Appendix J

Peer Review of Mercury Lamp Drum-Top Crusher Study: Response to Comments

Background

The universal waste regulations, set forth in 40 CFR 273, were formulated in order to ease the regulatory burden associated with the collection of universal waste and to thereby facilitate the entry of these hazardous wastes into the RCRA hazardous waste management system. The original federal list of universal wastes included certain hazardous waste batteries, pesticides, and mercury-containing thermostats. Hazardous waste fluorescent lamps were added to the federal list of universal wastes on January 6, 2000 (64 FR 36465). One of the issues raised during the notice and comment period of this rulemaking was the use of Drum Top Crusher (DTC) devices for lamp management. A DTC device fits over the top of a standard 55-gallon drum and crushes the spent lamps into the drum. The DTC device is used to simplify handling of the spent lamps by reducing their volume.

At the time that hazardous waste lamps were added to the universal waste list, some states already allowed the use of DTC devices. EPA provided some general guidance to states with regard to the appropriate use of DTCs for lamp management (64 FR 36477) and determined that further, more detailed information or guidance regarding the use of DTC devices needed to be informed by an assessment of DTC device performance. Therefore, in 2003, EPA performed a study assessing the performance of DTC devices.

EPA prepared a draft report for the DTC Device Study (the Study), *Mercury Lamps Drum-Top Crusher Study Report*. RTI International (RTI), under contract to EPA, arranged for an independent review of the draft report, dated September 20, 2004, by recognized technical experts. This review was conducted by letter format in a manner consistent with EPA's Office of Research and Development and Science Policy Council *Peer Review Handbook* (December, 2000). The peer review was sought so that EPA may benefit from additional viewpoints and perspectives. Each reviewer certified that they had no actual or potential conflicts of interest; therefore, these reviews provided impartial evaluations of the scientific information and study findings. The following experts served as reviewers of the report:

- Carl Herbrandson, Ph.D., Minnesota Department of Health
- Steven Lindberg, Ph.D., Corporate Fellow Emeritus (retired)
  Environmental Sciences Division, Oak Ridge National Laboratory
- Michael McLinden, M.S., C.I.H., New Jersey Department of Environmental Protection

This report presents a compilation of the reviewers' verbatim comments on the draft report and the Agency's responses to these comments. Many substantive comments were made by the reviewers. As a result of these comments, EPA extensively revised the study report. Many sections of the report were rewritten, expanded upon, or moved in order to address the concerns of the commenters and provide a clear, thorough discussion of the DTC Device Study. Because of this extensive revision, several of the specific statements that the reviewers quoted and commented on are not in the revised report. Agency responses to these comments explain why the text was changed and addresses the substantive portions of the comments. The comments and responses are grouped by subject and generally follow the order of the report.

Comments Answering Questions Posed to the Reviewers by EPA

EPA posed the following specific questions to the reviewers:

1. General Design/Execution of the Study: Is the design and execution of the Study appropriate for evaluating the likely Hg releases from DTCs in use?
2. Laboratory Methods/QA/QC: Are the laboratory analytical methods and QA/QC procedures appropriate and adequate to generate reliable data?
3. General Results/Conclusions: Do the data generated by the Study support the conclusions presented in the report? If not, in what regard? Are other conclusions supported by the data generated?
4. Effects of Temperature and Humidity: DTC operations were performed at three locations under temperature and humidity conditions that varied at the different sites. The report does not attempt to quantify the effects of temperature and humidity on mercury releases from DTC devices in operation. Are the data generated by the Study adequate to assess the impacts of temperature and humidity on Hg release from DTCs in operation?
5. Background Hg: The DTC Study was conducted at operating commercial lamp recycling facilities. As a result, background mercury levels in the areas of the Study were much higher than would be expected to occur in buildings that do not use Hg in routine operations. How should the background levels of mercury be considered in assessing DTC releases of Hg?
6. Mass Balance Study: One portion of the Study consisted of a Mass Balance Study of mercury being put into the DTC devices, and the mercury released from the devices (Chapter 5). Estimated recoveries ranged from 34% to 67%. A number of possible reasons for the low recovery rates are discussed in the report. Do the sources of error described in the report adequately address the low recoveries? Are other sources of error plausible (and should be considered in any subsequent Mass Balance Study)?
7. Operator Observations: Are the operator observations presented in chapters 6 and 7 appropriate?
8. Study Limitations: Does the discussion of study limitations (Chapter 8) identify all important weaknesses in the Study not elsewhere identified in the report?

The reviewers' answers and the corresponding responses are presented below.

1. <u>General Design/Execution of the Study</u>*: Is the design and execution of the Study appropriate for evaluating the likely Hg releases from DTCs in use?*

> ***Carl Herbrandson's Comment:*** Mercury emissions from DTCs, as mass of mercury released or as a fraction of mercury released from each fluorescent bulb, were not characterized in this study. The study was not designed appropriately for evaluating likely mercury releases during DTC use. The study measured containment area air concentrations, which was also an objective of the study. "The objective of the project was to evaluate the performance of the DTC devices in terms of mercury emissions and potential for worker exposure to adverse levels of mercury releases due to the operation of these devices." The potential for worker exposure to adverse levels of mercury releases due to operation of DTCs was effectively evaluated.

Response: EPA agrees that mercury emissions from DTCs in use were not measured in this Study. The discussion presented in this report has been modified to more clearly state that the Study was designed to evaluate DTC device performance in terms of worker exposure.

Steven Lindberg's Comment: No. The study was flawed, resulting in serious contamination which makes it difficult to quantify actual Hg releases.

Response: Mercury releases from DTC devices were not quantified in the Study. The Study was designed to evaluate mercury exposures that could result from the use of DTC devices and changes in mercury exposure over time. The data collected during the Study provide information about which activities involved in DTC device operation are associated with the highest mercury exposure and about how devices perform over time, in terms of their ability to prevent mercury exposure. Contamination, due to mercury present in the testing environment, was an issue. The limitations due to background mercury are discussed in Chapter 6 of the revised report, and background air sampling data (Jerome analyzer readings and analytical air samples) are presented in Chapter 4 of the revised report.

Steven Lindberg's Comment: Statements made in Section 7 suggest that the design was compromised to decrease costs of the study.

Response: The reviewer did not specify what statements in Section 7 suggest that cost concerns caused the study team to compromise the study design. However, one of the major concerns expressed was that the testing was conducted at lamp recycling facilities and thus, high background concentrations of mercury were present. (See next comment and response for specific response to this concern.) In addition, the study team made many ad hoc decisions in response to data that was collected during the early phases of the Study. A thorough review of the original study design by researchers more experienced in mercury sampling would most likely have lead to an improved study design. As with any large-scale study, cost and time considerations were important because inattention to these constraints (i.e., planning more sampling than could be completed in the amount of time allotted for a given test) would have made it difficult or impossible to complete the Study. However, the primary concern in designing the DTC Device Study was to assess the performance of the four DTC devices tested, and concerns about the cost of the testing were secondary to completing the objectives of the Study.

Steven Lindberg's Comment: The notion that these devices might be used at major existing recycling facilities seems poor justification for the chosen sampling locations. My experience in seeing these devices in the field is that they are used primarily at small to moderate-sized generators of used bulbs, such as small industries and hospitals.

Response: There were several reasons why lamp recycling facilities were used as the sites for the Study. Not all of these reasons were clearly explained in the draft study report. The revised report includes the following, more detailed explanation as to why the Study was conducted at lamp recycling facilities:

- These facilities possessed the appropriate permits to process mercury-containing fluorescent lamps.

> - These facilities had ample supplies of lamps that were provided at no cost to the study team.
> - The facilities had the capacity to process and dispose of the drums of lamp debris, with no shipping, manifesting, or disposal arrangement required of the study team.
>
> The study team made every effort to isolate the study area from normal lamp processing operations. **(pg. 78)**

The study team considered other locations for the Study. However, some states require permits for the operation of a DTC device, and it was not feasible to obtain state permits within the timeframe of the Study.

The containment structure used for testing the DTC devices was constructed in order to simulate field conditions for DTC use by creating a small, confined space, similar to a boiler room or janitor's closet. The containment structure was also intended to isolate the test area from the rest of the lamp recycling facility, as best as possible.

Steven Lindberg's Comment: Perhaps the only questions these data could answer are "Do the tested DTC's have serious operating problems [yes], and do they capture all of the Hg from the feed lamps [no]?"

Response: EPA agrees that the data collected for this report should primarily be used to answer qualitative questions. The purpose of this Study was to provide information regarding possible worker exposures due to DTC device use. The agency believes that there are many insights that can be gained from the data collected in the Study. Chapter 7 of the revised report discusses the study results.

– *<u>Laboratory Methods/QA/QC</u>: Are the laboratory analytical methods and QA/QC procedures appropriate and adequate to generate reliable data?*

Carl Herbrandson's Comment: Generally, yes. The use of a realtime monitor (Jerome) also provided supporting confirmation of the analytical results. The effectiveness of the MCE filters, as the first stage of the sample collection train, to capture and retain aerosol Hg could be suspect and was not demonstrated.

Response: The effectiveness of the mixed cellulose ester (MCE) filters is discussed at the beginning of Chapter 4 of the revised report. It is possible that the MCE filters were not effective for capturing aerosol mercury; however, the total amount of mercury in the air sampled was effectively measured because any aerosol that was not captured in the MCE filter was captured by the Hydrar tubes (the second stage in the sample collection train).

Carl Herbrandson's Comment: Jang et al., 2005 shows an HCl / nitric acid solution removes a maximum of 36% of the Hg from bulb waste. Therefore, the effectiveness of the methods employed in this study to measure the amount of Hg in spent bulbs should be confirmed.

Response: In the revised report, a reference to Jang et al., 2005 is included in the section describing the extraction (in Chapter 5). Additionally, the need for a valid laboratory method for quantifying the amount of mercury in spent lamps, with appropriate QA/QC procedures, is suggested in Section 7.4 as an area where further work is needed.

Steven Lindberg's Comment: In 3 decades of working with Hg I have never heard of Hydrar solid sorbent tubes. This does not mean they are unacceptable, but in the absence of strenuous QA tests, I was unable to verify the validity of data generated by this approach. My group has sampled Hg at levels in air and solids from background (pg of Hg) to highly enriched (mg of Hg), and or approaches have involved various sorbent traps (activated iodated C, gold), automated instruments (Jerome, Tekran, Lumex) and chemical extraction methods (such as for methylmercury). I found no QA testing of these tubes that provided any evidence of their ability to quantitatively collect Hg under conditions encountered. I would describe the methods as less than adequate (Appendix D titled Data Chem Methods was blank in my copy).

Response: According to OSHA's *Occupation Safety and Health Guideline for Mercury Vapor*, which can be found at http://www.osha.gov/SLTC/healthguidelines/mercuryvapor/recognition.html, "Determination of a worker's exposure to airborne mercury vapor is made using a Hydrar or Hopcalite tube (200 mg section), SKC brand with a prefilter/cassette." (The prefilter used in the Study was a mixed cellulose ester filter.) In addition to the OSHA guideline, Hydrar tubes are an acceptable medium for sampling mercury vapor in an industrial setting according to the National Institute for Occupational Safety and Health (NIOSH [1994]. NIOSH manual of analytical methods, 4th ed. Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 94–113.).

Steven Lindberg's Comment: I was surprised that readily available, widely used and accepted methods were not employed. Although the Lumex data could have been very valuable, the users seemed to have encountered several problems deploying this instrument, which many others have used successfully.

Response: EPA agrees that the Lumex data would have been very valuable. The study team attempted to record data with the Lumex but was unable to do so because the instrument was not functioning properly.

Steven Lindberg's Comment: The Jerome is a valuable instrument when properly used. However, there seemed to be no serious attempt to perform a sampling or analytical intercomparison between these two methods (see comment on Section 4 below). This would have proved useful in evaluating the Hydrar method. Also, the most interesting Jerome data were relegated to the Appendices and the trends not discussed (see below).

Response: The study team found that the Jerome data were valuable, and EPA agrees with the reviewer that the importance of the Jerome data was understated in the draft report. Unfortunately, because of problems with the data loggers, there were not enough Jerome data for each device at each location to perform any rigorous statistical analyses. The revised report highlights the Jerome data. Also, averages of the Jerome data and the analytical air sample (Hydrar tube) data were graphed together to better facilitate comparison of the results from the two air sampling methods; these graphs are in .Appendix A, Figures 26, 35 and 43, of the revised report.

Steven Lindberg's Comment: The supplied raw analytical data tables suggested that up to half of the samples were below detection. This seemed odd given the enriched background under which the study was performed.
Also, I noted that the detection limits seem to have varied by over an order of magnitude (<0.1 to <1.1 ug) which is worrisome.

Response: Aside from the blank Hydrar tube samples, the samples that were below the detection limit were the MCE filter samples. The report was revised to highlight the fact that the majority of the MCE filter results were below the detection limit. (See earlier comment and response under "Laboratory Methods/QA/QC" for specific response to this concern.) The actual detection limits were based on the actual sampling media (0.1 µg per Hydrar tube or MCE filter). The "less than" values in the raw data tables vary because the total volume of air sample varied for each MCE filter/Hydrar tube. The units used for the final reporting value reported were mg/m^3, so the volume of air affected the "less than" value for each individual sample.

– *General Results/Conclusions: Do the data generated by the Study support the conclusions presented in the report? If not, in what regard? Are other conclusions supported by the data generated?*

Carl Herbrandson's Comment: Generally, the data supported the results and the conclusions of the report. With the following exceptions:

- There is no analysis of data showing that Manufacturer A's device performed better than the other devices in the PVS. While data from Phase 2 suggests this to be true, data from Phase 1 are equivocal.
- Data available are not sufficient to allow a mass balance calculation. Therefore, mentioning "a large fraction unaccounted for" may be misleading.

Response: An analysis was performed to support the assertion that there was a decrease in the performance of the devices from Manufacturer B and C but not the device from Manufacturer A. This is discussed in Chapter 4 of the revised report.

EPA agrees with the commenter regarding the Mass Balance Conclusions so the report was revised to eliminate the Conclusions section. The Mass Balance Study discussion was revised so that no definitive statements based on the data were made. Instead, the problems with the Mass Balance Study were presented along with the data so that this information could be used by future researchers.

Steven Lindberg's Comment: It would be difficult to draw any quantitative conclusions from the data presented in the report.

Response: EPA agrees, and thus, the conclusions presented in the report are primarily qualitative.

- <u>*Effects of Temperature and Humidity*</u>*: DTC operations were performed at three locations under temperature and humidity conditions that varied at the different sites. The report does not attempt to quantify the effects of temperature and humidity on mercury releases from DTC devices in operation. Are the data generated by the Study adequate to assess the impacts of temperature and humidity on Hg release from DTCs in operation?*

Carl Herbrandson's Comment: NO. There are too many variables. Differences between sites include: building configurations, proximity to industrial crushers, air currents within the buildings, potential changes in DTCs as a result of shipping, as well as seal leakage and potential maintenance issues could also confound a relationship. Differences between PVS phases 1 and 2 in Virginia may show a temperature/humidity effect, and some site related variables may be controlled, but showing a relationship between temperature/humidity and emissions would require showing that differences are outside any expected variability (i.e., multiple tests would be needed, at different times, and with cold temperature tests both before and after warm temperature tests).

Steven Lindberg's Comment: No, the data are not adequate. This question required a systematic approach under controlled conditions.

Michael McLinden's Comment: I expect temperature would directly influence the amount of mercury released from crushed/broken lamps as well as the amount escaping from the DTC devices, higher temperatures would volatilize more mercury. As for relative humidity, my guess is that since mercury is thirteen times as dense as water, it would not have a significant affect on mercury volatilization. As for your question "Are the data generated by the study adequate to assess the impacts of temperature and humidity on Hg release from DTCs in operation?" It may be helpful to graph results of a particular sampling location (e.g., all area air sample taken at feed tube) for all three Extended Field Tests. You could then compare the graph with ambient air temperatures to see if temperature affected the results.

Response: The Study was not designed to evaluate the effects of temperature on the measured mercury concentrations. After the Study began, the study team recognized that ambient temperature could significantly impact the amount of mercury that volatilized when the lamps were crushed, so temperature data was collected. The peer reviewers were specifically asked to comment on the adequacy of the temperature and humidity data for the purposes of assessing any possible effects that environmental conditions may have had on the results of the Study. Based on the comments made by the reviewers, no attempt was made to assess the impacts of temperature and humidity on DTC performance in the revised report.

- <u>*Background Hg*</u>*: The DTC Study was conducted at operating commercial lamp recycling facilities. As a result, background mercury levels in the areas of the Study were much higher than would be expected to occur in buildings that do not use Hg in routine operations. How should the background levels of mercury be considered in assessing DTC releases of Hg?*

Carl Herbrandson's Comment: High background mercury in the testing areas was handled properly in the report: background Hg was recorded and reported. Certainly if longterm testing had occurred in a pristine setting, wipe samples could have provided some useful data about the potential for DTCs to contaminate work areas. However, it is not clear how the background concentrations may have impacted the mercury vapor data acquired during the reported experiments. Background mercury vapor concentrations could be subtracted from the test data, but this would have required substantial data supporting the use of specific background concentrations.

Response: In the revised report, more complete background data are presented in the results section (Section 4.2). The background air sample data was compared to the air samples taken during testing to show that the mercury concentrations measured during testing were significantly higher than the background levels at each facility.

Carl Herbrandson's Comment: Data from Jerome #2 is not shown in the figures. As noted in the report, air leaks and exchanges occurred whenever the bay doors at the testing facilities were open. The readings from Jerome #2 could provide useful information for evaluating the variability of background mercury vapor concentrations.

Response: EPA agrees that the data from the Jerome Mercury Vapor Analyzer that was used to sample the air outside the containment structure during testing would have enhanced the analysis and discussion of the background data. Unfortunately, due to problems with the Jerome data loggers, the real-time background data is not available.

Carl Herbrandson's Comment: The report should note that the background concentrations in locations at some distance from the 'industrial' crushers suggest that exposures near operating industrial crushers may be above levels of concern for the general public; and that Hg contamination on floors near the containment areas suggests that tracking of mercury from facilities like these may be significant.

Response: The potential for exposure to the general public is discussed in Chapter 7 and several other sections of the revised report. The Study was not designed to measure possible migration of mercury off site from the lamp recycling facilities, so the report does not make any statement about the possibility of significant amounts of mercury being released due to tracking from the facilities.

Steven Lindberg's Comment: The decision to perform these tests under the chosen conditions represents a fatal flaw in this study. The problems of such serious contamination cannot be overcome without a revised study design. Since the background was never adequately controlled, or even quantified (too few samples, too much variability), I don't see how any quantitative conclusions can be drawn from the study as designed and performed.

Response: As stated above, there were many reasons that the lamp recycling facilities were chosen as the sites for this Study. EPA agrees that the background mercury is a serious confounding factor in the Study, and the majority of the conclusions drawn in the report are qualitative. In response to the reviewers' concerns about the low number of background samples, a more thorough presentation of all available background mercury samples measured using the Hydrar tubes and using the Jerome Mercury Vapor Analyzer is included in the results section (Chapter 4) of the revised report, and the chapter about limitations (Chapter 6) discusses several ways in which the background samples may bias the results.

– *Mass Balance Study: One portion of the Study consisted of a Mass Balance Study of mercury being put into the DTC devices, and the mercury released from the devices (Chapter 5). Estimated recoveries ranged from 34% to 67%. A number of possible reasons for the low recovery rates are discussed in the report. Do the sources of error described in the report adequately address the low recoveries? Are other sources of error plausible (and should be considered in any subsequent Mass Balance Study)?*

Carl Herbrandson's Comment: Calculations and estimates used in the "mass balance" should not be reported. Instead, for the benefit of future investigators, the problems with attempting to show a mass balance with the available data should be detailed. Other potential sources of mass balance loss are described in accompanying comments.

Steven Lindberg's Comment: Considering all of the assumptions, analytical errors, and background problems, I would not accept that even the stated range of recoveries is accurate. Given the analytical and sampling errors, and the flawed design, it is not surprising that correction factors as large as 95% were applied in an attempt to close the mass balance. It is never explained why there was no attempt to quantify the losses based on the air concentration data.

