COMPENDIUM OF REPORTS

From the

PEER REVIEW PROCESS

For

AERMOD

February 2002

U.S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Emissions, Monitoring and Analysis Division
Research Triangle Park, North Carolina 27711

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I. BACKGROUND

In 1991, the American Meteorological Society (AMS) and the U.S. Environmental Protection Agency (EPA) initiated a joint effort to develop a vastly improved air quality model. A committee was formed (AERMIC [the **A**MS/**E**PA **R**egulatory **M**odel **I**mprovement **C**ommittee]) to upgrade the current models which were developed nearly two decades ago. Much progress has occurred in the scientific knowledge of atmospheric turbulence and dispersion and so a need had been recognized to update the regulatory air quality models based on more up-to-date science. The goal of such an update would be to improve the accuracy of these models.

AERMIC chose to focus on the development of a new model, AERMOD (**AER**MIC's Dispersion **Mod**el), for estimating the near-field concentrations from a variety of stationary sources. That is, AERMOD is designed to handle the same source types currently addressed with the EPA recommended Industrial Source Complex Model (ISC3), including sources located in various terrain settings.

AERMOD, along with its associated preprocessors (AERMET - the meteorological data preprocessor, AERMAP - the terrain data preprocessor), was submitted to the EPA's Office of Air Quality Planning and Standards for consideration as a regulatory dispersion model. Part of this process was the technical review of the model by experts outside of the Agency and separate from AERMIC, i.e. a peer review of the new air dispersion modeling system. This compendium provides the documentation of that peer review process and the conclusions drawn from the external review of the model.

This peer review process of the AERMOD modeling system had 5 distinct steps. Each step generated a corresponding document as listed below (in chronological order):

1. The scope of work (instructions) given to a contractor who, in turn, selected and managed the peer review committee (this step started the peer review process and defined the charge or mission to the peer review committee);

2. The first report from the peer review committee;

3. The response from AERMIC to the peer review committee's comments;

4. The final report from the peer review committee after reviewing the updated documents; and,

5. The final responses from AERMIC to the peer review committee's final report.

All five documents are bundled together (and provided in a compressed format) for the reader's convenience. For brevity, only the conclusions and the general comments are included in the reports in this compendium. The detailed or line-by-line comments and the draft versions of the reports that were reviewed by the peer-review committee are provided in the docket which supports the EPA proposing to use AERMOD for regulatory applications (docket number **A-99-05**).

In addition, the Peer Review Committee's final summary and conclusions were copied from Report III and included immediately following the section listing of instructions given to the contractor and the Peer Review Committee. This section was created for the reader's convenience so that this important information could be easily found up front in the compendium.

II. THE EPA'S INSTRUCTIONS TO THE PEER REVIEW COMMITTEE CONTRACTOR.

Task 1. Establish a list of qualified peer review candidates.

The contractor shall identify a list of qualified candidates to provide a technical review of the AERMOD air dispersion. The candidates qualifications shall including the following:

1. Considerable experience and understanding in the formulation, application, performance of air quality dispersion models for short-range (near-field) situations (i.e. distances from sources generally less than 30 to 50 km).

2. Knowledge of the current state-of-the-art scientific understanding of turbulence and dispersion in the planetary boundary layer for flow in both flat and complex terrain settings.

3. Familiarity and experience with existing regulatory dispersion models and their applications and the regulatory framework under which they are commonly used.

Examples of scientists that AERMIC believe meet the above qualifications include: Bruce Turner (Trinity Consultants), Steve Hanna (Chief Editor, Journal of Applied Meteorology), Helga Oleson (Danish Air Pollution Laboratory), Roger Brower (Versar), Bruce Egan (Woodward and Clyde), Mark Garrison (Engineering Associates), Dick McNider (University of Alabama), Robert L. Miller (Oak Ridge National Laboratory). Steve Hanna recently chaired the committee for the Atmospheric Modeling Division program peer review for EPA/ORD.

Task 2. Select the peer review committee.

The contractor shall set up a peer review committee of 3 individuals from the list of qualified candidates. The contractor shall call the members of the list of qualified candidates and determine their availability and their interest in participating in the peer review process. The contractor shall continue to call list members until the committee of 3 members is set. If the contractor cannot find 3 qualified people to serve on the committee within the schedule alloted for this activity, the Work Assignment Manager (WAM) shall be contacted immediately and be informed of the problem and determining the next steps to complete the selection process.

The contractor shall establish one peer review committee member as the chairperson. This chairperson shall coordinate and run the peer review meeting describe below in Task 4.

Task 3. Provide the necessary documents to the peer review committee.

The contractor shall provide to the peer review committee, copies of all the necessary background information as supplied by the WAM. The purpose of the peer review is to obtain the committee's comments on the formulation, documentation, evaluation results, and user friendliness of AERMOD and its companion preprocessor programs: AERMET, the meteorological preprocessor, and AERMAP, the terrain and receptor preprocessor. The contractor shall contact the WAM to obtain a complete listing of this background information; but, it shall contain, at a minimum, the following documents:

1. 2 AWMA papers describing the earlier versions of the AERMOD;
2. The Phase I and Phase II test reports;
3. The user guides (3: [AERMET, AERMAP, and AERMOD]);
4. The model formulation document;
5. A computer copy of the AERMOD, AERMET, and AERMAP models (the contractor shall identify the preferred method of computer model transfer for each committee memeber--the WAM will provide assistance to the contractor, if necessary, to complete this part of the materials transfer); and,
6. A detailed list of questions that the peer review committee shall address during this process.

A copy of each of these documents will be supplied by the WAM. Based on current planning, these background documents are scheduled to be completed by March 1, 1998 (the AWMA papers are currently available). The contractor shall instruct the peer review committee to read all the supplied background documents and focus their review on responding to a list of specific questions. The list of questions provided to the peer review committee shall include, at a minimum, the following:

1. Model formulation
   - 1.1. As a steady-state, plume-based, regulatory model, does AERMOD represent the state-of-the-art in its handling of boundary layer turbulence and dispersion?
   - 1.2. Within the context of regulatory dispersion models in the US, does AERMOD represent significant scientific advances over ISC3?
   - 1.3. What do you think are the most important scientific advancements of AERMOD?
   - 1.4. Are there any areas or features of AERMOD in which an improved formulation or treatment would be desired? If so, please discuss whether you think the revised treatment would lead to better performance and how much.

2. Documentation
   - 2.1. Is the current organization of the Model Formulation Document and User's Guides appropriate or would an alternative be desired?
   - 2.2. Is the presentation of the model clear and explanatory? Please note any specific sections of the documentation that were unclear or confusing.

2.3. Is the documentation sufficient for an typical ISC-type user to guide them in the use of the model and its preprocessors. Do you think training sessions would be particularly useful?

3. Evaluation and Performance
   3.1. How do you rate the performance of AERMOD relative to ISC3 and the other models included in the evaluation exercises?
   3.2. From a model design, scientific, and performance perspective, what comments do you have on the replacement of ISC3 with AERMOD for regulatory applications?
   3.3 When considering the eight data bases used to evaluated the model, would additional evaluation of AERMOD be desirable?

4. User Friendliness of Entire Package
   4.1. Please comment on the user friendliness of the entire AERMOD package, in terms of the documents and/or the model codes.
   4.2. Please list any areas where you feel improved user friendliness is needed. (Although the AERMIC committee has focused its resources on development of the model algorithms themselves, the committee recognizes the usefulness of graphical user interfaces and is aware that several private contractors are developing ones for the AERMOD system. These will clearly enhance the user friendliness of the model).

[Later, two more questions were forwarded to the peer review contractor]

Additional EPA Question 4.1 Dated 3/18/98 - Is the AERMOD approach to modeling urban sources scientifically sound and state of the art?

Additional EPA Question 4.2 Dated 3/24/98 - Do the building downwash algorithms within AERMOD represent the current state of science and are these algorithms appropriate to regulatory applications?

III. SUMMARY OF THE PEER REVIEW COMMITTEE FINAL COMMENTS.

For the reader's convenience, the section below was copied directly from Report III. This important information has been included near the beginning of the compendium to help locate and read the final conclusions of the Peer Review Committee.

> "We believe that AERMOD represents a significant improvement over ISC3. There are many new state-of-the-science concepts and approaches in AERMOD, including a unique "interface" that creates complete temperature, wind and turbulence profiles from even the barest minimum input data. However, we feel that, because of these new approaches, AERMOD is more likely than simpler models like ISC3 to need an extended break-in period when its use in routine applications can be thoroughly tested. It is worth noting in this regard that all of the AERMOD evaluation data bases (except for Prairie Grass) involved tall, non-downwashed, highly buoyant power plant stacks (the shortest stack in the group was 84 meters in Indianapolis). The vast majority of ISC3 applications involve modest stacks with modest buoyancy flux values, most of which are subject to some degree of aerodynamic downwash, as well as area and volume source configurations which were not evaluated or tested (at least not in the documentation provided) to determine how AERMOD predictions compare to predictions using ISC3.
>
> "We are concerned about the accuracy of the concentrations predicted by the downwash algorithm in AERMOD, since the same downwash algorithm is used in both ISC3 and AERMOD. Considering that something has to be incorporated, it seems alright for the present to include the convoluted H-S and S-S procedures that are currently incorporated into the ISC3 models with the simplification that variances will be added rather than using virtual sources. Then if the PRIME research project makes an appropriate case for alternate procedures, these can be included in the next AERMOD. Hopefully, that would be a substitution, not a melding of H-S, S-S and PRIME.
>
> "In the course of applying AERMOD to many different sources, in many different settings, with many different meteorological data bases, users may discover aspects of AERMOD that would be desirable to change. It is possible to minimize the number of situations where this would occur by conducting a thorough, exhaustive, independent set of sensitivity tests aimed at understanding the underlying reasons for model performance and the interrelationship of model components, rather than just the end results of the model. Such a thorough analysis is not likely to happen in the near future, however, and it therefore might be appropriate to allow for an interim period when AERMOD can be accepted as a "refined" model but that its use would not be required. This would be especially appropriate since some applications cannot be correctly handled by AERMOD (e.g., those involving deposition) and some algorithms (e.g., downwash) are likely to experience additional changes in the near future.

"Our basic conclusion is that AERMOD is ready to be proposed as a replacement to ISC3. However, it would be a mistake to treat AERMOD as "finished" and not needing any further evaluation or dialogue regarding its performance and its use as a routine model. It is acknowledged by AERMIC that model changes, involving downwash and deposition in particular, are going to be made in the next year or two. We suggest that the period during which these additional changes are being evaluated and implemented could be regarded as an interim period where AERMOD can be used as a "refined" model. The use of AERMOD could be conditioned on developing site-specific information regarding its performance, possibly relative to ISC3 and the performance of the model's interface in terms of generating meteorological profiles. After an interim approval period, the information and model improvements (if any) generated through these comparisons and evaluations could be assessed. An advantage of the interim approval period would be the generation of a wealth of information about the model and its performance and use in the real world."

REPORT I. THE FIRST PEER REVIEW REPORT (dated 4/23/98)

1. Introduction

A Peer Review Panel has been assembled by the EPA in order to review the various documents produced by the AMS/EPA AERMIC group on their new AERMOD dispersion model. The Peer Review Panel consists of Dr. Steven Hanna (chairman) of George Mason University, Mr. Mark Garrison of ERM, Inc., and Mr. Bruce Turner of Trinity Consultants, Inc. Administrative support to the Peer Review Panel is provided by Mr. Edward Carr and his colleagues at SAI/ICFKAISER. The EPA is proposing to possibly replace the ISCST3 regulatory model with the new AERMOD dispersion model, and asked to panel to provide specific technical comments on the documents as well as to provide answers to a set of questions concerning whether AERMOD is ready for use as a regulatory model.

After the Peer Review Panel was set up in mid-March 1998, a group of AERMOD documents was delivered to each member. Page-by-page specific comments on seven of these documents are given in Appendices I through VII of this report. These seven documents included one report describing the technical formulation, three reports describing model evaluations, and three user's guides. It should be noted that several "older" conference papers were included in the group of documents sent to the Panel but were not reviewed because they describe previous versions of the model and outdated evaluations.

The Panel was also asked to address a set of 12 general questions related to whether AERMOD was ready for use as a regulatory model. Section 2 contains our responses to these questions.

Two conference calls were held on 2 and 3 April between the Panel, the AERMIC group, and SAI staff. About 12 persons participated in these calls. The 2 April call lasted about three hours and the 3 April call lasted about 1 ½ hours. The group discussed the 12 general questions plus a set of specific questions provided by the Panel to the EPA before the calls. In addition, we discussed several details concerning the seven individual reports.

During April, the panel has used e-mail communications in order to generate the current report. Several draft versions of sections have been prepared, reviewed by the Panel members, and revised. The comments in this report represent a unanimous viewpoint.

On 17 April, the EPA asked that the Panel provide a two to four page summary of our conclusions and recommendations. That information is provided in Section 3.

2. Answers to General Questions asked by EPA

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The EPA asked the panel to address 12 general questions related to whether AERMOD was ready for use as a regulatory model. Our responses to these 12 questions are given below.

EPA General Topic Area 1. Model Formulation

EPA General Question 1.1 - As a steady-state, plume-based, regulatory model, does AERMOD represent the state-of-the-science in its handling of boundary layer turbulence and dispersion?

Panel Response to EPA General Question 1.1 - Within the resources available to AERMIC and the data available with which to evaluate the model, the AERMOD represents a very good attempt to incorporate additional knowledge of boundary layer turbulence and dispersion into a model framework. In addition, instead of just having a number of disconnected algorithms that independently address different source situations, terrain types, and meteorological conditions, there has been a significant effort to merge calculations continuously from one situation to the next. As a result, there will not be large jumps in calculated values in going from one source scenario, terrain type, or meteorological condition to the next.

EPA General Question 1.2 - Within the context of regulatory dispersion models in the US, does AERMOD represent significant scientific advances over ISC3?

Panel Response to EPA General Question 1.2 - If the model is run with the minimum of input meteorological data, the results may or may not be better than the models currently being used such as ISC3. If, instead, the model is run with a set of input meteorological data that represents nearly the full complement of data that can be accepted by AERMOD, then one would expect results to be better. However, at this point no data set that represents a nearly complete data set has been used to independently evaluate AERMOD. The developmental model testing exercise included some high quality data sets such as Kincaid, Indianapolis, and Prairie Grass, but a number of adjustments were made to AERMOD to better fit the observed concentrations. It is, of course, unknown whether these adjustments, or some of them, will better fit the universe of all situations or whether these are adjusting away from most situations to just fit the peculiarities of a specific data set. Since AERMOD is able to include more boundary layer observations than the ISC3 regulatory model, it would seem that it would represent better science.

The Panel feels that the plume rise and dispersion algorithms in AERMOD represent the state-of –the-art for plume modeling. Of course, a wealth of Eulerian grid models exists (K-models, Large Eddy Simulation Models, and Computational Fluid Dynamic models), but these advanced models require much computer time and therefore are not suitable for calculating concentrations for the thousands of hours required by the EPA. AERMOD accounts for "continuous stability classes " via its use of the Monin-Obukhov length, for non-Gaussian vertical velocity distributions in the convective boundary layer, for lofting and partial penetration of plume, for similarity theory in the near-surface stable layer, and for terrain effects through an elegant simplified approach.

