PEER REVIEW OF THE EPA ANALYTICAL MODEL: MERCURY EMISSIONS FROM THE DISPOSAL OF FLUORESCENT LAMPS

COMMENT RESPONSE DOCUMENT

Office of Solid Waste
U.S. Environmental Protection Agency

March 1998

INTRODUCTION

Background

On July 27, 1994, the U.S. Environmental Protection Agency (EPA) published a proposed rule addressing the management of spent mercury-containing lamps (59 FR 39288). In the proposal, the Agency presented two options for changing the regulations governing spent mercury-containing lamps:

- Add mercury-containing lamps to the universal waste regulations (UW option).
  - — Under this option, spent mercury-containing lamps that failed the TC would be subject to universal waste regulations. (See 40 CFR Part 273 for existing universal waste regulations applicable to specified types of spent batteries, pesticides, and thermostats.) The proposed standards for generators and consolidation points of spent lamps include procedures for maintaining the condition of lamps (e.g., proper packaging), and storing the lamps (e.g., storage time limits, labeling), notifying EPA as specified, and responding to releases. The proposed standards for transporters of spent lamps include procedures for proper packaging of broken/unbroken lamps, storing and treating lamps (e.g., dilution prohibition), and responding to releases. Destination sites (e.g., landfills and recyclers) receiving spent lamps would be subject to the RCRA hazardous waste regulations at 40 CFR Part 264-270 and 124, as applicable.
- Conditionally exclude mercury-containing lamps from regulation as hazardous waste (CE option). Under this option, generators would qualify for the exclusion if they satisfy two conditions:
  - — Generators would be required to either dispose of these lamps in a municipal landfill that is permitted by a State/tribe with an EPA-approved municipal solid waste permitting program, or
  - — If generators do not send these lamps to a municipal solid waste landfill, they would send them to a state permitted, licensed, or registered mercury reclamation facility; and
  - — Generators must keep records of the lamps shipped to management facilities.

Under this option, generators would be able to ship their lamps as part of their municipal waste stream, avoiding the RCRA hazardous waste generator standards (e.g., manifesting, record keeping), and ship the lamps to either a Subtitle C or D landfill, or a reclamation facility.

In June 1997, the Agency finalized development of a study on mercury emissions from the management and disposal of mercury-containing lamps. The study consisted of a Mercury Emissions Model (Model), a user guide entitled A User's Guide to the Mercury Emissions Model (User Guide), and a report entitled Mercury Emissions from the Disposal of Fluorescent Lamps (Report). The study was designed to assist interested parties in examining the amounts and sources of mercury emissions that might be produced in managing and disposing of spent lamps under the options. The Model provides emissions estimates for a modeling period extending from 1998 to 2007. Emissions estimates include both disposal emissions and net emissions. Installation of energy-efficient T8 lamps will reduce demand for electricity, which in turn reduces mercury emissions from utility boilers (in particular, coal-fired boilers). Net mercury emissions are defined as the difference between disposal emissions and the emissions avoided from energy savings.

In July 1997, EPA made the study available to the public and accepted public comments during the 45-day comment period, plus an extension. The final Response-to-Comment Document on the public comments is available in the EPA RCRA docket established for this action.

A panel of experts also reviewed the draft Model, Report and User Guide independently of EPA and provided their comments to the Agency. The panel was comprised of three independent individuals with general and specialized expertise in mercury- and lamps-related issues. The Agency has reviewed their comments and revised the study as appropriate. The Agency also prepared this Response-to-Comment Document, which is available at the EPA RCRA docket.

Purpose of Document

EPA has reviewed all comments received from the reviewers and, in response to many, corrected, clarified or otherwise revised the mercury study, as appropriate. The purpose of this document is to identify each substantive comment received on the study and provide an Agency response. Any steps taken by the Agency to modify the study are identified in the Agency's response.

Please note that, for the most part, this document does not address comments that are outside the scope of the study, such as comments on the regulatory options themselves. However, EPA has reviewed and acknowledges receipt of these comments.

Major Issues and Responses

In the following paragraphs, the Agency summarizes the major comments received and identifies where revisions to the study have been made. (Note: Not all revisions to the study are included in this summary.)

- Two of the reviewers noted that the Model currently estimates elemental and divalent mercury emissions, but not particulate emissions. (The Model includes a placeholder in its emissions tables in case a user wants to add particulate emissions to the Model.) One of the reviewers believed that the Model should be revised to estimate particulate emissions, believing that there is a strong possibility of fugitive dust emissions during bulb and waste transport/handling. The other reviewer believed that distinguishing between divalent and particulate mercury emissions is unnecessary and misleading, since "particulate" describes the physical form of the mercury only. The Agency notes that, when developing the Model, the Agency encountered considerable uncertainty about the extent to which mercury particulates would be emitted. For example, the Mercury Study: Report to Congress (Volume III, December 1997) provides that there remains "considerable uncertainty as to the actual speciation factors for each point source type (p. 4-4)." At the same time, the Agency believes that mercury vapor emissions are of primary concern in the management and disposal of lamps and thus decided to focus on the vapor emissions. Finally, the Agency notes that no negative comments were received during the NODA public comment period on the Model's speciation assumptions. For these reasons, the Agency has decided against revising the speciation assumptions in the Model, but will note the reviewers' concerns as a potential limitation to the Model.

- Two of the reviewers expressed concern that the Model does not address mercury inter-species transformation. In particular, one of the reviewers indicated that inter-species transformation of mercury is well known to occur in many media and that, in particular, the oxidation of reduced Hg^0 to Hg^{2+} and vice versa, is widely recognized. The Agency agrees that inter-species transformation can occur in lamp waste management and disposal, particularly in Subtitle D landfills. However, for several reasons, the Agency has decided against revising the Model to account for this possibility. First, the Agency notes that, even within the scientific community, uncertainty exists about the speciation of mercury. This belief is expressed in the final Mercury Study: Report to Congress (Volume III, December 1997). The Agency believes that trying to determine what the exact inter-species assumptions should be for each management and disposal activity could potentially increase the Model's uncertainty and be too labor-intensive for the purposes of the Model. Therefore, instead of integrating inter-species transformation into the Model, the Agency has decided to retain the current speciation assumptions. The Agency also notes that a number of commenters on the NODA generally supported the Model's assumptions.

Thus, the Agency has decided against revising the Model, but will note the reviewers' concern as a potential limitation to the Model.

- One reviewer expressed concern that the Report does not discuss EPA's assumption that the use of T8 and T12 lamps is independent of the regulatory options. The reviewer believed that the Report should discuss the increased disposal costs under the proposed UW and CE regulations (e.g., if used lamps must be handled to prevent breakage). The Agency agrees, and has revised the final Report to discuss EPA's assumptions.

- Each of the reviewers raised questions about the reliability of the Model's data and assumptions and generally believed that the Model relies heavily upon its data and assumptions. EPA agrees that data on lamp mercury emissions are limited and a number of assumptions were made in developing the Model when data were unavailable. The Agency notes that the Model's data were obtained from what the Agency believes to be the best available and most reliable sources (e.g., government agencies, lamp waste handlers, and specially prepared reports reviewed and approved by government agencies).

COMMENTS AND RESPONSES

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1. Dr. David F. Grigal, University of Minnesota

Comment No. 1-1. I agree with the documentation in the Report that states that because of lack of scientific data, this Model is a qualitative study based in part on quantitative analyses. The Model is a relatively simple and well structured tool for estimating mercury emissions from the disposal of fluorescent lamps. The Model includes numerous factors that could influence lamp use and emissions from disposal, and the authors have provided a thorough discussion of these factors in the Final Report. While scientific data are not currently available for detailed estimates of the magnitude of all these variables, their inclusion tends to indicate completeness and flexibility of the Model.

