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Science Advisory
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AN SAB REPORT: REVIEW OF THE INDOOR AIR ENGINEERING RESEARCH PROGRAM

REVIEW OF THE OFFICE OF RESEARCH AND DEVELOPMENT INDOOR AIR ENGINEERING RESEARCH AND DEVELOPMENT PROGRAM

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

EPA-SAB-EEC-93-009

OFFICE OF THE ADMINISTRATOR
SCIENCE ADVISORY BOARD

April 15, 1993

Honorable Carol M. Browner
EPA-Administrator
U.S. Environmental Protection Agency
401 M Street, SW
Washington, D.C. 20460

Subject: Science Advisory Board Report on Review of ORD's Draft "Indoor Air Engineering R&D Program"

Dear Ms. Browner:

The Science Advisory Board (SAB) has completed its review the Air and Energy Engineering Research Laboratory's (AEERL) air engineering research and development (R&D) program and is pleased to submit this report summarizing our findings. On July 20 and 21, 1992, the Indoor Air Engineering Research Subcommittee (IAERS), consisting of members and consultants of the SAB's Environmental Engineering Committee (EEC) and the Indoor Air Quality and Total Human Exposure Committee (IAQTHEC), reviewed a very well prepared briefing document, received detailed briefings from the program managers, engaged in dialogue with this group, and offered advice to the AEERL research team regarding this topic.

In accordance with the "charge to the committee," the IAERS review focused on source characterization and source-exposure modeling (well established research programs); microbial contaminant control/bioresponse testing and new strategic directions (emerging research areas). The IAERS recognized that the current in-house research program resources, supplemented by judicious use of contractor support and cooperative agreements, and leveraging other projects are achieving positive and impressive results. This report offers comment and recommendations in six different categories which are briefly described below.

1) The AEERL's source characterization effort is a mature program with strong in-house capabilities. The productivity of the program is reflected in many ways, including the leadership role that the AEERL

has established both in this country and abroad, the successful effort to develop many publications in peer-reviewed journals and staff participation and sponsorship of targeted specialty conferences. It is also observed by the Subcommittee that the future direction of the program, while appropriate, is ambitious, given the present levels of funding. The IAERS endorses this ambitious research program, but stresses that the resources available to carry out the research program are not adequate, nor do the expenditures reflect the high level of societal concern regarding indoor air issues.

2) Current mathematical modeling efforts are noteworthy. They could be improved by integrating other related Agency efforts into the Indoor Air Quality (IAQ) model. Refinements in the mathematical representation of mixing and transport processes, to the extent that they would have practical value in managing risks from indoor air exposures, and further sensitivity studies would also help provide an improved understanding of the uncertainty in the analysis.

3) Research on microbial contaminants in indoor environments should continue to emphasize preventive approaches to control conditions leading to the presence and growth of these organisms over methods to control them through the use of biocides and other non-preventive remedies. Research design should be bolstered in the selection of indicator species and certain other research parameters (e.g., eye irritations, coughing, allergic reactions, and headaches).

4) Bioresponse-based testing is proposed as a reasonable extension of current airborne chemical testing. Collaboration with established research efforts already in progress, including the activities of the Health and Environmental Research Laboratory (HERL) is necessary to move forward in this area. Establishing correlations between the biological and chemical data should be considered a priority for all these research efforts. While this review focused on the engineering research area and the health-based assessment was not reviewed in detail, priority should be given to establishing correlations between engineering issues and health-based testing and coordination.

5) The strategic directions thrust addresses AEERL's future R&D program. Emphasis on pollution prevention and cost-effectiveness modeling is important to maintain. Improvements in the dissemination ("diffusion", that is dissemination is a form that enable the recipients to use) of this and all the other information gained in

ongoing efforts needs to be encouraged so that the information can be utilized throughout the Agency and the user community.

6) An overall plan reflecting all four program areas should be developed. The resources, funding and expert staff needed in the areas of microbial contaminant control and new strategic directions should be obtained. Alternatively, the mission should be reduced to the established program areas until adequate resources are obtained to guarantee a quality program.

This SAB report offers a number of recommendations which are meant to improve and refine an already excellent research program. Much of the research is conducted in the AEERL facility under the direction of the Agency staff. Their work is highly leveraged and their outreach efforts are excellent.

We appreciate the opportunity to conduct this review and look forward to your response to the scientific advice transmitted herein.

Sincerely,

Dr. Raymond C. Loehr, Chair
Executive Committee
Science Advisory Board

Mr. Richard A. Conway, Chair
Environmental Engineering Committee
Science Advisory Board

Dr. Robert B. Pojasek, Chair
Indoor Air Engineering Research
Subcommittee
Environmental Engineering Committee
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ABSTRACT

The Indoor Air Engineering Research Subcommittee (IAERS) of the Environmental Engineering Committee (EEC) of the EPA Science Advisory Board (SAB) has prepared a report on the Agency's Office of Research and Development (ORD), Air and Energy Engineering Research Laboratory's (AEERL) indoor air engineering research and development (R&D) program. The IAERS met on July 20 and 21, 1992.

