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Future Directions and Research Needs

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In this paper, three perspectives for indoor air issues are considered: *a*) air inside of our homes and offices is a major component of our overall living environment and has potentially great impact on public health; *b*) there are important scientific questions raised specifically to indoor air that will require skills and expertise to develop and interpret research and data collection efforts; and *c*) from a risk assessor's point of view, the types and quality of scientific information is critical to the process of health risk assessment to risk managers to make the best decisions regarding environmental risks from indoor air. The primary focus of this presentation is to highlight suggested future directions and needs of the U.S. Environmental Protection Agency that formed the core of a report to Congress on assessment and control of indoor air pollution. The five major areas that constitute the current EPA indoor air research strategy are monitoring/building studies; health effects; source characterization/mitigation; health impact/risk assessment; and program management/technology transfer. Additionally, major trends and research needs are discussed, including greater emphasis on noncancer effects and multiple pollutants at low levels and the need for more sensitive measures for detecting adverse health effects to more effectively characterize chemically sensitive individuals and population subgroups.

Introduction

My task is somewhat multifaceted in that it encompasses some of the points raised at the workshop: to suggest future directions considered before convening this workshop, as well as those based on discussions we have heard over the last 3 days and to outline research needs to be considered for indoor air issues.

We have considered three perspectives for indoor air issues. The first is that air inside of our homes and offices is a major component of our overall living environment and that it has potentially great impact on public health. The second perspective is that there are important scientific questions raised specifically about indoor air and that these questions are complex, difficult, and will require great skills and expertise to develop and interpret research and data collection.

The third perspective is from a risk assessor's point of view. As a scientist who must assess human health risks and is at the midpoint between research and data collection and those who make risk management decisions, I realize the importance of having the best scientific information to aid me in informing and educating risk managers to enable them to make the best decisions regarding environmental risks from indoor air.

We realize that risk assessment is not the only input into risk management. One also has to deal with the social, economic, and political issues. However, the scientific issues often play a predominant role, and I welcome conferences of this sort to bring together the scientists who can identify and clarify the issues, suggest new approaches, and focus on the most critical questions.

I might also add that in terms of trying to pull this talk together and realizing that it was to be a summary of what went on at the conference as well as some of the ideas that came into it, we had to look from a boarder perspective. It could not just be what I have thought, or what the offices thought, or what the Environmental Protection Agency (EPA) has thought about in terms of research and data collection needs. It was extremely important to initiate collaboration between the public and private sectors with regard to this research and data collection. To the extent that we can in our discussion today, we will try to identify those issues and look for possibilities for collaboration.

Risk Assessment Paradigm

The risk assessment paradigm developed in the 1983 publication from the National Academy of Sciences (*1*) is a useful framework in which to present the risk assessment process. In that process the hazard identification, dose-response assessment, exposure assessment, and risk characterization are defined and illustrated. It is very important to realize that this is a process and the product is risk characterization. The ultimate goal of the use of the information that we have talked about, the ultimate goal of the scientific discussion that goes on, is to characterize risks that have low probability, occur at various times, often long after exposure. In such characterizations of risks, understanding the mechanism by which an adverse effect occurs is important so that a weight of evidence can be provided. Risk characterization is the critical stage in the assessment in that it allows decisions to be made.

I would now like to share with you our indoor air strategy that Assessment and Control of Indoor Air formed the core of a report on Pollution to Congress that EPA presented in 1989 (*2*).

EPA Indoor Air Research Strategy

Five major areas that make up the current EPA indoor air research strategy are monitoring/building studies, health effects, source characterization/mitigation, health impact/risk assessment, and program management/technology transfer. These five

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areas provide a framework for research and data collection and constitute the current EPA indoor air research strategy.

Monitoring/Building Studies

The monitoring and building studies are critically important for understanding exposures and characterizing health risks from indoor air. The major goals in this regard are the development and validation of diagnostic protocols, analytical techniques, and comprehensive large-building models. These goals can best be accomplished by conducting investigations and demonstration studies as well as coordinating and maintaining comprehensive databases on the studies.

The real question that P. Lioy brought up in his earlier comments was What is it that we measure, and how does that measurement really give us definitive information about the indoor air environment? We must develop and validate protocols for analytical techniques and air dispersion modeling that must include not only volatiles, but also particulates, as well as combinations and mixtures of these that will affect the type and route of exposure. When we conduct field and demonstration studies, we need to ask how the experimentally designed studies relate to specific types of issues that we find in our homes or office buildings. Other questions to keep in mind for building and monitoring studies are How do we extend those studies to the personal environment? How do we go about coordinating and maintaining a database that will provide the baseline or background information from which to make our decisions? Baseline information in this case means trying to catalogue responses or information that are obtained from buildings for which occupants have raised indoor air risk questions and those that have not. This is important so that we have a sense of the differences between such buildings and so that we have a sense of what kinds of issues might be involved in making some sort of a determination on potential for health effects.