Response: EPA agrees with the reviewer about his characterization of the Model. No further response is required.

Comment No. 1-2: Scientific data concerning potential mercury emissions associated with the handling and disposal of fluorescent lamps are limited; numerous assumptions and estimates are therefore used in the Mercury Emissions Model. The estimated values that are discussed in the Final Report seem reasonable, and they can be easily substituted in alternative simulations as better data become available. Because of the lack of data, I am sympathetic with the authors and their need to use gray literature to arrive at the assumptions. I did not consider my review to include a review of the gray literature used to derive the assumptions and I cannot therefore comment on the quality of the information used from these sources. A critical review of scientific, peer-reviewed studies was lacking in the Final Report, but as noted above, the Model is flexible and allows the user to input different values at any time.

Response: EPA agrees with the reviewer that data on lamp mercury emissions are limited and that a number of assumptions were made in developing the Model. EPA also agrees about the desirability of peer reviews in the analytical process, but cannot be sure that all studies used in the Model received a peer review. The Agency notes, however, that the Model's data were obtained from what the Agency believes to be reliable sources. A number of the Model's assumptions are based on information obtained from government sources responsible for tracking mercury and lamp data, such as the EPA, State of Florida Department of Environmental Protection, and the Energy Information Administration. The Agency also consulted with lamp manufacturers, lamp waste handlers (e.g., lamp recyclers) and others involved in lamp waste management and disposal to obtain input based on their first-hand experience. Finally, certain other assumptions (e.g., emissions factors) were derived from specially prepared reports and studies, some of which received review and approval by a government agency. Because of these reasons, the Agency has confidence in the data used in the Model.

Comment No. 1-3: The Model identified three major elements that could influence mercury emissions associated with the use and disposal of fluorescent lamps: inputs, waste management and disposal methods, and energy savings that result in decreased use of fossil fuels containing mercury (i.e., coal). Some of the assumptions in the Model are clearly outside my area of expertise, and others are potentially outside anyone's expertise. For example, the number of lamps per unit commercial floor space is outside my area. I submit that the assumption of an increased lighting demand of 2.4 percent annually (p. 2-2) is really outside anyone's expertise.

Response: EPA agrees with the reviewer about the difficulty in predicting the increased lighting demand for commercial floorspace. However, the Agency believes that it has chosen a reasonable predictor, i.e., the estimated growth rate in commercial floorspace as estimated in the Energy Information Administration's Commercial Buildings Characteristics- 1992.

Comment No. 1-4: I generally agree with the assumptions used in the Model as described in the Final Report. Regarding inputs, the modelers assumed that T8 populations are independent of the waste disposal policy, citing currently low disposal costs and interviews with firms declining to participate in lamp replacement programs. However, there was no discussion of increased disposal costs under the proposed UW and CE regulations (e.g., if used lamps must be handled to prevent breakage), and there were no interviews with firms who had participated in lamp replacement programs.

Response: EPA agrees with the reviewer that the draft Report does not justify the Agency's belief that the use of T12 and T8 lamps is independent of the regulatory options. EPA has corrected this omission in the final Report. The Agency has added language to the final Report, as follows, based on its own analyses and input from Green Lights staff who have worked directly with participants in lamp replacement programs:

> A number of commenters believe that the higher compliance costs under the UW option would be a disincentive for certain building owners from conducting lighting upgrades. These commenters believe that the CE option would expedite upgrades and are concerned that the Model assumes that upgrades are independent of the policy option. In response to these comments, EPA has revisited its assumptions and performed a number of additional calculations on the impact of disposal costs on a lighting upgrade's internal rate of return (IRR). The Agency has found that, holding all other lamp operating costs constant, the cost of lamp disposal had minimal impacts on an upgrading project's IRR. At a $0.50/lamp transportation and recycling cost, the IRR for a typical project over ten years was 51 percent. At a $1.00/lamp transportation and recycling cost, the IRR was 50 percent — only a slight decrease in IRR despite a 100 percent increase in waste management costs. Because of these reasons, EPA continues to believe that the use of T8 lamps is independent of the policy options.

Comment No. 1-5: Utility savings could not be resolved by the modelers, and were summarily dismissed from the Model. I agree that it is relatively easy to estimate energy savings derived from switching from T12 to T8 lamps, but it would appear to be virtually impossible to predict how this might affect the amount of energy produced with coal versus oil and gas.

Response: EPA agrees that the Report does not resolve the issue about whether lighting upgrades from T12s to T8s would produce mercury emissions savings from utility boilers. EPA also agrees about the difficulty of predicting these effects on utilities. In the absence of conclusive documentation on utility emissions savings, the Agency made the simplifying assumption that use of energy-efficient lamps would result in a corresponding reduction in mercury emitted from coal-fired boilers. The Agency believes that retaining this assumption in the Model, along with a discussion of the limitation in the Report, is acceptable for purposes of the study.

Comment No. 1-6: Users of the Mercury Emissions Model have the ability to easily change any of the numerous input variables, resulting in a very flexible model. Changes to the Model can therefore be made as better scientific data become available, and for evaluating user-defined scenarios. The ability to calculate emissions for individual States is currently lacking and should be considered if the Model is updated.

Response: EPA does not completely agree with the reviewer's concern about State-specific emissions. The Model can analyze disposal patterns among States and estimate emissions on a State basis. The User Guide does not discuss this capability, since the Agency believes such manipulations are beyond the purpose of the Guide. Note that the Model does not include State-specific data; rather, the user needs to obtain this information independently.

Comment No. 1-7: All those who evaluate the Model and the Report should realize that the results of the study (Final Report, Table 3-1) are wholly dependent on the assumptions that were incorporated into the Model, suggesting that further scientific data may be needed to improve accuracy.

Response: EPA agrees that the Model's results are highly dependent on its data and assumptions and that a degree of uncertainty exists in these inputs. This was openly recognized in the July 11, 1997 notice of data availability (NODA), where the Agency stated: "The study is considered by EPA to be a qualitative study based partly on quantitative analyses. It is considered qualitative by EPA due to limitations of the data. The study should be used in combination with available scientific knowledge to help evaluate primary and secondary mercury emissions potentially associated with the management of spent lamps." See response to Comment No. 1-2 for additional information on the data sources used.

Comment No. 1-8: The EPA's conclusions from the Model tended to focus on the major assumptions and estimates used in the Model (e.g., that most lamps are broken prior to

disposal; that emissions from coal-fired boiler are independent of spent lamp management), and not on the finding that absolute emissions, regardless of the disposal method, are relatively minimal. Further refinement may not be necessary, however, since even baseline emissions from lamps were estimated at only 902 kg of mercury per year, or about 0.5 percent of total mercury emissions from anthropogenic sources.

Response: The Agency agrees that a primary purpose of the Model is to help in evaluating particular policy issues, such as the protectiveness of best practices during transportation. The Agency also agrees that the Model adequately serves these purposes. As stated in the July 11, 1997, NODA, EPA believes that an appropriate use of the Model is as a "qualitative study based partly on quantitative analyses." The Agency has used the Model in combination with available scientific knowledge to help evaluate mercury emissions under the options.

Comment No. 1-9: The magnitude of potential mercury emissions attributed by the Model to the use, handling, and disposal of fluorescent lamps was consistent with previous estimates, and despite the waste disposal option that is selected, represents a relatively small proportion (< 1%) of total mercury emissions from anthropogenic sources.