The review focused on four specific program areas: two of the areas (emission measurements and source-exposure modeling) are well established; the other two areas (microbial contaminant control and new strategic directions) are emerging research areas. The IAERS found the AEERL approach to indoor air research to be appropriate and the program very successful in terms of peer-reviewed publications and participation in professional organizations as well as focused specialty conferences related to indoor air engineering research issues, and the research program's overall impact on the research field. These accomplishments are particularly noteworthy, especially considering the modest budget and in-house personnel resources devoted to this activity.

The IAERS encouraged the AEERL staff to explore how their research should rely on and interact with other government and private research programs. The IAERS also recommended that a unified conceptual model should be developed to effectively inventory sources and sinks. A number of broad-ranging recommendations were made, with focus on improving an excellent existing research program, to address prevention of microbial contaminants and to improve technical outreach to particular target groups, such as allergy specialists, building designers, building operators and managers, homeowners, indoor air quality model users, and university researchers.

Key Words: Indoor Air, Indoor Air Engineering, Indoor Air Engineering Research, Indoor Air Research

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1. EXECUTIVE SUMMARY

This report presents the Science Advisory Board's (SAB) review of the Office of Research and Development's (ORD), Air and Energy Engineering Research Laboratory's (AEERL) "Indoor Air Engineering Research and Development (R&D) Program," (June 1992 document, See Appendix A - reference 2). On July 20 and 21, 1992, the Indoor Air Engineering Research Subcommittee (IAERS) of the SAB's Environmental Engineering Committee (EEC), in cooperation with the SAB's Indoor Air Quality Total Human Exposure Committee (IAQTHEC) reviewed the document, received detailed briefings from researchers and research managers who developed the document, discussed the approaches, technical rationale, and merits of the research and offered technical advice on this important research area. Additional review occurred in mail correspondence with the IAERS and the EEC. The EEC conducted a public review on this draft report at its October 28 and 29, 1992 meeting. Throughout the process, the IAERS offered additional commentary to refine the recommendations contained herein.

The findings and recommendations are aimed at improving the current indoor air engineering R&D program (hereafter referred to as "the R&D program", or "the document" supporting this program). The following highlights key findings and recommendations:

1.1 Source Characterization

The productivity of the AEERL staff is reflected in many ways, including its leadership role in the United States and abroad, the sizeable number of peer-reviewed articles in technical journals, and in their participation and sponsorship of targeted specialty conferences.

a) The IAERS finds that the AEERL's approach to source characterization is appropriate, and has strong in-house capabilities.

b) The focus of the AEERL research program has logically evolved from small chamber studies to field studies, and represents a good balance between small chamber testing, modeling, and test-house studies. However, the IAERS believes that, because nonresidential facilities have different ventilation characteristics as well as different sources and sinks of indoor air contaminants, it is important to have a large-scale test facility for non-residential environments, and recommends that the AEERL obtain such a test facility. It will also be desirable to have more interaction with field

monitoring programs of other groups to reinforce the practicality of the data.

c) The present emphasis on high vapor pressure compounds has been adequately justified; however, it may be appropriate now to include new information from the literature regarding lower vapor pressure organic compounds as possible indoor air pollutants.

d) A unifying conceptual model should be developed to effectively inventory sources and sinks. An analogy exists in the Underground Storage Tank (UST) research program which utilizes a conceptual model with 13 loci for physicochemical interactions in the subsurface environment.

e) Other specific recommendations on improving source characterization research are offered, such as the need to systematically characterize criteria used for selecting sources and source strengths for analysis, the need to emphasize pragmatic applications of the research to realize reduced risks in IAQ, and the need to obtain more input from engineers and architects to ensure effective transfer of data and technology.

f) It is recommended that a formal plan for technical outreach be developed for effectively providing information to the EPA program office for public distribution.

1.2 Modeling

While the current research program has been very successful, the IAERS suggests refinements to the current directions and focus for the research which it believes will lead to continued and increased quality and positive impacts. Accomplishments of the modeling effort are particularly noteworthy, especially given the modest budget and limited in-house personnel resources devoted to this activity.

a) The IAERS concludes that the Indoor Air Quality (IAQ) modeling component of the AEERL research program is important, appropriate, rigorous, and well directed.

b) The IAERS believes that perceived barriers of responsibility within the Agency may be limiting broader interactions. For instance, the AEERL research program has been unnecessarily constrained by focusing on organic air toxics. Other critical issues in the Agency, such as asbestos and lead exposure, would greatly benefit from the type of integrated IAQ model

developed by the AEERL staff. These problems require similar consideration of the benefits of source control versus alternative measures for exposure reduction.

c) Further sensitivity studies on models are needed to examine the effects of environmental factors such as temperature (T) and relative humidity (RH), and to examine the behavior of the model at low concentrations where sink processes are likely to dominate initial source effects, so that appropriate desorption mechanisms can be identified.

d) The IAERS believes that the Heating, Ventilation and Air Conditioning (HVAC) Industry needs more information on mitigation of indoor air pollution-oriented issues, rather than a single focus on energy conservation. The IAERS believes that the real utility of the model for exposure assessment will come when it is interfaced with realistic, flexible models for air exchange, ventilation, human activities, and the interaction between these factors. The IAERS recommends research focused to evaluate non-ideal mixing and transport, as well as research in large chamber and field studies by including multiple sample points in chambers or rooms with source emissions.

e) The IAERS believes that an important part of the IAQ modeling program is the development and transfer of the model and its capabilities to the user community. Specifically, the IAERS recommends expanding this technology transfer, with focus on particular target groups, such as model users, building designers and managers, university researchers and students.