Response: EPA agrees that the uncertainty in the Mass Balance Study is too high to estimate the different fractions of mercury. The discussion of the Mass Balance Study was revised to present the data collected, the calculations, and the problems encountered. The air concentration data was used to calculate the amount of mercury released; however, there was a significant mass of mercury unaccounted for.

– *Operator Observations: Are the operator observations presented in chapters 6 and 7 appropriate?*

Carl Herbrandson's Comment: Yes. Inclusion of operator observations can provide important subjective information and insight.

Steven Lindberg's Comment: These were possibly the most useful contribution. The DTC's as a whole seemed poorly designed, and the problems encountered were not surprising. The safety suggestions offered are valuable, although several were also noted in the manufacturer's guidelines. It is interesting to note that these manuals contained misinformation concerning Hg.

Response: The operator observations are included in Chapter 7 of the revised report.

- <u>Study Limitations</u>*: Does the discussion of study limitations (Chapter 8) identify all important weaknesses in the Study not elsewhere identified in the report?*

  Carl Herbrandson's Comment: Additional study limitations are discussed in the accompanying comments.

  Steven Lindberg's Comment: In general, the major limitations were noted, but several more could be listed, as noted both above and below.

  Response: The study limitations are discussed in Chapter 6 of the revised report. EPA has responded to all comments in this document.

Additional Comments of Peer Reviewers and Agency Responses

The additional comments provided by the reviewers follow. General comments are presented first, and specific comments are organized to follow the order of the report.

General Comments

Carle Herbrandson's Comments: This study was a very good initial study of DTCs. The study showed operator exposures to mercury vapor may regularly be above the TLV (for the duration of operation) and often above the PEL. Adverse health effects are consistently seen in studies of workers exposed at the TLV (0.025 mg/m^3 for 8-hour day). Therefore as a scientist in the field of public health, I would recommend to my state environmental agency that additional study should be conducted prior to allowing the use of DTCs. These studies should answer the following questions:

a. Can contamination accumulate in areas where DTCs are used? Can this contamination be tracked? Is there a need to establish decontamination areas and procedures for operators?
b. Can the circumstances of use of DTCs be controlled so that the general public is not exposed to potentially hazardous levels of mercury?
c. What fraction of the mercury in a fluorescent bulb is emitted from DTCs, in all phases of operation?
d. Are there regulations that will ensure control and proper disposal of full drums?
e. How do emissions from currently operated 'industrial' recycling processors and DTC emissions compare? Can the use of DTCs reduce the overall emissions from spent fluorescent bulbs to the environment?
f. Can we objectively evaluate the apparent tradeoff between potential decreased environmental emissions and the potential for significant exposures to more individuals – individuals exposed to emissions or contamination associated with DTCs?

I would hope that, without answers to the above questions, DTC usage does not increase.

Response: The questions posed by the reviewer are excellent research questions. While the Agency is not suggesting that DTC devices not be used until these questions are answered, EPA agrees that regulators should carefully consider the possible effects to human health and the environment that would come from allowing the use of DTC devices. This then can be compared to continuing to have the majority of mercury containing fluorescent lamps disposed of in MSW landfills.

Carle Herbrandson's Comments: The order of presentation of data on DTC devices in all tables and figures should be A, B, C, D. Data are always more confusing when they are listed in different order in different places. If the actual sampling order was different than the reporting order (A,B,C,D), then the sampling order should be noted in table/figure footnotes.

Response: The presentation of the data has been changed to A, B, C, D order.

Carle Herbrandson's Comments: Pg 92 last line – there is no section 3.6.2.1.

Michael McLinden's Comment: There is no Section 3.7, perhaps it should read Section 3.5.2.1. There is no section 3.9.1.

Response: All references within the report were checked and revised to ensure that they were correct.

Steven Lindberg's Comments: Although the nature of this project led to moderately difficult objectives, they should have been achievable by an experienced research group with sufficient planning. In my opinion, this project and the report do not meet the stated objectives. The primary reasons relate to the apparent inexperience of the project team in working with Hg and an inability to anticipate potential problems. Detailed comments follow the questions below.

Response: While some objectives of the Study were not met, the data collected in this Study provide valuable information to regulators and users of DTC devices. EPA agrees however, that a more thorough review of the sampling and study plan by researchers more experienced with mercury monitoring would have been beneficial to the study team to avoid some of the problems encountered during the Study.

Executive Summary

Note to the reader: The Executive Summary that was included in the draft report given to the reviewers was extensively revised. The Executive Summary in the revised report provides the reader with the background of the Study and the results of the Study, in a concise form. Many of the comments made by the reviewers are not directly relevant to the revised report; however, responses to the concerns raised by these comments are provided below.

Carl Herbrandson's Comment: The executive summary introduction says that the use of DTCs "will likely increase." This will certainly be true, in the absence of regulatory action. Does this report assume that there will be no regulatory action taken? Or that additional testing will not occur before DTC-use increases?

Response: EPA is not proposing any changes in regulations; the purpose of this Study was to provide information about the use of DTC devices. The statement that DTC use "will likely increase" is no longer in the Executive Summary. The issue of the use of DTC devices was discussed in the final notice for the addition of hazardous waste lamps to the federal list of universal waste (64 FR 36477). Authorized state programs have the authority to make regulatory decisions about the use of DTC devices as part of their universal waste management programs.

Carle Herbrandson's Comment: Pg 5 (TLV) of 0.25 mg/m^3 - - should read 0.025 mg/m^3

Response: The TLV listed in the Executive Summary now reads 0.025 mg/m^3.

Carl Herbrandson's Comment: The conclusions and recommendations section of the Executive Summary includes the statement that "Additional recommendations for engineering controls, PPE, equipment isolation, and worker medical monitoring may apply in site-specific situations." Does this suggest a different level of regulation than is typically seen in Haz Waste regulations? Are equipment isolation, PPE, …controls EPA wants to recommend only at certain sites?

Response: EPA is not proposing any changes in regulations; the purpose of this Study was to provide information about the use of DTC devices. The statement quoted by the reviewer, which is no longer in the Executive Summary, reflects the fact that EPA expects that there will be a broad range of conditions under which DTC devices will be used. The members of the operator and operator's assistant wore Tyvek® coveralls, Kevlar® gloves, safety glasses, and, at times, full-face respirators while conducting the Study.

Michael McLinden's Comment:

> ***Report Text:***
> The Manufacturer D device was removed from the study after the second round of testing due to its inability to control mercury emissions below Occupational Health and Safety Administration (OSHA) and the American Council of Governmental and Industrial Hygienists (ACGIH) standards.
> ***Comment (Suggested Text Changes Highlighted):*** The Manufacturer D device was removed from the study after the second round of testing due to its inability to control mercury emissions below Occupational Safety and Health Administration (OSHA) and the American Conference of Governmental Industrial Hygienists (ACGIH) standards.

Response: The correction suggested in the above comment was made in the revised report.

Steven Lindberg's Comment: The accuracy and precision of the data are never mentioned. There seems to be a lack of any serious attempt to reproduce these results, and no replicates are discussed.

Response: There is no longer a discussion of the data in the Executive Summary. The study design did not call for replicate testing because one of the basic assumptions of the Study was that there would be changes in device performance over time. Multiple air samples were collected during each test. The variability between air samples collected for each device during a specific testing event were used to determine the variance associated with the measured mercury concentrations.

Steven Lindberg's Comment: Phrases suggesting that emissions were measured are inaccurate. There were no measurements of emissions performed in this Study, only estimates made, based on concentration data.

Response: The report has been revised to make it clear that emissions were not measured. The concentrations near the feed tube and exhaust port were measured.

Michael McLinden's Comment: Although this is a good recommendation [*medical monitoring program for device operators*], OSHA does not require specific biological monitoring in order to use respiratory protection, only a questionaire and/or physical exam. I agree that respiratory protection should be used, however based on established industrial hygiene hierarchy to control workplace contaminants respiratory protection would be recommended only after engineering and administrative controls were explored. Engineering controls should be instituted first in order to reduce employee exposure below the PEL. If engineering controls are not feasible (and I believe they would be feasible in this case) then administrative controls would be explored. Repiratory protection is used as a last resort or while instituting engineering controls.

Response: These recommendations are not in the Executive Summary, but some of the issues are discussed in Chapter 7 of the revised report. The revised report mentions the established industrial hygiene hierarchy (Chapter 7).

Michael McLinden's Comment: In order for an air purifying respirator to work (and be certified by NIOSH) it must have adequate warning properties to indicate when the filter/cartridge has reached break-through. Mercury cartridges do not have adequate warning properties; however, some manufacturers (e.g., MSA mersorb cartridge) have received approval for cartridges equipped with an end of service life indicator (ESLI) so employee can check for break through. Special SOPs (e.g., wearing a belt-mounted cartridge so employee can see the ESLI, or providing mirrors so a worker could see ESLI on his full-face APR) would have to be developed for using APR with Hg.

Response: This fact was not addressed in the revised report; however, EPA will consider this point in drafting additional guidance.

Scope of Study

Carl Herbrandson's Comment: The study objective was to evaluate the performance of DTCs with respect to potential mercury emissions and potential exposures to workers operating DTCs. The study does provide useful data and information on the potential exposures to DTC operators. However, mercury emissions from DTCs, as mass of mercury released or as a fraction of mercury released from each fluorescent bulb, were not characterized in this study.

Response: EPA agrees that the Study was designed to assess worker exposure due to operation of DTC devices and not to measure mercury emissions. The revised report reflects this point – that is, the fact that mercury emissions from DTC devices were not characterized in this Study.

Steven Lindberg's Comment: Several design decisions mentioned in this section are hard to reconcile with an assumed experience of working with environmental or occupational levels of Hg. The decision to locate the study at recycling facilities is surprising and suggests a lack of understanding of (or experience with) the behavior of elemental Hg vapor. It's surprising that someone didn't realize the impact of this decision sooner.

Response: There were several reasons why lamp recycling facilities were used as the sites for the Study. Not all of these reasons were clearly explained in the draft study report. The revised report includes the following, more detailed explanation as to why the Study was conducted at lamp recycling facilities:

> - These facilities possessed the appropriate permits to process mercury-containing fluorescent lamps.
> - These facilities had ample supplies of lamps that were provided at no cost to the study team.
> - The facilities had the capacity to process and dispose of the drums of lamp debris, with no shipping, manifesting, or disposal arrangement required of the study team.
>
> The study team made every effort to isolate the study area from normal lamp processing operations. **(pg. 78)**

The study team considered other locations for the Study; however, it was not feasible to obtain permits for each site within the timeframe of the Study. The most important reason for using the lamp recycler facilities for the Study was the fact that they had permits for lamp crushing.

The containment structure used for testing the DTC devices was constructed in order to simulate field conditions for DTC use by creating a small, confined space, similar to a boiler room or janitor's closet, and also to isolate the test area from the rest of the lamp recycling facility.

EPA also agrees that future studies conducted in a testing environment with very low background mercury levels, involving the measurement of emissions, would be helpful in evaluating the effectiveness of DTC devices.

Data Collection Methodology

Michael McLinden's Comment: Which model, Jerome-411 or newer model?

Response: The model for the Jerome was 431-X. This information is included in the revised report.

Michael McLinden's Comment: Were any background samples collected at the end of the week to determine if background Hg levels had risen during the week due to normal facility processing of lamps? It may be possible that background levels on Monday are lower than Friday levels if the facility is shut down for the weekend.

Response: Background samples were not specifically taken at any point after the first day at each facility. However, during EFT #2, EFT #3, and PVS-II, one overnight air sample was taken outside of the containment structure after each day of testing. These air sample results are presented Table 4.1 and Table 4.2 in the revised report along with the other background sample data and the Jerome background sample data that was manually recorded throughout the Study. Based on this limited sampling, there was no observable trend indicating an increase in background concentrations throughout the week.

Carl Herbrandson's Comment: Table 3.1 is poorly designed – not very understandable.

Response: Table 3.1 in the draft report described the types of analytical air samples that were taken during each portion of the Study. This table has been replaced by four distinct tables – Tables 3.1, 3.2, 3.3, and 3.4 – in the revised report, which describe the samples for each portion of the Study (the Performance Validation Study, Extended Field Test #1, Extended Field Test #2 and #3, and "U"-tube Test).

Carl Herbrandson's Comment: Last sentence on page 26 – not clear. 2 samples "in sequence, for a total duration of 4 minutes per sample." Does that mean a total duration of 8 minutes?

Steven Lindberg's Comment: The intent of ceiling samples was never clearly described, but they seem to be interpreted as representative of maximum exposure. Why?

Response: The description of the ceiling samples that were described on page 26 of the draft report was clarified in the final report. The original description was:

> Short-term ceiling samples were air samples collected over a short duration in time (for this study the sample period was 12 minutes) in order to evaluate the airborne concentration at a specific time. These samples were collected to attempt to quantify airborne concentrations at the estimated time of maximum exposure determined to be during the drum changes. Readings taken on the Jerome Mercury Vapor Analyzer indicated that maximum exposure conditions most probably occurred during drum changes. Thus, the ceiling samples were collected during one of the drum changes for each device. Two samples were collected on the operator's shoulder, in sequence, for a total duration of four minutes per sample.

The revised description is:

> The ceiling samples were another set of personal air samples, which were collected to attempt to quantify airborne mercury concentrations at the estimated time of maximum exposure. Readings taken on the Jerome analyzer indicated that maximum exposure conditions most probably occurred during drum changes. Thus, the ceiling samples were collected during one of the drum changes for each device during PVS-Phase II, EFT #2, and EFT #3. Two samples were collected on the operator's shoulder, in sequence; each ceiling sample was collected for 4 minutes. **(pg. 18)**
>
> ***
>
> Short-term ceiling air samples were introduced into the Study during this round of testing. As described above, ceiling samples were air samples collected over a short duration in time in an attempt to quantify airborne concentrations at the estimated time of maximum exposure.
>
> Readings taken on the Jerome analyzer indicated that maximum exposure conditions most probably occurred during drum changes. Drum change sample results from EFT #1 showed that the ambient concentration of mercury is sufficiently high during drum changes such that the samples did not need to be 12 minutes in order to exceed detection limits. Thus, two short-term, personal air samples were collected in sequence during one of the drum changes for each device. The sampling time was four minutes per sample, for a total duration of eight minutes. **(pg. 21)**

Steven Lindberg's Comment: The decision to cut the plastic on the floor was a fatal flaw.

Response: The study team attempted to rectify the problem with the contaminated wipes samples. Because many of the pre-test wipe results were higher than the post-test wipe results, the wipe sample data were not used in the report and were only included in the Appendix. Later, the plastic was cut outside in the parking lot; however, the number of pre-wipe samples exhibiting high amounts of mercury did not decrease.

Steven Lindberg's Comment: The Lumex was "written off" with a brief comment regarding inoperability. Were any attempts made to rectify the problems?

Response: EPA agrees that the real-time data would have been an asset to the Study; however, although the study team attempted to correct the problems with the Lumex, the device obtained for the Study did not operate correctly.

Michael McLinden's Comment: Was the DTC decontaminated between EFT #3 and PVS-Phase II? Would contaminated DTC indicate lower performance when compared to Phase I using a clean DTC device?

Response: The DTC devices were not decontaminated between EFT #3 and PVS-II. This may have slightly elevated the results from PVS-II. This is discussed in the revised report.

Steven Lindberg's Comment: The NIOSH methods applied are never described in detail, but are simply defined as being unpublished. The normal set of QA tests one would expect are missing.

Response: Due to an error in distributing the report to reviewers, Appendix D was omitted, so the reviewers did not receive a copy of the analytical methods. The National Institute for Occupational Safety and Health (NIOSH) method for sampling mercury vapor in air, Method 6009, and the draft NIOSH method for sampling mercury aerosol in air, Method 9103, were used in the Study. Copies of all NIOSH methods and laboratory methods used are contained in Appendix E of the revised report. Method 6009 is published, and Method 9103 is unpublished. Field QA/QC samples results (i.e., trip blanks and field blanks) are in Chapter 4 of the revised report. All laboratory QA/QC procedures specified in the methods were followed by the laboratory analyzing the samples (Data Chem Laboratories), and, as is standard procedure for commercial analytical laboratories, the laboratory QA/QC data should be on file at Data Chem.

Steven Lindberg's Comment: The duration of the samples is not discussed, but the number of samples "below detection" suggests they were too short. Why was this not resolved with a simple change in design?

Response: The duration of the sample and the volume of air sampled are listed along with the raw data in Appendix A, Table 1. As discussed above, the majority of "below detection" samples were the MCE filter samples. This is discussed in the report in Chapter 4, footnote 12. The purpose of the MCE filter samples was to measure the concentration of mercury aerosols inside the containment structure during operation of the DTC device; the "below detection" results may indicate that no aerosols were formed or that the MCE filters were not the most appropriate media for the detection of mercury aerosols. The Study was not designed to make evaluate the likelihood of either possibility. Further study of this question is suggested in Section 7.4 of the final report. The Hydrar tube samples were not “below detection”.

Steven Lindberg’s Comment: Hydrar tubes are never defined. Were the air flows checked during sampling? Were they recorded continuously?

Response: Hydrar tubes are one of the acceptable media for sampling mercury vapor in NIOSH Method 6009. Each air pump was calibrated before and after sampling. The two calibration values were averaged to determine the approximate velocity at which air was being drawn through the pump. The air flows on the pumps were not checked during sampling or continuously recorded.

Steven Lindberg’s Comment: The reliance on sorbent tubes for much of the data biased the concentrations measured to temporal means. Spikes in exposure were generally not detected unless the Jerome was being used.

Response: EPA agrees that the use of sorbent tubes resulted in measurements that did not allow for the measurement of spikes in exposure. The Jerome Mercury Vapor Analyzer was included in the study design to identify spikes in exposure; unfortunately, problems with the Jerome data-loggers prevented the study team from collecting Jerome data for every device at every location. In general, the Study was designed to measure worker exposure during device operation; this evaluation was best served by collecting samples that were a temporal average of mercury concentrations that the operator of a DTC device would be exposed to under test conditions.

Steven Lindberg’s Comment: Swipe samples are never quantitatively defined (surface area wiped, duration of wipe, composition of solvent, etc). Why were the pre/post swipe samples not collected at the same locations? How can they be quantitative? The extreme variability reflects these problems. The statement at the end of p. 29 regarding replicate sampling is wrong. Upon encountering high variability, one should attempt to increase the number of replicate samples, not decrease it.

Response: The wipe samples were moved from the main report to Appendix F in the revised report. The method for collection and the wipes used for sampling (Clorox® Wash N Dri) are described in greater detail in the revised report. The reviewer is correct in noting that the number of replicates should have been increased instead of decreased to account for sample variability.

Steven Lindberg’s Comment: Was any attempt made to sample the air in the drum headspace? The elevated concentrations one would expect to find there suggest a considerable Hg pool, unless the volume was very small.

Response: The air in the headspace of the drum was tested during EFT #1 and EFT #2 using the Jerome Mercury Vapor Analyzer. The results are given in Chapter 4.

Carl Herbrandson's Comment: It would be helpful to include, in the section on wipe samples and perhaps in the section on study limitations, some discussion of the Hg permeability of polyethylene. Hg can permeate through polyethylene. Polyethylene cannot be used for taking water-Hg samples because the water will take up some Hg from air, through the container. Does a wipe sample from the polyethylene containment wall take Hg that has permeated the material? Does it only take Hg that is oxidized, complexed or bound and cannot pass through the material? Or is it likely that this permeability is not significant enough to affect these data?

Steven Lindberg's Comment: The choice of polyethylene film was also a serious flaw. Most people experienced with sampling for Hg in air are aware of the well-known ability of Hg vapor to both penetrate through and sorb onto polyethylene, rendering any conclusions regarding the behavior of Hg within these enclosures highly uncertain and subject to considerable error. It is difficult to understand why these problematic approaches continued to be applied for so long before drawing attention.

Michael McLinden's Comment: Plastic absorbs mercury vapor, might this bias your results low due to Hg absorbtion by the plastic? It would have been helpful to collect a bulk sample of polyethylene before arriving at the facility to set up the containment and a bulk sample of the plastic containment wall just prior to dismantelling to see how much Hg was absorbed by the plastic.