Response: EPA notes the reviewer's observation, but emphasizes that, although most mercury emissions are associated with combustion, all releases contribute to the mercury reservoirs in land, water and air. In addition, mercury has been shown to be transported in the atmosphere many miles from the source of its release. The deposition of atmospheric mercury into surface waters, its presence in runoff from soil, or the recycling of mercury from sediment into the water column can result in the accumulation of the metal in many animal species, particularly aquatic organisms. The EPA has recently published a Mercury Study Report to Congress (December 1997) that examines many of the health effects resulting from mercury exposure. Examples of mercury-related risks include neurotoxicological problems and developmental effects in fetus and adults (e.g., "Mad Hatters" disease), and accumulation of the metal in many animal species, particularly aquatic organisms. For example, fish with high levels of mercury in their tissues have exhibited increased mortality, reduced reproductive success, impaired growth, and behavioral abnormalities. Therefore, the Agency believes that technical requirements are needed to minimize the release of mercury from lamps into the environment.

Comment No. 1-10: I am not familiar with ACCESS, and because of that I had a few minor problems in editing inputs. They were minor, however, and I am convinced that the documentation cannot possibly provide enough detail for all users. In general, the Model ran "cleanly" and performed as advertised. The Reports and graphical output were well put together and easy to read. Because the Model is complex, it is apt to run slowly on many desktop PCs.

Response: EPA agrees with the reviewer that the Model may run slower on certain systems.

Comment No. 1-11: I wish that the creators of the Model would have allowed the user to easily return to the defaults that were installed with the Model. In a milieu of "what-ifs", a user soon loses the original default values and they may be nearly impossible to resurrect. A "reset" button for default input variables would be helpful to the average user, but lacking that option even a simple warning to save the original inputs by copying the files would be useful.
Response: EPA agrees that, if the Model is updated, a number of improvements could be made to enhance user-friendliness. However, please note that the Model does include a save function that allows users to save particular Model settings. This function should reasonably address the reviewer's concern.

Comment No. 1-12: I am professionally acquainted with mercury emissions from soils and land applied wastes, and my major point of concern is the manner in which emissions from Subtitle D (municipal solid waste) landfills were treated. From the discussion in the Final Report (p. 2-21), point-time measurements of mercury emission rates were used to determine the absolute amount of mercury emitted. We know, however, that mercury emissions are related to biological activity and degradation kinetics. Landfills are biologically active environments, as demonstrated by the production of decomposition products such as methane. I predict that mercury emissions will continue and in fact become cumulative as long as the wastes in the landfill continue to biologically degrade. These long-term emissions were not incorporated into the Mercury Emissions Model, and could underestimate emissions from Subtitle D landfills.

In spite of that concern, however, this study becomes "much ado about nothing". Any reasonable set of assumptions, including alteration of those with which I am most familiar, will not markedly change the low levels of lamp disposal emissions as a fraction of total emissions (p. ES-4). I am therefore comfortable with the results.

Response: EPA agrees that landfill emissions can vary over time, but disagrees that the Model fails to consider longterm landfill emissions. The Agency refers the reviewer to the comment letter received on the NODA by the State of Florida (Docket No. F-97-FLEA-FFFFF). The letter cites a study, prepared by a research team led by S.L. Lindberg of Oak Ridge Laboratories, that quantified the primary sources of mercury vapor releases to the atmosphere at municipal Subtitle D landfill operations in south Florida. The mercury vapor pathways included landfill gas releases from passive and active vent systems, passive emissions from landfill surface covers of different ages, and emissions from daily activities on a working face. The research team conducted scaling studies of mercury releases at a Subtitle D landfill (referred to as Landfill 5) to produce annual mercury release rates (e.g., 2.6 E-04 mg Hg/kg of MSW). Based on these analyses, the study concludes that, "(a)ssuming 0.44 mg of Hg/kg of municipal solid waste at (Landfill No. 5), the twelve year aggregate release accounts for > 0.2 percent of the mercury in the mass balance exercise (p. 2)." EPA notes that that emissions rate is consistent with the central emissions factor of 0.2 percent for Subtitle D landfills as used in the Model. Note that, as discussed by Florida, the study's mass balance exercise and calculations of mercury emissions rates from broken lamps were based upon a

limited data set of field measurements, estimates of MSW mercury content, and reasonable assumptions.

Finally, the Agency agrees with the reviewer that any revised assumptions would not markedly affect the Model's outputs.

2. Dr. Steven E. Lindberg, Oak Ridge National Laboratory

Comment No. 2-1: P. ES1-4: For those not familiar with waste regulations, the jargon and acronyms can be confusing and should be clearly defined in a table of terms.

Response: EPA agrees that a number of acronyms are used throughout the Report. To address any potential confusion, the Agency has spelled out each acronym where it first appears in the Report and believes this assists in minimizing any confusion. However, in light of the reviewer's further concerns, the Agency will add a list of acronyms to the final Report.

Comment No. 2-2: The effect of limiting the Model to the commercial sector of bulb use should be clarified.

Response: EPA agrees that the Model does not analyze certain types of floorspace (e.g., industrial floorspace) and that this omission results in an underestimation of the total number of lamps disposed. The Agency will clarify this limitation in the final Report.

Comment No. 2-3: P. 1-2: It is not clear if the small quantity generator definition means 100 kg of Hg or 100 kg of Hg-containing waste. In either case, state what approximate number of bulbs this could entail.

Response: The Agency does not agree that the Report is unclear about whether the conditionally exempt small quantity generator (CESQG) threshold applies to 100 kilograms of mercury or to lamp waste in its entirety (mercury, glass, and aluminum). Page 2-23 of the draft Report states that "(b)ased on the lamp weights reported by RTI, monthly generation of about 350 4-foot lamps per month would be necessary to exceed the 100 kg/month threshold for CESQGs, which equates to about 4,200 lamps discarded per year." EPA believes this statement is sufficiently clear to indicate that the entire lamp waste is subject to the 100 kilogram threshold.

However, the Agency believes the draft Report is not sufficiently clear about a limitation in its approach to calculating the number of lamps subject to the CESQG threshold. The Model's calculation assumes that commercial buildings generate lamp wastes as their only hazardous waste stream. EPA acknowledges this is a simplifying assumption, since a percentage of commercial buildings do generate other hazardous waste streams which would also be included in the CESQG calculation. However, the Agency believes that the majority

of commercial floorspace is found in office buildings that do not generate significant quantities of hazardous waste and that the assumption is therefore reasonable for purposes of the analysis. Nonetheless, the Agency will note this limitation in the final Report.

Comment No. 2-4: P. 1-3: Does the Model ignore all lamps other than 4'? What effect has this assumption on the results?

Response: The Model analyzes emissions from four-foot lamps only. The Agency notes that there are other types of mercury-containing lamps, including eight-and twelve-foot linear, U's, HIDs, as well as specialty lamps found in certain signs. However, the Agency believes that, because most of the data on lamps (e.g., mercury content, usage patterns, etc.) is available for four-foot linear lamps, the Agency elected to focus on four-foot linear lamps. The Agency believes that, as a general rule, the major conclusions of the study can be extended to other lamp types (e.g., breakage during transport is likely to be a major source of emissions). The Agency, therefore, sees no fundamental deficiency in examining only the population of four-foot lamps for purposes of the Report.

Comment No. 2-5: P. 2-4: This seems to be the first mention of the assumption regarding the fate and speciation of Hg in bulbs. This is perhaps the most critical, and poorest, most unfounded, assumption made in the Model. Although stated as "very uncertain" the impact of this assumption is not at all clearly made. User-designed model sensitivity tests with different speciation assumptions (not as easy to do as expected) illustrate that this one assumption can result in order-of-magnitude differences in long term Hg emissions. This assumption basically states that Hg in one form in bulb waste can never be transformed into another species. The inter-species transformation of Hg is well known to occur in many media. In particular, the oxidation of reduced Hg^0 to Hg^{2+} and vice versa, is widely recognized.