1.3 Microbial Contaminants

The IAERS commends the AEERL staff for undertaking this new and challenging research program and believes that an expanded and long-term sustained effort needs to be incorporated into EPA's overall research agenda. Given the emerging nature of this research program, the IAERS recommends several actions to target limited resources, as well as to bolster funding for this important research area.

a) The IAERS concurs with the AEERL's research priorities to generate scientific data and develop standard test methods to incorporate engineering solutions into biocontaminant programs. The IAERS concurs with the AEERL that emphasis should be given to preventive approaches to control conditions leading to biologic contamination over methods to control organisms through biocides and other non-preventive remedies.

b) It may be useful to select indicator microbial species that are hardest to control, on the theory that those methods which control these would capture many other species simultaneously. Use of an expert panel would help identify criteria for selecting such priority biocontaminants. Likewise, the IAERS believes that additional in-house resources and expertise are needed to critique and take full advantage of feedback from outside specialists.

c) The IAERS encourages the AEERL staff to re-evaluate the basis for selecting ceiling tiles as the primary substrate in the dynamic chamber tests. There is a need to expand emphasis on dynamic chamber tests in the next phases of research as well as the need to test lower RH values, based on the state-of-the-art practices for drying out buildings.

d) The IAERS encourages the AEERL staff to explore how their research should rely on and interact with other government and private research programs, noting particularly the need to interact with the American Institute of Architects (AIA), American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE), American Society for Testing and Materials (ASTM), Centers for Disease Control (CDC) and its National Institute for Occupational Safety and Health (NIOSH), Interagency Committee on Indoor Air Quality (CIAQ), Consumer Product Safety Commission (CPSC), National Institutes of Health (NIH), various universities and others.

e) While the AEERL's current target audiences emphasize academic institutions and technical organizations, there may be a need to reach out to a more diverse set of interests, such as allergy specialists, homeowners, commercial building operators/owners, and consultants specializing in indoor air issues.

1.4 Bioresponse-Based Testing

The IAERS agrees that bioresponse-based testing of emissions is a reasonable extension of chemical-based testing. The IAERS further notes that this is potentially a very important research area that, in conjunction with chemical measurements, could provide an integrated approach to assessing the impacts of emissions to the indoor environment. The IAERS also notes that, by analogy, the EPA already has established the concept of bioresponse-based testing and toxicity reduction evaluation (TRE) within its water effluent guidelines program.

a) The IAERS commends the AEERL staff for the full use of cooperative agreements, and encourages further cooperation with the Agency's Health

and Environmental Research Laboratory (HERL) and the solicitation of competitive awards and other mechanisms to encourage broader participation within this research area.

b) The IAERS recommends that priority be given to establishing correlations between biological response and the chemical composition of air emissions, so that subsequent research efforts can be properly focused.

c) The IAERS raises concerns regarding the issues of time-dependence of exposures, the rationale for relating the frequency of respiration in animal assays to the immediate response measures proposed, and the question of odor perception in "control" or clean air atmospheres.

d) The IAERS recognizes that the overall expenditures in this program are modest relative to the size of the problem, but encourages more proactive development of specific budget and resource estimates along with recommendations for joint cooperation with the HERL.

1.5 Strategic Direction

The IAERS recognizes that the future strategic direction of the AEERL R&D program, while considered ambitious and appropriate, is important and commendable.

a) The IAERS recommends that the AEERL look at a number of management options, inclusive of pollution prevention, and utilize cost-effectiveness (CE) modeling. The IAERS recognizes that not all avoided risks can be assigned a monetary value, but to the maximum extent practicable, those that can should be explicitly identified.

b) The AEERL R&D program should continue to stress comparative studies, focusing on the complementary roles of prevention and control strategies to develop practical guidance for building and product designers.

c) The IAERS recommends that the AEERL emphasize pollution prevention over other control strategies.

d) The developers of models need to be sensitive to site-specific applications, such as in the development and utilization of studies where building designer and operator involvement are sought.

e) The IAERS recommends that the AEERL staff examine the recent literature which relates the inter-relationship between CE and pollution prevention areas to ensure consistency of approach. The IAERS further recommends that model development should be conducted with building designers and architects so that the model results are consistent with their existing cost and evaluation methods.

f) The IAERS encourages the AEERL to remain sensitive to the impact of IAQ strategies on fire protection, particularly with regard to the effect of stairwell and entrance-exit design for safe egress of occupants and fire fighters and other emergency response personnel, especially during a fire emergency, and especially for high-rise structures.

1.6 Additional Considerations

The IAERS recognizes that the current in-house research program resources, supplemented by judicious use of contractor support, cooperative agreements, and leveraging with other projects, are achieving positive and impressive results. The IAERS further notes that:

a) The AEERL should add appropriate staff necessary to lead the prioritized projects to develop a well-qualified and well-rounded multidisciplinary research team to deal with an expanded charge, and

b) An overall plan should be presented and either funds be allocated to more adequately reflect the stated mission of the program, or that the mission be modified to focus more on exposure control strategies, bioresponse measures and cost-effectiveness studies. If needed, justification for additional funding and resource allocations should be prepared.