However, the Panel points out that there are several existing models (e.g., OML, ADMS, HPDM, and SCIPUFF) that also account for the scientific advances mentioned in the previous paragraph. We feel that the EPA should have looked more thoroughly at these available models and demonstrated where AERMOD would represent an advance.

EPA General Question 1.3 - What do you think are the most scientific advancements in AERMOD?

Panel Response to General Question 1.3 – The rational inclusion of straightforward procedures to handle terrain influences would appear to be an advancement. This is easy to expect as the treatment of terrain effects in ISC3 is very rudimentary. In contrast, the treatment of terrain in CTDMPLUS is much more complex and required simplification.

Another scientific advance is the elimination of the use of the six discrete Pasquill stability classes and its associated complete linkage of vertical and horizontal dispersion. AERMOD replaces this method with the continuous stability class method related to the use of the Monin-Obukhov length.

The treatment of strongly convective conditions by the pdf approach, which allows vertical distributions to be non-Gaussian, should be more realistic. Furthermore, the plume lofting and penetration model represents a significant advancement.

Since surface releases disperse differently than releases above the ground, the fact that these are handled differently in the model (via similarity theory) should be a step in the right direction.

As pointed out in our answer to the previous question, we feel that there are other models available (e.g., OML, ADMS, HPDM, SCIPUFF) which can be considered "scientifically advanced" and which should have been more thoroughly investigated.

EPA General Question 1.4 - Are there any areas or features of AERMOD in which an improved formulation or treatment would be desired? If so, please discuss whether you think the revised treatment would lead to better performance and how much.

Panel Response to General Question 1.4 - The development of an advanced building downwash module by the PRIME project should be followed closely to see if the outputs of that program are representing improved treatment of building downwash. The current treatment of downwash in ISC3 (which we believe has been transferred with almost no change to AERMOD) considers zones of turbulence behind structures to be of the same size for all wind speeds. One would expect these zones, which are largely caused by the mechanical turbulence of wind moving past structures, to be highly dependent upon wind speed. Furthermore, the current treatment in ISC3 allows highest concentrations involving building downwash to frequently be calculated to occur during stable conditions with light wind speeds, conditions when structure downwash would actually be expected to be at a minimum. Also, the ISC downwash module does not properly treat strongly buoyant plumes from short stacks near buildings. The panel recommends that the results of the PRIME project be considered, as well as the current algorithm in ADMS, which is based on Britter's studies of building downwash.

The panel believes that the AERMOD approach to urban dispersion requires further development and evaluation. The current approach produces unstable boundary layers over urban areas at night. The formulas should be tested with urban boundary layer data, as well as concentration data.

As stated in our specific review comments, the Panel believes that many of the scientific modules in AERMOD have not yet been adequately justified using comparisons with data. For example, the Technical Formulation report (see Appendix I) contains no tables or figures demonstrating the degree of agreement of the various parameterizations with meteorological or concentration observations. These new algorithms may indeed represent scientific advancements, but they have not been demonstrated to the satisfaction of normal peer review criteria.

2. Documentation

EPA General Question 2.1 - Is the current organization of the model formulation document and User's Guide appropriate or would an alternative be desired?

Panel Response to EPA General Question 2.1 - The organization of the material into the separate documents for Formulation and for User Guides seems appropriate. In addition, the structure of the material within each document seems reasonable. Users will be grateful that the familiar structure of the ISC3 user's guide has been retained wherever possible. It would be useful to have a clearer recommendation concerning the use of detailed on-site meteorological data such as vertical profiles of wind velocity, turbulence, and temperature. It would also help to add some schematic diagrams to explain difficult concepts such as the specification of terrain heights.

EPA General Question 2.2 - Is the presentation of the model clear and explanatory? Please note any specific sections of the documentation that were unclear or confusing.

Panel Response to EPA General Question 2.2 – Specific comments on each document are given in the seven appendices.

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Formulation - The document consists of lists of equations with brief discussions of each equation given in the text. Although the new algorithms appear to represent significant technical improvements over ISC3, the document would be greatly enhanced by adding justifications for the many parameterizations (including supporting figures and table), by adding schematic diagrams to better explain the methodology, and by including discussions of comparisons with similar state-of-the-art models such as OML, ADMS, HPDM, and SCIPUFF. Additionally, it would be helpful to have, with most equations, the units of the variables in the equation and the numerical values of constants such as c_p.

User's Guides - There are numerous places in the user's guides where it is indicated that adjustments can be made to accommodate larger numbers of sources, receptors, etc. It is indicated that the program then has to be compiled. The panel is not sure all users understand the process of compiling a program. This is well-explained in Chapter 4 of the AERMOD User's Guide. We suggest that where compiling is mentioned a reference should be made to this chapter where the full explanation is given.

There seems to be some minor inconsistencies between the various programs in the AERMOD series. Redirect symbols are used with the various programs of AERMET but are not used with AERMOD or AERMAP. This is not terribly significant but causes users to have to be quite careful (which, of course, is not a bad thing).

The User's Guides seem to explain things well and have just about the right amount of redundancy so that users can look up information that they need quite easily.

It is suggested that schematic diagrams be added to aid understanding of topics such as terrain height specification and requirements for meteorological inputs.

EPA General Question 2.3 - Is the documentation sufficient for a typical ISC-type user to guide them in the use of the model and its preprocessors? Do you think training sessions would be particularly useful?

Panel Response to EPA General Question 2.3 - This question can best be answered by actually running the model and seeing if there are areas of difficulty. Presumably this exercise was carried out by the so-called "beta-testers". There were insufficient funds for the Peer Review Panel to run the model execution and experiment with various scenarios. Therefore, it is not possible to answer this question in a complete way. As mentioned above, we expect some confusion concerning the use of meteorological data when extensive on-site data are available. We also expect some users to experience problems with the terrain processor due to a lack of schematic diagrams.

We would expect that the instructions in the user's guide should be sufficient for most users to be able to run the models. If it appears that there are places in the user's guides where further information should be given, a revision to the user's guide (in the way of page changes) should correct the problem. Therefore, we would not expect it necessary to have training sessions to teach running the model.

The area where some training may be required in the future is in the sensible use of the model. With some experience it will be found that increased efforts should be made to provide the proper meteorological information in order to achieve the best performance of the model. As experience is gained through both applications of the model and sensitivity testing, it may be desirable to have training sessions that discuss the importance of the various data inputs and suggest good ways of obtaining these data.

3. Evaluation and Performance

EPA General Question 3.1 - How do you rate the performance of AERMOD relative to ISC3 and the other models included in the evaluation exercises?

Panel Response to EPA General Question 3.1 - Any model evaluation exercise is limited by the availability of appropriate data and manpower and funds. Since several components of the model were "tuned" or calibrated using the five data sets reported as the Developmental Evaluation Report, the “evaluation” results using these data must be set aside in answering this question. Of course it is a positive result that AERMOD agrees with these five data sets with reasonable mean bias. However, it is true that the performance of ISC3 and other models could have been improved if they were also tuned with these five data sets. The panel recommends that a measure of model scatter (e.g., geometric variance, VG, or Normalized Root Mean Square Error, NMSE) be included in the set of performance measures. The panel also feels that a “scientific” evaluation should include a technical peer review of the model components. Documentation of the changes that were made to the model during and following the developmental evaluation should appear in a separate section with a summary table.

The three data sets used in the Independent Performance (Phase II) Evaluation all represent the running of the model with what seems to be the barest minimum of input data and the evaluation of the concentration predictions with only a few (6 to 10) routine monitors. The Panel feels that it is short-sighted to anticipate that most users will run the model with a bare minimum of data. From the model description, AERMOD would be expected to perform best when furnished data inputs that have not been routinely available for running the current regulatory models. If an evaluation with a more complete data set could be included (i.e., one that has vertical profiles of temperature, wind, horizontal fluctuation and vertical fluctuation), and the statistical results demonstrated improved estimates from the model, then there would be some incentive for obtaining improved data inputs even for relatively routine model application.

Two areas of application that need to be further evaluated are 1) situations involving significant topography and 2) situations involving a considerable amount of building downwash. Many future applications of the model, if it is adopted for regulatory use, would be expected to involve at least one of these two situations. The Cinder Cone Butte, Hogback, and Tracy tracer studies should be used to further evaluate the performance of AERMOD in terrain (all three data sets contain extensive meteorological observations and sampling networks. The PRIME data set should be used to test the building downwash component of AERMOD.

The model has not been independently tested in a scenario with a near-surface source. Several such tracer data sets from NOAA/ARL could be used for these tests. Furthermore, the detailed Bull Run power plant tracer data set should be used for further evaluations for tall stack plumes.

The evaluations should be expanded to include other similar models such as OML, ADMS, HPDM, and SCIPUFF.

EPA General Question 3.2 - From a model design, scientific, and performance perspective, what comments do you have on the replacement of ISC3 with AERMOD for regulatory applications?

Panel Response to EPA General Question 3.2 - The model design is reasonable, although more guidance is needed on the use of meteorological input data. The science in the model appears to represent state-of the-art concepts, but as mentioned above, there is a need to justify the various constants of parameterization and explain the model components by use of schematic diagrams. The panel feels that AERMOD has not been adequately evaluated with independent data, since the three data sets in the Independent Performance Evaluation Report are all "routine" data sets that do not include extensive onsite meteorological observations or spatial coverage of concentration monitors. The sources in these studies were not straightforward, either, since all involved multiple stacks and some involved sources widely spread over the domain.

The panel recognizes that there are other state-of-the-art models already available, such as OML, ADMS, HPDM, and SCIPUFF. At least one of these models should be included in each of the new evaluations. For example, the few evaluations of HPDM that were carried out in conjunction with the Independent Performance Evaluation report suggest that HPDM is performing as well as AERMOD and therefore should also be considered as an alternate replacement model for ISC3.

EPA General Question 3.3 - When considering the eight data bases used to evaluate the model, would additional evaluation of AERMOD be desirable?

Panel Response to EPA General Question 3.3 – The Panel feels that, in reality, only three data bases were used to evaluate the model. It is necessary to make clear to the readers of the so-called "Development Evaluation" document that the algorithms in AERMOD were changed based upon the initial results obtained with these five data bases. The model predictions were then compared against the predictions of other models (e.g., ISC3) which did not have the benefit of any tuning. Therefore, the results with these five data bases must be interpreted in a different light than the results for the three truly independent data sets reported in the Independent Performance Evaluation document. And these three independent data sets are similar in that they all involve routine data bases. No independent evaluations were carried out with detailed tracer data bases or with source releases near the ground.

Yes, it would certainly be desirable to perform additional evaluation of the model. Comments to this effect have been made in the Panel's answers to questions above. The areas most in need of further evaluations are: 1) The use of meteorological data that represent a more complete set than those for the Phase II Evaluation; that is, profiles of wind, temperature, and vertical and horizontal fluctuations (the Bull Run data base would be very useful); 2) The use of detailed tracer data in situations involving complex terrain (the Cinder Cone Butte, Hogback, and Tracy data bases should be used); 3) The use of observations in situations involving structure downwash (the PRIME data base should be tested), and 4) The use of observations from sources near the ground (NOAA/ARL and DOD have several tracer data bases available from Dugway Proving Ground and the Nevada Test Site).

Additional EPA Question 4.1 Dated 3/18/98 - Is the AERMOD approach to modeling urban sources scientifically sound and state of the art?

Panel Response to EPA Question 4.1 – The Panel understands that the primary way in which urban areas influence AERMOD is through the assumption that a surface source of anthropogenic heat based upon population will cause the nighttime urban boundary layer to be unstable. Also an increase of the nighttime mixing height dependent upon population is calculated. Furthermore, roughness lengths will be assigned appropriate to the urban environment. It is unsettling that these procedures were devised through calibration of the model concentration predictions with observations at Indianapolis. There was no attempt made to evaluate the fundamental predictions of heat flux and mixing depth at Indianapolis, even though those data are available. The panel notes that there are no urban data sets in the three independent data sets used for the Phase II evaluation. Consequently, there is no independent evidence that the urban algorithms in AERMOD will match field data.

Additional EPA Question 4.2 Dated 3/24/98 - Do the building downwash algorithms within AERMOD represent the current state of science and are these algorithms appropriate to regulatory applications?

Panel Response to EPA Question 4.2 - It is the panel's opinion that the building downwash algorithms that are currently in ISC3, which were moved intact to AERMOD, have some deficiencies. For example, these algorithms have problems with light-wind stable conditions and with strongly-buoyant plumes from short stacks. There are indications that some of these deficiencies may be overcome by the results of the PRIME project. I think that rather than placing any burdens on AERMIC at this time, it would be best to wait and see what results from PRIME and then consider what changes might be appropriate to improve AERMOD. Furthermore, the Panel understands that the ADMS model contains advanced building downwash algorithms that should be considered for inclusion in AERMOD.

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3. Conclusions and Recommendations

AERMOD Development and Evaluation Process – The Panel notes that, up until CTDMPLUS, models (such as ISC3ST) proposed for regulatory use by the EPA were generally imposed on users with a minimum of technical justification and evaluation. The process for proposing CTDMPLUS in the late 1980's was greatly improved, since extensive technical justifications and evaluations with detailed tracer data sets were included. The process for submittal of AERMOD is another step in the right direction, as demonstrated by the very fact that the Peer Review Panel has been formed and asked to prepare the current report. The Panel applauds this trend. However, the development of AERMOD by the AERMIC committee (composed of EPA and AMS scientists) has proceeded over the past several years with minimal funding. The scientists who composed the primary boundary layer and dispersion algorithms have done so on nearly a volunteer basis. The budget for evaluations and documentation was relatively small. Thus the Panel finds a model which appears on the surface to represent significant scientific advancements over ISC3, but which is not adequately documented, including detailed justifications for new parameterizations, and which is not thoroughly evaluated with a wide range of tracer studies and routine data sets. The comments by the Panel are intended to be at the level of the peer review of a journal article, and therefore naturally do not take into account the shortfall in funding necessary to do a thorough job. Perhaps the EPA/AMS AERMIC committee can carry out the necessary further evaluations by "leveraging" funds obtained from a variety of interested parties, such as DOD, API, and EPRI.

Discussion of Availability of Similar Models and Evaluations with the Same Data Sets as AERMOD – While the Panel recognizes that the technical algorithms in AERMOD represent the state-of-the-art, we are concerned that the impression is given that AERMOD is unique in this regard. In fact, there are several models available which also contain similar state-of-the-art technical algorithms (e.g., OML, ADMS, HPDM, and SCIPUFF). For example, all these models account for the non-Gaussian nature of the vertical velocity probability density function in the convective boundary layer. And these models have been available (software, technical documents, evaluations, experience of many users) for several years. The only one of these models that is mentioned in the AERMOD reports is HPDM, which was compared with AERMOD and ISC3 in some of the evaluation exercises (and which did quite well in these comparisons). A natural question that should be addressed is why AERMIC did not simply adopt one of these similar models? The public will ask why the EPA doesn't simply adopt, say, ADMS? What advantages does AERMOD have over, say, ADMS or OML or HPDM or SCIPUFF? These issues should be addressed in the model formulation document and in the evaluation documents, which should include comparisons of statistical results for all relevant models.