In the absence of further data, there is little justification to use the 2 percent/98 percent split between elemental and divalent Hg in T12-T8 lamps (Table 2-2,3). A relevant publication demonstrating the effect of reduction processes on Hg volatility in solids contaminated with divalent Hg was recently published (Carpi and Lindberg, 1997). Even NEMA documents indicate order-of-magnitude (30 times) higher volatilization from bulbs than this assumption indicates (NEMA Technical Brief, see References).

A recent study of fluorescent bulbs quantified losses due to breakage under controlled conditions (Tetra Tech, 1995). Single 4' bulbs were crushed in sealed containers and Hg losses monitored for up to 22 days for uncovered bulbs and bulbs covered with 15-30 cm soil. Following a transient spike after breakage, the uncovered-bulb emissions appeared to stabilize over a 2-week period at levels far above those which have been measured from Hg-contaminated soils. The initial pulse, which could be attributed to pre-existent Hg vapor, represented an emission rate of 4.8E6 ng m-2 h-1 (4.8 mg m-2 h-1), and decreased to ~ 5E5 ng m-2 h-1 (0.6 mg m-2 h-1) after 4 d. Over the following 16-day period, emissions varied between ~ 4E5 and 1E6 ng m-2 h-1 (0.4 to 1 mg m-2 h-1), but exhibited no clear trend,

except a moderate decrease from day 15 to 20. Considering that the highest Hg emission rate we have measured over background soils is ~ 50 ng m-2 h-1 (Carpi and Lindberg 1998) and ~ 200 ng m-2 h-1 over contaminated soils (Lindberg et. al. 1995), these emissions are clearly of potential importance.

After 20 days, emissions from bulbs covered with 15 cm of dirt were ~ 1E5 ng m-2 h-1, and did not decrease appreciably during the last 7 days of the study (Tetra Tech, 1995). These rates are still far above background soils. Over the 20-day period, the authors estimated that these bulbs released about three percent of the total Hg contained, suggesting to us that broken bulbs could be a long term Hg source to the atmosphere. This study did not completely simulate conditions during handling of MSW, in which bulb debris could be scattered over larger areas and exposed to different conditions (e.g. sunlight, heat). Therefore, it is clearly important to assess the long-term stability of the Hg in bulb waste, especially under conditions of elevated temperature and solar radiation, parameters known to elevate Hg emissions from wastes (e.g. Carpi and Lindberg, 1997). If the EPA Model assumes that only 0.2 percent of Hg in bulbs is in the volatile elemental form, this ignores the possibility for continued loss of Hg resulting from phase changes of Hg in lamp dust, and leads to significantly lower predicted Hg emission rates.

Our own research has some bearing on Hg emissions from land filling of lamps and other Hg-bearing waste (Lindberg and Price, submitted). The abstract of our paper is included in Appendix
A of this review.

Response: EPA thanks the reviewer for the abstract on mercury emissions from landfills. The Agency agrees that the long-term stability of mercury in landfills depends on a number of factors and that inter-species transformation can occur. EPA has used its best professional judgment to assume that inter-species transformation would not be a major factor in most lamp waste management operations (e.g., transportation, crushing) and Subtitle C disposal (i.e., landfilling). Note: Under Subtitle C of RCRA, spent lamps must be stabilized consistent with EPA treatment standards before being landfilled. Barring an unusual event, the solidified waste matrix should minimize the escape of mercury to the environment. Given this, EPA notes that Subtitle D landfilling is the activity where inter-species transformation is most likely to occur. However, the Agency has decided against revising the Model to account for this possibility.

The Agency notes that, even within the scientific community, uncertainty exists about the speciation of mercury. This belief is expressed in the final Mercury Study: Report to Congress (Volume III, December 1997): "There remains considerable uncertainty as to the actual speciation factors for each point source type (p. 4-4)." In developing the Model, the Agency was uncertain of an appropriate speciation for each lamp waste management or disposal activity analyzed in the Model and believed that incorporation of inter-species transformation would make the Model more complex for the user and its results more

uncertain. Thus, the Agency chose not to incorporate inter-species transformation into the Model and used speciation assumptions believed to be generally applicable across a range of activities. The Agency also designed the Model so that it reports total emissions only, i.e., it avoids reporting by species.

Having reviewed the public's comments on the draft Model (i.e., received during the public comment period on the NODA), the Agency notes that no commenter expressed concern about the absence of inter-species transformation in the Model. A number of commenters advanced their own data supporting emissions factors far below those included in the Model, while several others generally supported the Model's estimates.

For these reasons, the Agency believes the current speciation assumptions in the Model are acceptable so long as the underlying assumptions and limitations are understood by the user. Therefore, EPA has decided not to revise the Model's speciation assumptions, but will revise the Report to discuss the potential limitation raised by the reviewer.

Comment No. 2-6: P. 2-5: Why not also rely on manufacturer's data on lamp sales?

Response: The Model does, in fact, incorporate Department of Commerce data on the number of lamps shipped between 1992 and 1994 to estimate the "installed base" of lamps. See page 2-5 of the draft Report for additional information.

Comment No. 2-7: How is the value of 0.85 T8s derived?

Response: In the Model, the Agency assumes that the typical lighting upgrade would involve "delamping," that is, many building owner/operators tend to reduce the number of lamps lighting their floorspace. In the Report, the Agency notes that many older buildings contain unnecessarily high numbers of bulbs and/or fixtures per square foot. During the upgrades, the bulbs and fixtures are redistributed to ensure more efficient lighting. This decreases the number of bulbs and/or fixtures in the building. The Agency estimated a delamping rate of 0.85 (i.e., 85 T8s replace 100 T12s), while noting that delamping rates vary.

The Agency obtained the delamping value from Green Lights staff, who work with building owner/operators in upgrading to energy-efficient lighting. The Green Lights staff maintain a data base of information on upgrade projects (e.g., tracking the number of lamps removed and replaced during upgrades), called the Marketing and Implementation Data Base. The data base is used by EPA to support Green Lights and other Energy Star programs. The Green Lights staff conducted runs of the data base to estimate the number of lamps delamped across the population of Green Lights participants. The analysis indicated an average delamping rate of 0.85.

Comment No. 2-8: P. 2-9: The assumption of 20 percent particulate emissions from utility boilers is too large; five percent might be more accurate (see SAB reviews of EPA Hg Report to Congress, 1998).

Response: The Agency obtained the particulate emissions estimate from the draft Mercury Study: Report to Congress (June 1996), which indicated that electric utility boilers emit about 20 percent particulate mercury. The estimate remained unchanged in the final report to Congress. See Table 4-2 on page 4-5 of the final report, third volume.

Comment No. 2-9: P. 2-11: Clearly explain how the emission factors are derived for each management step. This is a critical assumption which is not clearly defined or defended.

Response: The Report explains the emissions factors for each management activity analyzed in the Model, beginning with transportation on page 2-15 of the draft Report. For each activity, the Report discusses data sources and key assumptions, limitations, and calculations used to derive emissions factors. The Agency believes this current level of detail is sufficient to clarify the Agency's approach to deriving emissions factors. Interested parties can visit the EPA RCRA docket to obtain further information from the data sources used.

Comment No. 2-10: It seems that at least one step in the flow trees is missing: temporary storage prior to transport. This could be a large potential source of loss.