This is the end of the Executive Summary. The body of the report follows on the subsequent text.

2. INTRODUCTION

The EPA ORD, Indoor Air Branch of the Air and Energy Engineering Research Laboratory (AEERL) at Research Triangle Park, North Carolina prepared a document entitled "Indoor Air Engineering R&D Program," (hereafter referred to as the document, or the R&D program. See Appendix A - reference 2). The Indoor Air Engineering Research Subcommittee (IAERS) of the Environmental Engineering Committee (EEC), with assistance from the Indoor Air Quality Total Human Exposure Committee (IAQTHEC) of the EPA Science Advisory Board (SAB), reviewed the document, dated June 1992, at a meeting on July 20 and 21, 1992. On those dates, the IAERS received detailed briefings from researchers and research managers who developed the document (See Appendix A - reference 3 for presentation materials), discussed the approaches, technical rationale, and merits of the research and offered technical advice on this important research area.

The basic topics covered in this review of the indoor air engineering R&D program included source characterization, source-exposure modeling, microbial contaminant control, and strategic directions for the research. Additional review occurred in mail correspondence with the IAERS and the EEC. The EEC conducted a public review for closure on this draft report at its October 28 and 29, 1992 meeting. Throughout the process, the IAERS offered additional commentary to refine the recommendations contained herein.

The IAERS was given the following charge which focused on the existing research and directions for future research. The original charge was transmitted, along with the document to be reviewed, to Dr. K. Jack Kooyoomjian, Designated Federal Official to the SAB's IAERS in a July 19, 1992 memo from Mr. Frank T. Princiotta, Director of the AEERL (See Appendix A - reference 4). The charge was subsequently modified at the July 20 and 21, 1992 review meeting (See Appendix A - reference 3, and see note below)[1]. The revised charge to the Subcommittee as presented at the meeting follows:

> a) Is the EPA/ORD approach to source characterization -- with its focus on developing methods for characterizing emissions, sink effects, and exposures --a rational and scientifically sound approach?

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1 The IAERS recognizes the modification of the charge made at the meeting and concurs with the emphasis on exposure. See Section 4, Modeling, page 11 for further discussion on this point.

b) Is the EPA/ORD approach to indoor air quality (IAQ) modeling for evaluation of source-related exposures and IAQ control options sufficiently rigorous and appropriately practical?

c) Are the EPA/ORD projects and plans for developing guidance on control of microbial contaminants reasonable and scientifically sound?

d) Is bioresponse-based testing of emissions from sources a reasonable extension of chemically-based testing? Is it likely to improve EPA's ability to assess the health and comfort risks of indoor sources?

e) Is there any aspect of the strategic direction of the indoor air engineering research program that should be re-evaluated?

The Subcommittee findings and recommendations respond directly to the charge, and address other issues raised as a result of the review. The charge was expanded by the IAERS to address the adequacy of fiscal and personnel resources and the adequacy of technology transfer to practitioners and to educational institutions as they relate to the above topic. The IAERS also wishes to note the earlier findings of the SAB in its Reducing Risk report (See Appendix A - reference 6) where indoor air issues were rated as a significant problem area. The findings and recommendations of the IAERS are derived primarily from the dialogue which occurred at the July 20 and 21, 1992 meeting, and from subsequent deliberations on the topic by the IAERS, its parent committee, the EEC, as well as the IAQTHEC as the coordinating committee.

This report is organized directly with each section addressing the charge, as well as the IAERS offering wider-ranging guidance to strengthen the implementation aspects of this important R&D program.

3. SOURCE CHARACTERIZATION

Is the EPA/ORD approach to source characterization -- with its focus on developing methods for characterizing emissions, sink effects, and exposures -- a rational and scientifically sound approach?

This is a mature program with strong in-house capabilities. The good productivity of the program is reflected in many ways, including the leadership role that the AEERL has taken, both in this country and abroad, the successful effort to develop many publications in peer-reviewed journals and the staff participation and sponsorship of targeted specialty conferences. For instance, the scientific validity of the approach developed for the small chamber studies is reconfirmed by its adoption as an ASTM method.

The Subcommittee believes that the AEERL's approach to source characterization is appropriate, and that the development of methods that aid in understanding the fundamental interaction of emissions and sink effects on individual exposures is important. The approach of using fundamental transport models should certainly help in relating emissions to other physical and chemical factors, as well as improve the ability to generalize this research. The focus of the program has logically evolved from small chambers to field studies. There is a good balance between small chamber testing, modeling and test-house studies. However, the Subcommittee believes that it is important to have a large-scale test facility for non-residential environments, and recommends that the AEERL obtain such a test facility. This could be a relatively modest-sized space (i.e., 2000 square feet) with a well controlled independent HVAC system. It would also be desirable to have more interaction with field monitoring programs of other groups to reinforce the practicality of the data.

The present emphasis on high vapor pressure compounds has been adequately justified. However, with new information appearing in the literature regarding semi-volatile organic compounds as possible IAQ pollutants, it may be appropriate to include them in the continuing work. It is also observed by the Subcommittee that the future direction of the program, while appropriate, is overly ambitious given the present level of funding.