Response: EPA agrees that use of polyethylene most likely biased the measured mercury concentration in the air samples and in the wipe samples due to mercury's ability to permeate through and sorb onto polyethylene. Vinyl sheeting would have most likely been a better choice of materials for the containment structure. This issue is discussed in Chapter 6 in the revised report.

Michael McLinden's Comment:

> ***Report Text:***
> Bulk samples were collected from the particulate filters and carbon filters for each device at the following frequencies:
> ***Comment (Suggested Text Changes Highlighted):*** Bulk samples were collected from the particulate filters and carbon filters for each device using the following procedures:

Response: The wording was changed as suggested. The description of the collection of samples from the pollution control media for each device was moved to Appendix H in the revised report.

Michael McLinden's Comment: Were any bulk samples collected and analyzed prior to the start of Phase I to detect background Hg contamination of the filter media (similar to hydrar Hg background contamination)?

Response: Blank samples of the pollution control media were taken and analyzed. The results are presented in Chapter 5. There was some background mercury in some of the pollution control media, but the mercury levels were quite low.

Michael McLinden's Comment: Please elaborate on what this "mercury absorbing powder" [*that was used to decontaminate the sampling spoons prior to* use] is.

Response: The "mercury absorbing powder," a product called "Hg-X," is described in the revised report. Hg-X reacts with elemental mercury to form HgS, a reaction that occurs readily under ambient indoor conditions.

Michael McLinden's Comment: Please elaborate a bit more on the condition of Manufacturer D DTC and any damage or modifications made to the device by the manufacturer. Sections 4.2.1 and 4.3.1 both give a bit more information but it is difficult to visualize the condition of the device and possible reason for such poor performance.

Response: Information about the problems with the Manufacturer D DTC device can be found in Section 3.5.3 and Appendix I of the revised report. There is a more detailed description than that presented in the draft report

Data Presentation and Evaluation

After reading the comments from the reviewers, EPA determined that the draft report contained insufficient data analysis. In order to answer many of the questions posed by the reviewers, the data collected during the DTC Device Study were reanalyzed, and the discussion of the data was expanded. Two significant changes to Chapter 4 of the report were the addition of background and blank data to this chapter (initially, this information was only presented in Chapter 8: Limitations) and the use of simple statistical comparisons, whenever possible, to evaluate study objectives.

Michael McLinden's Comment: I agree with your conclusion [regarding whether the OSHA PEL is a ceiling or TWA], however, the regulated community will most likely disagree. The Ceiling limit is more difficult to comply with since a short (15 minute) excursion above the ceiling would indicate an over-exposure and violation where as when calculating the 8 hr TWA for the PEL a short excursion would be averaged out over the eight hour shift resulting in no violation. Critics will discount the argument that the PEL has been exceeded arguing that OSHA policy and intent is to enforce the standard as an eight hour TWA. It may be wise to also present a calculated/estimated 8 hr TWA based on Jerome readings. Either extrapolate to 8 hrs using an "average" Jerome Hg reading thought to be representative of the entire 480 minute workday or calculate the concentration (C1) during the actual duration of Jerome sampling (T1) and add to background dose (C2) for the remainder of the shift (T2).

$$\text{8 hr TWA} = \frac{\text{C1 T1} + \text{C2 T2}}{\text{480 minutes}}$$

Response: The OSHA exposure limit for mercury is published in the CFR as a ceiling limit, so the PEL was treated as a ceiling limit for the purposes of this Study. It would be inappropriate for EPA to comment on the discretion that OSHA uses or may use when implementing its own regulations. Also, there is not sufficient Jerome data to perform TWA calculations for each device. EPA did not extrapolate the data to 8 hours because of the potentially widely varying use patterns for DTC devices.

Michael McLinden's Comment: FYI while the TLV is an 8 hour TWA over a 40 hour week, the REL is a TWA based on a 10 hr workday in a 40 hr week to allow for extended work shifts such as overtime). Recommended exposure level (REL) should be recommended exposure limit.

Response: The REL was not used for evaluation in the Study, so the description of the REL was removed from the revised report.

Steven Lindberg's Comment: Background values are often mentioned, but rarely defined as to location. It is never quite clear how any "background or blank" data were treated. What is the meaning of values such as 0.0059/0.014 in Table 4.18? Are these reps? Is this a range? Was N=2?

Response: In the revised report, there is a more complete discussion of blank and background samples in both the data collection section (Chapter 3) and the results section (Chapter 4). The table is not in the revised report. The results for the background air samples can be found in Table 4.1 and Table 4.2.

Carl Herbrandson's Comment: Discussion of the implications of the vapor phase and aerosol data would be helpful. Does the very low level detected in only 7 of about 177 MCEF samples suggest that only Hg vapor is emitted from the DTCs? Or is Hg aerosol that sticks to the MCEF volatilized by the sampling vacuum pump? Does this study help to answer these questions? Should future studies assume that there is no aerosolization?

Response: The draft report did not discuss the low number of the MCE filter samples that had detectable levels of mercury. The revised report contains the following discussion to address this:

> It is important to note that, out of the 199 analytical air samples collected, only eight mercury aerosol (MCE filter) samples had values above the detection limit, and all blank MCE filter samples were below the detection limit. Because the amount of mercury aerosol was not high enough to measure, the air results discussed in this chapter only address the mercury vapor (Hydrar tube) samples. The results for the MCE filters can be found in Appendix A, Table 1. Future research may be necessary to determine whether aerosols were not detected because no aerosolization occurred or because any aerosol mercury collected on the MCE filter was vaporized by the sampling vacuum pump and subsequently sorbed onto the Hydrar tubes.
>
> **(footnote 12, pg. 21)**

The DTC Device Study was not designed to answer the questions posed by the reviewer. EPA agrees that these questions are important and that could be considered for future study.

Steven Lindberg's Comment: Comparisons with the Jerome are mentioned, but never discussed in detail or presented quantitatively. Was there a systematic approach to performing a method intercomparison? It would have been useful to see overlain plots of the Hydrar and Jerome data for periods both were used at the same location. The data "comparison" is inadequate for evaluation of the validity of the airborne Hg data (see above). The only mention of the results of any method comparisons on p. 58 is inadequate ("analysis of Jerome…indicate a similar pattern…"), especially given the objective of the study (to evaluate performance, to quantify emissions, mass balance determination, etc.). The numbers of replicate samples collected was similarly inadequate.

Response: In the revised report, averages of the Jerome data and the analytical air sample (Hydrar tube) data were graphed together to better facilitate comparison of the results from the two air sampling methods. The Jerome data was not complete (due to the malfunctioning data loggers) and did not include enough sampling events to create an overlay plot or to justify statistical comparisons between the two types of data. The language in the report has been revised to reflect the fact that no quantitative comparisons between the Jerome data and the Hydrar data were made. Graphical comparisons of the data are presented in Appendix A, Figures 26, 35 and 43, of the revised report.

As noted above, the study design did not call for replicate testing because one of the basic assumptions of the Study was that there would be changes in device performance over time. Multiple air samples were collected for each device during each test.

Michael McLinden's Comment: After being in the containment for such a long time I'm supprised the gold foil [*on the* Jerome] didn't get overload/over-ranged. Did you have any "over-ranging" problems which necessitated purging the foil??

Response: The model 431-X Jerome analyzer has an improved film regeneration circuit, which makes the sensor last longer than earlier models. When the sensor became saturated while the Jerome analyzer (model 431-X) was attached to the data logger or computer, the analyzer automatically regenerated the sensor and then resumed sampling. The Jerome graphs in Appendix A note when the Jerome was regenerating.

Michael McLinden's Comment: Why were the results inside containment lower than TLV while results outside containment were occassionally above the TLV? – is it due to data logger failing and no data gathered? Which Jerome data-logger failed? Please clarify.

Response: The results inside the containment structure that were lower than the TLV were collected at a different time than the results outside the containment structure that were above the TLV. Thus, there is no data suggesting that the mercury concentration was higher outside the containment structure than inside the containment structure at any point in time. These different Jerome analyzer readings do show that there was variability in the mercury levels. This is clearer in the revised report. Both Jerome data-loggers failed at different points during the Study.

Steven Lindberg's Comment: The statement on p. 47 "as measured by the ambient airborne emissions" is in error. There were no measurements of emissions performed in this study, only estimates based on concentration data.

Response: The report has been revised to make it clear that emissions were not measured.

Michael McLinden's Comment: What size & wattage lamps were processed in Phase II, T-8, T-12? You provide the number of lamps but not the number of each size lamp and wattage of each lamp processed as you did in Table 4.1. In Phase II did you use all Phillips Lighting "Alto" lamps? If you used lamps other than Phillips "Alto" you would have processed more mercury, also if you processed larger lamps you would again process more mercury (in Phase I Manufactruer B device processed 611 T-8 lamps). This seems more likely to contribute to higher phase II result than the higher Phase II background levels.

Response: There were not sufficient Phillips Lighting "Alto®" lamps for use in PVS-II. Because the waste lamps were from different manufacturers, and therefore did not contain a standard amount of mercury, the types of waste lamps processed were not recorded during PVS-II. The possible effects of crushing waste lamps other than Alto® lamps could have impacted the results during PVS-II, and the possible impacts are discussed in the revised report.

Michael McLinden's Comment: Were these low results [*in PVS-phase* I] due to colder temperature resulting in less Hg being volatalized ?.

Response: The temperature most likely had some affect on the amount of mercury that was volatilized during the different parts of the Study; although, this could not be quantified. This is discussed in Section 6.2 of the revised report.

Carl Herbrandson's Comment:

- Location of background, TLV and/or PEL lines on figures 4.2, 4.3, 4.4 and 4.5 aren't at the correct locations. (no background line for Fig 4.1) Similarly, these lines in Appendix A don't always line up right.
- Table 5.2 – Is the "measured mercury" the "average mercury quantity"? Aren't you really reporting the mean of the measured values? Means and averages are confused in this table and others (e.g. Table 5.5).
- %CV is more informative than Std Dev in many of the tables, especially where the means have large ranges (e.g. Table 5.5). What, actually, does the "Standard Deviation" in Table 5.8 describe? This standard deviation may provide some (poor) measure of the mixing between a few locations in the containment area, but still, this column should be omitted. The column contains the standard deviation of measurements that are not realistically comparable. Each measurement describes a unique volume of the containment area. It isn't known if the air at these various locations was moving or quiescent, or if the volume that the concentration described was large or small.
- Appendix A, Table 2-5 label box described as "% valid data" should be renamed something like "% locations with increase".

Steven Lindberg's Comment:

- The term NA is not defined or explained (why not analyzed, or not attempted, or not applicable?).

- The % difference numbers in Table 4.6 are in error based on the definition of the validation (if the Phase II results are > Phase I, the differences would normally be expressed as + values, not -).
- Table 4.9 would have benefited by an inclusion of the corresponding Hydrar trap data.
- Several tables express data with a greater number of significant digits than are justified.
- Several tables show ranges in data, but means and SD would also be useful.
- The Figures (here and in App's) are inconsistently labeled.

Michael McLinden's Comment:

- TABEL ENTRY [*Table 4.6*]: MANUFACTURER C, On Operator during Filter Changes -118%/105%   Should 105% be a negative number?

Response: There were several errors on the labels for the figures and tables throughout the draft report. These errors have been corrected, and the titles for the figures and tables have been changed to provide a more detailed description of the data being presented.

- The PEL and TLV lines were corrected for all figures, and lines for background concentrations were added.
- The "average mercury" actually is the calculated mean. The labels in the tables were corrected. Standard deviations were calculated to describe many means, but this statistic is only presented if it is valid for the measurements being averaged.
- The column describing "% valid data" was removed from the table in Appendix A.
- All notations in tables, such as NA or ND, are now defined in the revised report.
- The % differences column was deleted from Table 4.6 (Table 4.9 in the revised report). Other statistics were used to compare phase I and phase II of the PVS.
- Averages of the Jerome data and the analytical air sample (Hydrar tube) data were graphed together to better facilitate comparison of the results from the two air sampling methods.
- Means and standard deviations are included wherever these descriptive statistics are appropriate and valid.

Michael McLinden's Comment:

Report Text:

As noted in the table, the Hydrar sorbent tube appeared to capture a greater amount of ambient mercury during the sample acquisition period (i.e., when the sample pump was in operation). Furthermore, two of the operator breathing zone samples (one for the Manufacturer C and one for the Manufacturer B) equaled or slightly exceeded the PEL. **The remaining results** for both devices **were above the TLV** and below the PEL. No U-tube tests were performed using the Manufacturer A or Manufacturer D devices.

Comment: In Table 4.19 the results for "Manufacturer B, Operator's right shoulder" indicate 0.018 mg/m3 which is lower than the 0.025 mg/m3 TLV.

Response: The text was corrected to reflect the fact that one of the operator shoulder samples for Manufacturer B was below the TLV. The table is not in the revised report (air sampling results can be found in Appendix A, Table 1).

Carl Herbrandson's Comment: Wipe sample results should be reported as μg/100 cm^2, not μg/sample.

Steven Lindberg's Comment: Was any attempt made to wipe the insides of the drums to determine the sorbed Hg? Was wipe efficiency/extraction/analysis ever determined with knowns? Was the parking lot "wiped" to determine if this approach was an improvement? The other problems with the study design mentioned above would still apply however.

Response: Due to difficulties with contamination, the wipe sample data was not used in the report to support any of the findings or observations; therefore, wipe sample data is presented in Appendix F in the revised report, instead of Chapter 4. The wipe sample results are reported as $\mu g/100cm^2$ in the revised report in Appendix F. The insides of the drums were not wiped. The wipe sample extraction method was developed by Data Chem as a NIOSH method and has been tested by Data Chem. The parking lot was not wiped, and there is no evidence that the change from cutting the polyethylene on the facility floor to cutting the polyethylene outside in the parking lot decreased contamination of the plastic sheeting.

Carl Herbrandson's Comment: Manufacturer A's device was run in ventilation mode throughout the course of the tests – including over night. Is it possible to estimate the mass of overnight emissions from available data? While these emissions are likely to be only a small fraction of the overall emissions for B and C, it is unclear what fraction of A's emissions occur in the ventilation mode.

Response: The data collected for overnight samples is shown in the revised report in Figure 4.15: Overnight Test Sample Results (pg. 63). There is not sufficient data to estimate the mass of overnight emissions.

Steven Lindberg's Comment: The problem of atmospheric contamination ("background") due to broken bulbs in bulb boxes should have been anticipated, or at least recognized sooner. The "box test" is not clearly defined until after the data are presented.

Response: EPA agrees that a more thorough review of the sampling and study plan by researchers more experienced with mercury monitoring would have been beneficial to the study team. The study team added the "Box Test" to the Study in order to quantify the atmospheric contamination due to broken bulbs in bulb boxes; the revised report more clearly defines the Box Test.

Michael McLinden's Comment: Can you elaborate on what happened [*in Figure 4*.6] during the 6th minute and again at the 28th minute to explain these spikes? Was the spike at the 6th minute due to handling and opening the top of the boxes? Also, can you explain why the concentration levels off from about the 8th minutes to the 19th minute but then begins a steady rise? Was the DTC in operation at any point during the test (e.g., from the 8th to the 19th minute) to influence the results shown in Figure 4.6? It may be helpful to explain the box test in more detail, this data alone may have important implications regarding Hg concentrations in and around storage locations of spent/broken lamps in general industry as well as at lamp recycling facilities. Were the air sampling results collected with the Jerome or with sampling pumps?

> ***Response:*** There is not sufficient data to speculate about the cause of the spikes in measured mercury concentration in Figure 4.6 (Figure 4.14 in the revised report). There is a general increase in the ambient mercury concentration, which may be due to mercury release from the broken lamps in the boxes; however, there is not enough data to fully substantiate this hypothesis. The DTC device was not operated during the box test. The air sampling results for the box test in Table 4.17 (same table number in draft report and in revised report) were collected using the Hydrar tubes and sampling pumps.

> ***Steven Lindberg's Comment:*** The phrase "outside the containment" is used, but never defined specifically. Some observations seem trivial (e.g. that the Hg sorbent is more efficient when the pump is running).

> ***Response:*** The phrase "outside the containment" generally referred to the area that was not inside the containment structure but was inside the room in the facilities in which the Study was being conducted. Wherever possible, the revised report specifically describes the locations "outside the containment" where samples were taken.

Mass Balance

One of the questions posed to the peer reviewers by EPA concerned the validity of the discussion of the error associated with the Mass Balance Study. The reviewers generally commented that the amount of uncertainty in the Mass Balance Study was too high to draw any conclusions from that portion of the Study. Therefore, the revised report concentrates on presenting the data collected during the Mass Balance Study, explaining the difficulties encountered during the Study, and providing suggestions for future mass balance studies involving DTC devices.

> ***Carl Herbrandson's Comment:*** The tenor of the mass balance discussion should be changed to focus on why available data can't provide the necessary information for a mass balance. Estimates and calculations should not be reported. A mass balance would be useful for determining the fraction of fluorescent bulb mercury that escapes into the environment from DTCs. However, even as a range estimating tool, this mass balance is not instructive.

> ***Steven Lindberg's Comment:*** The issue of quantitative uncertainty must be addressed for all of these measurements. This is especially true for the mass balance. The uncertainties and assumptions of the mass balance computations must be clearly stated. A serious and critical assessment of uncertainties involved in this particular study might indicate the impossibility of drawing any quantitative conclusions.

> ***Response:*** EPA agrees that the uncertainty in the Mass Balance Study is too high to estimate the different fractions of mercury. The discussion of the Mass Balance Study was revised to present the data collected, the calculations, and the problems encountered. While the high degree of uncertainty does limit the types of analyses that can be performed to evaluate the study results, the data were collected in the field under conditions that were as close to a

probable management scenario as possible. The revised report acknowledges the limitations of this set of data.

Michael McLinden's Comment: I agree with your decision not to use Jerome readings for this portion on the study [*Mass Balance Study*].

Michael McLinden's Comment: Hgu [the amount of mercury captured by the device] missing the amount of Hg adhering to the inside of the DTC device. Hg may have been bound to interior metal and plastic parts of the DTC, this may lower your recovery. Mercury may have been absorbed by plastic containment, lowering your Hgr [the amount of mercury released by the device] result. It might have been wise to collect a pre and post bulk sample of the plastic containment.

Response: These factors are discussed in the revised report in Chapter 5 and Chapter 6. (Note: Hg_U was changed to Hg_C in the revised report. Hg_C is the amount of mercury captured by the device.)

Steven Lindberg's Comment: How much Hg was added to these lamps during manufacturing? The amounts analyzed seem low, depending on date of manufacture.

Response: Table 5.1 in the report lists the amount of mercury added to each type of lamp. The Phillips Lighting Alto® lamps are specifically manufactured to avoid adding excessive amounts of mercury by precisely dosing each lamp.

Carl Herbrandson's Comment: The study design optimized the ability to measure potential exposure concentrations, not the mass emitted from the DTCs. These are two very different goals and require different tools. Attempts to calculate the mass emitted from many different air-Hg concentrations assumes each sample location represents a volume of air in the containment area that is characteristically similar to the other sample locations in: virtual volume, air flow, mixing, replacement rate (or containment area input rate) and removal rate (or containment area exhaust rate). It is likely that each measurement location was very different, and weighting of individual sample results would be necessary to calculate a reasonable emission rate/mass – an impossible task given the study design.

Steven Lindberg's Comment: Why was no attempt made to estimate the gaseous loss based on the air concentration measurements?

Response: EPA recognizes that the Mass Balance Study was not properly designed to achieve the goals stated in the study plan. Mercury emissions were not measured during the DTC Device Study. The air concentration data was used to estimate the amount of mercury released; however, because the study design was not optimal for precise measurement of mercury emissions, there was a significant mass of mercury unaccounted for.

Steven Lindberg's Comment: Given the uncertainties in all the raw data, the SD's shown in Table 5.8 seem much too low. What do they represent?

The number of air exchanges was never measured, but can have an important effect on the calculations. How was this evaluated?