Response: "Transportation" as used in the Model includes all activities up until delivery of the lamps at the final destination site. This is stated on page 2-15 of the draft Report. Thus, temporary storage of lamps is subsumed under the "transportation" activity. EPA believes this is a reasonable assumption. For example, under the CE option, it is assumed that 100 percent of lamps would break during "transport" in the absence of best practices. In estimating mercury emissions, the Model need not make a distinction about whether the lamps actually break before or during transport.

Comment No. 2-11: In addition to emissions from bulb waste in containers and landfills, there is also the strong possibility of fugitive dust emissions during bulb and waste transport/handling. This issue seems to be ignored in this Model. Dust emissions in lamp waste management and disposal processes are well known (D. Reinhart, pers. comm.). Once the bulb dust has been dispersed, it can wash into waterways or continue to release volatile Hg to the air. This is another major shortcoming of the Model approach.

Response: The Agency notes the reviewer's concern about the omission of fugitive dust from the Model. When developing the Model, the Agency encountered considerable uncertainty about the extent to which mercury particulates would be emitted. The Agency notes that vastly differing opinions have been expressed about whether the Model should include particulate emissions at all. Ralph Turner, one of the Agency's peer reviewers on the Model, believes that "(t)he distinction between divalent mercury and particulate mercury also seems

unnecessary and misleading. 'Particulate' describes the physical form of the mercury only. Microscopic beads of elemental mercury in the lamp phosphor would be accurately described as particulate mercury, as would be mercuric oxides (which happen to also represent one type of "divalent" mercury)." The Mercury Study: Report to Congress (Volume III, December 1997) also provides that there remains "considerable uncertainty as to the actual speciation factors for each point source type (p. 4-4)." At the same time, the Agency believes that mercury vapor emissions are of primary concern in the management and disposal of lamps and thus has decided to focus on the vapor emissions. For these reasons, the Agency has decided against revising the speciation assumptions in the Model, but will note the reviewer's concern as a potential limitation to the Model.

Comment No. 2-12: P. 2-15: Provide better technical support for all of the assumptions here regarding the behavior of Hg in bulbs and bulb waste (e.g. why must Hg "migrate" from various sources prior to emission? If the waste is dispersed, and the Hg is reduced, it will volatilize over time. Perhaps the meaning here of migration should be clarified).

Response: EPA agrees that the statement should be clarified. The reviewer is referring to page 2-15 of the draft Report, where the Agency explains the fate of the mercury in the lamp after breakage during transport. The draft Report states that "(m)ercury is also incorporated into the components of the lamp (i.e., the phosphor powder, end caps, and glass). After breakage, the mercury must migrate from the phosphor, end caps, and glass prior to being emitted." In this context, "migrate" means to volatilize or desorb (i.e., be emitted) from the lamp. EPA will clarify this in the final Report.

Comment No. 2-13: As stated previously, NEMA's own estimates for Hg emissions from bulbs transportation over time yield much larger relative loss rates than the 0.06-0.2 percent values given here. Many of the comments made earlier on these assumptions apply here as well. Conditions for transport are not well defined here (e.g. wind speed effects on volatilization would be large, as would temperature). Some might argue that a high-end emission factor for divalent Hg could easily be 100 percent (i.e., total Hg loss as dust and by volatilization).

Response: The Agency is unaware of the NEMA data on transportation emissions referenced by the reviewer. The Agency obtained its estimates from the NEMA report, Environmental Risk Analysis: Spent Mercury-Containing Lamps, A Summary of Current Studies (February 20, 1995). The Model uses NEMA data to estimate a 1.1 percent emissions as the low transportation emissions factor. The high emissions factor is estimated at 6.8 percent. The Agency believes that this range, spanning a factor of six, is adequate for purposes of the study.

Further, the Agency acknowledges that, depending on wind, temperature and other conditions, actual mercury emissions from lamp transport could differ from the estimates in the Model. The Agency has attempted to include in the Report as much information on the emissions factors for each management activity as reasonably practicable. For each activity,

the Report discusses the data source and primary assumptions, limitations, and calculations used to derive emissions factors. The Agency believes the current level of detail is sufficient to clarify the Agency's approach to deriving emissions factors. In addition, interested parties can visit the EPA RCRA docket to obtain further information on the data sources used. For these reasons, the Agency has decided against including additional background information (e.g., conditions for transport) in the Report.

Comment No. 2-14: P. 2-18: Here is an example (one of many) where the misuse of too many significant digits implies smaller uncertainty in the model than actually exists ("…crushing would be about 2.82%.). Again, the fate of the crushed material is ignored. Here and elsewhere, references should be cited to critical assumptions (e.g. Hg in powder can be recovered).

Response: EPA agrees that a degree of uncertainty exists in the Model's emissions factors, but disagrees that the Report understates uncertainty in its data. With regard to lamps crushing, the draft Report lists a series of assumptions used to derive the central emissions estimate of 2.82 (p. 2-18). The Agency believes this list of assumptions gives the reader a clear sense that the 2.82 emissions factor is, itself, an estimate based on assumptions. Further, the Agency has rounded the emissions factor to 2.8 in the Model, as indicated in the Report. In this light, the Agency does not believe the Report's discussion of lamps crushing downplays the uncertainty of the emissions estimate.

In addition, the Agency believes the current level of detail is sufficient to clarify the Agency's approach to deriving emissions factors and determining the fate of the lamps themselves. In the case of crushed lamps, the Report assumes that all crushed material is transported offsite and landfilled. See the flow diagrams on pages 2-12 to 2-14 of the draft Report to track the fate of crushed lamps. Finally, the Agency makes the data sources available to the public at the EPA RCRA docket if further information is desired.

Comment No. 2-15: P. 2-19: A citation to 19 is made here, but the assumptions used in that report to get a 99 percent recovery are not stated.

Response: The Report indicates that RTI has concluded that a well-managed facility using advanced equipment will have overall mercury recovery rates of 99 percent of total mercury. The Report references the RTI report, Management of Used Fluorescent Lamps: Preliminary Risk Assessment (October 1992) as the source document. In that report, RTI indicates that "air emissions and mass balance information for fluorescent lamp recycling facilities was only available for MRT system AB (p. 174)." MRT AB is a reclamation facility in Sweden that uses a fully developed, commercial scale system to reclaim mercury from used fluorescent lamps and powders as well as other mercury-containing products. On pages 140-148, the RTI report discusses the MRT AB reclamation process in some detail. Among other things, the report provides the information presented in Table 1, as excerpted from page 146 of the

report. The table indicates that MRT AB has a recovery rate of 98.8 percent (rounded to 99 percent by RTI).

Table 1: Parameters and Mercury Outputs/Recovery at MRT AB Recycling Facility

Parameter	Amount of Mercury
Input	25 kg Hg (i.e., 1M lamps x 25 mg Hg/lamp)
Output- Total Residue	199 g Hg (0.8%)
Output - Vapor	103 g (0.4%)
Output - Total	199 g (residue) + 103 g (vapor) = 302 g (1.2%)
Mercury Recovery (percent input)	24,698 g (98.8%)

Comment No. 2-16: P. 2-20: The assumptions of five percent Hg retention in fly and bottom ash seems high. Provide references. Most if not all Hg is lost in volatile phases during combustion. Again, the speciation transformation issue must be considered here as well (Section 2.3.1.4).

Response: The Agency obtained data on fly and bottom ash from the RTI report, Management of Used Fluorescent Lamps: Preliminary Risk Assessment Final Report (p. 116). EPA will cite this data source in the final Report.

Comment No. 2-17: P. 2-21: The lack of good measured Hg emission data from landfills is recognized. Results from our recent study may be the only direct measurements in this regard. We saw a very clear signal of important Hg losses during MSW deliveries to a working face, which we ascribed to processes such as volatilization of Hg during bulb breakage and or dispersal from already broken bulbs. Our results are briefly described in Appendix A.