There are several recommendations that would help the laboratory prioritize its efforts. These include:

a) A unifying, conceptual model should be developed to effectively inventory sources and sinks. This would link into the cataloging effort currently underway. One recommendation is to use the format of the loci (also listed

as LOCI) model developed by RREL-Edison (EPA/600/2-91/053) (See Appendix A - reference 5) as an example, as well as Appendix B - Glossary of Terms and Acronyms.

b) The AEERL needs to systematically characterize criteria used for selecting sources and sizes for analysis.

c) There is a need to examine the process by which certain environmental parameters (e.g., T, RH) are being considered in the dynamic chamber tests.

d) Consideration should be made of emissions from processes and people.

e) More feedback from engineers and architects should be obtained to ensure an effective transfer of data and dialogue with this audience.

f) A formal plan for technical outreach should be derived for effectively providing information to the EPA program office for public distribution.

g) Some consideration should be made to emphasize pragmatic applications of this research to realize reduced risks.

4. MODELING

Is the EPA/ORD approach to indoor air quality (IAQ) modeling for evaluation of source-related exposures and IAQ control options sufficiently rigorous and appropriately practical?

The inclusion of an IAQ modeling component in the AEERL research program is appropriate and important. The AEERL staff properly recognizes the role of modeling as both a predictive tool for particular evaluations and assessments, and as a means of integrating the various components of the research program. This is evident in the role that modeling has played in identifying the need for more mechanistic source representations, and the importance of sink processes in IAQ assessments. It is also evident in the planned role for modeling in evaluating the results of current and future research on source control, ventilation and air cleaning options. The AEERL modeling program has properly emphasized the importance of field validation studies, consistent with the general guidelines provided to the Agency by the SAB (See Appendix A - reference 1 - The Modeling Resolution). As such the overall approach to modeling taken by AEERL is judged to be appropriately directed and rigorous.

The excellent quality of the IAQ modeling effort is evident by the number and quality of peer-reviewed journal publications, conference presentations and organization, development of useful working tools, and the general impact on the direction and progress of the research community. Accomplishments of the modeling effort are particularly noteworthy, given the modest budget and in-house personnel resources devoted to this activity. The IAERS does, however, have suggestions on refinements to the current directions and focus for the research which we believe will lead to continued and increased quality and positive impacts. These include areas of technical focus, as well as mechanisms for dissemination of results, and are discussed below.

a) Further sensitivity studies of the model are needed to examine the effects of environmental factors such as temperature (T) and relative humidity (RH), and to examine the behavior of the model at low concentrations where sink processes are likely to dominate initial source effects, so that appropriate models for desorption can be identified.

b) The IAERS notes the importance of mixing and transport processes for exposure evaluations. While development of a model for predicting exposure to intimate sources is included in the proposed research plan, the importance of localized gradients and channeling effects for personal

exposure is such that broadened and greater emphasis is recommended. Non-ideal transport models will be especially important when evaluating biocontamination, where particle processes must be considered in addition to the gas phase transport. Evaluation of non-ideal mixing and transport, to the extent that it would have practical value in managing risks from indoor air exposures, should be included as a regular part of experimental evaluations in large chamber and field studies by including multiple sampling points in chambers or rooms with source emissions.

The importance of modeling and validation of personal exposure estimates was noted by the IAERS. There was some concern that initial emphasis on source characterization may have limited utility of the IAQ model for exposure characterization. Some of the confusion was because the initial charge to the IAERS did not mention "exposure" prediction as an objective of the modeling program, nevertheless, the IAERS recognizes the modification of the charge made at the meeting and concurs with the emphasis on exposure.

The model can be appropriately used for exposure assessment, so long as realistic building and human activity descriptions are selected. However, there does not appear to be sufficient emphasis on determining these for the IAQ model. The reason given for this is that the AEERL responsibility is constrained to providing a tool for individual exposure, as opposed to population exposure, which is the responsibility of the Health and Environmental Research Laboratory (HERL). The IAERS believes that this constraint is too limiting, and that the real utility of the model for exposure assessment will come when it is interfaced with realistic, flexible models for air exchange, ventilation, human activities, and the interaction between these factors (i.e, certain activities involve the initiation of sources, or the changing of air flow patterns by opening doors, windows, etc.). The division of responsibility between AEERL and HERL appears to be artificial, and may be slowing the needed progress. Collaboration on joint model development should occur; additional resources (if they are needed) should be provided to facilitate this collaboration. This effort should include increased emphasis on field studies and methods for validating exposure predictions.

The IAERS believes that artificial barriers of responsibility within the Agency may be limiting broader applications, and greater interaction with other programs is encouraged. For instance, another area where the limited focus of the AEERL research program has, until now, been appropriate to promote quality progress with limited resources, but where future impact may be unnecessarily constrained, involves the sole focus of the research program on organic air toxics. Other critical issues to the Agency, including asbestos and lead exposure, would greatly benefit from the type of integrated IAQ model developed by the AEERL

staff. Similar issues arise as to the benefits of source control versus alternative measures for exposure reduction (for example, in remodeling old homes with lead-based paint), and the model could provide useful insights for these issues.

An important part of the IAQ modeling program is the transfer of the model and the modeling capability to the user community. To date, this has been very successful within the IAQ research community.