Michael McLinden's Comment: Looking at Figures 27 and 28 in Appendix A it indicates that it took over four hours to fill two drums. Two air changes seems very low for this time period. Making an air tight containment, even sealing plastic with duct tape, is difficult to achieve as demonstrated in asbestos abatement containments which are similar in design and generally tighter than your containment. I suspect you are under estimating the air changes and under estimating fugitive emissions through the door and walls of the containment.
As per Appendix C, [*Manufacturer A*] Drum Top Crusher process description - the fan draws 25 CFM:
25 CFM = (1,440 CF) / (57.6 Minutes)
One Air Change in Minutes = (CF) / (CFM)
(1,440 CF) / (25 minutes) = 57.6 Minutes for one air change
(60 minutes) / (57.6 minutes) = 1.04 Air Changes per hour
(1.04 ACH) X (4 hours) = 4.16 Air Changes over the four hour it takes to fill two drums.
Please elaborate on how you estimated the number of air changes.

Response: The averages shown in Table 5.8 of the draft report were the averages of the air samples from the Performance Validation Study – Phase I. This portion of the Study had the lowest amount of variability between the air samples. The standard deviation is no longer included in this table.
Table 5.8 now includes the data used for the calculation of the number of air exchanges, in addition to the values for the amount of mercury released from the devices.
In the draft report, the numbers of air changes were estimated based on general knowledge. In the revised report, the volumetric flow rate of the DTC device fan was used to estimate the number of air exchanges, following the suggestion of one of the reviewers.
The Mass Balance Study only involved filling one drum per device, so the duration ranged between 86 and 112 minutes. The calculations used to estimate the number of air exchanges for each device are explained in Chapter 5 of the revised report.

The assumption that the Manufacturer A device released a similar amount of mercury as the Manufacturer B and Manufacturer C devices is based on the calculations described in Chapter 5. While this assumption is most likely not correct, additional attempts were not made to correct the estimate for Hg_R because the amount of mercury estimated as being released was very small as a percentage of the total mercury processed through each DTC Device (Hg_R).

Carl Herbrandson's Comment: Problems in estimating barrel content. These problems are well documented in the report and appendix.

Response: As discussed in the limitations section (Chapter 6), the phosphor powder, which tends to contain the largest fraction of the mercury in the drum, sifts to the bottom due to the vibration of the drum in operation. Therefore, any sample taken from a full 55-gallon drum of crushed lamps would likely not be representative of the contents of the drum. Based on such a sample, a determination, that the waste contained in such a drum is not hazardous, may be questionable.

Steven Lindberg's Comment: I could not find any blank data for the contents and components of the DTCs.

Michael McLinden's Comment: New drum filters may be contaminated with background Hg, did you test a filter for backgound?

Response: The blank data for the components of the DTC devices were presented in Table 5.11 in the draft report. These data are presented earlier in Chapter 5 (in Table 5.6) in the revised report.

Steven Lindberg's Comment: Detailed method descriptions for obtaining representative samples of any substrate are lacking.

Response: The description of the collection of samples from the pollution control media of the DTC devices is included in the revised report in Appendix H.

Carl Herbrandson's Comment: Problems with measuring filter/carbon content (e.g. high %CV in carbon samples implies non-uniform capture and poor capture/mass estimate).

Carl Herbrandson's Comment: Errors on the order of 2400, 1100 and 1800 times the estimated mercury vapor emissions; 2, 0.5 and 2 times the calculated barrel contents; or 18, 0.9 and 78 times the calculated filter/carbon mercury could account for the discrepancies in the quantitative mass balance. There is no apparent consistency to the possible error.

Steven Lindberg's Comment: Given the gross differences among the activated C weights used in each DTC, the conclusion that Mfg A device "released" about the same amount of Hg as DTC's B & C seems in error.

Carl Herbrandson's Comment: Jang et al. Waste Management 25 (2005) 5–14 showed a maximum of 36% recovery with an acid extraction of Hg from fluorescent bulbs. Can additional mercury can be released from the bulbs by heating them (part of QA/QCing the methods?)? (This could increase the discrepancy in the attempted mass balance.)

Steven Lindberg's Comment: Did the team attempt to test the method for measuring Hg in lamps? Although some Hg may condense, quantitative condensation seems unlikely.

Response: The study team did not test the method for measuring mercury in spent lamps. The values measured in the spent lamps were slightly lower than the amounts of mercury reported to be added to each Phillips Lighting, Alto® lamp as discussed in Section 5.2 and shown in Table 5.1 and Table 5.2 of the revised report. A reference to Jang et al., 2005 is also included in Section 5.2. Additionally, at the end of Chapter 5 of the revised report, EPA suggests that any future research quantifying the amount of mercury in spent lamps should develop and test a laboratory method with appropriate QA/QC procedures.

Steven Lindberg's Comment: The recovery data in Table 5.11 suggest serious analytical problems which could have influenced much of the other data. Where are similar data for the other sample types and analytical methods?

Response: The recovery data in Table 5.11 for the matrix spikes of the pollution control media do suggest serious analytical problems. These data were presented to help explain the problems with the mass balance. Data Chem Laboratories followed the appropriate QA/QC described in the analytical methods, which are included in Appendix E of the revised report. All QA samples met the criteria specified by the test method being used. The Data Chem Laboratory reports are included in Appendix B.

Operator Observations and Safety Concerns

Steven Lindberg's Comment: Statements made here, and elsewhere, refer to data which are not clearly identified as to their source (Table or Fig. #).

Response: The reviewer did not list specific instances in which data were not clearly identified; however, in the revised report, the actual table and/or figure numbers were included whenever a reference was made to specific data.

Michael McLinden's Comment:

> ***Report Text:***
> Lamp breakage was a common issue for all devices. The fragile lamps often broke before they could be fed into the devices, causing, in some instances, visible release of mercury-containing phosphor powder. The ergonomic orientation of the feed tubes on several devices also exacerbated this problem, where, for example, the operator either had to lower the lamps to waist level or raise them up to shoulder level in order to insert them into the feed tube.
> ***Comment:*** I'm not sure ergonomic is the best/correct word for this situation.

Response: "Ergonomic" was changed to "configuration". **[pg. 86]**

Lessons Learned

Steven Lindberg's Comment: One is left with the impression that the study and sampling design was compromised to decrease costs.

Response: As discussed above, the study team made every effort to carefully collect field data that represented possible mercury exposures associated with DTC device operation. The primary concern in designing and conducting the DTC Device Study was to assess the performance of the four DTC devices tested with regard to operator exposure, and concerns about the cost of the testing were secondary to completing the objectives of the Study. Nevertheless, EPA recognizes that certain decisions made regarding the design of the Study do present problems in analyzing the data.

Limitations

Steven Lindberg's Comment: A statement such as "each facility had a measurable concentration of mercury in ambient air" misrepresents the severity of existing and ongoing contamination encountered during this study, and the degree to which this problem compromised this study and its conclusions. Blanks defined as containing "trace amounts of Hg" but in actuality containing microgram amounts of Hg are also misleading.

Response: The two statements commented on by the reviewer, as well as several other statements on the same topic, were changed in the revised report to better emphasize the degree to which background mercury levels may have impacted the study results. Background mercury concentrations are discussed in Chapter 6 of the revised report.

Steven Lindberg's Comment: Many comments in this section indicate that a thorough design evaluation should have been conducted prior to the study. Surely, some, if not many, of the problems encountered in the field could have been anticipated.

Response: EPA agrees that a review of the original study design by researchers more experienced in mercury sampling would likely have lead to an improved study design.

Steven Lindberg's Comment: Given the degree of variability noted in many of the samples, the assumption that each milliliter of air contains approximately the same concentration of mercury as the adjacent milliliter seems subject to large uncertainty.

Response: The analytical air samples collected thousands of milliliters of air under several different operating and non-operating conditions. These data provide information about possible worker exposure to mercury, as opposed to the specific concentration of mercury in each milliliter of air.

Steven Lindberg's Comment: The data in Table 8.3 should include the appropriate statistical summaries. These data do not support the conclusion drawn below the table regarding concurrence between lab and field blanks (e.g. data from 3/26).

Response: Table 4.4 contains the field blank data. This data was moved to Chapter 4 so that the blank data and the air sampling data could be discussed together. The averages and standard deviations are now presented with these data.

Michael McLinden's Comment: I agree with your conclusion, sample volume is the critical value for calculating concentration, flow rates need to be within the range specified by the analytical method.

Response: The discussion as to whether variations in air sampling pump flow rates may have affected the study results was removed from the revised report.

Conclusions and Recommendations

Carl Herbrandson's Comment: Data from this study shows: high mercury vapor concentrations in existing facilities; high levels of removable (trackable) mercury on floors of existing bulb recycling facilities; and, high mercury vapor concentrations near bulb-transport boxes containing broken bulbs. These data suggest that bulb transport containers and currently operating recycling facilities should be studied for ways to improve their mercury retention and control.

Response: This is an area where further study would be helpful. Some of these topics where included in Section 7.4 (Future Areas for Study).

Steven Lindberg's Comment: As discussed above, the application of any, much less several, correction factors adds significant uncertainty in any conclusions drawn from these data. This results in an inability to draw firm conclusions in my opinion. The study should have encouraged support for the design of improved DTC's, as those tested left much to be desired. The misinformation on Hg included in the manufacturer's manuals should also have been noted.

Response: The correction factors applied to the mass balance data are no longer included in the main body of the revised report. This information is included in Appendix G. The uncertainty associated with the data does limit the information and knowledge that can be drawn from this study; however, a significant amount of relevant information was gained in performing this study. The discussion presented in the revised report was written to provide information about DTC device performance. The report is not a guidance document; however, it provides observations noted in conducting the Study.

Michael McLinden's Comment: Venting outdoors would defeat the purpose of using the DTC device to control emission, suggest venting to a pollution control device rather than simply to outside air.

Response: The revised report does not suggest venting outdoors. The Study was not designed to make specific recommendations or determinations about the most appropriate ventilation for a room in which a DTC device is operated.

Appendices

Steven Lindberg's Comment: As mentioned above, these tables and figures relate poorly to the text, carrying in many cases different and undefined labels compared to comparable items in the main text. There were also no captions. Several experiments are illustrated here which are never described elsewhere (e.g. real world tests).

Response: The tables and figures in the appendices were extensively revised in the final report, including adding captions, to make them clearer and more consistent. The use of terminology such as "real world tests" was removed. The names used for the study components in the original sample and study plan (now contained in Appendix D) were not the names that were used in the report. These inconsistencies have been corrected.

Steven Lindberg's Comment: The scale chosen for the Y axis (Hg concentration in mg/m3) would have been more readable if converted to ug/m3.

Response: The units of mg/m^3 were chosen for the y-axis of the graphs because the OSHA PEL is reported as 0.1mg/m^3.

Steven Lindberg's Comment: The Jerome data were buried in the appendices, with no discussion, despite the capture of several interesting temporal trends in airborne Hg. Why were these never compared directly to the Hydrar data?

Response: In the revised report, wherever possible, the Jerome data were highlighted, discussed, and compared to the Hydrar data. Due to problems with the data loggers, there were significant gaps in the Jerome data, making the uncertainty of the data too high to make quantitative comparisons.

Michael McLinden's Comment: Appendix C – initial paragraph and paragraph below Table AE both reference "the mass balance equation in section 6.0," perhaps this should be Section 5.0.

Response: The discussion regarding the sampling errors and corrections for the Mass Balance Study is now in Appendix G; references to the Mass Balance Study in Appendix G were corrected in the revised report.

Steven Lindberg's Comment: Finally, Appendix D titled Data Chem Methods was blank.

Response: There was an error in distributing the report, and Appendix D was not included in the draft report received by the reviewers. All of the analytical methods and any modifications are included in Appendix E of the revised report.

Mercury Lamp Drum-Top Crusher Study Peer Reviewers:

- Carl Herbrandson, Ph.D., Minnesota Department of Health
- Steven Lindberg, Ph.D., Corporate Fellow Emeritus (retired)
  Environmental Sciences Division, Oak Ridge National Laboratory
- Michael McLinden, M.S., C.I.H., New Jersey Department of Environmental Protection

Carl Herbrandson

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St. Paul MN 55101
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Education

1991 - 1996 **University of Minnesota**, Minneapolis, MN. Degree: Ph.D. in Toxicology

1969 - 1973 **Case Western Reserve University**, Cleveland, OH. Degree: B.A. in English

Research and Professional Experience

1996 – present ***Research Scientist 3***, Minnesota Department of Health, St. Paul, MN

- Toxicologist and Health Assessor for Site Assessment and Consultation Unit, a cooperative partner grantee of the Agency for Toxic Substances and Disease Registry, Center for Disease Control, Atlanta GA
- Review health hazards and risks associated with exposure to chemicals in the environment; evaluate data and conduct health assessments; model potential human exposures; investigate biomarkers which may indicate exposures; and determine the likelihood of conducting successful exposure or health investigations.
- Focus is currently on complex multimedia evaluations with an emphasis on environmental chemistry. Two focus areas of work are fate, exposure and toxicity of heavy metals (primarily mercury and arsenic) and quantitative evaluation of the six potential routes of exposure to organic and inorganic compounds in sediments.
- Recommend sampling and remediation criteria for environmental media.
- Write technical evaluations of potential health impacts of environmental exposures to toxic chemicals for U.S. Agency for Toxic Substances and Disease Registry concurrence.
- Write public health information sheets for affected communities about potential effects of exposure to environmental chemicals and procedures for prudent avoidance or reduction of exposure.
- Represent the Minnesota Department of Health in meetings with responsible parties, state and federal agencies, in interviews with news media, and in interactions with the public.

1996 ***Research Associate***, University of Minnesota, St. Paul, MN

- Design and perform experiments to identify a sex pheromone from Eurasian Ruffe (*Gymnocephalus cernuus)*.
- Endocrine manipulation of fish reproductive cycle; extraction of steroids, prostaglandins and bile acids excreted by fish; *in vitro* receptor binding studies; and *in vivo* electrophysiological studies.

1992 - 1996 ***Graduate Research Assistant***, University of Minnesota, Minneapolis, MN

- Develop laboratory model for investigating toxicodynamic and toxicokinetic interactions of a chemical and a physical stressor on a whole organism in an aquatic environmental system.
- Thesis: Toxicological Effects of Suspended Solids and Carbofuran on *Daphnia magna*, Graduate School of the University of Minnesota, February 1996

1984 – 1991 ***Engineering Research Specialist***, Unisys, Eagan, MN

- Invented and developed a system for passively monitoring the growth rate of YIG crystals which are used as the active element in solid state magnetooptical switches and optical isolators.
- Designed and developed a system for mounting lasers into connectorized fiber optic packages while maintaining laser coupling efficiency into a 6 µm core over a 75° C temperature range.
- Designed and developed a computer automated station for testing superconducting tunnel junctions to be used as sensors.

Invited Lecturer/Instructor

2005 ***Seminar***, University of Minnesota Duluth Medical School: Toxicology/Public Health response to a recent mercury spill. Public health concerns coupled with an emergency response incident required rapid development of public health clearance criteria, modeling likely juvenile exposure, and development of new biomarkers of exposure.

2004 ***Grand Rounds***, Minnesota Poison Control System, Hennepin County Medical Center: Rosemount Woods Mercury Incident. The behavior of a chemical in the environment is important when evaluating exposures and undertaking a successful cleanup.

2004 ***Grand Rounds***, Regions Hospital Department of Emergency Medicine: Rosemount Woods Mercury Incident. Problems related to understanding chemical exposures during an emergency incident: biomarkers, kinetics, analytical issues, and people.

2004 ***Grand Rounds***, University of Minnesota School of Public Health: Public Health and a mercury spill. The responsibility of public health experts in an emergency is to support local officials, communities and medical practitioners.

2003 ***Guest Lecturer***, Toxicology Program, University of Minnesota Graduate School: Toxicology in State Government. When and how we evaluate exposures and assess health.

2003 ***Guest Lecturer***, University of Minnesota School of Public Health: Mercury. The environmental chemistry of mercury: sources, exposures, fate and toxicity.

2003, 2001 ***Guest Lecturer***, Toxicology Program, University of Minnesota Graduate School: Aquatic Toxicology. An introduction to chemicals in the aquatic environment and how they affect aquatic species.

2002 ***Guest Lecturer***, University of Minnesota School of Public Health: Mercury and Arsenic - two toxic heavy metals. How do they behave in the environment and why are we concerned about them?

2001 ***Grand Rounds***, Minnesota Poison Control System, Hennepin County Medical Center: Mercury and Chromated Copper Arsenate. Presentation to poison control specialists, toxicologists and medical practitioners on the environmental chemistry, bioavailability, kinetics and toxicity of mercury and CCA. Included measuring mercury volatilization from the amalgam fillings of audience volunteers with a realtime mercury vapor analyzer and a discussion of the data.

2000 ***Invited Presentation***, Minnesota Metal Finishers Association, Minneapolis, MN: Health concerns associated with metal finishing operations. A review of current epidemiology and toxicology related to aerosols and vapors emitted by metal finishing companies.

2000 ***Invited Presentation***, Minnesota Environmental Health Association Annual Meeting, Brainerd, MN: Clandestine methamphetamine labs. A discussion of potential meth lab exposures and the cleanup criteria derived by the Minnesota Department of Health.

1999 ***Invited Presentation***, Bi-National Forum Meeting, Thunder Bay, Ontario, Canada: Issues related to improving and assuring air quality. Air monitoring, dispersion modeling, chemical reactions in the troposphere, health effects, risk assessment and current regulations were discussed.

1996, 1998 ***Assistant Professor / Instructor***, Department of Fisheries and Wildlife, University of Minnesota. FW 5460: Pollution Impacts on Aquatic Systems. Course was offered during the winter quarter every other year on the principles and experimental techniques for investigating the impacts of chemical pollutants in aquatic environments.

Presentations at ATSDR Partners in Public Health Meetings

2001 **Evaluating sediments at contaminated sites.** What do we know about the behavior of chemicals in sediments? How do groundwater and freeze-thaw cycles affect the integrity of large volumes of chemical wastes in sediments?

2001 **Are clandestine methamphetamine laboratories a public health concern?** Evaluating potential exposures to hazardous chemicals in Clan labs.

2001 **Air modeling or air monitoring?** While ambient air monitoring data are often requested by health assessors, dispersion modeling of stack testing data is typically more useful in evaluating potential hazards from facility emissions.

1999 **Weight of evidence in health assessments.** When quantitative health assessments cannot be performed it is often necessary to use a weight of evidence approach to qualitatively evaluate a potential public health hazard.

Peer reviewed / refereed publications

- Baker, B., C. Herbrandson, T. Eshenaur and R. Messing (2005). Measuring Exposure to an Elemental Mercury Spill — Dakota County, Minnesota, 2004. Morbidity and Mortality Weekly Reports 54(6): 146-149.
- Herbrandson, C., Bradbury, S.P., and Swackhammer, D.L. (2003). Influence of suspended solids on acute toxicity of carbofuran to Daphnia magna: I. Interactive effects. Aquatic Toxicology, 63(4):333-42
- Herbrandson, C., Bradbury, S.P., and Swackhammer, D.L. (2003). Influence of suspended solids on acute toxicity of carbofuran to Daphnia magna: II. An evaluation of potential interactive mechanisms. Aquatic Toxicology, 63(4):343-55
- Herbrandson, C., Bradbury, S.P., and Swackhammer, D.L, (1999) New Testing Apparatus for Assessing Interactive Effects of Suspended Solids and Chemical Stressor on Plankton Invertebrates. Environmental Toxicology and Chemistry, 18:4 679-684.

Selected, authored ATSDR Health Assessment Reports on mercury

2005 **Rosemount Woods mercury incident**. Report includes discussion of: decontamination; the need for exposure and medical screening during the incident; methods of evaluating individual exposures; the environmental chemistry of mercury; quality assurance and control issues related to the use of real-time mercury vapor analyzers; evacuation criteria; re-occupation criteria; vehicle clearance criteria; discussion on the clearance of personal property, and risk communication.

2003 **Drum-top bulb crusher demonstration at the Minneapolis-St. Paul International Airport**. Report reviews published information about mercury contained in and released from fluorescent light bulbs when they are discarded, as well as data acquired during a demonstration of a fluorescent bulb crusher. Regulatory restrictions on the use of this machine in Minnesota are discussed.

2003 **Onyx Special Services, Incorporated**. Report is a review of issues related to human health following attempts to cleanup a mercury recycling facility.