Response: EPA thanks the reviewer for providing information on landfill emissions estimates. EPA has acknowledged the many data limitations of the Model regarding landfilling and other activity emissions. This was openly recognized in the NODA. Having reviewed existing studies on landfill emissions, as well as public reaction to the Model's emissions estimates, the Agency is satisfied that the Model's assumptions incorporate among the most reliable data on landfill emissions. See response to Comment No. 2-5 for additional discussion of landfill emissions rates.

Comment No. 2-18: P. 2-24: It is not clear how the value of 20 percent for the partitioning coefficient for drum top crushing was derived. This entire treatment appears to assume that crushed material is somehow stabilized to prevent Hg loss. Clarify. Again, the lack of consideration of fugitive dust loss compromises this discussion of waste flows.

Response: The Agency used its best professional judgment to estimate the rate of drum top crushing at 20 percent. As noted in the Report, the Agency believes that large buildings, in

particular, may find crushing an economical volume reduction technique and that large buildings encompass about ten percent of floorspace. Therefore, the Agency conservatively estimated that large buildings (i.e., 10% of floorspace), as well as a fraction of medium-size and small buildings (i.e., another 10%), would choose to crush their lamps prior to landfilling. Further, the Model assumes that emissions are produced during crushing, as explained on page 2-18 of the draft Report. Finally, see response to Comment No. 2-11 for a discussion of fugitive dust emissions.

Comment No. 2-19: P. 3-2, Tables: It would be most useful to have a table similar to 3-1 which also shows the total amount of Hg being handled in each case.

Response: The Agency agrees that additional tables could be added to provide further clarification of mercury emissions from the scenarios. However, the Agency has attempted to avoid including too much information in the Report, since the Model's data, assumptions and outputs are available in report, graphic or other forms from the Model itself. Therefore, the Agency has decided against including additional tables in the Report.

Comment No. 2-20: A summary table showing all of the relevant assumptions for each scenario and case would be useful for reference.

Response: The Agency does not believe such a summary table is essential, since key assumptions are concisely presented in tables and text throughout the Report. This information is also conveniently available in the Model.

Comment No. 2-21: The statement "coal-fired emissions …independent of policy options" is not clearly derived, nor is its intent clear. The possibilities of both Hg speciation changes and fugitive dust losses must be acknowledged regarding their potential role in altering modeled Hg losses.

Response: EPA agrees with the reviewer about the need for the Report to clarify its assumptions about utility boiler emissions and use of T8 lamps. See response to Comment No. 1-4 for a discussion. See response to Comment No. 2-5 for a discussion of mercury speciation.

Comment No. 2-22: P. 1-16: The means of obtaining State level data are not given.

Response: EPA notes the reviewer's concern, but clarifies that the primary objective of the User's Guide is to familiarize the user with basic Model functions, not to explain all possible Model capabilities. This is stated in the document: "The document presents instructions on how to use the basic features of the Model (p 1)." EPA believes that, once a user becomes familiar with the basic functions, he or she is prepared to explore the more advanced functions independently, such as editing State data. Indeed, this is clarified the in the User Guide, where it states that the Model "has the capability to account for differences in disposal patterns

as a function of State, i.e., you can vary the disposal patterns among States, and estimate emission on a State basis. However, we are not going to describe this feature as this is beyond the scope of this User's Guide (p. 3)."

Comment No. 2-23: The choice of menu colors is unfortunate, at least as it appears on my system. Several items are difficult to read due to color choice. Some of the screens do not match those given in the text (in name or order). During several attempts to edit building data, the Model hung up (message: 1 or more values prohibited by valid rule > = 92 < = 07; this recurred for each mouse click, and the entire Model run had to be aborted in order to proceed).

Response: EPA notes the reviewer's difficulties with the Model. The Agency conducted numerous test runs and demonstrations of the Model prior to release to the public, and did not encounter problems or complaints concerning the color of the user screen. The Agency is also unaware of any such complaints from the public commenters or via technical support provided during the public comment period.

The Agency also was unaware that certain screens do not match those given in the text and apologizes for any inconvenience to the reviewer. The Agency will review the User Guide and make needed corrections.

In addition, users can expect to encounter system failure from time to time in loading or using most large computer models, such as the lamps Model. EPA is unaware of further steps to take to resolve this concern.

Finally, the message "1 or more values prohibited by valid rule > = 92 < = 07" indicates that the reviewer may have attempted to input data outside of the modeling period of 1992 to 2007. This is not allowed by the Model.

Comment No. 2-24: P. 17-18: The entire section on Lamp Hg Content caused problems on several occasions. Upon first running the Model, there was only the one screen as shown in Section 7.4, p. 17, and no apparent means to alter these assumptions. After another Model reload there appeared to be 7 further screens available in this option which could be edited. The meaning of several screens here was not clear, and often the purpose of "0 values" was not apparent. The statement at the bottom of the page implies that there is no possibility for speciation transformation of Hg, which is untrue. This entire set of screens should be made easier for the user to edit logically. The assumptions of speciation and Hg content are among the most crucial in the Model. Again, emissions due to dust loss are ignored.

Response: A user can edit lamp mercury content data directly from the screen shown on page 17 of the User Guide. Further, a user can access a number of other screens by double-clicking on the buttons at the bottom of the screen. These buttons allow the user to create or delete records or to review information on mercury content options.

In addition, "0 values" are used as placeholders in the Model to enable data inputs as future data become available on lamp mercury content.

Finally, the Agency notes the reviewer's concern about speciation transformation and fugitive dust. See response to Comment Nos. 2-5 and 2-11, respectively, for the Agency's views on these issues.

Comment No. 2-25: P. 21-29: The section on Emissions from Disposal Activities also contains assumptions crucial to the output of the Model. These are largely assumptions that are untested. However, this section is even more difficult, if not impossible to edit. It was totally unclear how to revise these data. Some of the emission rates are in error (e.g. the assumption of a 0 emission rate for elemental Hg from incinerators), and others are without support. Several of the activities shown on p. 22-23 could not be found in the Model.

Response: The Agency agrees with the reviewer that certain assumptions in the Model are uncertain. See response to Comment No. 1-2 for the Agency's views of data sources and reliability.

In addition, the user can edit the emissions factors directly from the user screen shown on page 21 of the User Guide. The assumptions, data and calculations behind these emissions factors are explained in Chapter 2 of the Report. Regarding municipal waste combustor (MWC) emissions, the Agency estimated that elemental emissions from MWCs would be zero. This is based on the assumption that all elemental mercury had been emitted prior to reaching the MWC and hence there is no elemental mercury left to emit. See pages 2-20 and 2-21 of the draft Report for additional information.

Finally, there are several places where the reviewer can locate the activities listed on pages 22 and 23 of the User Guide. The Agency recommends looking under the "Edit Menu" for partitioning coefficients.

Comment No. 2-26: P. 30: In some screens of the Model it is unclear how to get back to the main menu, and in other cases the previous menu is only accessible after aborting to the main menu.

Response: The Agency recommends that, as a general rule, the reviewer use the "help" function when difficulties arise. To access the Main Menu, a user can click on the upper-left hand corner of the user screen, which will back-track through the screens.

Comment No. 2-27: Scenario building and modeling: After creating new policy options, they could not be accessed to pull them into a new scenario. The Model would be more useful if all choices were available as menu choices. The actions taken by the Model during scenario building are not always as stated in this section. Many of the screen or option names in the Model do not coincide with the names in the Users Guide. It is particularly difficult here to

determine how to learn to revise the Hg content. It is not always apparent in the Model which selection has been "highlighted" (as a result of the choice of colors). When new building types were added to test some new scenarios, the Model continued to bomb out, but the error messages were not clear as to what was required to fix the problem. When it was attempted to add State level data to large building types, several errors were generated. Attempts to delete the State choices to fix the Model were unsuccessful, they now appeared to be permanent parts of the Model data base. Reloading the Model was the only fix.

