		wood		wood from SB dup		wood		wood		wood	
Days after break	calm	agitated	calm	agitated	calm	agitated	calm	agitated	calm	agitated	calm	agitated	calm	agitated
1	254	797	27	828	446	342	<20	564			<20	<20	149	2056
2														
3									<20	<20			23	165
4					203	800	68	680						
5					<20	526	<20	367						
6														
7					22	319	72	943						
8					92	242	27	452						
9														
10														
11					55	551	<20	1060						
12					83	634	<20	673						
13					161	718	56	376						
14					36	366	<20	574						
15					34	253	<20	200						
16														
17														
18					20	360	81	552						
19					33	282	<20	717						
20														
21					35	211	<20	564						
22							43	559						
23														
24														
25							<20	173						

Appendix K:

Wood Floor Mercury Contamination Measurements

Trial	SE dup		SF wait		SG		SH		SI		SJ crack	
Date of Breakage	6/19/2007		6/19/2007		6/19/2007		6/21/2007		6/21/2007		6/25/2007	
Floor Type	wood		wood		wood		wood from SG		wood		wood	
Days after break	calm	agitated	calm	agitated	calm	agitated	calm	agitated	calm	agitated	calm	agitated
1							39	199	44	744	<20	31
2	35	1282	30	91	<20	195						
3	26	360										
4							24	196	<20	77		
5												
6												
7												