Additional efforts to expand this technology transfer, with focus on particular target groups, is recommended. These include:

a) Model users: Actively solicit comments by providing a brief questionnaire when the software is distributed. Since the software is distributed without charge, the request that these questionnaires be completed and returned to EPA should be viewed as a necessary and reasonable requirement of users.

b) Building designers, managers and operators: Efforts to interface with and serve the needs of this group can lead to widespread, practical application of the methodology, with a potentially great impact on IAQ. To accomplish this, there will be a need to expand the capabilities of the model to deal with larger, more complex buildings (the current emphasis has been on residential and small commercial buildings), and to readily allow for summary representations of model output (i.e., total exposure, peak concentration, etc.) comparable in detail to other design criteria used by building professionals. The plan to incorporate a cost component to the model provides the opportunity for closer interaction with the building design and management community. An important issue that requires further consideration is whether to preset the model with default values for particular design scenarios, so that the model will be easy to use, even for novice architects and engineers, or to require individualized input so that a high level of user expertise is mandated.

c) University researchers and students: The internal focus of the research program has been successful, however, it is time to encourage broader participation. The AEERL program is in the forefront of IAQ model development, and more indoor air researchers and specialists can benefit from the expertise, leadership, and experience of the AEERL in-house staff. Research projects on individual sources, sinks, and transport factors should be encouraged. The model itself would be very useful as a classroom educational tool, for both architects and engineers. This type of model transfer would lead to future designers, builders and managers becoming

more aware of the need for considering indoor air environmental quality in their activities.

5. MICROBIAL CONTAMINANTS

Are the EPA/ORD projects and plans for developing guidance on control of microbial contaminants reasonable and scientifically sound?

The IAERS commends the AEERL staff for undertaking this new and challenging research program and believes that an expanded and long-term sustained effort needs to be incorporated in EPA's overall research agenda. This emerging research program is responding to heightened public concerns over biological contamination in buildings and numerous private ventures attempting to respond to those concerns. Clearly, there is a prevalence of conjecture and anecdotal evidence in this area with little scientific data available to design appropriate prevention and control programs. In particular, the Subcommittee concurs with the following research priorities:

a) To generate scientific data and standard test methods which can be used by EPA and other organizations for biocontaminant programs.

b) To incorporate engineering solutions into biocontaminant programs.

c) To emphasize preventive approaches to control the conditions leading to biologic contamination over methods to control organisms through biocides and other non-preventive remedies.

Given the emerging nature of this research program, the Subcommittee believes that very basic questions need to be addressed by the research and makes the following recommendations which recognize the need to both target limited resources, as well as to bolster funding for this important research area:

a) In general, the plan needs better specification of the research problem including enunciation of research hypotheses. The plan should retain the preventive approaches to control the conditions leading to biologic contamination over methods to control organisms through biocides and other remedies.

b) Indicator species are used in most every EPA media program, such as E. coli for drinking water. This allows inexpensive screening tests in place of very expensive tests for specific chemicals or agents. While not without its problems, it may be useful to select indicator species in the indoor air research program that are hardest to control, on the theory that those methods which are effective for those indicator species would control many

other species simultaneously. Use of an expert panel would help identify such criteria for selecting priority biocontaminants.

c) Funding and manpower constraints underscore the need to clearly understand and specify criteria for selecting various research parameters--particularly the organisms for analysis. While the choice of penicillium fungi may be practical and reasonable, further specification of desirable testing characteristics is warranted to justify that choice. For example, some species are particularly sensitive to temperature (T) and relative humidity (RH); others are viable under a wide range of environmental conditions.

d) The IAERS believes that additional in-house resources and expertise are needed to critique and take full advantage of feedback from outside specialists. Such complementary expertise is common practice for EPA's chemical research programs, but wholly absent from this project. Specialized training in microbiology could be secured for existing staff to develop greater expertise within EPA. Likewise, an interagency transfer from the CDC could be brought in to oversee the program.

e) The IAERS raises specific questions concerning the basis for selecting ceiling tiles as the primary substrate; the need to simulate more realistic types of surface contamination versus use of sterilized surfaces in tests; the need to expand emphasis on dynamic chamber tests in the next research phases; and the use of lower RH values based on state-of-the-art practices for drying out buildings (i.e., less than 20% RH versus 33% RH).

f) It is critical for the AEERL staff to explore how this effort should rely on and interact with other government research programs in EPA, NIH, CDC, and its NIOSH and elsewhere. This interaction will build on existing successful efforts to obtain support from widely-recognized private and public institutions (e.g., various universities, ASTM, ASHRAE, CPSC, AIA). Clearly, significant progress cannot be made in the area of biologic contamination without additional resources and expertise. As such, it may be advisable to ask the CIAQ to devise a programmatic and budgetary strategy for conducting research in this area.

g) Preliminary results from the first-phase static chamber tests with penicillium already have yielded results which could greatly improve the effectiveness of current prevention strategies. This points to the need for EPA to devise an education and outreach strategy for the microbial contaminant program. While the AEERL's current target audience

emphasizes academic institutions and technical organizations such as ASTM, EPA program offices should reach out to other audiences including allergy specialists, homeowners and building operators, building managers, and popular magazines.

6. BIORESPONSE-BASED TESTING

Is bioresponse-based testing of emissions from sources a reasonable extension of chemically-based testing? Is it likely to improve EPA's ability to assess the health and comfort risks of indoor sources?