2002 **Chemically contaminated South Minneapolis residence**. Report reviews mercury vapor data acquired using hopkalite tubes (1998) and 2 different realtime monitors (2000, 2001) to evaluate indoor contamination in a house where an amateur chemist used many processes to reclaim precious metals from disposed products.

2001 **Mercury from a gas regulator spill**. Mercury in a low-pressure gas regulator was spilled in the basement of a residence. This report evaluates exposures that may have resulted from the spill and the cleanup.

2001 **Mercury in a Marine residence**. Report evaluates the potential exposures that may occur when thermometers (4) are broken in a home.

Steven E. Lindberg

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Education

Duke University	**B.S.**	1969	Chemistry
Florida State University	**M.S.**	1973	Chemical Oceanography
Florida State University	**Ph.D.**	1979	Geochemistry

Professional Experience

1971-1974	**Graduate Fellow**, Florida State University Department of Oceanography, Tallahassee.
1974-1986	**Research Associate and Staff Member**, Oak Ridge National Laboratory, Oak Ridge, TN.
1987	**Visiting Professor,** Institute of Bioclimatology, University of Göttingen, Germany.
1994	**Visiting Scientist**, Swedish Environmental Research Institute, Göteborg, Sweden.
1995	**Visiting Professor**, University of Stockholm and University of Lund, Sweden
1996-1997	**Visiting Scientist**, Institute of Hydrophysics, GKSS Fed. Laboratory, Geestacht, Germany
1995-*present*	**Adjunct Professor**, School of Public Health, University of Michigan, Ann Arbor, MI; Dept. of Ecology and Evolutionary Biology, The University of Tennessee, Knoxville, TN
1987-1999	**Senior Research Staff Member**, and Group Leader for Atmospheric and Biogeochemical Cycling
2000-*present*	**ORNL Corporate Research Fellow**, Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, TN.
2002	**Visiting Scientist**, Institute of Ecosystem Studies, NY

Honors and Awards

- Alexander von Humboldt Foundation Fellowship Award, 1986-1987
- Elected Fellow, American Association for the Advancement of Science, 1992
- Lab-wide Publication and Technical Achievement Awards, 1985, 1986, 1997, and 2001
- Nominated for Ernest Orlando Lawrence Award, 1990, and ORNL Scientist of the Year, 2001
- American Men and Woman of Science, Who's Who in Science and Technology
- Environmental Sciences Scientific Achievement Award, 1984
- Oak Ridge National Laboratory Significant Achievement Awards: 1983, 1985, 1992, 1995

Professional Activities

- Associate Editor, Environmental Reviews, Science of the Total Environment, Tellus (Sweden)
- Member, Review Boards: EPA Science Advisory Board for Mercury, Swedish EPA Mercury Panel
- Chairman, International Conference on Mercury as A Global Pollutant, 1995-1996; 1999-2001
- Director for Atmospheric Research, Integrated Forest Study, 1986-1990
- Chairman, United States National Atmospheric Deposition Program, 1988-1989
- Conference Chairman (1986-87) and Member of Conference Honorary Committee (since 1983) for the International Conference on Heavy Metals in the Environment

Publications

Six books edited, and over 200 publications authored in the open literature, with more than 110 in refereed journals in the fields of atmosphere/surface exchange, trace metal chemistry, and biogeochemical cycling. Invited lecturer or plenary speaker on atmospheric deposition, mercury, and canopy interactions at more than 100 institutes and conferences in North America, Europe, South America, and Asia.

Funded Proposals, Contracts, and Grants (with ORNL collaborators unless otherwise noted):

1970-1979

- 1975-1976, "Trace Element Emissions from Coal Fired Power Plants" (with A Andren). US Dept. of Energy (DOE) ($50,000).
- 1975-1976, "Geochemical Cycling of Hg in a River-Reservoir System" (with R Turner). NSF-RANN ($90,000).
- 1978, "Mercury Emissions from Mine Spoils" (with D Jackson). NSF-RANN ($75,000).
- 1977-1980, "Trace Element Deposition, Stream Chemistry, and Cycling in Forest Watersheds" (with R. Turner). US DOE ($1,000,000).

1980-1989

- 1981-1982, "Dry Deposition to Petri Dish and Foliar Surfaces" (with C Davidson, CMU). US Environmental Protection Agency (EPA) ($30,000).
- 1981-1983, "Acid Deposition/Forest Canopy Interactions: Mechanisms of Sulfur and Nitrogen Deposition to Forests." Electric Power Research Institute (EPRI) ($675,000).
- 1981-1984, "Atmosphere/Canopy Interactions: Wet Deposition and Rain Chemistry." US DOE ($900,000).
- 1985-1989, "Integrated Forest Study (IFS) of the Effects of Atmospheric Deposition on Forest Nutrient Cycles" (with D Johnson) EPRI (total project $11,600,000).
- 1985-1989, "Atmosphere/Canopy Interactions: Development of Surface Analysis Methods for Dry Deposition." US DOE ($920,000).
- 1987, "Deposition and Atmospheric Chemistry of Nitrogen Compounds" (with G. Gravenhorst, U. Gottingen). West German Federal Ministry for Technology and Alexander von Humboldt Foundation ($45,000).
- 1989, "Atmospheric Deposition and Red Spruce Nutrition in the Great Smoky Mountains National Park" (with D Johnson and H Van Miegroet). USDA Forest Service ($225,000).

1990-1999

- 1990, "A Soft Ionization Mass Spectrometer for the Simultaneous, Real-time Analysis of Biogenic Non-
- methane Hydrocarbons in the Forest Canopy Airspace" (with M Payne, W Chen, and P Hansen). ORNL Seed Money Committee ($100,000).
- 1990, "Integrated Forest Study of the Effects of Atmospheric Deposition on Forest Nutrient Cycles: Synthesis of Results." (with D Johnson) EPRI ($198,000).
- 1990, "Atmospheric Deposition and Red Spruce Nutrition in the Great Smoky Mountains National Park-Testing the Al Hypothesis" (with H Van Miegroet). USDA Forest Service (total project $235,000).
- 1990-1991, "Development of Methods for Network Sampling of Air Toxics in Precipitation" (with S. Vermette, ISWS) USGS ($70,000).

- 1991-1994, "Atmosphere/Canopy Interactions: Surface Analysis of Dry Deposition in Complex Terrain". US DOE ($700,000).
- 1992-1996, "Air/Surface Exchange of Mercury (MASE): Development of Flux Methods and Models". EPRI ($1,195,000).
- 1993-1995, "Elevational Trends in Deposition in the Smoky Mountains" (with S. Nodvin, USBS). NPS ($150,000).
- 1994-1995, "Aerosols at the Sea/Land Interface". (with B Wiman, U Lund) Swedish NFR (NSF) (30,000Kr).
- 1996, "Emission of Mercury from Freshwater Lakes". USEPA ($18,000).
- 1996-1997, "Emission of Mercury from soils in the Elbe River Floodplain". (with R. Ebinghaus, GKSS) German BMFT (15,000DM).
- 1996-1999, "Mercury Emissions from Wetlands in the Florida Everglades". South Florida Water Management District ($400,000).
- 1997-1998, “Mercury Fluxes and Exposure over Contaminated Industrial Soils”. ABB Engineering ($32,000).
- 1997-2000, "Mercury Emissions from Landfills in Florida". Florida DEP ($190,000).
- 1997-2000, “Natural Mercury Emission Study (NaMES): Their Role in the Global Cycle". (with M. Gustin, UNR) EPRI (total project $580,000).
- 1997-2000, "Air/Surface Exchange of Mercury in the Lake Superior Watershed". Lake Superior Trust ($250,000).
- 1998-1999, "Intercomparison of Speciation Methods for Reactive Gaseous Mercury in Ambient Air". (with
- W. Stratton, Earlham College) Florida DEP ($20,000).
- 1998-2000, "Air Mass Trajectories of Mercury Transport in the Arctic Environment" (with T. Meyers, ATDD) NOAA ($100,000).
- 1998-2003, “Atmospheric Deposition in Mountainous Terrain: Scaling up to the Landscape”. (with K Weathers and G Lovett, IES) USEPA and NPS (total project $580,000).
- 1999, “Pilot Studies with Stable Isotopes to Quantifying Air/surface Exchange Rates of Hg, USDOE ($280,000).
- 1999-2000, “Dry Deposition of Mercury in the Florida Everglades”. (with G. Keeler, UMAQL) Florida DEP (total project $200,000).
- 1999-2000, “Emission of Mercury from Chlor-alkali Plants”. (with J. Kinsey, NERL) USEPA (total project $200,000).
- 1999-2000, “Chlor-alkali wastes: Assessing their Role as a Mercury Source in the Great Lakes”. (with J. Nriagu, UM) Great Lakes Protection Fund (total project $225,000).
- 1999-2000, “Evaluating a reactive gaseous mercury sampler for the Arctic”. USEPA and Florida DEP ($65,000).

2000

- 2000-2002, “The role of plants & soils in the biogeochemical cycling of Hg on an ecosystem level, (with UNR/DRI), EPA EPSCOR, ($60,000).
- 2000-2002, “Mercury transport and fate through a watershed: The role of Hg reduction reactions, (with J. Nriagu), USEPA STAR Grant, ($260,000).
- 2000-2004, “Applications of Stable Isotopes to Quantifying Air/surface Exchange Rates of Hg in Whole-ecosystem Manipulation Studies at the ELA, Canada, USDOE ($1,270,000).
- 2000-2004, “Fugitive Mercury Emissions from Non-combustion Sources in the Great Lakes Region, (with Frontier Geosciences), USEPA, GLNPO, ($200,000).

- 2001-2002, "Methylmercury Production in Florida Landfills". Florida DEP ($140,000).
- 2001-2003, “Mercury Emissions from Natural Processes: Scaling to the Landscape". (with M. Gustin, UNR) EPRI ($170,000).
- 2001-2004, "Dynamic Oxidation of Mercury in the Arctic Environment" (with S. Brooks, ATDD) NOAA ($295,000).
- 2002-2005, “Assessment of Natural Source Mercury Emissions” (with UNR/DRI), EPA STAR, (total project $891,500).

[grants last updated in Dec, 2002]

Students Supervised:

Advisor to ORNL Student Interns

- S. Henry, B.S., Chemistry, Earlham College (1976)
- S. Kimbrough, B.S., Biology, College of the South (1976)
- W. Petty, B.S., Biology, Grinnell College (1986)
- A. Pendergrass, B.S., Civil Engineering, Auburn University (1993)
- T. Kuiken, B.S., Chemistry, Rochester State (1999)
- J. Ramierez, Chemistry, U. Puerto Rico (2000)

Advisor to Postdoctoral Researchers at ORNL

- Dr. G. Lovett (Ph.D., Ecology, University of New Hampshire), ORAU Postdoctoral Fellow (1982–1984) (currently Sr. Scientist, Institute of Ecosystem Studies, NY)
- Dr. D. Schaefer (Ph.D., Biogeochemistry, University of New Hampshire), ORAU Postdoctoral Fellow (1986– 1988, currently Asst. Prof., University of Puerto Rico)
- Dr. K.-H. Kim (Ph.D., Marine Chemistry, University of South Florida), ORNL Postdoctoral Fellow (1992– 1994, currently Asst. Prof., University of Seoul, Korea)
- Dr. Hong Zhang (Ph.D., Soil Chemistry, University of Vermont), ORNL Postdoctoral Fellow (1998–2001, currently Assoc. Prof., Tennessee Tech. University, Cookeville)
- Dr. Weijin Dong (Ph.D., Plant Physiology, Tulane University), ORNL Postdoctoral Fellow (2000–2002, currently Assoc. Prof., McNeese State University)

Adjunct Faculty Committee Member for Graduate Students

- C. Potter, Ph.D. in Ecology, Emory University (1983–1985)
- M. Hoyer, Ph.D. in Atmospheric Chemistry, Air Toxics Laboratory, School of Public Health, University of Michigan (1992–1995)
- A. Rea, Ph.D. in Air Quality, Air Quality Measurements Laboratory, School of Public Health, University of Michigan (1994–1998)
- J. Shubzda, M.S. in Forestry, School of Fisheries, Forestry, and Wildlife,
- The University of Tennessee (1995–1999)
- A. Carpi, Ph.D. in Environmental Toxicology, Cornell University (1994–1996).
- A. Vette, Ph.D. in Air Quality, Air Quality Measurements Laboratory, School of Public Health, University of Michigan (1996–1999).
- M. Goodsite, Ph.D. in Atmospheric Chemistry, Department of Chemistry, University of Copenhagen, Denmark (2000-present).

Invited Faculty Opponent for Ph.D. Defense

- W. Ivens, Ph.D. in Biogeochemistry, University of Utrecht, The Netherlands
- (1989–1991)
- Z. Xiao, Ph.D. in Inorganic Chemistry, Chalmers University of Technology, Göteborg, Sweden (1994–1995)
- M. Coggin, Ph.D. in Atmospheric Chemistry, University of Galway, Ireland (1999-2000)
- J. Benesch, M.S. in Environmental Science, University of Nevada, Reno (2001-2002)

Expert External Reviewer for Habilitation to Professor

- Dr. D. Godbold, Habilitation candidate, University of Göttingen, Germany (1990)
- Dr. R. Ebinghaus, Habilitation candidate, University of Lüneberg, Germany (2002)

Informal PhD Advisor

- D. Walschlager, Ph.D. in Geochemistry, University of Hamburg, Germany (1995-1996)
- T. Frescholtz, M.S. in Environmental Science, University of Nevada, Reno (2001-2002)
- K. Scott, Ph.D. in Microbiology, University of Manitoba, Winnipeg, Canada (2001-2002)

Publications-*(in prep and submitted)* *[updated Apr 2003, published list starts below]*

Lindberg, S.E., G. Southworth, E.M. Prestbo, D. Wallschläger, M. A. Bogle, J. Price. Gaseous methyl-and inorganic mercury in landfill gas from landfills in Florida, Minnesota, and California. Atmos. Envir. (in prep).

Schroeder, W.H., A. Steffen, K. Scott, T. Bender, E. Prestbo, R. Ebinghaus, J.Y. Lu and S. E. Lindberg. First International Arctic atmospheric mercury research workshop. Atmos. Envir. (submitted).

Amyot, M., G. Southworth, S.E. Lindberg, H. Hintelmann, J.D. Lalonde, C. Gilmour, J.W.M. Rudd, C.A. Kelly, R. Harris, F.M.M. Morel, A.Poulain, Ken Sandilands. Evolution of dissolved gaseous mercury in large lake enclosures amended with $^{200}HgCl_2$. Can J. Fish Aq Sci (submitted).

Southworth, G. R., S. E. Lindberg, H. Zhang, J. S. Kinsey, F. Anscombe, and F. Schaedlich. Fugitive mercury emissions from a chlor-alkali facility: sources and fluxes to the atmosphere. Atmos. Envir. (submitted).

Kinsey, J. S., Swift, J., Bursey, J., Lindberg, SE, and Southworth, G. Characterization of mercury emissions from the cell building at a U. S. chlor-alkali plant. Atmos. Envir. (submitted).

Lindberg, S., G. Southworth, M. Bogle, T. Blasing, H. Zhang, T. Kuiken, D. Wallschlaeger, J. Price, D. Reinhart, H. Sfeir, J. Owens, and K. Roy. Airborne emissions of mercury from municipal solid wasteNew measurements from three landfills in Florida. JAWMA, (submitted).

W. Dong, S.E. Lindberg, T. Meyers, and J. Chanton. A proposed mechanism of gaseous mercury emission mediated via aquatic plant in the Florida Everglades. Atmos. Envir. (in prep.)

Brooks, SB, K. Scott, and SE Lindberg. Surface Mercury Hg(0) Emissions during Annual Snowmelt at Barrow, Alaska. J. Geophys. Res. (in prep. 5/02).

Brooks, SB, M. Goodsite, SE Lindberg, M Landis, and R. Stevens. Aircraft Studies of Atmospheric Mercury Conversion in the Arctic Marine/Coastal Boundary Layer. Nature (in prep. 6/02).

Tate, Scherbatskoy, Donlon, Keeler, Shanley, Lindberg. Dry Deposition of Hg to a Northern Hardwood Forest (in prep 5/02).

Brooks S., and S. E. Lindberg. Estimates of Springtime Atmospheric Mercury Deposition rates at Barrow, Alaska from Stable Boundary Layer Inverse Method. J. Geophys. Res. (in revision).

Publications (in print) *[updated Apr 2003, new submissions listed above]*

Books and Whole Journal Issues:

L. Levin, D. S. E.Lindberg, and D. Porcella (Guest Eds.). 2000. Special Issue on Mercury Biogeochemistry. Science of the Total Environment: Vols. 259-260-261, 511 pp. Elsevier Publ., N.Y.

Gustin, M-S., S. E. Lindberg, and M. A. Allan (Guest Eds.). 1999. Special Issue: Nevada SToRMS mercury flux intercomparison study: Constraining mercury emissions from naturally enriched surfaces: Assessment of methods and controlling parameters. J. Geophys. Res: 104, No. D17, pp. 21829-21896. American Geophysical Union Publ., Washington.

Lindberg, S. E. (Sr. Guest Ed.). 1998. Special Issue: Atmospheric Transport, Chemistry and Deposition of Mercury. Atmospheric Environment: 32, No. 5, 134 pp. (807-940). Pergamon Press, U.K.

Johnson, D.W., and S.E Lindberg (Eds.). 1992. Atmospheric Deposition and Forest Nutrient Cycling, Ecological Studies Vol. 91, Springer-Verlag, New York, 707 pp.

Norton, S., S. E. Lindberg, and A. L. Page. (Eds.) 1990. Soils, Aquatic Processes, and Lake Acidification, Advances in Environmental Sciences Series Acidic Precipitation, Vol. 4. Springer Verlag, NY., 293 pp.

Lindberg, S. E., A. L. Page, and S. Norton. (Eds.) 1990. Sources, Deposition, and Canopy Interactions, Advances in Environmental Sciences Series Acidic Precipitation, Vol. 3. Springer Verlag, NY., 332 pp.

Lindberg, S. E. and T. C. Hutchinson (Eds.). 1987. Proceedings of the Sixth International Conference on Heavy Metals in the Environment, New Orleans, LA, September 15-18, 1987, CEP Limited Publishers, Edinburgh, UK.

Shriner, D. S., C. R. Richmond, and S. E. Lindberg (Eds.) 1980. Atmospheric Sulfur Deposition. Ann Arbor Science Publishers, Ann Arbor, MI, 568 pp.

Journal Papers and Book Chapters:

In Press

Gustin, M-S., and S.E. Lindberg. Understanding the role of natural ecosystems in the biogeochemical cycle of Hg. Proc. Air Quality-III (in press).

2000's

Johnson, D.W., Benesch, J.A., Gustin, M.S., Schorran, D.E., Coleman, J., and Lindberg, S.E. 2003. Soil gaseous Hg and CO2 concentrationsresponse to watering, plants, and evidence against diffusion control of Hg flux, Science of the Total Environment 304: 175-184.

Gustin, M.S, M. Coolbaugh, M. Engle, B. Fitzgerald, R. Keislar, S. Lindberg, D. Nacht, J. Quashnick, J. Rytuba, C. Sladek, H. Zhang, R. Zehner. 2003. Atmospheric Mercury Emissions from Mine Wastes and Surrounding Geologically Enriched Terrain. Envir. Geol. 43:339-351.

J. Ericksen, M.S. Gustin, D. Schorran, D. Johnson, S. Lindberg, and J. Coleman. 2003. Accumulation of atmospheric mercury in forest foliage, Atmos. Envir. 37:1613-1622.

Hintelmann, H., V. St.Louis, K. Scott, J.Rudd, S. E. Lindberg, D. Krabbenhoft, C. Kelly,A. Heyes, R. Harris, and J. Hurley. Reactivity and mobility of newly deposited mercury in a Boreal catchment, 2003. Envir. Sci. & Technol. 36:5034-5040.

Lindberg, S. E., W. Dong, and T. Meyers. 2002. Transpiration of gaseous mercury through vegetation in a subtropical wetland in Florida. Atmos. Envir. 36: 5200-5219.

Zhang, H, Lindberg, S, Gustin, M, and Xu, X. Towards A Better Understanding of Mercury Emissions from Soils. IN Cai, Y, and Braids, O. C. Eds., Biogeochemistry of Environmentally Important Trace Elements, ACS Symposium Series 835, American Chemical Soc, Washington.