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Desired Additions to AERMOD Description of Model Formulation Document – The Panel recommends that, besides the addition of discussions of available alternate models discussed above, the Model Formulation document should be enhanced to include justifications for new parameterizations. Supporting figures and tables should be added, including comparisons of "intermediate" variables such as net radiation, heat flux, turbulence, plume rise, and plume spread. There are several new "constants" and power law coefficients proposed with no supporting evidence as would be required in any peer-reviewed journal article. Furthermore, because of the use of many confusing variables (there are over a dozen sigmas and z's used in the document) it would be a great help to include schematic diagrams illustrating these definitions and approaches (e.g., the method for estimating the terrain height around a receptor).

Approaches to Modifications to Account for Urban Dispersion and Building Downwash Need Further Study - The Panel feels that the modifications in AERMOD to account for urban dispersion are preliminary and may need revision. It is troubling that the current methodology assumes that the boundary layer is always unstable at night in an urban area. This assumption should be tested with boundary layer observations in urban areas, instead of relying simply on tuning the concentration predictions with concentration observations at Indianapolis. Furthermore, the building downwash algorithms in AERMOD are identical to those in ISC3. The community has identified a few problems with these algorithms (e.g., light-wind stable conditions and strongly-buoyant plumes from short stacks), and these problems are being addressed by the PRIME program. In addition, the AERMOD developers should investigate the state-of-the-art building downwash algorithms that were developed by Britter and that are already in ADMS

Specific Recommendations for Input Data – The Panel believes that, while most of the information in the User's Guides is excellent, there will be confusion concerning which meteorological input data are best for a specific scenario. This problem is seen especially for situations where data are available from several on-site locations and from vertical profiles measured by sounders. What exactly should a user do? The predicted concentrations can vary by a factor of two or more depending on whether the modeler uses the tower next to the stack, the tower on the hill, the tower on the top of a tall building, the rawinsonde sounding, or the 915 MHz sounding. Also, the Panel would like to see a demonstration that the new terrain algorithm will produce repeatable results when applied to the same scenario by several independent modelers.

Additional Data Sets for Evaluation –

Complex Terrain - As important as terrain is in many source impact assessments that are carried out, it would seem to the Panel to be important to execute AERMOD for the three data bases that were used to develop CTDMPLUS - Cinder Cone Butte, Hogback Ridge, and Tracy. These data sets are desirable because they involved detailed monitoring networks and extensive meteorological observations. If possible, useful information might result if the evaluations were carried out with two options for input data: first, using all available data; and secondly, using a degraded data base that might more closely resemble the type of data frequently available to users. This evaluation exercise should also include ADMS, which contains the Hunt-Britter algorithms.

Flat Terrain Site with Detailed Meteorological Inputs - Using an independent data base such as Bull Run, it would be helpful to see how the model performs when complete vertical profiles of temperature, wind, horizontal fluctuations and vertical fluctuations are available. This data base could also be “degraded” to compare results when less data are available. The evaluation exercise should also include OML, ADMS, HPDM, and SCIPUFF.

Building Downwash - As stated above, the results that come from the PRIME project should be carefully reviewed. If these results are credible and indicate that useful changes should be made to the building downwash algorithm in AERMOD, then recommendations should be made and follow-up action taken. In addition the building downwash module in ADMS should be reviewed and considered for implementation. The revised model should be evaluated with the building downwash data (field and laboratory) collected during PRIME. It would also be useful to carry out sensitivity studies to be sure that the combination of the new AERMOD model with the old ISC3 building downwash modules yields results that correspond to what one might expect. The panel would like to be assured that the AERMOD dispersion calculations do not link with the building downwash algorithms to produce some totally unexpected result.

Further Evaluations with Ground-Level Sources – Since AERMOD’s revised similarity theory approach for ground-level sources was strongly calibrated to the Prairie Grass data, it is desirable to evaluate the similarity model against an independent data base. The most promising candidates would be the recent tracer studies carried out by Dugway Proving Ground.

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Appendix I Comments on AERMOD Description of Model Formulation

Comments by Peer Review Panel on document by Cimorelli et al., entitled AERMOD DESCRIPTION OF MODEL FORMULATION, dated 10 March 1998

General

G-1 The review panel understands that this 81-page document was written with the intent of providing some brief technical discussions of the model equations and assumptions. However, in order to meet the standards of a peer-reviewed technical document, it is necessary to much more fully explain the background, justification, and testing of the model components.

G-2 At present, aside from the flowchart in Figure 1, there is not a single explanatory figure or table in the document. Because of the use of many complicated definitions of variables and the presence of many logical steps and decision points in the model, it is necessary to provide figures that explain these complicated variables and procedures. As it is, the review panel is lost in many places (e.g., the definition of terrain heights).

G-3 More background information should be given concerning related models (OML, HPDM, ADMS, SCIPUFF). There are many models already available that include the scientific advances in AERMOD.

G-4 Attribution should be given to the original references rather than intermediate references (e.g., the wind profile equations were originally given by Businger, not Wyngaard; most of the plume rise equations were originally suggested by Briggs).

G-5 The Section numbering convention led to major confusion for the three reviewers. Instead of simply putting 2, the full 6.b.2 number should be given. The caps vs lower case vs bold heirarchy should be modified so that it is more rational (e.g., lower case applies to a lower-level section, etc.). The section headings should be expanded to be more descriptive (e.g., add in CBL or in SBL).

G-6 The ordering of the sections should be switched around so that topics follow in orderly progression. Now there are many many forward references to equations that don't appear until many pages later. This is because, for example, the source and plume rise sections are at the end rather than at the beginning. The entire document should be reorganized so it flows from one topic to the next and so there are no forward references.

G-7 A clear recommendation is needed concerning the use of on-site meteorological data. Should all available on-site meteorological data (e.g., surface fluxes, detailed vertical profiles of winds, temperatures and turbulence) be used in AERMOD? Or is it better to use parameterized meteorological variables in some cases? What do we do if there are data available from more than one on-site tower (e.g., one at stack base, another 5 km to the west, and another on a hill 2 km to the east)

[Detailed, line-by-line comments for Appendix I in the original report are removed for brevity]

Appendix II Comments on Overview of AERMOD Evaluation Studies

Comments by Peer Review Panel on document by AERMIC entitled Overview of AERMOD Evaluation Studies, dated March 1998.

This six-page document provides an overview of the two more detailed documents that describe the developmental evaluation and the independent evaluation.

General Comments

G-1 The review panel recommends that the so-called development evaluation be downplayed and perhaps renamed (results of model calibration with developmental data sets). It is not fair to evaluate AERMOD versus ISC when AERMOD has had its parameters tuned with the data set while ISC has not had the benefit of this tuning.

G-2 The review panel finds that the so-called independent evaluationö was interesting, but was limited to only three sites where only routine data were available. No near-surface sources were tested. It is not possible to conclude that AERMOD is a significant improvement over ISC and other model until a comprehensive evaluation is carried out using a variety of scenarios, including some sites with high-quality on-site meteorological observations and tracer releases.

G-3 In most of the model-to-model comparisons, HPDM performed as well as AERMOD. Why is HPDM not being recommended for adoption by the EPA, too?

G-4 The models included in the evaluations should be expanded to include OML, ADMS, and SCIPUFF, which are all state-of-the-art models very similar to AERMOD.

[Detailed, line-by-line comments for Appendix II in the original report are removed for brevity]

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Appendix III Comments on Developmental Evaluation

Comments by Peer Review Panel on document by Lee et al. entitled DEVELOPMENTAL EVALUATION OF THE AERMOD DISPERSION MODEL

General

G-1 As the review panel has mentioned elsewhere, this report should be renamed to something like results of model calibration with developmental data sets. The AERMOD Technical Document describes the intensive tuning and calibration that was done with these data sets. Similar tuning was not done with the other models (ISC3, HPDM, CTDMPLUS) that are compared with these data. It was therefore not a level playing field.

G-2 A measure of the scatter is needed (e.g., VG or NMSE).

G-3 The meteorological data that were used from each site should be clearly explained.

G-4 The legends and captions of the figures should be expanded so that they can be better understood by the readers.

G-4 It would help if a list could be given, in as brief a form as possible, of the changes that were made to AERMOD as a result of the Developmental Evaluation.

[Detailed, line-by-line comments for Appendix III in the original report are removed for brevity]

Appendix IV Comments on Performance (Phase II) Evaluation

Comments by Peer Review Panel on document by PES, Inc., entitled PERFORMANCE (PHASE II) EVALUATION OF THE AERMOD DISPERSION MODEL dated March 1998

General

G-1 - The terminology for this phase II study needs to be cleared up and a single definition settled on. The Summary Report refers to this phase as an INDEPENDENT evaluation, while the current document refers to it as a PERFORMANCE evaluation.

G-2 As mentioned in our review of the Developmental Evaluation report, the peer review panel recommends that the Phase I developmental study be downplayed, since much tuning was done with AERMOD. Emphasis should be on the current report, which uses more independent data sets.

G-3 Despite the use of data from three sites, it should be stressed that the evaluation exercise is very limited and should be greatly expanded. The three sites all involve elevated stack plumes, routine SO2 monitoring systems, and minimal on-site meteorology. Before accepting the model, the EPA should evaluate it with additional data sets, including ground level releases, sites with extensive on-site meteorological observations, sites where tracer studies were carried out with dozens of monitors on well-designed arcs, and sites where detailed complex terrain studies were made (e.g., Cinder Cone Butte, Hogback, Tracy).

G-4 The report should acknowledge the existence of similar advanced models such as OML and ADMS and SCIPUFF and explain why those models were not included in the evaluations.

G-5 The rationale for accepting AERMOD would also lead to accepting HPDM. Does the committee plan to recommend HPDM, too, on the basis of its performance in this report?

G-6 Nearly all of the many figures need improvement. Figure numbers are hand-written and captions are often non-existent. The captions should contain sufficient information that the figure stands alone in the sense that the reader can understand it without referring to the text.

G-7 The model evaluations should include a measure of the scatter, such as VG or NMSE. The five-page discussion of the results should be greatly expanded to adequately cover what is presented in 27 figures and 7 tables.

G-8 - The AERMOD interface is a key component of the model, providing complete profiles of wind, temperature and turbulence from the surface up to 5000 meters above the surface, extrapolating data up to that level from even the barest minimum (10 m) measurement height. The Panel recommends that some evaluation of the performance of the interface be provided as part of the overall evaluation of the model. Evaluation of the interface can be accomplished by performing sensitivity tests and/or by comparing predicted profiles against data. Comparisons against data can be accomplished by utilizing meteorological measurements alone, which should increase the number of potential data sets considerably over those that have concurrent measured pollutant concentrations. Of particular interest is how the interface performs when driven by minimal data, and further how sensitive it is to small changes in input parameters such as Zim.

G-9 - AERMOD has a tendency to underpredict the upper end of the frequency distribution at Martins Creek even though the robust high concentration - RHC - is overpredicted slightly for 24-hr averages. Marginal performance from a regulatory perspective should trigger a more detailed review of the predictions to find evidence that would (hopefully) support the model predictions. An examination of the emission rates - total over all sources - associated with predicted and observed concentrations, however, suggests that the model could underpredict substantially when considering the average emission rate of the highest 25 predicted observed and modeled concentrations (Table 4.10 of the Phase II evaluation document; avg during obs is approx 1300, during pred. 2300 g/s). This tendency, coupled with an even more distinct tendency to underpredict the upper end of the frequency distribution at Lovett where normalized concentrations were reported, suggests that further model formulation changes may be called for. The Panel believes that the tendency to underpredict at Martins Creek might be influenced by the interface prediction of less stable temperature gradients at plume level than those used by other models (thereby resulting in higher plume rise and lower Hcrit). Evaluation of the interface, and further diagnostic analysis of the meteorological conditions associated with high predicted and observed concentrations, could provide some insights into whether this is the case and could potentially lead to changes in the interface as opposed to changes in the terrain interaction formulation.

[Detailed, line-by-line comments for Appendix I in the original report are removed for brevity]

Appendix V – Comments on "User's Guide for AERMOD"

The AERMOD users guide is similar in organization to the ISC3 users guide. This structure should help new users gain familiarity with the new model. Some general comments follow:

In past updates to the ISC3 model, the EVENT processor which makes it possible to identify source-specific contributions and meteorological conditions associated with selected events, has always lagged behind the appearance of the new model. Some consideration should be given to including the EVENT processing directly in AERMOD so that this lag does not occur.

Given the importance of AERMOD's interface that generates profiles of winds, temperature, and turbulence, it would be helpful to have an option that prints out the generated profile for selected hours in a format that can be compared directly to the input data. Ultimately, the understanding, acceptance, and use of AERMOD will be enhanced by the degree to which users (not all users, but those who are involved with modeling routinely and who are committed to understanding the tools that they use) can determine how the model is carrying out its calculations. Experience has shown that the profiles generated by the interface are a key element in this understanding, and an easy way to review the profiles for selected hours would be quite helpful.

REPORT II. AERMIC'S RESPONSE TO THE FIRST PEER REVIEW REPORT

(Dated 12/98)

1. INTRODUCTION

In the following, AERMIC responds to comments provided by a Peer Review Panel (Hanna et al., 1998) that assessed several documents describing the dispersion model AERMOD. The Panel was established in mid-March 1998 at the request of EPA and reviewed documents related to the AERMOD development: 1) a Model Formulation Document (MFD) describing the dispersion model algorithms, 2) three reports summarizing model evaluations, and 3) three user's guides. In addition, the Panel focused on twelve general questions posed by EPA concerning the formulation and evaluation of AERMOD and its potential for replacing ISC3 as a regulatory model for short-range dispersion applications.

AERMIC is grateful to the Panel for their quick response and review of the AERMOD documents, and their recommendations on this model development activity. In Section 2, we give responses to Panel's answers to the 12 general questions. Although we do not agree with all of the comments raised by the Panel, we believe that their comments have played an important role in: 1) producing a more complete MFD, 2) recommending some of the needs for further model development (e.g., the downwash model), and 3) suggesting areas for further model evaluation efforts.

REPORT II. AERMIC'S FIRST RESPONSE

2. RESPONSE TO THE PANEL'S ANSWERS TO THE TWELVE GENERAL QUESTIONS

General Question 1.1. As a steady-state, plume-based, regulatory model, does AERMOD represent the state-of-the-science in its handling of boundary layer turbulence and dispersion?

[Unfortunately, the Panel did not give a direct answer to this question. Their answer is qualified by "Within the resources available to AERMIC and the data available" ..... "represents a very good attempt" and thus is ill-defined. Does a "very good attempt" mean that we succeeded or failed? There are some later hints that the Panel thought that AERMOD features were state-of-the-science (e.g., answers to questions 1.2 (page 4), 1.3 (pages 4 and 5), 3.2 (top of page 10)). We hope that the peer review committee will draw a conclusion on this question.]

General Question 1.2. Within the context of regulatory dispersion models in the US, does AERMOD represent significant scientific advances over ISC3?

[Again, the Panel did not give a direct answer to this question, i.e., the AERMOD state-of-the-art science relative to ISC3. The first part of their answer refers to the type of meteorological input and its effect on the quality of the predictions relative to those of ISC3. They state: "Since AERMOD is able to include more boundary layer observations than the ISC3 regulatory model, it would seem that it represents better science." Again, this is a qualified remark. The Panel states, however, that AERMOD's plume rise and dispersion algorithms represent the state-of-the-art in plume modeling, but do not state whether or not this is an advance over ISC3.]