The IAERS agrees that the bioresponse-based testing of emissions is a reasonable extension of chemical-based testing. This is potentially a very important research area that, in conjunction with chemical measurements, could provide an integrated approach to assessing the impacts of emissions to the indoor environment. By analogy, the EPA already has established the concept of bioresponse-based testing and toxicity reduction evaluation (TRE) within its water effluent guidelines program. Lessons already learned from the other media programs may be useful. The IAERS offers the following suggestions and observations:

a) The AEERL has unique skills and strengths to contribute to an overall program of bioresponse-based testing. Specifically, the Subcommittee noted the available in-house and extramural skills with regard to the generation and characterization of relevant complex mixtures representative of potential indoor exposures to specific sources, and the opportunity to couple this capability with objective biological endpoints.

b) The Subcommittee commends the AEERL staff for the establishment of cooperative agreements both with Dr. Leaderer and his colleagues at the J.B. Pierce Laboratory at Yale University and with Dr. Molhave and colleagues at Arhus University in Denmark that seek to establish objective measures of response. These are two of the leading research groups studying the effects of low level VOC exposure. In addition, IAERS encourages further cooperation with the Agency's HERL, and, as time and resources permit, solicitation of competitive awards and cooperative agreements, as well as other mechanisms to encourage broader participation within this research area. Priority should be given to engineering issues and health-based testing and coordination, such as establishing correlations between biological response and the chemical composition of air emissions, so that subsequent control efforts can be properly focused. Continued collaboration and linkage between AEERL and HERL on the engineering and health effects to examine the biological aspects is encouraged.

c) Specific concerns raised by the IAERS include the issues of the time-dependence of these exposures, the rationale for relating frequency of respiration in animal assays to the immediate response measures proposed,

and the question of odor perception in "control", or clean air atmospheres. Some questions that need to be addressed by the research include: (1) How are time-varying exposure concentrations considered within the traditional dose-response framework? (2) What are the underlying biological mechanisms relevant to the analogy between respiratory frequency and odor or other immediate irritant effects? (3) How is the co-variate of odor perception controlled for in the design of objective response studies?

d) The IAERS recognizes that the overall expenditures are modest relative to the size of the problem, but encourages more proactive development of specific budget and resource estimates within this sub-program, including explicit details of joint cooperation with the HERL.

7. STRATEGIC DIRECTION

Is there any aspect of the strategic direction on the indoor air engineering research program that should be re-evaluated?

The future proposed directions of the AEERL R&D program, while considered ambitious, are appropriate, important and commendable. The IAERS recommends that:

a) With regard to IAQ, common sense dictates that if pollution is not produced, it will not pose harm to the environment or to building occupants. However, when indoor air pollutants are generated, avoidance of indoor air pollutant sources may not be altogether practical in some instances. Therefore, alternative management options or some combination of options inclusive of pollution prevention may have to be considered (e.g., air cleaning or venting). These management options can be investigated utilizing cost-effectiveness (CE) modeling.

b) The AEERL R&D program should continue to stress comparative studies, focusing on the relative roles of prevention and control strategies. Building and product designers need such practical guidance that evolves from this R&D activity.

c) The IAERS agrees with the AEERL staff that it will be necessary in the R&D program to consider CE as an important, and perhaps critical, tool in the area of IAQ pollution prevention: CE must be included in the context of the proposed program. It will be important to have such tools that enable recognition of the CE activities which encompass pollution prevention objectives related directly to improving IAQ. Additional emphasis upon CE model development is warranted.

d) Less quantifiable and longer-term costs associated with control options that lead to the Agency's waste management hierarchy, as it relates to pollution prevention must be recognized. At a minimum, the CE model should specify "routine" cost factors and identify other increments associated with pollution prevention objectives. Not all avoided risks can be expressed in monetary terms, but to the maximum extent practicable, these should be explicitly identified.

e) The AEERL program should be undertaken with a clear recognition of objectives. For instance, one question that should be asked: Is the model to

be developed intended for design purposes, or alternatively, to support a more far-reaching context, such as a regulatory development or interest?

f) Models can easily be "misapplied." Moreover, the developers of models should be sensitive to site-specific applications, such as in the development and utilization of scenarios where building designer and operator involvement should be sought. In addition, the similarity between "effectiveness" and "productivity" models should be considered in the context of their ultimate utility to the target audience.

g) It will be important to clearly define the target audience. Moreover, the desired impact (e.g., pollution prevention) upon the targeted audience should be determined. Some guidance needs to be provided as to trade-offs which address alternative management strategies, (i.e, combinations of pollution prevention, air cleaning and venting).

h) It should prove worthwhile, early in the exercise of developing CE models to consider what models already exist, and how they might relate to the proposed effort.

i) The AEERL program must account for current initiatives reported in the literature. In particular, recent literature which relates to the inter-relationship between CE and pollution prevention areas of investigation should be examined to identify the applicability of current knowledge in this area.

j) It is recommended that CE model development be conducted in collaboration with building designers and architects so that the model results are consistent with their existing cost and evaluation methods. The CE model results should easily interface with these methods, to encourage its use for various indoor air applications. Interaction with and review by an economist will be needed to ensure that life cycle costs are appropriately calculated. Peak concentrations and ambient emissions should be added to the measures of effectiveness which may be considered for particular applications.