Wallschlèger, D., Kock, H.H., Schroeder, W.H., Lindberg, S.E., Ebinghaus, R. and Wilken, R.D. 2002. Estimating gaseous mercury emissions from contaminated floodplain soils to the atmosphere with simplified field measurement techniques. Water, Air, Soil, Pollut. 135: 39-54.

Van Miegroet, H. I.F. Creed, N.S. Nicholas, D.G. Tarboton, K.L. Webster, J. Shubzda, B. Robinson, J. Smoot, D.W. Johnson, S.E. Lindberg, G. Lovett, S. Nodvin, S. Moore. 2001. Is there synchronicity in N input and output fluxes at the Noland Divide Watershed, a small N-saturated forested catchment in the Great Smoky Mountains National Park? In Optimizing Nitrogen Management in Food and Energy Production and Environmental ProtectionProceedings of the 2nd International Nitrogen Conference on Science and Policy. TheScientificWorld 1 (S2), 480-492.

Lindberg, S. E., Brooks, S.B., C-J. Lin, K. J. Scott, M. S. Landis, R. K. Stevens, M. Goodsite, and A. Richter. 2002. The Dynamic Oxidation of Gaseous Mercury in the Arctic Atmosphere at Polar Sunrise, Envir. Sci. & Technol. 36: 1245-1256.

Zhang, H, Lindberg, SE, Barnett, MO, Vette, AF, Gustin, MS. 2002. Dynamic flux chamber measurement of gaseous mercury emission fluxes over soils, Part 1 Simulation of gaseous mercury emissions from soils measured with dynamic flux chambers using a two-resistance exchange interface model. Atmospheric Environment 36: 835-846.

Lindberg, SE, Zhang, H, Vette, AF, Gustin, MS, Barnett, MO, and Kuiken, T. 2002. Dynamic flux chamber measurement of gaseous mercury emission fluxes over soils, Part 2 Effect of flushing flow rate and verification of a two-resistance exchange interface simulation model. Atmospheric Environment 36: 847-859.

Zhang, H., and S.E. Lindberg. 2002. Dissolved gaseous mercury in Whitefish bay and the Taquemenon River watershed in the Michigan Upper Peninsula: Distribution and dynamics. Water, Air, Soil, Pollut. 133: 379-389.

Rea, A.W.; Lindberg, S.E.; Scherbatskoy, T. 2002. Mercury accumulation in foliage over time in two northern mixed-hardwood forests. Water, Air, Soil, Pollut. 133: 49-67.

Lindberg, S. E., S. Brooks, C-J Lin, K. Scott, T. Meyers, L. Chambers, M. Landis, and R. Stevens. 2001. Formation of reactive gaseous mercury in the arcticevidence of oxidation of Hg° to gas-phase Hg-II compounds after arctic sunrise Water, Air and Soil Pollution: Focus, 1: 295-302.

Lindberg, S.E., S.B. Brooks, M. Landis, and R. Stevens. 2001. Comments on atmospheric mercury species in the European Arctic: Measurements and modeling, Atmospheric Environment 35:5377-5378.

Levin, L., Lindberg, S. and Gustin, M. 2001. Uncertainties in Mass Balance of U.S. Atmospheric Mercury Emissions. IN *Air-Surface Exchange of Gases and Particles Poster Proceedings* (D. Fowler,

C. E. R. Pitcairn, L. Douglas and J-W. Erisman, Eds.). Publ. By Center for Ecology and Hydrology, Edinburgh.

Lindberg S. E. and T. P. Meyers. 2001. Development of an automated micrometeorological method for measuring the emission of mercury vapor from wetland vegetation. Wetland Ecology & Management, 9: 333-347.

St.Louis, VL, JW Rudd, CA. Kelly, BD.Hall, KR. Rolfhus, KJ. Scott, SE. Lindberg, and W Dong. 2001. The importance of the forest canopy to fluxes of methyl mercury and total mercury to boreal ecosystems, Envir. Sci. & Technol. 35: 3089-3098.

Munthe, J., I. Wängberg, N. Pirrone, Å. Iverfeldt, R. Ferrara, P. Costa, R. Ebinghaus, X.Feng, K. Gårdfelt, G. Keeler, E. Lanzillotta, S. E. Lindberg, J. Lu, Y. Mamane, E.Nucaro, E. Prestbo, S. Schmolke, W. H. Schroeder, J. Sommar, F. Sprovieri, R.K.Stevens, W. Stratton, G. Tuncel, A. Urba. 2001. Intercomparison of methods for sampling and analysis of atmospheric mercury species. Atmos. Env. 353007-3017.

Lindberg, S.E., D. Wallschlaeger, E. Prestbo, N. Bloom, J. Price, and D. Reinhart. 2001. Methylated mercury species in municipal waste landfill gas sampled in Florida. Atmospheric Environment 35: 4011-4015.

Lindberg, S. E., Brooks, S., Lin, C-J., Scott, K., Richter, A., Meyers, T., Stevens, R., and Landis, M. 2001. Studies of interactions between reactive gaseous mercury and elemental mercury vapor during polar spring at Point Barrow, Alaska. Proc. of International Symposium on the Measurement of Toxic and Related Air Pollutants Symposium held in Research Triangle Park, North Carolina, September 1214, 2000.

Rea, A.W., S.E. Lindberg, and G. Keeler. 2001. Dry deposition and foliar leaching of mercury and selected trace elements in deciduous forest throughfall. Atmospheric Environment 35: 1352-2310.

Zhang, H, and S.E. Lindberg. 2001. Sunlight and iron(III)-induced photochemical production of dissolved gaseous elemental mercury in fresh water. Envir. Sci. & Technol. 35: 928-935.

Stratton, W. J., S. E. Lindberg, and C.J. Perry. 2001. Atmospheric Mercury Speciation: Critical evaluation of a mist chamber method for measuring reactive gaseous mercury, Envir. Sci. & Technol. 35: 170-177.

Zhang, H., S. E. Lindberg, F. J. Marsik, and G. J. Keeler. 2001. Mercury air/surface exchange kinetics of background soils of the Taquamenon River watershed in the Michigan Upper Peninsula. Water, Air, Soil, Pollut. 126: 151-169.

Lindberg, S. E., S. Brooks, C-J Lin, K. Scott. 2001. Recent research on missing sources and sinks in the global mercury cycle: The role of the Arctic. Proc. NIMD Forum-01, publ. by the National Institute of Minamata Disease Press, pp. 53-58.

Gustin, M..S. and S. E. Lindberg. 2000. Assessing the contribution of natural sources to the global mercury cycle: The importance of intercomparing dynamic flux measurements. Invited paper for Fresenious Journal of Analytical Chemistry, 366: 417-422.

Zhang H., and S. E. Lindberg. 2000. Air/water exchange of mercury in the Everglades I: The behavior of dissolved gaseous mercury (DGM). Science of the Total Environment 259: 123-134.

Lindberg, S. E., and Zhang H. 2000. Air/water exchange of mercury in the Everglades II: Measuring and modeling evasion of mercury from surface waters. Science of the Total Environment 259: 135144.

Gustin, M..S. and S. E. Lindberg, K. Austin, M. Coolbaugh, A. Vette, and H. Zhang. 2000. Assessing the contribution of natural sources to regional atmospheric mercury budgets. Science of the Total Environment 259: 61-72.

Rea, A.W., S.E. Lindberg, and G. Keeler. 2000. Development of a washing technique for measuring dry deposition of mercury to foliage and surrogate surfaces, Envir. Sci. & Technol. 34: 2418-2425.

Lindberg, S.E., S. Brooks, C-J Lin, T. Meyers, and L. Chambers. 2000. **BAMS**- the **B**arrow **A**rctic **M**ercury **S**tudy: a preliminary description of recent measurements of mercury depletion events at Point Barrow, Alaska. CD-ROM Proceedings, 25th International Conference on Heavy Metals in the Environment, Ann Arbor, MI (6-10 August, 2000).

Marsik, F.J., G. Keeler, E. G. Malcolm, J. T. Dvonch, J. A. Barres, S. E. Lindberg, H. Zhang, R. K. Stevens and M. S. Landis. 2000. FEDDS: The Florida Everglades Dry-Deposition Study. CD-ROM Proceedings, 25th International Conference on Heavy Metals in the Environment, Ann Arbor, MI (6-10 August, 2000).

Lindberg, S. E., P. J. Hanson, W. Stratton, T. Meyers, K. Kim, A. Carpi, H. Zhang, J. Owens, M. Gustin, R.Turner, J. Munthe, F. Schaedlich, J Price, M. Barnett, and D. Wallschlèger. 2000. The Role of Mercury Air/surface Exchange Processes in the Global Biogeochemical Cycle: a Brief Summary of Research by the ORNL Mercury Group, Proc. NIMD Forum-99, publ. by the National Institute of Minamata Disease Press.

Lindberg, SE, A. Vette, C. Miles, and F. Schaedlich. 2000. Application of an automated mercury analyzer to field speciation measurements: Results for dissolved gaseous mercury in natural waters. Biogeochemistry, 48(2), 237-259.

Lindberg, S. E., W. J. Stratton, P. Pai, and M. Allan. 2000. Measuring and modeling concentrations of a water-soluble gas-phase mercury species in ambient air. Fuel Proc. Technol. 1288: 65, 143-156.

Wallschlèger, D., Kock, H.H., Schroeder, W.H., Lindberg, S.E., Ebinghaus, R. and Wilken, R.D. 2000. Mechanism and significance of mercury volatilization from contaminated floodplains of the German river Elbe. Atmos. Environ 34:3745-3755.

1990's

Weathers, K.C., G.M. Lovett, S.E. Lindberg, S.M. Simkin, D.N. Lewis and M.L. Chambers. 1999. Atmospheric deposition in mountainous terrain: Scaling up to the landscape. EOS, Trans. American Geophysical Union: 80, 390.

Lindberg, S. E., D. Reinhart, P. McCreanor, and J. Price. 1999. Pathways of mercury release in municipal solid waste disposal: A preliminary data report. Proceedings Sardinia 99, Seventh International Waste Management and Landfill Symposium, 4-8 October, 1999, pp. 225-232. CISA, Environmental Sanitary Engineering Centre, Cagliari, Italy.

Gustin, M-S., S. E. Lindberg, and M. A. Allan. 1999. Preface to the Nevada StoRMS mercury emissions project special issue. J. Geophys. Res: 104, 21829-21830.

Lindberg, S.E., Zhang, H., Gustin, M., Vette, A., Owens, J., Marsik, F., Casimir, A., Ebinghaus, R., Edwards, G., Fitzgerald, C., Kemp, J., Kock, H.H., London, J,. Majewski, M., Poissant, L., Pilote, M., Rasmussen, P., Schaedlich, F., Schneeberger, D., Sommar, J., Turner, R., Walshlager, D., and Xiao, Z. 1999. Increases in mercury emissions from desert soils in response to rainfall and irrigation. J. Geophys. Res: 104, 21879-21888.

Zhang, H. and Lindberg, S.E. 1999. Processes influencing the emission of mercury from soils: a conceptual model, J. Geophys. Res: 104, 21889-21896.

Gustin, M-S., S. E. Lindberg, Casimir, A., Ebinghaus, R., Edwards, G., Fitzgerald, C., Kemp, J., Kock, H.H., London, J,. Majewski, M., Owens, J., Marsik, F., Poissant, L., Pilote, M., Rasmussen, P., Schaedlich, F., Schneeberger, D., Sommar, J., Turner, R., Vette, A., Walshlager, D., Xiao, Z., and Zhang, H. 1999. The Nevada SToRMS Project: Measurement of mercury emissions from naturally enriched surfaces. J. Geophys. Res: 104, 21831-21844.

Lindberg, SE, and J Price. 1999. Measurements of the airborne emission of mercury from municipal landfill operations: A short-term study in Florida. J. Air and Waste Man. Assoc. 49:174-185.

Ebinghaus, R., Tripathy, R., Wallschlèger, D., and Lindberg, S.E. 1999. Natural and anthropogenic mercury sources and their impact on the air-surface exchange of mercury on the global scale. IN Ebinghaus, R., Turner, R., LaSerda, D., Vasiliev, O., and Salomons, W. (Eds.), Mercury contaminated sites: Characterization, risk assessment, and remediation, pp. 1-50. Springer-Verlag Environmental Science Series.

Lindberg, S. E., P. J. Hanson, T.P. Meyers, and K-Y Kim. 1998. Micrometeorological studies of air/surface exchange of mercury over forest vegetation and a reassessment of continental biogenic mercury emissions. Atmos. Envir. 32:895-908.

Carpi, A. and S.E. Lindberg. 1998. Application of a teflon dynamic flux chamber for quantifying soil mercury fluxes: tests and results over background soils. Atmos. Envir. 32:873-882.

Lindberg, S. E. 1998. A Listening and Liberating Science: The Ultimate Problem of Education. IN The Art of Natural Resource Management: Poetics, Policy, Practice (Eds.: B.L.B. Wiman, I. M. B. Wiman, S. L. Vanden Akker), pp. 348-351. Lund University Press.

Lindberg, S. E. and W. J. Stratton. 1998. Atmospheric mercury speciation: Concentrations and behavior of reactive gaseous mercury in ambient air. Envir. Sci. & Technol. 32:49-57.

Carpi, A., S. E. Lindberg, E. M. Prestbo, and N. S. Bloom. 1997. Global and regional impacts of elemental and methyl mercury emitted by soils to the atmosphere. J. Env. Qual. 26:1650-1655.

Hanson, P. J., T. Tabberer, and S. E. Lindberg. 1997. Emissions of Mercury Vapor from Tree Bark. Atmos. Envir. 31: 777-780.

Kim, K-H., P. J. Hanson, M. O. Barnett, and S. E. Lindberg. 1997. Biogeochemistry of mercury in the air-soil-plant system. Met. Ions Biol. Syst., 34: 185-212.

Carpi, A. and S. E. Lindberg. 1997. The sunlight mediated emission of elemental mercury from soil amended with municipal sewage sludge. Envir. Sci. & Technol. 31:2085-2091.

Lindberg, S. E. 1996. Forests and the Global Biogeochemical Cycle of Mercury: The Importance of Understanding Air/vegetation Exchange Processes. IN: Baeyens, W., Ebinghaus, R., Vasiliev, O. (eds.): Global and Regional Mercury Cycles: Sources, Fluxes and Mass Balances. NATO-ASI-Series, Vol. 21, Kluwer Academic Publishers, Dordrecht, The Netherlands, 359-380.

Iverfeldt, A., S.E. Lindberg, S. Karamata, G. Anoshin, M. Horvat, T. Laperdina, A. Obolenskiy, K. Osmonbetov, C. Ramel, N. Roslyakov, and V. Tausen. 1996. Working group report on terrestrial mercury cycling. IN: Baeyens, W., Ebinghaus, R., Vasiliev, O. (eds.): Global and Regional Mercury Cycles: Sources, Fluxes and Mass Balances. NATO-ASI-Series, Vol. 21, Kluwer Academic Publishers, Dordrecht, The Netherlands, 543-546.

Meyers, T.P., M.E. Hall, and S.E. Lindberg. 1996. Use of the modified Bowen ratio technique to measure fluxes of trace gases. Atmos. Envir. 30: 3321-3329.

Meyers, T.P. and S. E. Lindberg, 1996: Use of the Modified Bowen Ratio technique for determining fluxes of mercury. Proceedings of the 22nd Conference on Agriculture and Forest Meteorology with Symposium on Fire and Forest Meteorology, January 28 - February 2, 1996, Atlanta, GA, American Meteorology Society, Boston, MA, pp. 11-14.

D. Holland, C. Simmons, L. Smith, T. Cohn, G. Baier, J. Lynch, J. Grimm, G. Oehlert, S. Lindberg. 1995. Long-term trends in NADP/NTN precipitation chemistry data: results of different statistical analyses. Water, Air, Soil Pollut. 85: 595-601.

Shubzda, J., S. E. Lindberg, C. T. Garten, and S. C. Nodvin. 1995. Elevational trends in the fluxes of sulfur and nitrogen in throughfall in the southern Appalachian Mountains: Some surprising results. Water, Air, Soil, Pollut. 85: 2265-2270.

Nodvin, S. C., H. VanMiegroet, S. E. Lindberg, N. S. Nicholas, and D. W. Johnson. 1995. Acidic deposition: Ecosystem processes and nitrogen saturation in a high elevation southern Appalachian watershed. Water, Air, Soil, Pollut. 85: 1647-1652.

Lindberg, S. E., Meyers, T. P., and J. Munthe. 1995. Evasion of mercury vapor from the surface of a recently limed acid forest lake in Sweden. Water, Air, Soil, Pollut. 85: 725-730..

Kim, K.-H., Lindberg, S. E., and Meyers, T. P. 1995. Micrometeorological measurements of mercury fluxes over background forest soils in eastern Tennessee. Atmos. Envir. 27:267-282.

Stratton, W. J. and S. E. Lindberg. 1995. Use of a refluxing mist chamber for measurement of gas-phase water-soluble mercury (II) species in the atmosphere. Water, Air, Soil, Pollut. 80: 1269-1278.

Lindberg, S.E., K-H. Kim, T.P. Meyers, and J.G. Owens. 1995. A micrometeorological gradient approach for quantifying air/surface exchange of mercury vapor: Tests over contaminated soils. Envir. Sci. Technol. 29:126-135.

Lindberg, S. E., K.-H. Kim, and J. Munthe. 1995. The precise measurement of concentration gradients of mercury in air over soils: a review of past and recent measurements. Water, Air, Soil, Pollut. 80: 383-392.

Vermette, S.J., M.E. Peden, T.C. Willoughby, S.E. Lindberg, and A.D. Weiss. 1995. Methodology for the sampling of metals in precipitation: Results of the National Atmospheric Deposition Program (NADP) pilot network. Atmos. Envir. 29: 1221-1230.

Kim, K.-H and S. E. Lindberg. 1995. Design and initial tests of a dynamic enclosure chamber for measurements of vapor-phase mercury fluxes over soils. Water, Air, Soil, Pollut. 80: 1059-1068.

Vermette, S.J., S.E. Lindberg, and N. Bloom. 1995. Field tests for a regional mercury deposition network: Sampling design and test results. Atmos. Envir. 29: 1247-1252.

Johnson, D. W. and S. E. Lindberg. 1995. Sources, sinks, and cycling of Mercury in forested ecosystems. Water, Air, Soil, Pollut. 80: 1069-1077.

Lindberg, S.E. and S.J. Vermette. 1995. Workshop on sampling mercury in precipitation for the National Atmospheric Deposition Program. Atmos. Envir. 29: 1219-1220.

Hanson, P. J., S. E. Lindberg, T. A. Tabberer, J. G. Owens, and K.-H. Kim. 1995. Foliar exchange of mercury vapor: evidence for a compensation point. Water, Air, Soil, Pollut. 80: 373-382.

Lindberg, S.E., J.G. Owens, and W. Stratton. 1994. Application of throughfall methods to estimate dry deposition of mercury. IN J. Huckabee and C. Watras, (Eds.), Mercury as A Global Pollutant, pp. 261-272. Lewis Publ.

Kim, K.-H. and Lindberg, S. E. 1994. High-precision measurements of mercury vapor in air: Design of a six-port-manifold mass flow controller system and evaluation of mass flow errors at atmospheric pressure. J. Geophys. Res. 99: 5379-5384.

Erisman J. W., C. Beier, G. Draijers, and S. Lindberg. 1994. Review of deposition monitoring. Tellus 46B: 79-93.

Ross, H., and S.E. Lindberg. 1994. Atmospheric chemical input to small catchments. IN B. Moldan and J. Cerny (Eds.), pp. 55-84, Biogeochemistry of Small Catchments: A Tool for

Environmental Research, United Nations SCOPE Series Vol. 51, John Wiley and Sons.

Kim, K.K., S.E. Lindberg, P.J. Hanson, T.P. Meyers, and J. G. Owens. 1993. Application of micrometeorological methods to measurements of mercury emissions over contaminated soils. In Proceedings of the Ninth International Conference on Heavy Metals in the Environment, Vol I. pp. 328331. CEP Limited Publishers, Edinburgh, UK. Text also reproduced in Proceedings of the First Workshop on Emissions and Modelling of Atmospheric Transport of Persistent Organic Pollutants and Heavy Metals, J.M. Pacyna et. al. (Eds.), USEPA Report EMEP/CCC-Report: 7/93, 1993.