[In the final paragraph, the panel comments about the lack of consideration given to several other models that include scientific advances (OML, ADMS, HPDM, and SCIPUFF) and that we should demonstrate where AERMOD represents an advance over these models. (AERMIC in fact did consider two of the models as discussed below.) However, the real question asked was whether or not AERMOD represented a significant advance over ISC3. Unfortunately, this question was not answered.]

With regard to OML, ADMS, HPDM, and SCIPUFF, none of these models was formally submitted to the EPA for consideration, although HPDM came close. In 1991, when AERMIC was formed, none of these models was available to EPA, with the possible exception of OML. AERMIC invited Drs. Helge

Olesen and Ruwim Berkowicz, the developers of OML, to one of its early meetings. We obtained users guides and formulation documents for OML. Like HPDM, OML does not treat terrain with significant elevations (above stack height), although it has simple algorithms to describe dispersion over rolling terrain. Due to the terrain handling limitation, further consideration was not given to HPDM or OML, since extensive modifications would be necessary to include terrain. We note, however, that a number of ideas are borrowed from or in common with these models; this commonality will be clarified in the final MFD.

ADMS is a proprietary model that was not available when the AERMIC activity began. Technical information about the model appears to be difficult to obtain without paying licensing fees. SCIPUFF's public availability as an operational model with full documentation also was limited when our development process began. In addition, SCIPUFF was not developed to the point where it is today.

General Question 1.3. What do you think are the most scientific advancements in AERMOD?

The Panel lists the following: 1) inclusion of straightforward procedures to handle terrain influences, 2) elimination of the discrete Pasquill stability classes and replacement of them by continuous stability classes using the Monin-Obukhov length (and we add planetary boundary layer variables), 3) treatment of strongly convective conditions by the PDF approach, 4) adoption of a plume lofting and penetration model, and 5) inclusion of a different dispersion treatment for surface sources than for elevated releases.

The Panel again states that there are other models (OML, ADMS, HPDM, and SCIPUFF), which should have been investigated more thoroughly. As noted above (our response to question 1.2), we did indeed review OML and HPDM and have a number of treatments (e.g., PDF approach with HPDM, convective scaling and PBL parameterization, etc.) that are similar to theirs. We believe that all major technical features included in these "other models," relative to ISC3, are also included in AERMOD (although the details do differ). These relationships have been clarified in the latest version of the MFD.

General Question 1.4. Are there any areas or features of AERMOD in which an improved formulation or treatment would be desired? If so, please discuss whether you think the revised treatment would lead to better performance and how much.

REPORT II. AERMIC'S FIRST RESPONSE

AERMIC is aware of the deficiencies of the ISC3 downwash approach as expressed by the Panel and has considered the PRIME model as an alternative. However, there is no thorough documentation of PRIME to permit a scientific evaluation of the model, and there has been no peer review of that model. Furthermore, there was insufficient funding to pursue an alternative downwash approach (PRIME, ADMS, or some other) as an improved treatment for downwash. We agree with the Panel that an alternative downwash approach should be considered.

We agree with the Panel that further development and testing of the urban dispersion model would be desirable, but the resources for this are not available. For example, considerable time will be necessary to prepare well-organized urban data sets that are similar in quality to other rural data sets. We also note that the MFD (March 1998) submitted for the Peer Review incorrectly stated that the model assumes an unstable planetary boundary layer (PBL) over the urban area at night. In fact, the PBL is modeled as stable, consistent with the surrounding rural area, but has enhanced convectively-generated turbulence due to the urban-rural temperature difference. The enhanced turbulence velocities are proportional to the urban nocturnal convective velocity scale, which depends on the urban mixed-layer height and the upward heat flux.

The Panel also states that many of the algorithms in AERMOD have not been adequately justified by comparison with data. We agree that more justification of some algorithms is necessary. However, in some cases, algorithms have been borrowed from other dispersion models (e.g., the PDF approach from Weil et al., 1997), and we rely on this earlier work for justification. In other cases (e.g., surface layer sources in the CBL), the model has been taken as an interpolation fit between two well-defined limits (a surface source and an elevated source) and dispersion data for intermediate source heights are lacking. Further justification is being provided in the MFD where necessary, and figures showing the variation of meteorological variables with height and other parameters have been added.

General Question 2.1. Is the current organization of the model formulation document and User's Guide appropriate or would an alternative be desired?

The Panel suggested that a clear recommendation should be made concerning the use and need for on-site meteorological data including vertical profiles. Recommendations and guidance of this will be developed from the meteorological degradation analysis, which has just been completed. These recommendations should be available for the next EPA Conference on Air Quality Modeling. The degradation analysis consists of evaluating the model against several air quality data sets using different levels or degrees of meteorological inputs---1) off-site data only (e.g., National Weather Service), 2) on-site data with only 10-m height tower and off-site temperature profiles, and 3) on-site data with meteorological profiles (and extrapolated profiles using PBL scaling), etc.

The Panel also recommended that schematic diagrams be added to explain some of the concepts. We agree with this and have added a number of such diagrams to the current version of the MFD.

General Question 2.2. Is the presentation of the model clear and explanatory? Please note any specific sections of the documentation that were unclear or confusing.

The Panel again recommends that the MFD be enhanced by adding justifications for parameterizations included in AERMOD and adding explanatory diagrams. We agree with this and have pursued it in the new version of the MFD as noted above (Question 2.1).

The Panel also recommends that discussions of comparisons with similar state-of-the-art models (OML, HPDM, ADMS, and SCIPUFF) be included. AERMIC will include general and some specific comments about these models. However, the real issue before the peer-review panel is the following: Is AERMOD a state-of-the-science model that is ready for regulatory use (for replacing ISC)?

As another suggestion, the Panel recommended that the units of variables be included with the equations in the MFD; we have added a full List of Symbols with units as another section to the MFD.

General Question 2.3. Is the documentation sufficient for a typical ISC-type user to guide them in the use of the model and its preprocessors? Do you think training sessions would be particularly useful?

Overall, the Panel seemed to think that the documentation would be sufficient for typical users. The area where they felt some confusion may exist and where training may be necessary is in the use of on-site meteorological data, particularly when extensive data (multiple-level towers, sodars, surface data, etc.) are available. AERMIC believes that results from the (recently completed) meteorological degradation analysis will be useful here, and guidance from this analysis will be available in the near future. [A draft of this document is now available for the Panel.]

REPORT II. AERMIC'S FIRST RESPONSE

General Question 3.1. How do you rate the performance of AERMOD relative to ISC3 and the other models included in the evaluation exercises?

The Panel states that the five developmental data sets (Kincaid SO2 and SF6, Indianapolis, Lovett, and Prairie Grass) should be "set aside" when addressing this question because model components were "tuned" or calibrated using this data. AERMIC disagrees with this "set aside" philosophy. Clearly, some tuning was performed using these data sets which were quite different in the nature of the sources and terrain: 1) tall stack, buoyant release in flat terrain (Kincaid), 2) tall stack, buoyant release near elevated terrain (Lovett), 3) tall stack, buoyant release in an urban area (Indianapolis), and 4) nonbuoyant surface release (Prairie Grass). However, since the core model algorithms apply to such a diverse range of conditions, we believe that there is an underlying model generality that is exemplified by these comparisons and should be noted.

We agree that ISC3 and other models could be tuned and improved using these same data sets. HPDM was tuned and improved with the Kincaid and Indianapolis data. In essence, one could say that ISC was the model chosen for the AERMIC development effort since we adopted that model's computer architecture. Early in our development effort (1992, 1993; e.g., see Weil, 1992), we referred to the model (which has evolved into AERMOD) as an updated or new version of ISC and called it ISC3! However, EPA recommended that we adopt a new name to avoid confusion with the PGT-based ISC Model familiar to the user community; hence, we adopted the name AERMOD. We agree with the Panel that one should expect AERMOD to perform as well as or better than the PGT-based ISC3, as it does. This should be taken in a positive light showing the applicability of AERMOD to a broader range of conditions.

We note that when CTDM was submitted to EPA in 1987 for regulatory consideration, the three developmental tracer data bases (Cinder Cone Butte, Hogback, and Tracy) were given equal weight with the "independent" data bases in judging model performance. These developmental data bases were not set aside, and, in fact, were used in assigning a "skill score" to the model.

The Panel "feels that a scientific evaluation should include a technical peer review of the model components." AERMIC believed that such an evaluation was being generated by the Peer Review just completed. At any rate, AERMOD will receive such additional scientific evaluation when the model is submitted for journal publication in 1999.

The Panel also states that changes made to the model following the developmental evaluation should appear in a separate section with a summary table. AERMIC feels that this is an unwieldy and unreasonable request, and we do not have the records to construct this table. We are unaware of other development efforts where a log of model changes was recorded as the development progressed.

The Panel states that the three data sets used in the Phase II Evaluation represent running of the model with the "barest minimum of input data." The AERMIC disagrees with this view. Each of the three source sites had meteorological towers with multiple levels of data, and the Martin's Creek plant had tower and sodar data (for winds) at multiple levels. We would interpret the "barest minimum" of meteorology to include only one level of on-site tower data and probably at the 10-m level.

The Panel suggests that most users would run the model with more than the bare minimum of data. Experience would suggest otherwise because the bare minimum would be the least expensive; of course, there are exceptions. Most users would go beyond the bare minimum only if: 1) compelled to do so by a regulatory agency, or 2) they felt there was a good chance of obtaining lower predicted concentrations and hence a higher emission limit. In fact, there are examples where users have argued against their own on-site, multiple-level tower data versus airport data collected some 20 km away; the on-site meteorology happened to yield higher ground-level concentrations!

The Panel discusses the value of running the model with more detailed on-site meteorology with vertical profiles of winds, temperature, and turbulence and comparing model results using this input against those with less-detailed meteorology. Such a study is being conducted under our meteorological degradation analysis and results of that will be reported at the next EPA Conference on Air Quality Modeling. From this analysis, recommendations and guidance will be developed on the AERMOD meteorological inputs.

The Panel recommends that AERMOD be evaluated further for situations of complex terrain and building downwash. AERMIC agrees with this recommendation and has followed it for complex terrain. Since the Peer Review, AERMOD has been evaluated further using 1) the Tracy tracer data set on which it performed as well as CTDM+, and 2) the Westvaco data set where AERMOD outperformed CTDM+ and ISC3. AERMIC also would like to test the downwash algorithm with the PRIME data set but currently does not have the resources to do this.

The Panel recommends further independent testing of AERMOD against data from a near-surface source and the Bull Run power plant---a tall stack buoyant plume. Of the two, we believe that the surface release is the more important, and we will address this as resources permit. We note that as of now AERMOD has been evaluated with 10 substantial data bases, which is comparable to or more than that used for any other model proposed for short-range regulatory applications.

Finally, the Panel recommended that other similar models (OML, HPDM, ADMS, and SCIPUFF) be included in the model evaluation exercise. As noted earlier, we did include HPDM in the Phase II evaluation using the Baldwin and Clifty Creek data bases. In evaluation, our first priority is comparing AERMOD to other models currently in use for regulatory applications, i.e., to determine AERMOD's use or fit as a replacement regulatory model.

General Question 3.2. From a model design, scientific, and performance perspective, what comments do you have on the replacement of ISC3 with AERMOD for regulatory applications?

Several panel comments here were raised previously and addressed under our earlier responses. A new comment is that the Panel "feels that AERMOD has not been adequately evaluated with independent data, since the three data sets in the Independent Performance Evaluation Report are all "routine" data sets that do not include extensive onsite meteorological observations..." AERMIC believes that these data sets are typical or better (Martin's Creek) in terms of on-site meteorology for routine, year-long air quality data sets. In the Phase II Evaluation, our emphasis is on such data sets because they are typical of the types of regulatory applications to which the model will be subjected in the future.

The Panel also points out that HPDM performs as well as AERMOD in the two independent data sets for which it was evaluated. AERMIC agrees with this and also notes the high-wind algorithm of HPDM was tuned in part using these two data sets---Baldwin and Clifty Creek. The Panel states that HPDM also should be considered as a replacement for ISC3. However, when HPDM was submitted earlier to EPA for consideration as a regulatory model, it was classified as simple terrain elevated-source model. Given the lack of a significant complex terrain algorithm, HPDM could not be considered as a viable replacement for ISC3. Of most importance, it is not within AERMIC's purview to decide on the submission of HPDM as a regulatory model or to select it for regulatory consideration (this is the responsibility of the EPA OAQPS).

General Question 3.2. When considering the eight data bases used to evaluate the model, would additional evaluation of AERMOD be desirable?

REPORT II. AERMIC'S FIRST RESPONSE

The Panel's comments here were raised earlier and addressed in our previous responses. We agree that further model evaluations would be desirable, but only can be addressed as resources permit. Of the four recommended areas for further evaluation, the one involving tracer releases in complex terrain has been addressed since completion of the Peer Review---the Tracy and Westvaco data sets were added to the evaluation. Of the three remaining recommendations, AERMIC believes that the priorities (highest first) are: 1) downwash conditions, 2) surface releases, and 3) data sets with more complete meteorology (more vertical profiles, etc.) than those used in the Phase II Evaluation. The AERMIC would also add urban sources to this list as a priority 2.

Additional EPA Question 4.1. Dated 3/18/98. Is the AERMOD approach to modeling urban sources scientifically sound and state-of-the-art?

The Panel states that the urban modeling procedures were developed through calibration of predicted concentrations with observations at the Indianapolis site. It is true that one dimensionless coefficient (alpha = 0.03) was adjusted by comparing predictions and observations. However, the basic expressions relating heat flux and urban mixed-layer height to city size (using the urban-rural temperature difference) were obtained from data given by Oke (1973, 1982). The latter studies covered Canadian cities with sizes ranging from populations P of 1.0E+03 to 2.0E+06; Indianapolis with a P = 700,000 falls within this range. We agree that comparisons of the heat flux and mixed-layer height predictions to observations at Indianapolis would be desirable.

The Panel also notes that there were no independent urban data sets in the Phase II Evaluation, which is true. Again, available resources were insufficient to include such data sets. However, we are unaware of other tracer data sets for tracking or tracing individual sources in urban areas that would permit unambigous evaluation of AERMOD for a single source. We recognize that multiple source and concentration data sets (e.g., SO2) exist for urban areas, but they would not permit evaluation of single-source dispersion within the urban environment. Furthermore, given the size of such data sets and the number of sources, use of them in model evaluation would require substantial resources.

Additional EPA Question 4.2. Dated 3/24/98. Do the building downwash algorithms within AERMOD represent the current state of the science and are these algorithms appropriate to regulatory applications?

As stated earlier, AERMIC agrees that there are deficiencies in the

REPORT II. AERMIC'S FIRST RESPONSE

ISC3 downwash algorithms as used in AERMOD. We are considering PRIME and other downwash treatments as a potential future replacement for the current treatment in AERMOD. This is one of our highest priorities for future work and will be addressed as resources permit.