This error message was common: "run time error, you don't have permission to view module". Updating of graphs rarely worked after selection of different detail. The button was not always accessible. The graphs and material they present do not allow comparison of critical results (e.g. showing on the same plot the results for different species or different emission rates).

Response: EPA notes the reviewer's difficulties with the Model and agrees that certain improvements could be made to ease data manipulation. However, the Agency does not believe such revisions are essential. As discussed, the Agency conducted numerous test runs and demonstrations with the Model and did not encounter the problems identified by the reviewer. In addition, the Agency is unaware of any comments received about these difficulties during the public comment period (i.e., via the technical assistance provided to the public) or in comments on the NODA. The Agency recommends that the reviewer use the "help" function when difficulties arise.

Comment No. 2-28: Some menus have typos (e.g. comerce).

Response: The Agency will review the Model and correct any errors found.

3. Dr. Ralph R. Turner, Frontier Geosciences, Inc.

Comment No. 3-1: The stated purpose for developing the Model is to assist OSW decision makers in preparation of a Final Rule addressing spent Hg-containing lamps. The presumption seems to be that there is a unique mix of handling, disposal, and/or recycling options that will minimize “emissions” and that the emissions outcome of selecting a given mix of options can be predicted with acceptable uncertainty. Differences in emissions among options must be greater than the uncertainty in the estimated emissions from a given option if this Model is expected to be a credible basis for Final Rule making. I was not left with a warm feeling that emissions under any option could be predicted with enough certainty to assure that a clear winner would stand out from the noise of uncertainty. For example, the lowest (5200 kg) and highest (8000 kg) 10-y cumulative emissions differ by about 40%. In contrast, the differences among “low”, “central” and “high” estimates are quite large . Furthermore, the Noncompliance/CESQG emissions are potentially significant as these spent lamps can theoretically end up anywhere. These unregulated disposals are captured in the Model and range from 10% (CE) to 80% (baseline) of the total disposal flow of mercury.

Response: EPA agrees with the reviewer that the Model's results are highly dependent on its data and assumptions and that a degree of uncertainty exists in these inputs. See response to Comment No. 1-7 for a discussion of data limitations.

EPA also agrees with the reviewer that, based on the Model outputs, a user could construe the Model to indicate that neither option was definitively better at controlling total emissions. For example, under the CE Low scenario, the Model estimated a ten-year cumulative emissions total of about 3,000 kilograms (rounded). This total is lower than the ten-year estimates for any of the UW Central or High estimates, which ranged from about 5,000 (UW-Rapid Central) to 13,000 kilograms (UW-Moderate High). On the other hand, the CE total is higher than any UW Low estimates, which ranged from about 1,000 (Rapid) to about 2,000 kilograms (Moderate).

However, the Agency believes that certain broad, comparative conclusions can be drawn from the Model, so long as the user understands its data, assumptions and design when interpreting its results. The Model uses a bounding approach (i.e., high, central and low estimates) to address the uncertainty regarding its inputs. This bounding captures the range of emissions data points produced by the Model. Given this, the Agency believes that a comparison between the CE and UW options could appropriately be done by focusing less on single data points (e.g., annual emissions totals) and more on the bounded range. For example, Table 3-1 of the Report indicates that, under the CE option, cumulative emissions (rounded) range from approximately 3,000 (Low) to 18,000 (High) kilograms. Cumulative emissions under the UW option range between approximately 1,000 (UW-Rapid Low) and 13,000 (UW-Moderate High) kilograms. As this shows, the bounded range under the CE option is higher than that of the UW option (about 3 times as high at the low end and 1.4 times as high at the high end). A user could therefore conclude qualitatively that the UW option is shown to provide a more effective range of protectiveness than the CE option given the data, assumptions and design of the Model.

Comment No. 3-2: I am skeptical of the “emissions avoided” part of this equation. As stated in the Final Report EPA is assuming that installation of high efficiency lighting will result in a proportional reduction in the use of coal to generate electricity. The report acknowledges that some utilities have indicated that this may be an optimistic assumption as reductions in gas, oil, hydro and nuclear generation could also occur and thus would not result in the assumed proportional reduction in mercury emissions. Certainly this is an important issue which could lead to underestimates in emissions. Incorporating options in the Model to adjust for less than one-to-one emissions reductions would seem prudent. Low, central and high adjustments could be selected using 1:1 and no reduction in coal usage as end members. The central adjustment could be the ratio of coal usage to the use all other energy sources.

Response: The Agency agrees that other approaches could be taken for estimating utility boiler emissions savings, but acknowledges that there is no general consensus on the most appropriate approach. In the absence of conclusive documentation on emissions savings, the

Agency has made the simplifying assumption that use of energy-efficient lamps would result in a corresponding reduction in mercury emitted from coal-fired boilers. The Agency believes that using this assumption in the Model, along with a discussion of limitations in the Report, is acceptable for purposes of the study.

Comment No. 3-3: Frankly, I had some difficulty understanding how the baseline situation of managing spent lamps under RCRA was distinct from the UW option which also seems to be keyed to TC results. The report notes that there is widespread noncompliance under RCRA. What suggests that UW would result in greater compliance?

Response: EPA acknowledges the difficulty in predicting building owners' behavior under the options. However, EPA expects that owners will have an increased incentive to comply with the UW option relative to the baseline. As EPA noted in the 1995 Universal Waste Final Rule, a primary goal of the rule was to separate universal waste from the municipal waste stream (60 FR 25494). The Agency expects that many of the mechanisms for increasing management of universal wastes outside of RCRA Subtitle D will also apply to lamps under the UW option (e.g., lower compliance costs and greater convenience in land waste management). The Agency also believes that the UW option may increase recycling rates in particular (e.g., because of increased ability to consolidate lamps), potentially lowering recycling prices and making recycling more attractive to noncompliant generators.

Comment No. 3-4: So, the Model has a lot to account for and will be no better than the aggregate of the assumptions and projections utilized under the existing and two proposed disposal management options under consideration. The authors have incorporated the necessary complexity into the Model to allow for the range of options and uncertainties. I might quibble about the division of lighting by building size but may have missed some subtle reason for that division.

Response: The Agency clarifies that "building size" is based on the average amount of commercial floorspace in each building size category. The Model estimates lamp disposal volumes based on the amount of lit commercial floorspace of buildings. Such a division has a number of benefits. It allows the Model to estimate the total number of lamps being disposed of based on differences in lighting densities (i.e., 50 ft^2 fixture for small, 65 ft^2 fixture for medium-size, and 80 ft^2 for large buildings). It also allows the Model to determine the total annual number of lamps being disposed of by site and to determine whether the site's lamps are subject to the RCRA small quantity generator conditional exemption.

Comment No. 3-5: I also might question why only 4-ft lamps were included. I could't help beginning to look up at the lighting in large buildings as I was reviewing this Model with the result that I noticed an awful lot of much longer (8 or 12- ft??) lamps. Is the Hg content of these lamps proportional to their length?

Response: EPA notes the reviewer's concern about eight- and twelve-foot lamps not being included in the Model. See response to Comment No. 2-4 for the Agency's reason for analyzing only four-foot lamps. Further, lamp manufacturers have indicated that the amount of mercury in lamps is roughly proportional to their size.