Lovett, G.M. and S.E. Lindberg. 1993. Atmospheric deposition and canopy interactions of nitrogen in forests. Can. J. For Res. 23:1603-1616.

Erisman J. W., C. Beier, G. Draijers, and S. Lindberg. 1993. Deposition Monitoring: Background Document. Appendix 6, IN Lövblad G., J. Erisman, and D. Fowler (Eds), Models and Methods for the Quantification of Atmospheric Input to Ecosystems, Published by The Nordic Council of Ministers, pp 163-183.

Feier C., S. Braun, J. Brook, G. Campbell, G. Draaijers, K. Hansen, D. Kallweit, R. Lenz, S. Lindberg,

H. Staaf, and R. Stary. 1993. Deposition Monitoring. Chapter 7, IN Lövblad G., J. Erisman, and D. Fowler (Eds), Models and Methods for the Quantification of Atmospheric Input to Ecosystems, Published by The Nordic Council of Ministers, pp 37-41.

Lindberg, S. E. and J. G. Owens. 1993. Deposition to Edges and Gaps in Mountain Forests: Throughfall Studies at Two Elevations in The Smoky Mountains. Biogeochemistry 19:173-194.

Johnson, D.W., S.E. Lindberg, H. Van Miegroet, G.M. Lovett, D.W. Cole, M.J. Mitchell, and D. Binkley. 1993. Atmospheric deposition, forest nutrient status, and forest decline: Implications of the Integrated Forest Study. IN Huettl, R., and Mueller-Dombois (Eds.), pp. 66-81, Proc. International Conf. on Forest Decline in the Pacific Rim., Springer-Verlag, NY.

Wu, Y-L., C.I. Davidson, Lindberg, and A. Russell. 1992. Resuspension of particulate chemical species at forested sites. Envir. Sci. Technol. 26:2428-2435.

Lindberg, S. E. and G. M. Lovett. 1992. Deposition and forest canopy interactions of airborne sulfur: Results from the Integrated Forest Study. Atmos. Envir. 26A:1477-1492.

Tjoelker, M.G., S. B. McLaughlin, R. DiCosty, S.E. Lindberg, and R.J. Norby. 1992. Seasonal Variation of Nitrate Reductase Activity in Needles of High-elevation Red Spruce Trees. Can. J. For Res. 22: 375-380.

Lovett, G.M., and Lindberg, S.E. 1992. Concentration and deposition of particles and vapors in a vertical profile through a forest canopy. Atmos. Envir. 26A:1469-1476.

Lindberg, S.E., T.P. Meyers, G.E. Taylor, R.R. Turner, and W.H. Schroeder. 1992. Atmosphere/surface exchange of mercury in a forest: Results of modeling and gradient approaches. J. Geophys. Res. 97: 2519-2528.

Bredemeier, M. and S.E. Lindberg. 1992. Stoffeinträge in Einzelniederschlags und periodischen Gesamt Niederschlagsproben in einem Fichtenwald: Ein methodischer Vergleich. Staub Reinhaltung der Luft 52: 67-72.

Lindberg, S. E., Garten C. T. Jr., Cape J. N., and Ivens W. 1992. Can sulfate fluxes in forest canopy throughfall be used to estimate atmospheric sulfur deposition?-A summary of recent results. IN, Slinn,

W.G.N. Precipitation Scavenging and Atmosphere-Surface Exchange, Vol. 3, Applications and Appraisals, pp. 1379-1390. Hemisphere Publ., Washington, DC, 1808 pp.

Johnson, D. W., S. E. Lindberg, and L. F. Pitleka. 1992. Introduction. Chapter 1 IN Johnson, D.W., and S.E Lindberg (Eds.). Atmospheric Deposition and Forest Nutrient Cycling , Ecological Studies Vol. 91, Springer-Verlag, New York, pp. 1-7.

Lindberg, S.E. Atmospheric deposition and canopy interactions of sulfur. 1992. IN Johnson, D.W., and Lindberg, S.E. (Eds.). Atmospheric Deposition and Forest Nutrient Cycling , Ecological Studies Vol. 91, Springer-Verlag, New York, pp. 72-90 in Chapter 5: Sulfur cycles.

Lindberg, S. E., D. W. Johnson and E. A. Bondietti. 1992. Background on research sites and methods.

Chapter 2 IN Johnson, D.W., and S.E Lindberg (Eds.). Atmospheric Deposition and Forest Nutrient Cycling , Ecological Studies Vol. 91, Springer-Verlag, New York, pp. 8-26.

Mitchell, M. J., R. B. Harrison, J. W. Fitzgerald, D. W. Johnson, S. E. Lindberg, Y. Zhang, and A. Autry. 1992. Sulfur distribution and cycling in forests. IN Johnson, D.W., and S.E Lindberg (Eds.).

Atmospheric Deposition and Forest Nutrient Cycling , Ecological Studies Vol. 91, Springer-Verlag, New York, pp. 90-140 in Chapter 5: Sulfur cycles.

Ragsdale, H. L., S. E. Lindberg, G. M. Lovett and D. A. Schaefer. 1992. Atmospheric deposition and throughfall fluxes of base cations. IN Johnson, D.W., and S.E Lindberg (Eds.). Atmospheric Deposition and Forest Nutrient Cycling , Ecological Studies Vol. 91, Springer-Verlag, New York, pp. 235-253 in Chapter 8: Base cations.

Schaefer, D. A., S. E. Lindberg and G. M. Lovett. Canopy Interactions. 1992. Processing of acidic deposition. IN Johnson, D.W., and S.E Lindberg (Eds.). Atmospheric Deposition and Forest Nutrient Cycling , Ecological Studies Vol. 91, Springer-Verlag, New York, pp. 444-449 in Chapter 11: Processing of acidic deposition.

Lindberg, S. E. 1992. Summary and synthesis of the Integrated Forest Study: Atmospheric deposition and its interactions with the forest canopy. IN Johnson, D.W., and S.E Lindberg (Eds.). Atmospheric Deposition and Forest Nutrient Cycling , Ecological Studies Vol. 91, Springer-Verlag, New York, pp. 571-580 in Chapter 14: Synthesis and modeling of the results of the Integrated Forest Study.

Johnson, D. W. and S. E. Lindberg. 1992. Implications of the Integrated Forest Study for understanding forest nutrient cycles. IN Johnson, D.W., and S.E Lindberg (Eds.). Atmospheric Deposition and Forest Nutrient Cycling , Ecological Studies Vol. 91, Springer-Verlag, New York, pp. 580-582 in Chapter 14: Synthesis and modeling of the results of the Integrated Forest Study.

Vermette, S. J., Peden, M., Hamdy, S., Willoughby, T., Lindberg, S. E., Owens, J. G., and Weiss, A. 1992. A pilot network for collection and analysis of trace metal wet deposition. IN Verry, S. and Vermette, S. J. (Eds.) Trace Metals in Atmospheric Deposition, USDA Forest Service Report No. NC150, North Central Forest Experiment Station, St. Paul, MN.

Vermette, S. J., Peden, M., Willoughby, T., Lindberg, S. E., and Weiss, A. 1992. Pilot network for metals in wet deposition. Preprint # 92-69.06, Air and Waste Mgmt. Assoc. 85th Ann. Mtg., 12 pp.

Lindberg, S. E., R.R. Turner, T.P Meyers, G.E Taylor, and W.H. Schroeder. 1991. Atmospheric concentrations and deposition of airborne Mercury to Walker Branch Watershed. Water, Air, Soil, Pollut. 56:577-594.

Johnson, D.W., H. Van Miegroet, S.E. Lindberg, R. Harrison, and D. Todd. 1991.Nutrient cycling in red spruce forests of the Great Smoky Mountains. Can. J. For. Res. 21:769-787.

Hanson, P.J. and S.E. Lindberg. 1991. Dry deposition of reactive nitrogen compounds: A review of leaf, canopy, and nonfoliar measurements. Atmos. Envir. 25A:1615-1634.

Petty, W., and S.E. Lindberg. 1990. A comprehensive 1-month investigation of trace metal deposition, atmospheric concentrations, and throughfall at a mountain spruce forest. Water, Air, Soil, Pollut. 53:213-226.

Lindberg, S. E., M. Bredemeier, D. A. Schaefer, and L. Qi. 1990. Atmospheric concentrations and deposition of nitrogen compounds and major ions during the growing season in conifer forests in the United States and West Germany. Atmos. Envir. 24A:2207-2220.

Wiman, B., M. Unsworth, S. E. Lindberg, B. Bergqvist, R. Jaenicke, and H-C. Hansson. 1990. Perspectives on aerosol deposition to natural surfaces: Interactions between aerosol residence times, removal processes, the biosphere, and global environmental change. J. Aerosol Science 21:313-338.

Taylor, G.E., P.J. Hanson, and S.E Lindberg. 1990. Deposition and emission of trace gases in controlled environments: A conceptual model, experimental methodologies, and application of results to the disciplines of physiological ecology and biogeochemistry. IN Payer, H.D. (Ed.), Environmental Research with Plants in Closed Chambers, Air Pollution Research Report 26:

Commission of the European Communities, Brussels, pp. 194-215.

1980's

Lindberg, S. E. 1989. Application of surface analysis methods to studies of atmospheric deposition in forests. p. 269-283, IN Ulrich, B. (Ed.), International Congress on Forest Decline Research: State of Knowledge and Perspectives, Kernforschungszentrums Karlsruhe GmbH.

Hanson, P. J., K. Rott, G. E. Taylor, Jr., C. A. Gunderson, S. E. Lindberg, and B. M. Ross-Todd. 1989. NO_2 Deposition to forest landscape surfaces. Atmos. Envir. 23: 1783-1794.

Hicks, B. B., D. R. Matt, R. T. McMillen, J. D. Womack, M. L. Wesely, R. L. Hart, D. R. Cook, S. E. Lindberg, R. G. de Pena and D. W. Thomson. 1989. A field investigation of sulfate fluxes to a deciduous forest, J. Geophys. Res. 94: 13003-13011.

Schaefer, D. A., S. E. Lindberg, and W. A. Hoffman. 1989. Fluxes of undissociated acids to terrestrial ecosystems by atmospheric deposition. Tellus 41B: 207-218.

Lindberg, S. E., and T. Butler. 1989. On composition of particles dry deposited to an inert surface at Ithaca, NY, and Author's response. Atmos. Envir. 23: 279-280.

Ottar, B., Lindberg, S. E., Voldner, E., Lindqvist, O., Mayer, R., Steinnes, E., and Watt, J. 1989. Special topics concerning interactions of heavy metals with the environment. In Pacyna, J. and Ottar, B. (eds.). Control and Fate of Atmospheric Trace Metals, NATO Advanced Science Institute Series, Kluwer Academic Publishers, Dordrecht, Holland, pp. 365-372.

Lindberg, S. E. 1989. Behavior of Cd, Mn, and Pb in forest canopy throughfall, In Pacyna, J. and Ottar, B. (eds.). Control and Fate of Atmospheric Trace Metals, NATO Advanced Science Institute Series, Kluwer Academic Publishers, Dordrecht, Holland, pp. 233-258.

Johnson, D. W. and S. E. Lindberg. 1989. Acidic deposition on Walker Branch Watershed. In Adriano, D. and W. Salomons (eds.). Acidic Precipitation, Vol. I: Case Studies, Advances in Environmental Sciences Series, Springer Verlag, NY. pp. 1-33.

Lindberg, S. E., R. C. Harriss, W. A. Hoffman, G. M. Lovett, and R. R. Turner. 1989. Atmospheric chemistry, deposition, and canopy interactions. IN D. W. Johnson and R. I. Van Hook (eds.) Analysis of Biogeochemical Cycling Processes in Walker Branch Watershed. Springer Verlag, Berlin, pp. 96163.

Lindberg, S. E., G. M. Lovett, D. A. Schaefer and M. Bredemeier. 1988. Coarse aerosol deposition velocities and surface-to-canopy scaling factors from forest canopy throughfall. J. Aerosol Science 19: 1187-1190.

Lindberg, S. E., D. Silsbee, D. A. Schaefer, J. G. Owens, and W. Petty. 1988. A comparison of atmospheric exposure conditions at high- and low-elevation forests in the southern Appalachian Mountains. In Unsworth, M. and Fowler, D. (Eds.). Processes of Acidic Deposition in Mountainous Terrain, Kluwer Academic Publishers, London, pp. 321-344.

Lindberg, S. E., and C. T. Garten, Jr. 1988. Sources of sulfur in forest canopy throughfall. Nature 336:148-151.

Lindberg, S. E. and R. R. Turner. 1988. Factors influencing atmospheric deposition, stream export, and landscape accumulation of trace metals in four forested watersheds. Water, Air and Soil Pollut. 39:123-156.

Richter, D. D. and S. E. Lindberg. 1988. Incident precipitation and forest canopy throughfall: Analyses of sampling methods. J. Envir. Qual. 17:619-622.

Johnson, D.W., A.J. Friedland, H. Van Miegroet, R.B. Harrison, E. Miller, S.E. Lindberg, D.W. Cole, D.A. Schaefer, and D.E. Todd. 1988. Nutrient status of some contrasting high elevation forests in the eastern and western United States. p. 463-469 IN: Proceedings of Symposium The Effect of Atmospheric Pollutants on Spruce Fir Forests in the Federal Republic of Germany and the Eastern United States, Burlington, VT, Oct. 18-23, 1987.

Lindberg, S. E., G. M. Lovett, and K. J. Meiwis. 1987. Deposition and canopy interactions of airborne nitrate. In T. C. Hutchinson and K. Meema (eds.) Proceedings Advanced NATO Workshop on Effects of Acidic Deposition on Ecosystems, Springer-Verlag, NY, pp. 117-130.

Johnson, D. W., S. E. Lindberg, E. A. Bondietti, D. W. Cole, G. M. Lovett, M. Mitchell, L. H. Ragsdale, and L. F. Pitelka. 1987. The Integrated Forest Study: A status report. Proc. Air Pollut. Control. Assoc. Annual Meeting, Paper 87-34.4, New York, June 21-26, 1987.

Barrie, L. A., S. E. Lindberg, W. H. Chan, H. B. Ross, R. Arimoto, and T. M. Church. 1987. On the concentration of trace metals in precipitation. Atmos. Environ., 21:1133-1135.

Petty, W. and S. E. Lindberg. 1987. An intensive study of Pb deposition to a high elevation spruce forest in the Appalachian Mountains. In Procedings of the sixth International Conference on Heavy Metals in the Environment, New Orleans, LA, September 15-18, 1987, CEP Limited Publishers, Edinburgh, UK.

Coe, J. M. and S. E. Lindberg. 1987. The morphology and size distributions of atmospheric particles deposited on foliage and inert surfaces. J. Air Pollut. Control Assoc., 37:237-243.

Lindberg, S. E., P. M. Stokes, E. Goldberg, C. Wren. 1987. Rapporteur's report on mercury. In T. C. Hutchinson and K. Meema (Eds.), Lead, Cadmium, and Mercury in the Environment, United Nations Scientific Committee on Problems in the Environment Series, John Wiley, NY, p. 17-34.

Lindberg, S. E. Emission and deposition of atmospheric mercury vapor. 1987. In T. C. Hutchinson and K. Meema (Eds.), Lead, Cadmium, and Mercury in the Environment, United Nations Scientific Committee on Problems in the Environment Series, John Wiley, NY, p. 89-106.

Lindberg, S. E. 1986. Collection and analysis of trace metals in continental precipitation at forested sites in southeastern U.S. In Barrie, L. (Ed.). Measurement of Metals in Precipitation, Atmospheric Environment Service Publishers, Toronto, Canada.

Hicks, B. B., M. L. Wesley, S. E. Lindberg, and S. M. Bromberg (Eds.), 1986. Proceedings of the Dry Deposition Workshop of the National Acid Precipitation Assessment Program. March 25-27, 1986. NOAA/ATDD, P. O. Box 2456, Oak Ridge, TN 37831.

Lovett, G. M. and S. E. Lindberg. 1986. Dry deposition of nitrate to a deciduous forest. Biogeochemistry, 2:137-148.

Lindberg, S. E., and S. B. McLaughlin. 1986. Current problems and future research needs in the acquisition, interpretation, and application of data in terrestrial vegetation - air pollutant interaction studies. IN. A. Legge and S. V. Krupa (Eds.), Air Pollutants and Their Effects on the Terrestrial Ecosystem, pp. 449-504. John Wiley and Sons, New York, NY.

Lindberg, S. E. 1986. Mercury vapor in the atmosphere: Three case studies on emission, deposition, and plant uptake. pp. 535-560, In Nriagu J. O., and C. I. Davidson (eds.) Metals in the Air. John Wiley and Sons, New York, 635 pp..

Lindberg, S. E., G. M. Lovett, D. R. Richter, and D. W. Johnson. 1986. Atmospheric deposition and canopy interaction of major ions in a forest. Science 231:141-145.

Mayer, R. and S. E. Lindberg. 1985. Deposition on heavy metals to forest ecosystems -- their distribution and possible contribution to forest decline. Proceedings Fifth International Conference on Heavy Metals in the Environment, CEP Consultants Ltd. Publishers, Edinburgh, UK, Vol. 1, 351-353.

Lindberg, S.E. 1985. The production history of the Waltham Maximus. Bull. Nat. Assoc. Watch and Clock Coll. 27:174-188.

Lovett, G. M., S. E. Lindberg, D. D. Richter, and D. D. Johnson. 1985. The effects of acidic deposition on cation leaching from a deciduous forest canopy. Can. J. For. Res. 15:1055-1060

Turner, R. R., S. E. Lindberg, and J. M. Coe. 1985. Comparative analysis of trace metal accumulation in forest ecosystems. Proceedings Fifth International Conference on Heavy Metals in the Environment, CEP Consultants Ltd. Publishers, Edinburgh, UK, Vol. 1, 356-358.

Lindberg, S. E. and R. C. Harriss. 1985. Mercury in rain and throughfall in a tropical rain forest. Proceedings Fifth International Conference on Heavy Metals in the Environment, CEP Consultants Ltd. Publishers, Edinburgh, UK, Vol. 1, 527-529.

Johnson, D. W., D. D. Richter, G. M. Lovett, and S. E. Lindberg. 1985. The effects of atmospheric deposition on K, Ca, and Mg cycling in two forests. Can. J. For. Res. 15:773-782.

Davidson, C. I., S. E. Lindberg, J. Schmidt, L. Cartwright, and L. Landis. 1985. Dry deposition of sulfate onto surrogate surfaces. Journal Geophysical Research 90:2121-2130.

Lindberg, S. E. and G. M. Lovett. 1985. Field measurements of particle dry deposition rates to foliage and inert surfaces in a forest canopy. Envir. Sci. Technol. 19:238-244.

Lindberg, S. E., J. M. Coe, and W. A. Hoffman. 1984. Dissociation of weak acids during Gran plot free acidity titrations, Tellus 36B:186-191.

Lindberg, S. E., G. M. Lovett, E. A. Bondietti, and C. I. Davidson. 1984. Recent field studies of dry deposition to surfaces in plant canopies. Air Pollution Control Association Meeting Proceedings, Vol. 6, Chapter 84-108.5, p. 1-15, APCA, Pittsburgh, PA.

Lovett, G. M. and Lindberg, S. E. 1984. Dry deposition and canopy exchange in a mixed oak forest determined from analysis of throughfall. J. Appl. Ecol. 21:1013-1028.

Lindberg, S. E., and R. R. Turner. 1983. Trace metals in rain at forested sites in the eastern United States. Proceedings Fourth International Conference on Heavy Metals in the Environment, pp. 107-114, CEP Consultants Ltd. Publishers, Edinburgh, UK, 1284 pp.

Lindberg, S. E., R. R. Turner, and G. M. Lovett. 1983. Mechanisms of the flux of acidic compounds and heavy metals onto receptors in the environment. In Löbel, J. and W. R. Thiel (Eds.) Acid Precipitation: Origin and Effects, p. 165-172. Lindau, FRG, June 1983. Verlag des Vereins Deutscher Ingenieure, Düsseldorf, FRG.