REPORT II. AERMIC'S FIRST RESPONSE

3. RESPONSE TO THE PANEL'S CONCLUSIONS AND RECOMMENDATIONS

AERMOD Development and Evaluation Process -- Here, the Panel's two major criticisms are those that have appeared earlier in their responses to the twelve questions: 1) inadequate documentation and justification for the new parameterizations in AERMOD, and 2) insufficient AERMOD evaluation over a wide range of tracer studies and routine data sets. We have addressed these comments in our earlier responses. However, in summary, AERMIC has added justification and further description of algorithms to the most recent version of the MFD.

Concerning the model evaluation, we reiterate that {\bf AERMOD has been evaluated against 10 substantial data bases} including: 1) four data sets for tall stack buoyant plumes in flat terrain (Kincaid SO2, Kincaid SF6, Baldwin, and Clifty Creek), 2) four data sets for tall stacks in complex terrain or near elevated terrain (Lovett, Martins Creek, Tracy, and Westvaco), 3) a buoyant elevated release in an urban environment (Indianapolis), and 4) a nonbuoyant surface release (Prairie Grass). We agree that more evaluation would be desirable (as always) especially for downwash conditions, urban sources, and surface releases. However, there is a key question to the AERMOD development process: Has there been enough evaluation already to justify replacing ISC3 by AERMOD? AERMIC believes that there has been.

Discussion of Availability of Similar Models and Evaluations with the Same Data Sets as AERMOD -- Here, it is stated that "While the Panel recognizes that the technical algorithms in AERMOD represent the state-of-the-art, we are concerned that the impression is given that AERMOD is unique in this regard." The impression that AERMOD is unique, as the Panel surmises from the AERMOD documentation, certainly was not intended. This impression will be removed by adding to the MFD a discussion of the general attributes of these other models. Clearly, AERMIC recognizes that other models contain similar state-of-the-art algorithms for dispersion; several AERMIC members participated in the development of other such models. We indicated in our earlier responses why OML and HPDM were not chosen by AERMIC for development---the absence of treatment for dispersion about significant elevated terrain. Concerning ADMS and SCIPUFF, we note that widely-available documentation for these models and/or a demonstrated applicability to the range of conditions required by a new US regulatory dispersion model (for full elevated terrain, downwash, etc) did not exist when the AERMIC activity began in 1991.

The Panel posed a question concerning adoption of one of the other models for submission to the EPA. However, another natural and relevant question is: Why not start with the ISC Model, which is quite familiar to the US-based user community, and adopt/modify it to overcome its limitations (lack of treatments for PBL scaling and state-of-the-art dispersion, full elevated terrain, vertical inhomogeneity in the PBL, etc.)? The latter approach is of course the path followed by AERMIC in developing AERMOD.

Desired Additions to AERMOD Description of Model Formulation Document -- We agree that the MFD needs to be enhanced with justifications for new parameterizations, etc. and have addressed this under our earlier responses.

Approaches to Modifications to Account for Urban Dispersion and Building Downwash Need Further Study -- As noted earlier, the MFD was in error in stating that the boundary layer is always unstable in an urban area (see general question 1.4). The other comments concerning downwash were addressed in our earlier responses.

Specific Recommendations for Input Data -- As stated earlier (general question 2.1), recommendations and guidance on meteorological input data will be developed from the meteorological degradation analysis, which has just been completed. This analysis used several of the data sets which had multiple levels of tower data.

Additional Data Sets for Evaluation

Complex Terrain -- As noted in our earlier responses, we added an evaluation of AERMOD with the Tracy data set, as recommended by the Panel, and also the Westvaco data set, which represents a more operational-type situation.

Flat Terrain Site with Detailed Meteorological Inputs -- We agree that it would be nice to evaluate the model against another tall stack, buoyant plume situation in flat terrain, but AERMOD already has been evaluated with four flat-terrain data sets. The recommended degraded meteorology exercise has been carried out with the Kincaid data set, which offers the same type of meteorological data as Bull Run.

Building Downwash -- The Panel's comments here were addressed under our responses to the twelve general questions.

Further Evaluations with Ground-Level Sources -- The Panel's comments here also were addressed under our responses to the twelve general questions. We certainly will consider the Dugway Proving Ground data for evaluation of surface-source dispersion, as resources become available.

REPORT II. AERMIC'S FIRST RESPONSE

4. RESPONSE TO APPENDIX I COMMENTS

Seven general comments and a voluminous number of specific ones were made in Appendix I on the MFD. Four of the general comments (G1, G2, G3, G7) were addressed earlier in this response (Section 2). Two of the general comments and many of the specific ones concerned either the format of the MFD or were editorial in nature. Most of them have been addressed in an updated and expanded version of the MFD; e.g., we have added the complete section number to all of the section and subsection headings in the document. There were recurring requests and comments concerning the referencing to earlier models---HPDM, OML, ADMS, and SCIPUFF; a general discussion of these models is given in the background section of the MFD.

A number of other substantive comments were included in Appendix I and many of them were dealt with in our earlier remarks (Section 2) or are being handled in the updated MFD. For example, we have added about 16 figures to the MFD with 3 or 4 pertaining to elevated terrain. However, there were also a number of comments with which we disagreed---e.g., the data base "set aside" philosophy, the request to evaluate four other models (HPDM, OML, ADMS, and SCIPUFF), including background on the AMS - EPA working group back to 1979, etc. Some comments also were unjustified. This includes the comment on why the beta test was not open and why Earth Tech did not participate in it. In fact, the beta test was open with AERMOD being placed on the EPA SCRAM Bulletin Board at the same time AERMIC asked specific individuals to review the model. Earth Tech and in particular Joseph Scire was invited to participate in both of the beta tests. Unfortunately, Joe was unable to do so due to a heavy work commitment at the time, but AERMIC did receive some comments from David Strimaitis.

REPORT II. AERMIC'S FIRST RESPONSE

5. RESPONSE TO APPENDIX II COMMENTS

[Comments by Peer Review Panel on document by AERMIC entitled "Overview of AERMOD Evaluation Studies", dated March 1998.]

General Comments –

G-1 – The review panel recommends that the so-called "development evaluation" be downplayed and perhaps renamed (results of model calibration with developmental data sets). It is not fair to "evaluate" AERMOD versus ISC when AERMOD has had its parameters tuned with the data set while ISC has not had the benefit of this tuning.

The large number of data sets involved in the developmental evaluation suggests that AERMOD has considerable skill in performing well for a diverse selection of sites. In addition, the expression that "parameters were tuned" is not an accurate one. The AERMOD formulation is based upon sound physical principals, rather than highly statistical fits to data. The diverse data bases confirm the selection and use of the model algorithms rather than drive their formulation. In terms of "fairness" in not tuning ISC, it should be noted that AERMOD represents a significant advance in U.S. regulatory model development. The purpose of the evaluation exercise is to verify that this new model performs at least as well as or better than an existing regulatory model, ISC. It should also be noted that ISC was developed, in part, as a result of the use of data from the Prairie Grass experiment. ISC has also been previously evaluated with several of the Phase I and II data bases, with fairly good results for the Kincaid, Indianapolis, Baldwin, and Clifty Creek data bases. Therefore, AERMOD was confronted with a significant challenge in performing better than ISCST3 on several of these data sets.

G-2 – The review panel finds that the so-called "independent evaluation" was interesting, but was limited to only three sites where only routine data were available. No near-surface sources were tested. It is not possible to conclude that AERMOD is a significant improvement over ISC and other model until a comprehensive evaluation is carried out using a variety of scenarios, including some sites with high-quality on-site meteorological observations and tracer releases.

The use of three data bases for an independent evaluation is a significant task that required considerable resources. In response to the peer review panel comments, two additional data bases (both involving complex terrain) were added to the list (Westvaco and Tracy). In addition, the American Petroleum Institute has carried out an independent series of evaluations of AERMOD, ISCST3, and ADMS on a tracer experiment conducted at a petrochemical complex, in which near-surface area and volume source types were tested.

G-3 – In most of the model-to-model comparisons, HPDM performed as well as AERMOD. Why is HPDM not being recommended for adoption by the EPA, too?

REPORT II. AERMIC'S FIRST RESPONSE

The submittal of HPDM to EPA for consideration as a guideline model is not the responsibility of AERMIC. In 1991, when AERMIC was considering the basis for a new model platform, HPDM had been withdrawn from consideration as a guideline model. HPDM did not address complex terrain effects, and this was seen as a major shortcoming of the model. However, many of the best features of HPDM, including several of the meteorological pre-processor formulations and a convective PDF algorithm, are incorporated in AERMOD.

G-4 – The models included in the evaluations should be expanded to include OML, ADMS, and SCIPUFF, which are all state-of-the-art models very similar to AERMOD.
The primary purpose of the AERMOD evaluation effort, as directed by the U.S. EPA, is to determine whether AERMOD performs as well as, or better than, the existing regulatory models. Evaluations including the OML, ADMS, and SCIPUFF models would be nice to do, but would consume valuable resources that are better directed toward more pressing priorities. It should also be noted that there are drawbacks to each of these models. OML has been developed for Denmark, and is not strongly oriented to address complex terrain sites. The ADMS model is a proprietary code that is not readily available. Evaluations involving ADMS are being separately conducted by API, and preliminary indications are that the ADMS formulations are not as advanced as those of AERMOD, and that the AERMOD evaluation performance is somewhat better than that of ADMS. In recent conversations with Dr. Ian Sykes, Mr. Robert Paine has learned that SCIPUFF is not quite ready for public release.

[Detailed responses to line-by-line comments in the original report are removed for brevity]

6. RESPONSE TO APPENDIX III COMMENTS

Comments by Peer Review Panel on document by Lee et al. entitled "DEVELOPMENTAL EVALUATION OF THE AERMOD DISPERSION MODEL" (undated but received March 1998)

General comments

G-1 – As the review panel has mentioned elsewhere, this report should be renamed to something like "results of model calibration with developmental data sets". The AERMOD Technical Document describes the intensive tuning and calibration that was done with these data sets. Similar tuning was not done with the other models (ISC3, HPDM, CTDMPLUS) that are compared with these data. It was therefore not a "level playing field".

The large number of data sets involved in the developmental evaluation suggest that AERMOD has considerable skill in performing well for a diverse selection of sites. In addition, the expression that "parameters were tuned" is not an accurate one. The AERMOD formulation is based upon sound physical principals, rather than highly statistical fits to data. The diverse data bases confirm the selection and use of the model algorithms rather than drive their formulation. In terms of "fairness" in not tuning ISC, HPDM, or CTDMPLUS, it should be noted that AERMOD represents a significant advance in U.S. regulatory model development. AERMIC knows of no precedent in which multiple models were "tuned" in preparation for a model evaluation study. The purpose of the evaluation exercise is to verify that this new model performs at least as well as or better than the existing regulatory models, ISC and CTDMPLUS. HPDM was included with two databases (Baldwin and Clifty Creek) because it was felt that HPDM should do well with these data sets, and AERMOD should have at least a comparable performance.

G-2 – A measure of the scatter is needed (e.g., VG or NMSE).
For the tracer data sets, the box and whisker plots provide a visual means to assess the prediction scatter. For full-year data sets, the sparse coverage of the monitors does not lend itself to meaningful scatter analyses.

G-3 – The meteorological data that were used from each site should be clearly explained.

This document has been absorbed into a more complete report that covers all of the major evaluations of AERMOD. Some expansion of the discussion of the meteorological data for the developmental evaluation was added.

G-4 – The legends and captions of the figures should be expanded so that they can be better understood by the readers.

OK.

G-4 – It would help if a list could be given, in as brief a form as possible, of the changes that were made to AERMOD as a result of the Developmental Evaluation.

A list of the changes desired are not available and would take considerable resources to reconstruct, if even possible. AERMIC is not aware of a precedent in which such information was provided.

[Detailed responses to line-by-line comments in the original report are removed for brevity]

REPORT II. AERMIC'S FIRST RESPONSE

7. RESPONSE TO COMMENTS APPENDIX IV

Comments by Peer Review Panel on document by PES, Inc., entitled "PERFORMANCE (PHASE II) EVALUATION OF THE AERMOD DISPERSION MODEL" dated March 1998 (about 200 pages of text including many figures)

General comments

G-1 - The terminology for this phase II study needs to be cleared up and a single definition settled on. The Summary Report refers to this phase as an "INDEPENDENT" evaluation, while the current document refers to it as a "PERFORMANCE" evaluation.

AERMIC internally referred to the "Phase II" evaluation as the independent evaluation. The terminology will be clarified in the general evaluation report that covers both the developmental and independent evaluations. The report that is the subject of these comments will remain as a resource, but will not be updated or placed in the EPA docket for the 7th Modeling Conference.

G-2 – As mentioned in our review of the "Developmental Evaluation" report, the peer review panel recommends that the Phase I developmental study be downplayed, since much tuning was done with AERMOD. Emphasis should be on the current report, which uses more independent data sets.

The large number of data sets involved in the developmental evaluation suggest that AERMOD has considerable skill in performing well for a diverse selection of sites. In addition, the expression that "parameters were tuned" is not an accurate one. The AERMOD formulation is based upon sound physical principals, rather than highly statistical fits to data. The diverse databases confirm the selection and use of the model algorithms rather than drive their formulation. The consistently good results obtained with AERMOD over the combination of the developmental and the independent evaluation databases provides a confirmation of the broad applicability of the model.

G-3 – Despite the use of data from three sites, it should be stressed that the evaluation exercise is very limited and should be greatly expanded. The three sites all involve elevated stack plumes, routine SO_2 monitoring systems, and minimal on-site meteorology. Before accepting the model, the EPA should evaluate it with additional data sets, including ground level releases, sites with extensive on-site meteorological observations, sites where tracer studies were carried out with dozens of monitors on well-designed arcs, and sites where detailed complex terrain studies were made (e.g., Cinder Cone Butte, Hogback, Tracy).

REPORT II. AERMIC'S FIRST RESPONSE

The use of three data bases for an independent evaluation is a significant task that required significant resources. In response to the peer review panel comments, two additional data bases (both involving complex terrain) were added to the list (Westvaco and Tracy). In addition, the American Petroleum Institute has carried out an independent series of evaluations of AERMOD, ISCST3, and ADMS on a tracer experiment conducted at a petrochemical complex, in which near-surface area and volume source types were tested.

AERMIC disagrees with the comment that the three independent databases described in this report involved "mininal" meteorological data. Each had a tall tower instrumented at multiple levels, and one site, Martins Creek, also had a sodar.

G-4 – The report should acknowledge the existence of similar advanced models such as OML and ADMS and SCIPUFF and explain why those models were not included in the evaluations.

The primary purpose of the AERMOD evaluation effort, as directed by the U.S. EPA, is to determine whether AERMOD performs as well as, or better than, the existing regulatory models. Evaluations including the OML, ADMS, and SCIPUFF models would be nice to do, but would consume valuable resources that are better directed toward more pressing priorities. It should also be noted that there are drawbacks to each of these models. OML has been developed for Denmark, and is not strongly oriented to address complex terrain sites. The ADMS model is a proprietary code that is not readily available. Evaluations involving ADMS are being separately conducted by API, and preliminary indications are that the ADMS formulations are not as advanced as those of AERMOD, and that the AERMOD evaluation performance is somewhat better than that of ADMS. In recent conversations with Dr. Ian Sykes, Mr. Robert Paine has learned that SCIPUFF is not quite ready for public release.