Comment No. 3-6: This reviewer agrees with the authors of the final report on the finding that transport and/or processing of spent lamps contributes the largest component of total emissions and should be a more important focus of Final Rule making than the choice of landfills (C or D). I found it interesting but not surprising that recycling (a category under "processing") leads to greater emissions than landfilling. This should be intuitive if it is recognized that few, if any, Hg recovery units can be counted on not to release some mercury. I examined the RTI report authored by Truesdale et al which reviewed recycling technology to verify the seemingly high emission factors used in the Model for recycling. True, there are some exceptional technologies, and some ordinary technologies conducted with exceptional skill, which could in principle achieve low emissions due to recycling.

Response: EPA notes the reviewer's views on lamp recycling emissions. Please note that the Agency has revisited some of its recycling emissions estimates in finalizing the Model. Several public commenters to the NODA raised concerns that EPA had misinterpreted data from the State of Florida on its recycling emissions estimates. EPA carefully reviewed available recycling emissions data and revised the Model's central and low emissions factors for divalent mercury emissions. EPA revised the central estimate from three percent to 1.09 percent and the low estimate from one percent to 0.07 percent.

Comment No. 3-7: (1) It was disconcerting that downloading Model from the internet required a version (3.0) of Acrobat Reader only available since last summer. Even after downloading the correct version (required 20 minutes to download!), the Model required more than a hour on my computer to download. Ultimately I had to obtain a CD rom copy to successfully install the Model. While this may not be a barrier to those who are constantly upgrading their hardware and software, it is certainly a barrier to the rest of us.

(2) Running scenarios with the Model on a 486 machine with Windows95 required excessive computation time (up to 8 minutes). After I moved the Model to a brand new machine (Compaq Presario running at 233 mHz) the computation time was tolerable at less than one minute. I can only hope that those decision makers who will use the Model will be adequately equipped.

(3) In spite of thrice reinstalling the Model I was never able to use the report module. Always received error message "run time error - you are not authorized to access this module" or something like that.

(4) I tried unsuccessfully to export data to a Excel spreadsheet. Clicking on this option did nothing obvious. If files were created, they were well hidden.

Response: The Agency notes the reviewer's difficulties in installing and running the Model. The Agency attempted to make the Model as user friendly and universally accessible as possible. Note that the Model includes a "help" function to assist users who have difficulty using the Model. The Agency expected that some users could have difficulty with the Model. During the public comment period for the NODA, the Agency attempted to address this concern by making technical assistance available by fax, phone (toll-free), and e-mail.

Comment No. 3-8: The Model wrongly assumes that mercury in the elemental form is 100% emitted when lamps are broken because this form of mercury is contained *entirely* in the vapor phase in each tube. First of all, the concentration of vapor phase elemental mercury in these lamps when they are not electrified is limited by the vapor pressure of the metal and thus can't exceed saturation. In air at 20 C this amounts to about 0.015 mg/liter (or about 0.015 mg/4-ft tube), and would not be very different from this value in the fractional atmospheric pressure and inert gas milieu inside a spent lamp. Thus it is not clear how the vaporous elemental mercury content could be so much higher (0.02 to 0.082 mg/lamp in Tables 2-2 and 2-3) than this amount. However, this issue is dwarfed by the fact that lamps can and do contain elemental mercury which is not in the vapor phase, and the so-called divalent mercury is fairly easily converted to elemental form under environmental conditions (sunlight, moisture, activities of microorganisms). If all the elemental Hg were lost to the atmosphere when lamps are broken (the default condition in the Model) the lamp debris would not continue to emit elemental (vaporous) mercury long after breakage occurred. For example, results from the Tetra Tech study indicated that after an initial peak flux of Hg from freshly broken lamps of about 40 ng/cm2/min the rate decreased over the first four days to about 1 ng/cm2/min and then was relatively constant through the end of the measurement period (20 days). Furthermore, it is not difficult to find tiny beads of elemental mercury in the debris of broken lamps produced a few years ago, and debris from recently produced bulbs will still saturate the headspace of a container with elemental mercury given a few hours.

Lastly, mercury is added to these lamps to generate UV radiation by electrically stimulating elemental mercury atoms in the gas contained in the lamp. It is hard to imagine that manufacturers would add mercury in any form but the elemental. I can imagine that mercurous oxide might be used due to its spontaneous dismutation to elemental and mercuric forms and the greater ease of dispensing small amounts per lamp using a mercury oxide.

How does this affect the Modeling under review here? Probably very little as long as it is understood that some fraction of the divalent mercury content in lamps is actually elemental mercury, or can be converted to elemental mercury during handling prior to final disposal.

Response: EPA notes the reviewer's concern about the Model's assumptions on speciation and mercury behavior in broken lamps. The Agency agrees with the reviewer that mercury behavior in lamps is more complex than portrayed in the Model. To simplify the Model's assumptions and reduce the amount of data uncertainty, the Agency has made the simplifying assumption that elemental mercury would be released as a vapor. Further, the Agency agrees

with the reviewer about the limitations of this assumption, but notes in the comment that speciation in the Model should not greatly affect the Model "as long as it is understood that some fraction of the divalent mercury content in lamps is actually elemental mercury, or can be converted to elemental mercury during handling prior to final disposal." The Agency will note this limitation in the final Report.

Further, the Model distinguishes among elemental, divalent, and particulate mercury emission factors because current data suggest that mercury deposition rates vary based on species. This is shown in Table 2, which is based on excerpted material from Table 5-1 on page 5-1 of the final Mercury Study: Report to Congress (Volume III, December 1997):

Table 2: Mercury Mass Budget in Metric Tons from RELMAP Simulation

Source/Fate	Hg^{0} [a]	Hg^{2+} [b]	Hg_p [c]	Total Mercury
Total U.S. anthropogenic emissions	63.5	52.3	26.0	141.8
Total deposited anthropogenic emissions	0.9	36.8	10.0	47.6
Deposition from background Hg^{0}	32.0	-	-	32.0
Mercury deposited from all sources	32.9	36.8	10.0	79.6
(All figures rounded to the nearest tenth of a metric ton)				

[a] Hg^{0} = Elemental Mercury
[b] Hg^{2+} = Divalent Vapor-Phase Mercury
[c] Hg_p = Particle-Bound Mercury

The table shows that, of the total U.S. anthropogenic emissions of elemental mercury, about one percent was deposited within the model domain (i.e., the contiguous U.S.). This deposition rate differs significantly from divalent mercury (70% deposition rate) and particulate mercury (38% deposition rate). The Model acknowledges these differences by tracking mercury emissions by species, enabling a user to conduct analyses involving mercury deposition if so desired. Note, however, that the Model reports emissions by total mercury emissions only, i.e., it does not report emissions by species.

Comment No. 3-9: The distinction between divalent mercury and particulate mercury also seems unnecessary and misleading. "Particulate" describes the physical form of the mercury only. Microscopic beads of elemental mercury in the lamp phosphor would be accurately described as particulate mercury, as would be mercuric oxides (which happen to also represent one type of "divalent" mercury). I suspect this terminology originates from mercury speciation measurements in emissions from incinerators (MWC) and power plants. I contend this terminology is not very meaningful for spent lamps. For example, the form of mercury in a spent lamp has no bearing on the form in which it will be emitted if the lamp is incinerated.

On the other hand the fraction of the mercury in spent lamps that is elemental, as opposed to that contained in oxides (divalent), will have a much greater likelihood of escaping during lamp handling and transport. The Model would not suffer if the distinction among forms of mercury in spent lamps were deleted. And maintaining the distinction is misleading to those without the background to recognize the fallacies just outlined.

Response: EPA acknowledges the reviewer's concern about the Report's distinguishing between mercury species and particulate emissions. See response to Comment No. 2-11 for the Agency's view on divalent and particulate mercury emissions.