Lindberg, S. E. and G. M. Lovett. 1983. Application of surrogate surface and leaf extraction methods to estimation of dry deposition to plant canopies. IN H. R. Pruppacher, R. G. Semonin, and W. G. N. Slinn (Eds.), Precipitation Scavenging, Dry Deposition and Resuspension. Elsevier Science Publ., New York, Vol. 2, pp. 837-848.

Lindberg, S. E. and R. C. Harriss. 1983. Water and acid soluble metals in atmospheric particles. Jour. Geophys. Res. 88:5091-5100.

Johnson, D. W., G. S. Henderson, D. D. Huff, S. E. Lindberg, D. D. Richter, D. S. Shriner, D. E. Todd, and J. Turner. 1982. Cycling of organic and inorganic sulfur in a chestnut oak forest. Oecologia 54:141-148.

Lindberg, S. E., R. R. Turner, and G. M. Lovett. 1982. Processes of atmospheric deposition of metals and acids to forests. Air Pollution Control Association Annual Meeting Proceedings, Paper 82-55M.3, Vol. 4, Chapter 10, pp. 1-14, APCA, Pittsburgh, PA.

Hoffman, W. A., Jr., S. E. Lindberg, and R. R. Turner. 1982. Characterization of covalent constituents in coal conversion solid wastes, Envir. Pollut. 4:219-229.

Lindberg, S. E. , R. C. Harriss, and R. R. Turner. 1982. Atmospheric deposition of metals to a forest canopy. Science 215:1609-1611.

Ferguson, N. M., S. E. Lindberg, and J. D. Vargo. 1982. A simple reverse-phase column clean-up for the determination of sulfate in aqueous leachates containing organic compounds. International Journal of Environmental Analytical Chemistry 11:61-65.

Lindberg, S. E., D. S. Shriner, and W. A. Hoffman, Jr. 1982. The interaction of wet and dry deposition with the forest canopy. Chapter 17. IN Acid Precipitation: Effects on Ecological Systems, pp. 385-409. Ann Arbor Science Publishers, Ann Arbor, MI, 506 pp.

Hosker, R. P., and S. E. Lindberg. 1982. Review Article: Atmospheric deposition and plant assimilation of airborne gases and particles. Atmos. Environ. 16:889-910.

Lindberg, S. E. 1982. Factors influencing trace metal, sulfate, and hydrogen ion concentrations in rain. Atmos. Environ. 16:1701-1709.

Chen, N.C.J., R. E. Saylor, and S. E. Lindberg. 1982. Plume washout around a major coal-fired power plant: Results of a single storm event. Chapter 2. IN Energy and the Environment, pp. 11-22. American Chemical Society.

Lindberg, S. E., R. R. Turner, D. S. Shriner, and D. D. Huff. 1981. Atmospheric deposition of heavy metals and their interaction with acid precipitation in a North American deciduous forest. Proceedings Third International Conference on Heavy Metals in the Environment, pp. 306-309. CEP Publishers, Edinburgh, U.K., 732 pp.

Lindberg, S. E. and R. C. Harriss. 1981. The role of atmospheric deposition in an eastern U.S. deciduous forest. Water, Air, Soil Pollut. 15:13-31.

Lindberg, S. E. 1981. The relationship between Mn and sulfate ions in precipitation. Atmos. Environ. 15:1749-1753.

Lindberg, S. E. 1981. A reply on the efficiency of in-plume mercury vapor collection by activated charcoal. Atmos. Environ. 15:631-634.

Lindberg, S. E. 1981. Mercury in the atmosphere - A new problem? Laboratory News, Oak Ridge National Laboratory, February 1981.

Parker, G., S. E. Lindberg, and J. M. Kelly. 1980. Atmosphere canopy interactions in southeastern U.S. forested watersheds. IN D. S. Shriner, C. R. Richmond, and S. E. Lindberg (Eds.), Atmospheric Sulfur Deposition, pp. 477-493. Ann Arbor Science Publishers, Ann Arbor, MI, 568 pp.

Lindberg, S. E., and R. P. Hosker. 1980. Effluent delivery and air mass/landscape interactions: An overview. IN D. S. Shriner, C. R. Richmond, and S. E. Lindberg (Eds.), Atmospheric Sulfur Deposition. pp 181-184. Ann Arbor Science Publishers, Ann Arbor, MI, 568 pp.

Hoffman, W. A., S. E. Lindberg, and R. R. Turner. 1980. Some observations of organic constituents in rain above and below a forest canopy. Environ. Sci. Technol. 14:999-1002.

Lindberg, S. E., and R. C. Harriss. 1980. Trace metal solubility in aerosols produced by coal combustion. IN J. Singh and A. Deepak (Eds.), Environmental and Climatic Impacts of Coal Utilization, Academic Press, NY, 655 pp.

Lindberg, S. E. 1980. Mercury partitioning in a power plant plume and its influence on atmospheric removal mechanisms. Atmos. Environ. 14:227-231.

Hoffman, W. A., S. E. Lindberg, and R. R. Turner. 1980. Precipitation acidity: The role of the forest canopy in acid exchange. Jour. Environ. Quality 9:95-100.

1970's

Lyon, W. S., S. E. Lindberg, J. F. Emery, J. A. Carter, N. M. Ferguson, R. I. Van Hook, and R. J. Raridon. 1979. Analytical determination and statistical relationships of 41 elements in coal from three coal-fired steam plants. IN Nuclear Activation Techniques in the Life Sciences, pp. 615-625. IAEA-SM-227/61, International Atomic Energy Agency, Vienna, Austria.

Lindberg, S. E., D. R. Jackson, J. W. Huckabee, S. A. Janzen, M. J. Levin, and J. R. Lund. 1979. Atmospheric emission and plant uptake of mercury from agricultural soils near the Almaden mercury mine. J. Environ. Qual. 8:572-578.

Turner, R. R., and S. E. Lindberg. 1978. Behavior and transport of mercury in a river-reservoir system downstream of an inactive chloralkali plant. Environ. Sci. Technol. 12:918-923.

Ausmus, B. S., S. Kimbrough, D. R. Jackson, and S. E. Lindberg. 1979. The behavior of hexachlorobenzene in pine forest microcosms: Transport and effects on soil processes. Environ. Pollut. 13:103-111.

Turner, R. R., S. E. Lindberg, and K. Talbot. 1977. Dynamics of trace element export from a deciduous watershed, Walker Branch, Tennessee. IN D. L. Correll (Ed.), Watershed Research in Eastern North America, pp. 661-681. Smithsonian Institution Press, Washington, DC, 419 pp.

Lindberg, S. E., and R. C. Harriss. 1977. Release of dissolved mercury and organic matter from resuspended near-shore sediments. J. Water Pollut. Control Fed. 7:2479-2487.

Lindberg, S. E., and R. R. Turner. 1977. Mercury emissions from chlorine production solid waste deposits. Nature 268:133-136.

Lindberg, S. E., R. R. Turner, N. M. Ferguson, and D. Matt. 1977. Walker Branch Watershed element cycling studies: Collection and analysis of wetfall for trace elements and sulfate. IN Correll, D. L. (Ed.), Watershed Research in Eastern North American. pp. 125-150. Smithsonian Institution Press, Washington, DC, 469 pp.

Andren, A. W., and S. E. Lindberg. 1977. Atmospheric input and origin of selected trace elements in Walker Branch Watershed, Oak Ridge, TN. Water Air Soil Pollut. 8:199-215.

Bate, L. C., S. E. Lindberg, and A. W. Andren. 1976. Elemental analysis of water and air solids by neutron activation. J. Radioanal. Chem. 32:125-135.

Lindberg, S. E., A. W. Andren, R. J. Raridon, and W. Fulkerson. 1975. Mass balance of trace elements in Walker Branch Watershed - The relation to coal-fired power plants. Environ. Health Perspect. 12:9-18.

Bate, L. C., S. E. Lindberg, and A. W. Andren. 1975. Analysis of water and air by neutron activation. Trans. Am. Nucl. Soc. 21(Suppl. 3):20-21.

Lindberg, S. E., A. W. Andren, and R. C. Harriss. 1975. Geochemistry of mercury in the estuarine environment. pp. 64-107. IN L. Cronin (Ed.), Estuarine Research, Vol. I: Chemistry and Biology. Academic Press, NY, 750 pp.

Lindberg, S. E., and R. C. Harriss. 1974. Mercury enrichment in estuarine plant detritus. Mar. Pollut. Bull. 5:93-95.

Lindberg, S. E., and R. C. Harriss. 1974. Mercury - organic matter associations in estuarine sediments and their interstitial water. Environ. Sci. Technol. 8:459-462.

Lindberg, S. E., and R. C. Harriss. 1973. Mechanisms controlling pore water salinities in a salt marsh. Limnol. Oceanogr. 18:788-791.

Reports

Marcy, S. M. Dam, D. Dasher, R. Dietz, L. Duffy, M. Evans, S. Juntto, S. Lindberg, L. Lockhart, S. Naido, T. O'Hara, J. Pacyna, A. Robertson, E. Yngvadottir, and G. Asmund. 2000. Mercury in the Arctic: An Update, In Arctic Monitoring and Assessment Program (AMAP) Report on Issues of Concern, AMAP Report 2000: 4, Stromsveien, Norway.

Lindberg, S. E., K. Roy, and J. Owens. 1999. PaMSWaD (Pathways of Mercury in Solid Waste Disposal): ORNL sampling operations summary and preliminary data report for PaMSWaD-I, Brevard County Landfill. A Report to the Florida Department of Environmental Protection.

Lindberg, S.E., Zhang, H., and Meyers, T.P. 1999. Final Report: Everglades Mercury Air/Surface Exchange Study (E-MASE). South Florida Water Management District, West Palm Beach, FL.

Lindberg, S.E. and Meyers, T.P. 1998. Everglades Mercury Air/Surface Exchange Study (E-MASE): Second Annual Report. South Florida Water Management District, West Palm Beach, FL.

Lindberg, S.E., Meyers, T.P., and Miles, C. 1997. Everglades Mercury Air/Surface Exchange Study (E-MASE): First Annual Report. South Florida Water Management District, West Palm Beach, FL.

Wilken, R-D.; Lindberg, S. E.; Horvat, M.; Petersen, G.; Porcella, D.; Schroeder, B.; Wisniewski, J. R.; Wisniewski, J.; Wheatley, B., Wheatley, M.; and Wyzga, R. 1996. Fourth International Conference on Mercury as a Global Pollutant: Conference Summary Report. GKSS Research Centre, Hamburg, Germany.

Expert Panel on Mercury (22 authors). 1994. Mercury Atmospheric Processes: A Synthesis Report. Workshop Proceedings, R. H. Osa (Coord. Ed.), EPRI/TR-104214, Electric Power Research Institute, Palo Alto, CA.

Turner, R.S., R.B. Cook, H. Van Miegroet, D.W. Johnson, J.W. Elwood, O.P. Bricker, S.E. Lindberg, and G.M. Hornberger. 1990. Watershed and Lake Processes Affecting Chronic

Surface Water Acid-Base Chemistry. National Acid Precipitation Assessment Program State-of-Science/Technology Report 10, 167 pp., NAPAP, Washington, DC.

Lindberg, S. E. 1990. Throughfall and foliar extraction. Section 5.3.2.2, pp. 206-208. In: Hicks, B.B., R. R. Draxler, D. L. Albritton, F. C. Fehsenfeld, M. Dodge, S. E. Schwartz, R. L. Tanner, J. M. Hales, T. P. Meyers, and R. L. Vong. Atmospheric Processes Research and Process Model Development. National Acid Precipitation Assessment Program State-of-Science/Technology Report 2, 298 pp., NAPAP, Washington, DC.

Lindberg, S.E. and D.W. Johnson (eds.). 1989. 1988 Annual Report of the Integrated Forest Study, ORNL/TM 11121, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Lindberg, S.E. and D.W. Johnson, (eds.). 1989. 1988 Annual Report of the Integrated Forest Study, ORNL/TM 11121, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Lindberg, S.E. and D.W. Johnson, (eds.). 1989. 1987 Annual Group Leader Reports of the Integrated Forest Study, ORNL/TM 11052, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Lindberg, S. E., D.W. Johnson, G. M. Lovett, G. E. Taylor, H. Van Miegroet, and J.G. Owens. 1989. Sampling and Analysis Protocols and Project Description for the Integrated Forest Study. ORNL/TM 11214, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Fox, D.G., A. Bartuska, J. Byrne, E. Cowling, R. Fisher, G. Likens, S. Lindberg, R. Linthurst, J. Messer, and D. Nichols. 1989. A screening procedure to evaluate air pollution effects on class I wilderness areas. U.S. Department of Agriculture Forest Service, Rocky Mt. Forest and Range Experiment Station,General Technical Report RM-168.

Lindberg, S. E. Bowersox, V., Bigelow, D., Knapp, W., Olsen, T. (Eds). 1985. Annual data summary of precipitation chemistry in the United States. National Atmospheric Deposition Program, Colorado State University, Fort Collins, CO.

Lindberg, S. E., Lovett, G. M., and Coe, J. M. 1984. Acid deposition/forest canopy interactions. Final report RP-1907-1, Electric Power Research Institute, Palo Alto, CA.

McLaughlin, S. B., D. J. Raynal, A. H. Johnson, and S. E. Lindberg. 1983. Forests, In the Acidic Deposition Phenomenon and Its Effects, Section E3, Effects on Vegetation. The Acid Deposition Phenomenon, Critical Assessment Review Papers, EPA-600/8-83-016BF.

Lindberg, S. E. 1983. Dry deposition to petri dish and foliar surfaces, Final report to Carnegie-Mellon University, In Davidson, C. I., and S. E. Lindberg, Final Report to EPA on Illinois Intercomparison Deposition Studies.

Turner, R. R., P. Lowry, M. Levin, S. E. Lindberg, and T. Tamura. 1982. Leachability and aqueous speciation of trace constituents in coal fly ash. EPRI report EA 2588. Electric Power Research Institute, Palo Alto, CA.

Hildebrand, S. G., S. E. Lindberg, R. R. Turner, J. W. Huckabee, R. H. Strand, J. R. Lund, and A. W.Andren. 1980. Biogeochemistry of Mercury in a River-Reservoir System: Impact of an Inactive Chloralkali Plant on the Holston River - Cherokee Reservoir, Virginia and Tennessee, ORNL/TM-6141, Oak Ridge, National Laboratory, Oak Ridge, TN.

Davidson, C. I., and S. E. Lindberg. 1980. Alternative viewpoints on surrogate surfaces. IN B. B. Hicks, M. L. Wesley, and J. L. Durham, Critique of methods to measure dry deposition: Workshop summary. pp. 66-70. EPA-600/9-80-050, Environmental Protection Agency, RTP, NC.

Lindberg, S. E., R. C. Harriss, R. R. Turner, D. S. Shriner, and D. D. Huff. 1979. Mechanisms and rates of atmospheric deposition of trace elements and sulfate to a deciduous forest canopy. ORNL/TM-6674. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 510 pp.

Turner, R. R., J. W. Elwood, C. Feldman, and S. E. Lindberg. 1978. Chemical speciation in fly ash leachates: Importance and determination with specific reference to arsenic. Project Completion Report to the Electric Power Research Institute, Palo Alto, CA.

Turner, R. R. and S. E. Lindberg. 1976. Interlaboratory comparison of trace metal analyses by graphite furnace atomic absorption spectroscopy. ORNL/TM-5422. Oak Ridge National Laboratory, Oak Ridge, TN. 2l pp.

Andren, A. W., S. E. Lindberg, and L. C. Bate. 1975. Atmospheric input and geochemical cycling of selected trace elements in Walker Branch Watershed. ORNL/NSF/EATC-13. Oak Ridge National Laboratory, Oak Ridge, TN. 68 pp.

Turner, R. R., S. E. Lindberg, and A. W. Andren. 1974. Concentrations of C, N, ^{137}Cs, and selected heavy metals in a sediment core from Lake Jackson, Florida. IN Job Completion Report for the State of Florida Game and Freshwater Fish Commission, Study VI, Lake Jackson Investigations.

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EDUCATION:

M.S., Occupational and Environmental Health Science
Hunter College, City University of New York (1994)
B.S., Zoology
San Diego State University (1982)
A.A., History
Ocean County College (1978)

PROFESSIONAL ASSOCIATIONS:

Certified in the comprehensive practice of industrial hygiene by the American Board of Industrial Hygiene (ABIH)

Diplomat of the American Academy of Industrial Hygiene (AAIH)

Full member of the American Industrial Hygiene Association (AIHA)

EXPERIENCE:

Research Scientist I (Industrial Hygienist) (8/04 - Present)
Center for Occupational Medicine
New Jersey Department of Environmental Protection
Senior industrial hygienist responsible for the development and implementation of occupational health policies, procedures and health and safety programs throughout the Department. Performed workplace exposure evaluations, air monitoring and training in order to maintain compliance with applicable regulations. Major projects included work on asbestos management, bloodborne pathogens, chemical hygiene plans, confined space entry, ergonomics, indoor air quality, mercury and other metals, noise, nuclear emergency preparedness, pesticides and respiratory protection.

Research Scientist I (5/98 – 8/04)
Office of Pollution Prevention & Right to Know
New Jersey Department of Environmental Protection
Promote pollution prevention initiatives in an effort to reduce environmental and occupational health exposures. Provide regulatory and technical assistance to industrial facilities to help increase efficiency and reduce the quantity of toxic (TRI) substances used, generated as waste and released to the environment. Represent the Office of Pollution Prevention on the DEP Mercury Workgroup. Former co-chair of the Pollution Prevention workgroup for the National Environmental Performance Partnership System (NEPPS) Steering Committee. Under an EPA grant, provide industrial hygiene technical assistance to the Office of Occupational Training and Education Consortium (OTEC) at Rutgers University. This project develops training programs designed to integrate pollution prevention and occupational health. Chairmen of the health & safety committee for the Division of Environmental Safety and Health (DESH).

Research Scientist II (8/96 - 9/98)
Division of Environmental and Occupational Health
New Jersey Department of Health and Senior Services
Working as a Health Assessor in the Hazardous Site Health Evaluation Program, performed health hazard investigations to evaluate potential public exposure to chemical and physical hazards associated with National Priority List (NPL) sites in New Jersey. Working with the

Agency for Toxic Substances and Disease Registry (ATSDR) reviewed environmental, demographic and public health data and evaluated potential human exposure pathways. Primary responsibilities included assisting with the development of a dose reconstruction model of a municipal water distribution system and the development of the occupational exposure portion of an epidemiological case-control study in support of a childhood cancer cluster investigation in Toms River, NJ.

Research Scientist III (7/94 - 7/96)
Office of Air Quality Management
New Jersey Department of Environmental Protection
Acted as project manager for a team of administrators, engineers and scientists developing State air Pollution control regulations for stationary sources. Major rules included Mercury Emissions from MSWIs, VOC-RACT, and Architectural and Industrial Maintenance Coatings Rules. Member of the Air Toxics Steering Committee providing advice to the Department concerning health exposure issues.

Research Scientist II (Industrial Hygienist) (9/89 - 7/94)
Center for Occupational Medicine
New Jersey Department of Environmental Protection
Senior industrial hygienist responsible for the development and implementation of occupational health policies and program specific health and safety programs for approximately 4,000 employees throughout the Department. Performed workplace exposure evaluations, air monitoring and training in order to maintain compliance with applicable regulations. Major projects included work on asbestos management, bloodborne pathogens, chemical hygiene plans, confined space entry, ergonomics, indoor air quality, mercury and other metals, noise, nuclear emergency preparedness, pesticides and respiratory protection.

Occupational Health Consultant (12/87 - 9/89)
Division of Environmental and Occupational Health
New Jersey Department of Health and Senior Services
Responsible for industrial hygiene activities related to asbestos including review and approval of asbestos management plans, abatement project inspections and air monitoring, and emergency response activities. Participated in various NJDHSS / EPA research projects concerning environmental exposure to asbestos.

PUBLICATIONS

Release of Mercury from Broken Fluorescent Bulbs. Journal of the Air & Waste Management Association, (February 2003) 53: 143-151.

Chromium Exposure Assessment of Outdoor Workers in Hudson County, NJ. The Science of the Total Environment, (July 1992) 122: 291-300.