G-5 – The rationale for accepting AERMOD would also lead to accepting HPDM. Does the committee plan to recommend HPDM, too, on the basis of its performance in this report?

The submittal of HPDM to EPA for consideration as a guideline model is not the responsibility of AERMIC. In 1991, when AERMIC was considering the basis for a new model platform, HPDM had been withdrawn from consideration as a guideline model. HPDM did not address complex terrain effects, and this was seen as a major shortcoming of the model. However, many of the best features of HPDM, including several of the meteorological pre-processor formulations and a convective PDF algorithm, are incorporated in AERMOD.

G-6 – Nearly all of the many figures need improvement. Figure numbers are hand-written and captions are often non-existent. The captions should contain sufficient information that the figure "stands alone" in the sense that the reader can understand it without referring to the text.

The final evaluation document will attempt to incorporate improvements suggested in this comment.

G-7 – The model evaluations should include a measure of the scatter, such as VG or NMSE. The five-page discussion of the results should be greatly expanded to adequately cover what is presented in 27 figures and 7 tables.

For tracer data sets, the box and whisker plots provide a visual means to assess the prediction scatter. For full-year data sets, the sparse coverage of the monitors does not lend itself to meaningful scatter analyses. In terms of the discussion of results, the report that covers all of the evaluations will not be significantly increased in size, so as not to overly burden the reader. The figures and tables speak for themselves.

G-8 - The AERMOD interface is a key component of the model, providing complete profiles of wind, temperature and turbulence from the surface up to 5000 meters above the surface, extrapolating data up to that level from even the barest minimum (10 m) measurement height. The Panel recommends that some evaluation of the performance of the interface be provided as part of the overall evaluation of the model. Evaluation of the interface can be accomplished by performing sensitivity tests and/or by comparing predicted profiles against data. Comparisons against data can be accomplished by utilizing meteorological measurements alone, which should increase the number of potential data sets considerably over those that have concurrent measured pollutant concentrations. Of particular interest is how the interface performs when driven by minimal data, and further how sensitive it is to small changes in input parameters such as Zim.

PES has conducted a limited number of sensitivity runs with degraded meteorological data sets to attempt to address the concerns stated in this comment. The results of the analysis will be part of the EPA modeling conference docket.

G-9 - AERMOD has a tendency to underpredict the upper end of the frequency distribution at Martins Creek even though the robust high concentration - RHC - is overpredicted slightly for 24-hr averages. Marginal performance from a regulatory perspective should trigger a more detailed review of the predictions to find evidence that would (hopefully) support the model predictions. An examination of the emission rates - total over all sources - associated with predicted and observed concentrations, however, suggests that the model could underpredict substantially when considering the average emission rate of the highest 25 predicted observed and modeled concentrations (Table 4.10 of the Phase II evaluation document; avg during obs is approx 1300, during pred. 2300 g/s). This tendency, coupled with an even more distinct tendency to underpredict the upper end of the frequency distribution at Lovett where normalized concentrations were reported, suggests that further model formulation changes may be called for. The Panel

believes that the tendency to underpredict at Martins Creek might be influenced by the interface's prediction of less stable temperature gradients at plume level than those used by other models (thereby resulting in higher plume rise and lower Hcrit). Evaluation of the interface, and further diagnostic analysis of the meteorological conditions associated with high predicted and observed concentrations, could provide some insights into whether this is the case and could potentially lead to changes in the interface as opposed to changes in the terrain interaction formulation.

In response to the peer review panel comments, the AERMOD terrain treatment was modified to incorporate additional CTDMPLUS-like features, and two additional data bases (both involving complex terrain) were added to the list (Westvaco and Tracy). The performance results of the new AERMOD model address the concerns discussed in this comment.

[Detailed responses to line-by-line comments in the original report are removed for brevity]

REPORT III. THE FINAL PEER REVIEW REPORT. (Dated Mar 3, 1999)

1 BACKGROUND

The EPA has assembled a peer review panel in order to review the various documents produced by the AMS/EPA AERMIC group on the new AERMOD dispersion model. The EPA is proposing to possibly replace the ISCST3 regulatory model with the new AERMOD dispersion model, and asked the panel of experts in air dispersion modeling to provide specific technical comments on the documents as well as to provide answers to a set of questions concerning whether AERMOD is ready for use as a regulatory model.

After the Peer Review Panel was set up in mid-March 1998, a group of AERMOD documents was delivered to each panel member. A total of seven documents were reviewed which included one report describing the technical formulation, three reports describing model evaluations, and three user's guides. The Panel was also asked to address a set of twelve general questions related to whether AERMOD was ready for use as a regulatory model. Two conference calls were held on 2 and 3 April discussing the between the Panel, the AERMIC group, and ICF Kaiser. A draft report was prepared by the panel and delivered to EPA on 23 April.

During the intervening period, AERMIC has taken our comments into consideration and has revised the "Model Formulation" and "Model Evaluation" documents, carried out evaluations with additional field data sets, and prepared a document containing point-by-point responses to our comments. This information was provided to the peer review panel on 23 December 1998 for additional review. This report contains comments on the revised "Model Formulation" and "Model Evaluation" documents and the AERMIC response document. In addition, we have revised our responses to the set of questions posed by the EPA to the Peer Review Committee.

REPORT III. FINAL PEER REVIEW REPORT

2 INTRODUCTION AND GENERAL COMMENTS

We believe that AERMOD represents a significant improvement over ISC3. There are many new state-of-the-science concepts and approaches in AERMOD, including a unique "interface" that creates complete temperature, wind and turbulence profiles from even the barest minimum input data. However, we feel that, because of these new approaches, AERMOD is more likely than simpler models like ISC3 to need an extended break-in period when its use in routine applications can be thoroughly tested. It is worth noting in this regard that all of the AERMOD evaluation data bases (except for Prairie Grass) involved tall, non-downwashed, highly buoyant power plant stacks (the shortest stack in the group was 84 meters in Indianapolis). The vast majority of ISC3 applications involve modest stacks with modest buoyancy flux values, most of which are subject to some degree of aerodynamic downwash, as well as area and volume source configurations which were not evaluated or tested (at least not in the documentation provided) to determine how AERMOD predictions compare to predictions using ISC3.

We are concerned about the accuracy of the concentrations predicted by the downwash algorithm in AERMOD, since the same downwash algorithm is used in both ISC3 and AERMOD. Considering that something has to be incorporated, it seems alright for the present to include the convoluted H-S and S-S procedures that are currently incorporated into the ISC3 models with the simplification that variances will be added rather than using virtual sources. Then if the PRIME research project makes an appropriate case for alternate procedures, these can be included in the next AERMOD. Hopefully, that would be a substitution, not a melding of H-S, S-S and PRIME.

In the course of applying AERMOD to many different sources, in many different settings, with many different meteorological data bases, users may discover aspects of AERMOD that would be desirable to change. It is possible to minimize the number of situations where this would occur by conducting a thorough, exhaustive, independent set of sensitivity tests aimed at understanding the underlying reasons for model performance and the interrelationship of model components, rather than just the end results of the model. Such a thorough analysis is not likely to happen in the near future, however, and it therefore might be appropriate to allow for an interim period when AERMOD can be accepted as a "refined" model but that its use would not be required. This would be especially appropriate since some applications cannot be correctly handled by AERMOD (e.g., those involving deposition) and some algorithms (e.g., downwash) are likely to experience additional changes in the near future.

Our basic conclusion is that AERMOD is ready to be proposed as a replacement to ISC3. However, it would be a mistake to treat AERMOD as "finished" and not needing any further evaluation or dialogue regarding its performance and its use as a routine model. It is acknowledged by AERMIC that model changes, involving downwash and deposition in particular, are going to be made in the next year or two. We suggest that the period during which these additional changes are being evaluated and implemented could be regarded as an interim period where AERMOD can be used as a "refined" model. The use of AERMOD could be conditioned on developing site-specific information regarding its performance, possibly relative to ISC3 and the performance of the model's interface in terms of generating meteorological profiles. After an interim approval period, the information and model improvements (if any) generated through these comparisons and evaluations could be assessed. An advantage of the interim approval period would be the generation of a wealth of information about the model and its performance and use in the real world.

REPORT III. FINAL PEER REVIEW REPORT

3 GENERAL COMMENTS ON AERMIC RESPONSES TO PEER REVIEW COMMITTEE REPORT

The document was prepared by the AERMIC committee in response to our April 1998 AERMOD Peer Review Report. In addition, AERMIC has provided a revised Model Formulation document and Model Evaluation document. Over the past month, we have read the three documents and feel that the Peer Review Committee should be pleased that so many of our suggestions have been seriously considered and satisfactorily addressed by the AERMIC committee.

The AERMIC responses suggest that they were disappointed that we did not provide more definite answers to their 12 general questions. However, we believe that we were not provided sufficient information to allow us to reach definite answers. The latest documents have improved the situation. Yet, even though AERMOD represents the state-of-the-art better than ISC3, AERMIC has not seriously considered similar models such as SCIPUFF or OML. On page 4 of their response, AERMIC states that "SCIPUFF's public availability as an operational model with full documentation was limited when our development process began". But that was 8 or 9 years ago. Since then SCIPUFF has been further developed and has been in the public domain with comprehensive documentation for several years.

Despite these reservations, our peer-review committee endorses the substitution of AERMOD for ISC, since AERMOD does represent the modern class of dispersion models and does provide an improvement to the current EPA models. Furthermore AERMOD does demonstrate satisfactory agreement with the various field data bases used for its evaluation. However, as mentioned in Section 1, none of these field data bases involved downwash.

AERMIC and the EPA still need to provide better guidance on the use of meteorological data for inputs. Also, they should carry out more comprehensive sensitivity tests in order to be sure that the model does not produce odd predictions under certain combinations of inputs. These sensitivity tests should include many types of real-world scenarios where downwash occurs.

REPORT III. FINAL PEER REVIEW REPORT

Comments on Vertical profiling of dq/dz: We were interested in how dq/dz is estimated, especially when no measurements are available, as with Martins Creek. We interpreted Figure 4 as a representation of what AERMOD generates (through its interface) when measurements are not available, given assumed micrometeorological parameters that represent a "strongly stable boundary layer" (MFD, p. 29). This figure raises several issues. For example, we were not able to reproduce Figure 4, given the parameters stated in the text and using equation (31). This may be simply our misunderstanding of how the figure was developed, but it may be a good candidate for an example illustration in an AERMOD training course.

If it is true that this curve (Figure 4) represents a typical profile of dq/dz as generated by the interface when there are no measurements available, then it is worth noting what the implications are for Martins Creek. At 183 meters (the height of the MC stacks), dq/dz essentially disappears, subject to the minimum value of 0.002 K/m. A sense of what this means in terms of plume rise can be gained by examining the above table, which represents calculated stable case plume rise for a highly buoyant stack, based on AERMOD formulas (version 98314).

These results show that, if lower potential temperature gradients are frequently predicted by the interface, then the difference in model performance between AERMOD and the other models (where low wind-speed, stable conditions will result in a much lower plume rise) is not hard to understand. In practice, however, shorter stacks may experience temperature gradients that are actually more conservative than the ISC3 defaults of 0.02 and 0.035 and the relative performance picture may be very different.

Example of using AERMOD plume rise for a highly buoyant stack

Plume rise calculations

wind speed	final stable plume rise (eq 122)	neutral length scale (eq. 124 - see note)	neutral limit (eq. 123)	calm rise (eq 125)	distance to final rise (stable)	unstable p.r. (eq. 116) @ dfr (stable)
Using dtheta/dz = 0.02						
1	276	48722	62968	324	167	454
2.5	203	19489	25156	324	417	335
5	161	9744	12578	324	834	266
Using dtheta/dz = 0.002						
1	595	48722	62890	769	542	979
2.5	438	19489	25156	769	1354	721
5	348	9744	12578	769	2708	573

Note: equation 124 in model code has ustar*ustar in the denominator

Inputs

0.02	0.002	dtheta/dz
0.0259	0.0082	BVF
0.0181	0.0057	BVFPrime
293	293	TA
450	450	TS
5	5	DS
35	35	VS
9.816	9.816	G
0.6	0.6	Beta1
0.124	0.124	U*
749.2	749.2	FB
4985.1	4985.1	FM
1680.3	1680.3	Distance to final rise (uns)
183	183	stack height

Some natural questions arise from this, including 1) how good a representation of vertical dq/dz is the interface's predictions, and 2) how sensitive are the predictions to the mechanical mixing height, a parameter that is not well defined and extremely difficult to measure/verify? These questions should be part of the ongoing dialogue as AERMOD continues to be evaluated and improved.

Other model formulation comments: Concerning the development of horizontal and vertical dispersion parameters, equation (96) does not appear to be correct, either as the result of making the indicated substitutions or in comparison to the formulation appearing in the model code (subroutine SIGZ). 2) The discussion on the contribution of plume meander was difficult to follow in the MFD and the model code. A sketch would be useful, 3) The plume rise discussion was relatively easy to follow, except that the issue of the effect of random vertical motions in the CBL was taken out of the plume rise section altogether. It would help to have a reference to eq. 64 in the section on plume rise in the CBL (Section 6.5.1), just to tie things together a little more neatly. Furthermore, if it is intentional not to calculate a "final rise" in the CBL, it would be useful to say so in section 6.5.1 - especially since, in the discussion on vertical inhomogeneity (section 4.2), reference is made to the distance to final rise and the calculation of the homogeneous layer limits is based in part on the "final" plume height.

Comments on AERMOD Interface: The interface contained in AERMOD that provides complete profiles to the model is based on approaches that are consistent with the current state-of-the-science regarding profiles of wind, temperature, and turbulence in the boundary layer and their relationship to micrometeorological variables. There was little attempt in the evaluation of the model, however, to address the question of how well the interface itself works, whether it is sensitive to parameters that are poorly understood and difficult to measure, and whether the entire interface approach is internally consistent.

Comments on Minimum Meteorological Data Requirements: As we understand the recommendation in this document, there is no reason to require that any data be collected beyond what is now routinely available (i.e., NWS data). The implication of this is that the interface works well enough to eliminate the need for collecting profiles of wind, temperature, and turbulence values. However, an unambiguous link has not been established between improved inputs and better model performance, i.e. the modeled atmosphere seems to do as well as the measured atmosphere.

We do not think that AERMOD should be held back because of these concerns, but we also believe that its implementation should be accomplished in a way that the evaluation and the dialogue concerning the profiling of meteorological variables would continue. In an interim implementation period, this dialogue could be continued by requiring that the use of AERMOD be accompanied by an analysis of the performance of the interface at the site in question – a statistical summary of profiled values, for example, could be generated and presented as part of a representativeness analysis. The performance of the interface for many different settings could be generated quickly, and an evaluation after the end of the interim period could provide additional evidence of the performance of the interface and possibly point the way to improvements - or, if the interface evaluations reveal nothing worthwhile, the requirement could be dropped.