k) In addition, EPA has cost manuals directed at small vent VOC control technologies for emissions to the ambient environment. These might be considered in the cost analysis.

l) It is considered advisable to provide the highest level of disaggregation of the costs in development of any of the computer models, in order to provide the most flexible cost models for a wide variety of users.

m) It is to be stressed that reduction of exposure to air contaminants must not simply be at the cost of increased export of contaminants to the outside environment. It would be inappropriate to vent contaminants to the outside air. CE analysis must be sensitive to this issue.

n) The IAERS encourages the AEERL to remain sensitive to the impacts of IAQ strategies on fire protection, particularly with regard to the effect of stairwell and entrance-exit design for safe egress of occupants and fire fighters and other emergency response personnel, especially during a fire emergency, and especially for high rise structures.

8. ADDITIONAL CONSIDERATIONS

The IAERS was mindful of resource constraints. The ORD research staff have made an earnest effort to implement Total Quality Management (TQM) principles in all its activities. The IAERS expects that the ORD staff should expect to seek continuous improvement to its research program, and to make incremental changes, within their resource constraints, to try to achieve their goals over some period of time which is likely to be longer than several fiscal years.

The IAERS could not come to a consensus on a prioritization of recommendations, because we tended to favor research areas that each member was familiar with. However, each member was comfortable with the continuous improvement observed within the research program. Instead of ranking the recommendations and having only the top three of four addressed fully, the IAERS asked that all the recommendations be addressed incrementally over time to better improve a research program that is already quite good.

The IAERS, during their review, identified two other points of concern, and considered them as a sixth charge. These two points are as follows:

a) The adequacy of fiscal and personnel resources to accomplish the R&D mission; and

b) The adequacy of information transfer to practitioners and to educational institutions.

8.1 Resource Allocation

With regard to resource allocations, two concerns were identified:

a) The allocation of resources should reflect the mission and objectives of indoor air engineering R&D; and

b) The research projects should be prioritized to match the available or anticipated resources.

The IAERS notes that $1,150K of the total budget of $2250K has been allocated to air cleaner testing and evaluation ($650K) to ventilation ($350K) and bioresponse ($250K, with a $175K Congressional add-on), and that no funds have been allocated to CE studies. We recommend that the funds be allocated to more adequately reflect the stated mission of the program or that the mission be

modified to focus more on exposure control strategies (i.e., ventilation and air cleaning), bioresponse measures and CE studies. We have been advised by the Agency ORD/RTP staff that $461K has been spent in prior years in cooperative agreements, but much of that funding was not spent directly on bioresponse research (mostly kerosene heater emissions).

The IAERS recognizes that the current in-house research program resources, supplemented by judicious use of contractor support and cooperative agreements, and leveraging other projects are achieving positive and impressive results. However, the IAERS also encourages the AEERL to add appropriate staff (e.g., architect, HVAC engineer, bioengineer, engineering economist) to lead the prioritized projects, so that an intrinsically thorough understanding of the procedures and outcomes can be developed by a well-qualified and well-rounded multidisciplinary research team to deal with an expanded charge.

Finally, the IAERS recommends that an overall plan be developed and presented that prioritizes all of the current and proposed R&D projects within available resources, and that, if needed, justification for additional funding and resource allocations be prepared.

APPENDIX A - REFERENCES CITED

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APPENDIX B - GLOSSARY OF TERMS AND ACRONYMS

AEERL	Air and Energy Engineering Research Laboratory
AIA	American Institute of Architects
AREAL	Atmospheric Research and Exposure Assessment Laboratory
ASHRAE	American Society of Heating, Refrigeration and Air Conditioning Engineers
ASTM	American Society for Testing and Materials
CDC	U.S. Centers for Disease Control (Atlanta, Georgia)
CE	Cost-Effectiveness
CIAQ	Interagency Committee on Indoor Air Quality
CORRE	Corporation on Resource Recovery and the Environment
CPSC	U.S. Consumer Product Safety Commission
EPA	U.S. Environmental Protection Agency (U.S. EPA, or "The Agency")
EEC	Environmental Engineering Committee (SAB/EPA)
FY	Fiscal Year
HERL	Health and Environmental Research Laboratory (U.S. EPA/ORD)
HQ	Headquarters
HVAC	Heating, Ventilation and Air Conditioning
IAERS	Indoor Air Engineering Research Subcommittee
IAQ	Indoor Air Quality
IAQTHEC	Indoor Air Quality and Total Human Exposure Committee
K	Thousand (dollars)
LOCI	Underground Storage Tank Conceptual Model Developed by the U.S. EPA/ORD Risk Reduction Engineering Laboratory (RREL)
NC	North Carolina
NIH	National Institutes of Health
NIOSH	National Institute for Occupational Safety and Health (NIOSH)
ORD	Office of Research and Development (U.S. EPA)
OTS	Office of Toxic Substances (U.S. EPA)
R&D	Research and Development
RH	Relative Humidity
RREL	Risk Reduction Engineering Laboratory (U.S. EPA/ORD)
RTP	Research Triangle Park
SAB	Science Advisory Board (U.S. EPA)
T	Temperature
TQM	Total Quality Management
TRE	Toxicity Reduction Evaluation
US	United States
VOC	Volatile Organic Compound

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