[Sections 4 and 5 contained the detailed, line-by-line comments and are omitted for brevity. In the last report, the AERMIC final responses, there is a general discussion response to these two omitted sections and provide a sense of the overall detailed comments]

REPORT III. FINAL PEER REVIEW REPORT

6 COMMENTS ON AERMOD MODEL PERFORMANCE DOCUMENT DATED 15 DEC. 1998

On balance, the evaluations demonstrate relatively unbiased performance over a wide range of source and receptor relationships reflected in a large number of data bases. Additionally, AERMOD tends to do better over most of the frequency distribution than most of the other models tested. However, at least part of AERMOD's good performance is due to adjusting the model to fit the data (e.g., complex terrain changes were made that affected model performance at Martins Creek and Lovett, but these changes were apparently made before the evaluations for Tracy and Westvaco). However, even if this is true, good performance over a wide range of data bases is still significant in terms of the likely performance of the model in the real world.

We have some remaining questions about model performance in complex terrain. The comments that we presented in our draft report were first, that the model performance at Lovett showed a distinct tendency towards underprediction at the upper end of the frequency distribution for all averaging periods, and second, that a slight tendency towards underprediction at Martins Creek did not stand up to further investigation when considering emission rates for predicted values vs. emission rates for observed values. AERMIC responded to these comments by saying that first, the incorrect plots had been provided for Lovett (the correct plots involved concentration comparisons, not normalized C/Q comparisons). Furthermore, some modifications to the complex terrain algorithms were made that improved model performance. And finally, AERMIC stated that the use of C/Q statistics is not warranted since the "low emission hours for Martins Creek are probably associated with full-load emissions from one or more of the shorter stacks, which were likely responsible for the bulk of the observed impacts".

The model changes had a noticeable effect on the upper end of the frequency distribution, particularly for Martins Creek. In the latest evaluation document, concentration Q-Q plots are provided for Lovett for 1-hr, 3-hr and 24-hr averaging periods and C/Q Q-Q plots are provided stratified by stable/unstable conditions. It is unclear from this whether the C/Q or the concentration comparisons are being suggested as the more correct comparisons. When impacts are clearly associated with a single source, C/Q comparisons are the most appropriate to use and therefore there is still some question as to AERMOD's performance at Lovett. We agree with AERMIC that at Martin's Creek it would probably be impossible to separate out the effects of different sources. However, if what AERMIC contends is true (that full-load emissions from short stacks cause high observations during low emission hours for Martins Creek), then AERMOD must be under-predicting the impacts from the shorter stacks since the shorter stacks are modeled at close to full load for most of the data base.

These concerns are not enough to conclude that AERMOD is so flawed that it cannot be recommended (particularly since AERMOD performed so well with the Tracy SF_6 data base). It is clear from the evaluations, however, that CTDMPLUS has a distinct tendency to overpredict by a substantial margin in situations (Lovett and Martins Creek - and to a lesser extent Westvaco) where emissions from a highly buoyant source are at an elevation just above terrain where monitors are located. AERMOD has a tendency to predict much lower values for these situations, and if chi/Q statistics are considered - or at the very least, emissions are taken into consideration qualitatively - performance becomes questionable. These results should be further analyzed and explained, in order to add a comfort level that the AERMOD predictions are more believable.

It is possible, additionally, to question the performance of AERMOD for surface releases and in urban settings, since for Prairie Grass and Indianapolis there is a slight tendency for underprediction relative to observations and relative to ISC3 (for Prairie Grass, the underprediction tendency appears both in the comparison of model predictions to RHC and in the 1-hr Q-Q plots, while for Indianapolis the tendency appears only in the Q-Q plots). Whether a regulatory model can be accepted for general use, even if it displays some tendency - albeit slight - to underpredict under some conditions, is a question that is important to consider. It is much easier to accept a model like ISC3 for regulatory applications based on fewer and less extensive evaluations, with its clear tendency to overpredict. AERMOD's performance has many desirable features, but its predictions are occasionally less than observations. The EPA should be open to further evaluations aimed at bolstering the current set of results - and making improvements if necessary - during an interim model approval period.

Although the authors make a point when they say that this model has used more evaluation data sets than previous models, we are concerned that only one evaluation data set related to surface releases (Prairie Grass) has been used. Because it has been found that the SO2 tracer was actually being deposited to some extent with downwind distance, we wonder if AERMIC has accounted for this mass loss in their evaluations. Furthermore, the results of the evaluation shown in Figures A-3 and A-5 indicate that the model tends to underestimate concentrations. Also see Figures A-4 and A-6. Is this a desirable attribute for a regulatory model?

REPORT III. FINAL PEER REVIEW REPORT

7. Revised Answers to EPA Questions Posed in Original Charge to Reviewers

EPA General Topic Area 1. Model Formulation

EPA General Question 1.1 - As a steady-state, plume-based, regulatory model, does AERMOD represent the state-of-the-science in its handling of boundary layer turbulence and dispersion?

AERMOD embodies state-of-the-science approaches to boundary layer turbulence and dispersion.

EPA General Question 1.2 - Within the context of regulatory dispersion models in the US, does AERMOD represent significant scientific advances over ISC3?

AERMOD represents significant scientific advances over ISC3. However, AERMOD is similar to other available state-of-the-art models such as SCIPUFF, OML, ADMS, CTDM, and HPDM.

EPA General Question 1.3 - What do you think are the most important scientific advancements in AERMOD?

AERMOD incorporates several scientific advancements, including the use of convective scaling and non-Gaussian pdfs of vertical velocity in convective conditions. Also, dividing streamlines are used for complex terrain. The vertical profiles of meteorological variables are developed based on state-of-the-art methods. However, the peer review committee mentions that such advancements are available is other models as well, such as SCIPUFF, CTDM, and HPDM.

EPA General Question 1.4 - Are there any areas or features of AERMOD in which an improved formulation or treatment would be desired? If so, please discuss whether you think the revised treatment would lead to better performance and how much.

The urban dispersion algorithms need more development and justification. An updated downwash algorithm is desired. It would be useful to remove the tendency towards underpredictions. The specification of meteorological inputs should be clarified.

2. Documentation

EPA General Question 2.1 - Is the current organization of the model formulation document and User's Guide appropriate or would an alternative be desired?

The separation of the technical details into a model formulation document (particularly the much-improved, current version of the MFD) is fine. The User's Guide is well-organized and useful.

REPORT III. FINAL PEER REVIEW REPORT

EPA General Question 2.2 - Is the presentation of the model clear and explanatory? Please note any specific sections of the documentation that were unclear or confusing.

The peer review panel had numerous concerns regarding the original March 1998 documentation, mostly regarding the MFD. The current version of the MFD is an improvement over the last version, and will provide users with a good description of the model. Further justification of algorithms is needed.

EPA General Question 2.3 - Is the documentation sufficient for a typical ISC-type user to guide them in the use of the model and its preprocessors? Do you think training sessions would be particularly useful?

The documentation is sufficient. Because the model is not simple, training sessions would be helpful for most users.

3. Evaluation and Performance

EPA General Question 3.1 - How do you rate the performance of AERMOD relative to ISC3 and the other models included in the evaluation exercises?

Overall, the performance of AERMOD is good over a wide range of scenarios. Some of the evaluations of AERMOD show a slight tendency for AERMOD to underpredict near the upper end of the frequency distribution. The model needs more evaluation for downwash scenarios.

EPA General Question 3.2 - From a model design, scientific, and performance perspective, what comments do you have on the replacement of ISC3 with AERMOD for regulatory applications?

The replacement of ISC3 with AERMOD for regulatory applications is appropriate. We recommend that this be done in a staged process so as to allow for testing of the new algorithms and the development of guidance for optimum meteorological inputs. All of the AERMOD evaluation data bases (except for Prairie Grass) involved tall stacks with buoyant plumes (the shortest stack in the group was 84 meters in Indianapolis), with little probability of downwash occurring. The vast majority of ISC3 applications involve modest stacks with modest buoyancy flux values, most of which are subject to some degree of aerodynamic downwash, as well as area and volume source configurations which were not evaluated or tested (at least not in the documentation provided) to determine how AERMOD predictions compare to predictions using ISC3.

EPA General Question 3.3 - When considering the eight data bases used to evaluate the model, would additional evaluation of AERMOD be desirable?

The number of data bases is actually ten, with the addition of Tracy and Westvaco. Additional evaluations of AERMOD in urban settings, for surface releases, and for downwash impacts would be desirable, as would further diagnostic evaluation of model performance in complex terrain. But use of the model should not be delayed pending the completion of these evaluations. An "interim" approval status might be appropriate for AERMOD while further evaluations are conducted, in particular while the downwash and deposition algorithms are being subjected to further testing and modification.

Additional EPA Question 4.1 Dated 3/18/98 - Is the AERMOD approach to modeling urban sources scientifically sound and state of the art?

The new urban formulation of AERMOD embodies many parts of a state-of-the-science approach. There are still issues remaining concerning the method of estimating stability in urban areas.

Additional EPA Question 4.2 Dated 3/24/98 - Do the building downwash algorithms within AERMOD represent the current state of science and are these algorithms appropriate to regulatory applications?

The building downwash algorithms in AERMOD are essentially the same as those currently in ISC3. Consequently, they should be suitable for regulatory applications. However, there is no information in the documentation provided as to how these algorithms work within AERMOD, and none of the evaluation data sets concerned downwash.

REPORT IV. THE FINAL RESPONSES FROM AERMIC. (Dated June 7, 1999)

1. Introduction

In the following, AERMIC responds to comments provided in the AERMOD Peer Review Final Report (Hanna et al., 1999) that assessed several documents describing the dispersion model AERMOD. In March 1998, a Peer Review Panel was established by EPA to review AERMOD, a new short-range dispersion model for industrial source applications and a potential replacement for the ISC3 Model. The Panel reviewed numerous documents pertaining to the formulation, user guidance, and evaluation of AERMOD and produced a Peer Review Report (Hanna et al., April 1998). As a result of the Panel's comments, AERMIC has: 1) revised and expanded the AERMOD Model Formulation Description (MFD, Cimorelli et al., 1998), 2) modified the AERMOD code accordingly, 3) evaluated the complex terrain portion of the model with two additional data bases (the Tracy and Westvaco data sets), and 4) revised and clarified the model evaluation documentation (Paine et al., 1998). The Panel has reviewed these revised documents, provided comments on them, and modified their responses to a set of twelve general questions posed by the EPA (Hanna et al., 1999).

As expressed in our earlier response (AERMIC, December 1998), AERMIC is grateful to the Peer Review Panel for their time, effort, and completeness in examining the revised AERMOD documents and providing their assessment. The basic conclusion of the Panel is that AERMOD is ready to be proposed as a replacement for the ISC3 Model for regulatory air quality applications,but they have some comments on further AERMOD development and evaluation work. In the following, we summarize and respond to what we perceive as the major issues or questions by the Panel concerning AERMOD, its evaluation and implementation. This is done by section of the final report (Hanna et al., 1999), but omitting Section 1 on "Background."

2. Response to Section 2: Introduction and General Comments

The Panel states that they believe AERMOD to be a significant improvement over ISC3 and that it contains many new state-of-the-science concepts and approaches including a unique meteorological interface. Their basic conclusion is that AERMOD is ready to be proposed as a replacement for ISC3. They raise four issues or concerns discussed below: 1) limitations of source types in the AERMOD evaluation, 2) the downwash algorithm, 3) the need for more experience with AERMOD results and sensitivity tests, and 4) the need for a "break-in" period.

2.1. Source Types in AERMOD Evaluation

The Panel noted that with the exception of Prairie Grass (surface release), all of the AERMOD evaluation data bases involved buoyant releases from tall stacks at power plants. They also noted that the majority of ISC3 applications pertain to "modest" buoyancy fluxes and "modest" stacks, many of which are subject to aerodynamic downwash.

AERMIC agrees that further testing and evaluation with "intermediate stack height" data bases would be desirable and would merit attention in the future given appropriate data sets and the resources to analyze them. We note two factors to reduce this concern. First, AERMOD has been formulated as a continuous function of source height (z_s) and buoyancy flux and tested in the limits of: 1) a nonbuoyant surface release (Prairie Grass), and 2) buoyant releases in the upper part of the atmospheric surface layer (lowest 10% of the boundary layer) or in the mixed-layer (upper 90%) of the convective boundary layer (CBL). Simple interpolation formulas are used that give a continuous variation of dispersion (σ_y, σ_z) with z_s between these limits. Thus, we believe that the parameterization of dispersion from intermediate stack heights should be reasonable.

Second, AERMIC has conducted a consequence analysis in which AERMOD and ISC were run for a large number (72) of source, meteorological, terrain, and urban/rural combinations. Thus, the difference between the AERMOD and ISC results or their similarity can be determined for the type of source, source height, etc. of interest.

2.2. The Downwash Algorithm

AERMIC plans to introduce an improved building downwash algorithm into AERMOD as resources permit. This could include the EPRI-sponsored PRIME algorithm or another alternative that overcomes the deficiencies of the existing ISC3 downwash model. AERMIC notes that the existing AERMOD downwash algorithm may be an improvement over that of ISCST3 because of the associated advances in the treatment of meteorological profiles in AERMOD. During the period in which the downwash model is incomplete, AERMOD can be used for other types of applications or for mixed applications in which the downwash algorithm does not dominate the highest concentration predictions. If the use of the current AERMOD with downwashed sources shows that other effects, such as terrain impacts, dominate, then AERMIC suggests that AERMOD can be used to assess compliance with ambient standards. Alternatively, another model such as ISC-PRIME could be used to assess a limited receptor area where downwash effects dominate. Since near-field downwash effects are likely to be influenced mainly by source effects rather than atmospheric turbulence, the use of ISC-PRIME in the near field and AERMOD everywhere else should be considered as a possible interim solution.

2.3. Additional AERMOD Experience

The Panel recommends that AERMOD be applied to a wide variety of sources, terrain settings, and meteorological data bases to learn more about the model behavior, i.e., conduct a large number of sensitivity tests. Exercises of this type have been conducted under two activities: 1) a Technology Transfer Workgroup (TTW) during 1998, and 2) a consequence analysis to compare AERMOD and ISC results.

2.3.1. TTW Activity

In 1998, EPA under the leadership of Mr. Robert Wilson of Region 10, assembled a TTW, to conduct a variety of test runs of AERMOD. The TTW had several participants from a number of states, EPA Regions, and even a representative from British Columbia. The numerous trial runs of AERMOD conducted by the TTW on a variety of source types provided valuable feedback to AERMIC and resulted in the elimination of some "odd predictions under certain combinations of inputs" referred to by the Panel. This is not to say that our work is complete in this area. AERMIC welcomes results from other work similar to that conducted by the 1998 AERMOD TTW, either by organized groups or individuals who are exercising the model.

We note that ISCST3 itself is not immune to unusual predictions caused by discontinuities in its formulation, or by known problems that have gone uncorrected due to their low priority. This has not prevented ISCST3 from being promulgated and maintained as a guideline model. AERMOD has been formulated and tested to eliminate, to the extent possible, any problems. However, AERMIC acknowledges that with testing conducted over time, adjustments in certain algorithms may be necessary.

2.3.2. Consequence Analysis

The consequence analysis is designed to provide regulatory design-concentration comparisons between old (ISC3) and new (AERMOD) models for a number of typical source scenarios. The purpose of such a study is to give the modeling community a sense of the regulatory impacts of using the new model for source types that they have or may evaluate. Although not designed to be an exhaustive sensitivity study, the consequence analysis for AERMOD and ISC3 included 72 combinations of source, meteorological, terrain, and urban/rural situations.

Although similar to the earlier consequence analyses in that 2 meteorological data bases and 2 different land classifications were used (urban and rural), the AERMOD consequence analysis evaluated all three types of sources (point, volume and area) in three types of terrain (flat, simple and complex). There were 24 flat terrain point source combinations (6 stack heights, 2 met sites, 2 land classifications); there were 8 simple terrain point source combinations (2 stack heights, 2 met sites, 2 land classifications); there were 8 volume source combinations (2 stack heights, 2 met sites , 2 land classifications); there were 4 area source combinations (1 release height, 2 met sites, 2 land classifications); and there were 32 point source combination for the complex terrain (2 stack heights, 2 buoyancy types [medium and high], 2 distances to the hills, 4 hill types).

We believe that this consequence analysis is comprehensive in that most reasonably expected source combinations have been evaluated by the latest version of AERMOD and successfully completed. Of course, other analyses such as the evaluation -data- base reruns became part of the testing of this last version of the model; thus, the testing of the model did not end with the consequence analysis. These many computer runs have satisfied AERMIC that the current version of the model is stable and does not provide erroneous results for the large majority of source combinations.

2.4. Break-In Period

The panel recommends that in view of the new approaches integrated into the AERMOD modeling system, there should be a time period during which the public gains experience with this new model, i.e., a break-in period. During this period, the panel notes that some enhancements to AERMOD (e.g., downwash, wet and dry deposition) also could be added as well as further model evaluations. AERMIC believes that the EPA OAQPS will establish something akin to a break-in period during which both AERMOD and ISC3 may be used.

3. Response to Sections 3 and 4: General and Specific Comments on AERMIC Response Document (December 15, 1998)

The comments in these two sections deal primarily with the AERMIC response (December 1998) to the Panel Peer Review Report of April 1998. As such they pertain to the earlier version of the AERMOD MFD (March 1998). The focus of the current response document is the Panel review of the most recent versions (December 1998) of the MFD and the model evaluation document. Thus, with the exception of the AERMOD development process discussed below, we do not address the discussion of the earlier AERMOD documents.

In a number of places, the Panel questions AERMIC's consideration of submodels and algorithms (dispersion, etc) from other models---ADMS, HPDM, OML, and particularly SCIPUFF---in developing AERMOD. We point out, however, that there are important links of AERMOD to earlier models. For example, the PDF model for buoyant plume dispersion in the CBL (Weil et al., 1986) was adopted in HPDM (Hanna and Paine, 1989; Hanna and Chang, 1993). This model has been modified since the HPDM version to deal more effectively with highly-buoyant plumes and CBL turbulence, including near-neutral conditions (Weil et al., 1997). This modification was made to provide a continuous variation of the modeled concentration field with source buoyancy and stability. The main point, however, is that the PDF model has an HPDM connection.

Likewise, the preprocessing of meteorological data in AERMET is similar to that done for HPDM (Hanna and Paine, 1989; Hanna and Chang, 1993) and CTDMPLUS (Perry, 1992) as stated in the most recent AERMOD MFD (December 1998); several of the processing schemes were borrowed from these earlier models. In addition, most or many of the profiling expressions for winds, temperature, and turbulence are similar to or are borrowed directly from earlier profile models as referenced in the Interface section of the MFD.

For terrain effects, much of our initial thinking of the problem was guided by concepts in CTDMPLUS, as indicated in the most recent MFD, e.g., the dividing streamline height and its dependence on wind speed, stratification, and hill height. However, our intent was to simplify considerably the concentration calculations for terrain effects by comparison to the treatment in CTDMPLUS, where subjectively-defined, idealized hill shapes and considerable terrain data are required to define them. In addition, the AERMOD vertical dispersion (σ_z) model for elevated plumes in stable conditions has its origin in the early CTDMPLUS developments.

For AERMOD, our main aim was to develop a simple plume model for routine air quality predictions much in the spirit of ISC3, but with dispersion and other processes based on state-of-the-art understanding. Three of our key design goals were to: 1) provide reasonable concentration estimates over a wide variety of conditions with minimal discontinuities, 2) be user friendly and require reasonable input data and computer resources as in the current ISC3 model, and 3) capture the essential physical processes while remaining simple.

REPORT IV. FINAL AERMIC RESPONSE

In considering SCIPUFF, part of our rationale for not pursuing it was: 1) the lack of complete documentation for the model when the AERMIC activity began, and 2) the absence of treatment for a number of conditions (full elevated terrain, downwash, etc) required by a new US regulatory model. SCIPUFF treatments for several of these conditions have been added since the AERMIC activity began. However, another major reason for not pursuing SCIPUFF was its basis---as a puff or integrated puff (for plumes) model and the detailed, numerically-intensive calculations and resources required for its operation. This contrasts with the relative simplicity of the plume models such as AERMOD and ISC3. Note that our goal was for the new model to be run with a year or perhaps five years of meteorological data to identify the worst-case concentrations for comparison with air quality standards. Our understanding is that SCIPUFF is not intended nor well-suited for operation in this mode. Instead, it is intended for modeling shorter time periods (e.g., 24 hours or less) in a more intensive and detailed manner (Sykes, 1999; private communication to R. Paine).

AERMIC is very interested in the numerous field data sets with which SCIPUFF has been evaluated as reported in the Panel final report (Hanna et al., 1999). We are especially interested in those data sets that fill some of the evaluation needs of AERMOD---continuous surface sources, short stacks in the planetary boundary layer, downwash situations, etc. We would be grateful for references to all of these evaluations, including those in the peer-reviewed literature.

In summary, we believe that AERMOD incorporates some of the best features of the other models mentioned by the Peer Review Panel. AERMIC is pleased that the Panel endorses the substitution of AERMOD for ISC.

4. Response to Section 5: Comments on AERMOD Description of Model Formulation: Dated 15 December 1998

In the following, we respond to the discussion of: 1) specific comments on the MFD, 2) vertical profiling of meteorological data, 3) other model formulation comments, and 4) minimum meteorological data requirements.

4.1. Specific Comments on the MFD

The Panel lists a number of specific comments by page (in the MFD) such as justification for certain assumptions, editorial comments, etc. AERMIC intends to update the MFD with further clarifications, corrections, etc. and these comments will be addressed in a future version of the MFD. Furthermore, the MFD will be updated on a continuing basis in the future as algorithms are modified and/or improved. In addition, AERMIC intends to publish several journal articles describing AERMOD and its evaluation. Many of the specific comments listed on pages 7 and 8 of the Panel Report also will be dealt with in these articles.

With respect to the urban boundary layer, further discussion of the model treatment of the nighttime situation will be given in an updated MFD. We note that in Eq. (129), a coefficient of 0.1 preceding the ln (P/P_o) term was omitted, but this was included in the AERMOD code. With this coefficient included, the urban - rural temperature difference is positive for population P > 100; a simple modification is being added to maintain a positive (or zero) temperature difference for all P.

4.2. Vertical Profiling of Meteorological Data

The Panel comments about the lack of an evaluation of the AERMOD Interface and its potential sensitivity to poorly-understood or difficult-to-measure parameters. The Interface uses parameterized profiles of wind, temperature, and turbulence that are generally consistent with profiles obtained by other investigators and that have been compared with observations (e.g., see the Paine and Kendall (1993) reference cited in the MFD as well as the Stull (1988) textbook and other references in the MFD). We have relied on these earlier model/observation comparisons for Interface support since there has been a fair amount of testing in this area, and we did not wish to repeat the same comparisons. However, this is not to say that the algorithms will always work perfectly, or not be overly sensitive to variations in certain input data. AERMIC welcomes reports of the modeling community's experience with the model in this regard.

A specific mention is made by the Panel of the temperature gradient profiling algorithm. The panel notes that the expected drop-off of the temperature gradient with height in stable conditions results in better AERMOD model performance for tall stack sources. It notes that the performance could be worse than ISC3 for short stacks since the AERMOD temperature gradients could be greater than the ISC default values. However, we note that the plume rise depends on the temperature gradient to the 1/3 power. Thus, for gradients a factor of 1.5 or 2 greater than the ISC values, the plume rise would be only 13% and 20% lower, respectively, than the ISC plume rise.

As noted earlier, a number of AERMOD/ISC3 comparisons have been carried out in the Consequence Analysis for different stack heights, buoyancy fluxes, stabilities, and downwind distances. One can consult this document to gain an idea of the AERMOD/ISC concentration differences for a particular scenario of concern.

4.3. Other Model Formulation Comments

These comments are generally of an editorial nature or require further explanation in the MFD and will be addressed in an updated MFD. We note that Eq. (96) does have an error; the 2 σ_{wT} term in the denominator should be replaced by σ_{wT} (t/2). The correct expression is used in the AERMOD code.

4.4. Minimum Meteorological Data Requirements

The AERMIC recommendations regarding minimum meteorological data for AERMOD are now available for review on EPA's SCRAM web site. It is not AERMIC's intent nor recommendation that only National Weather Service (NWS) data be used in, or sufficient for, all applications. The NWS data may be acceptable for some sources in simple terrain settings. However, in complex terrain, one may need a tall tower and sodar to provide the meteorological input if representative data from NWS sources are not available. Consideration of meteorological data representativeness on a case-by-case basis is an important aspect of the recommendations.

5. Response to Section 6: Comments on AERMOD Model Performance Document Dated 15 December 1998

The Panel notes that even if AERMOD's formulation were adjusted to improve its performance on some of the databases, its consistently good performance on a large number of databases is significant. The adjustment that improved the performance at the Lovett and Martins Creek plants was the σ_z formulation for stable conditions, Eq. (96) with the correction noted above. This formulation adopts the same Lagrangian time-scale model used in CTDMPLUS (see Venkatram et al., 1984); it results in a smaller σ_z than in the earlier AERMOD version and hence higher concentrations on elevated terrain.

5.1. Performance at Lovett

The Panel notes some confusion in the choice of concentration C or C/Q, where Q is the emission rate, in forming the quantile - quantile (q-q) plots for Lovett and Martins Creek. At Lovett, the concentration q-q plots were examined for the 1-, 3-, and 24-hr average concentrations, whereas C/Q plots were presented for the 1-hr averages segregated by stability, i.e., convective and stable. For averaging times greater than 1 hr, we adopted the C q-q plots because Q can vary over the 3- or 24-hr period, and there is an issue of the representative Q for normalizing C. For steady operation of a single source, the 1-hr average q-q plots could be presented either as C or C/Q. The choice of the C q-q plots was done primarily for consistency with the 3- and 24-hr averages and because the data record contained some low emission hours with highly uncertain Q values as discussed below.

The use of C/Q plots for the data separated by stability was a carryover from our earlier analysis and was not intended to confuse. However, we can understand the potential for confusion because of the underpredicted C/Q values at the upper end of the q-q plots. The plots (Figs. A-27, A-28) in the most recent AERMOD evaluation document (December 1998) contain data with quite low and uncertain Q values at the upper end. For the convective periods (Fig. A-27), the mean and maximum SO_2 emission rates for the data record were 160 g/s and 360 g/s, respectively. The highest observed C/Q value (5.87) was obtained for a Q = 2.2 g/s, which is only 1.4% of the mean Q, and the observed C was only 12.9 μ g/m^3. In contrast, the highest observed C during convective conditions was 442 μ g/m^3 with a Q = 129 g/s, and yields a C/Q = 3.43. Thus, one can see that the C/Q ratios for the very low Q hours can give a misleading impression about performance, i.e., the highest observed C/Q values are associated with relatively low concentrations. We believe that the cases with extremely low Q's should be de-emphasized; hence, we chose to focus on the C q-q plots for assessing performance. Similar findings occurred for the stable hours (Fig. A-28), where the Q's for the highest two observed C/Q values were only 4 and 5.4 g/s.

In hindsight, it would have been better to have eliminated the C/Q q-q plots or to have restricted the analyzed cases to some minimum Q as had been done in the earlier CTDMPLUS work, where a minimum Q = 40 g/s was adopted. In summary, we believe that focusing attention on the C q-q plots (Figs. A-24 to A-26) is the appropriate course for judging the AERMOD performance.

5.2. Performance at Martins Creek

For the Martins Creek plant, there are three reasons for choosing the C q-q plots for assessing model performance. The first two are the same as above for Lovett: 1) variation of Q over the 3- or 24-hr period and selecting a representative Q, and 2) de-emphasizing any cases with low and uncertain Q values. The third reason is that other sources in the Martins Creek area contribute to the concentrations; thus, there is again the issue of a representative Q for normalizing the concentrations. In addition, it should be noted that the modeling of the concentrations from the other sources is less than ideal because the Martins Creek meteorological measurements were used for all sources. The other sources---Hoffman-LaRoche, Warren County Resource Recovery Facility, and Metropolitan Ed Portland Station---are approximately 9, 12, and 15 km from the Martins Creek sodar site (see Fig. 10 in the model evaluation document). Probably the most questionable extrapolated variable is wind direction, and hence there is the problem of getting the plumes from the different sources properly "aimed." This is always a problem in air quality modeling. However, it is particularly exacerbated in the situation of a winding river valley surrounded by elevated terrain with non-colocated sources and only one meteorological site.

5.3. Overall Performance at a Number of Sites

The Panel questions the AERMOD performance for surface releases and the Indianapolis (urban) power plant because there is a slight tendency for underprediction relative to observations and to ISC3. They go on to state: "It is much easier to accept a model like ISC3 for regulatory applications based on fewer and less extensive evaluations, with its clear tendency to overpredict." However, the last statement is not true. ISC3 underpredicts the highest concentrations for the Kincaid SF_6 1-hr concentrations and the Kincaid SO_2 concentrations for 1-, 3-, and 24-hr averages based on the robust highest concentration (RHC, Table 1). Underpredictions also are found in the q-q plots for the same cases (Figs. A-8, and A-19 to A-21). We note that the ISC3 underpredictions for these cases are more significant than those of AERMOD for the Prairie Grass and Indianapolis data.

It is probably fair to say that a single model will not perform uniformly well or the same at a large number of sites due to a variety of factors: 1) random or stochastic variability in the observed concentrations (Note that models, as used here, are intended to predict ensemble mean or average concentrations over a large number of repetitions, whereas the observed concentrations are single realizations obtained from such an ensemble, i.e., from a statistical or probability distribution of concentration.), 2) uncertainty or errors in the meteorology and/or unrepresentative meteorological inputs, 3) errors in the model physics (e.g., unaccounted-for site features), etc. For regulators and regulatory applications, a key question is: Within what tolerance or range of the peak observed concentrations, especially on the low side, are the model predictions acceptable? This is especially an issue when considering a large number of data bases and comparisons with varying degrees of performance. An example of the performance range can be found in Table 1 of the model evaluation document. For 1- to 24-hr average concentrations, the lowest and highest ratios of modeled/observed RHC's are 0.72 and 1.72 for AERMOD, and 0.45 and 9.11 for ISC3; for CTDMPLUS and the complex terrain sites only, the lowest and highest ratios are 0.77 and 5.56. Thus, one can see that AERMOD has the narrowest range of ratios centered about the ideal value of 1. This is not to say that the model is perfect, but it does have the smallest range of variation.

We believe that model evaluation and model performance over a wide range of data bases are important topics and require further analysis and discussion.

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