In terms of the trends that might come out of this type of work, clearly, we are talking about integrated protocols in these studies. We have heard discussions during this conference about the types and routes of exposure that are particularly important for indoor air; it goes beyond the issue of inhalation and raises questions of dermal and oral exposures, not only for individual chemicals, but multiple chemicals and mixtures. We heard from J. A. J. Stolwijk and J. E. Woods in their presentations that it was going to be extremely important to coordinate the physical examination of the buildings and people, monitoring, analysis, and the exposure assessment procedures to accurately describe the indoor air picture.

In addition, we must address the question of increased emphasis on human activity patterns, the exposure issues that relate to human activity, and the avoidance issues that relate to human activity. Factoring such issues into our exposure scenarios will be tremendously important.

Health Effects

We talked at length about the issue of health effects. Health effects have been a major issue during the conference. The four major goals of EPA's assessment of indoor air health effects are to *a*) identify or develop sensitive functional or physiological measures, *b*) identify and characterize chemically sensitive individuals and population subgroups, *c*) conduct cross-species extrapolation studies, and *d*) develop and apply methods for biomonitoring.

We focused on neurotoxicity, inflammation, allergic responses, and pulmonary effects in discussions during this conference. Previously, in other programs we have focused on carcinogenic effects and death in terms of end points of concern when regulatory decisions were made. But it is clear that we now need to look at more sensitive measures for detecting health effects.

There has been a fair amount of discussion identifying chemically sensitive individuals and population subgroups. The National Academy of Sciences has been asked by one of our offices at EPA to look specifically at the question of hypersensitivity. We have talked at great length about trying to characterize chemically sensitive individuals and population subgroups, particularly with regard to the need to combine experimental and clinical studies. We hope that there will be an ongoing discussion of these issues that could help us in terms of dealing with the question of hypersensitivity as the Academy develops its study.

As noted earlier, another area to focus on is conducting cross-species extrapolation studies. The cross-species extrapolation issue will continue to be an issue for us because we are continuing to use experimental and clinical data on chemicals obtained by routes of exposure that are not necessarily by the route that we might expect in the indoor environment. We need to characterize these types of approaches in the assessment process.

We need to develop and apply methods for biomonitoring. EPA's programs have focused primarily on the association between chemical exposure and carcinogenicity in the past, but we want to look at biomonitoring that can be applied to noncancer health effects, some of which are reversible, as well as other areas that might be of particular concern to us.

In terms of the trends in this area, biomarkers for exposure, adverse effects, and sensitivity are important. It is clear from the discussions at this conference that there are few examples to suggest that we have the data to deal with these types of biomarkers. It is here that we need to collect more information. The presentations on environmental tobacco smoke (ETS) give a good example of some success that we might have with dealing with biomarkers, but the database will have to be large.

In addition to the biomarkers issue, we need to question the relevance of these biomarkers in terms of peak exposures or cumulative exposures, which were discussed at this conference. This distinguishing factor is going to be important as one begins to develop the questions of dose response, pharmacokinetics, and biological models for these effects.

Some other issues that were discussed in the conference related to the measure of human variability and how to characterize the population with regard to such variability. J. Brain talked about animal models that were necessary. However, information on human variability will continue to be derived from studying autoimmune response in humans and from clinical investigations.

One of the issues that I found particularly interesting during the panel discussion was the importance of dealing with both primary and secondary effects of chemicals. In addition to a primary effect, one has to look at effects of chemicals on behavior and the way chemicals affect adaptation. (If you choose to use the

term "adaptation" in our discussions about responses to indoor air.) Adaptation can have an impact on promoting existing lesions, e.g., in terms of carcinogenicity. Secondary effects that have alluded us in the past in terms of dealing with some of the issues of health risk assessment are going to be extremely important issues with regard to the indoor air problems that we have heard about.

Source Characterization and Mitigation

In regard to indoor air source characterization and mitigation, the three major goals of EPA are to *a*) develop methods for measuring pollutant emissions, *b*) enlarge EPA's database on sources and emissions, and *c*) develop methods for evaluating air cleanness, source control options, and ventilation strategies.

We are seeking to develop methods for measuring pollutant emissions. We are continually finding ourselves in a situation where we do not know how to measure what we think may be important in our indoor environment. In addition, we need to collect information in a usable way so that people will have an opportunity to evaluate sources of emissions and continue to develop methods that will help us to mitigate such emissions. We need to develop methods for evaluating particular types of air cleaning devices that we might use, or source controls, ventilation strategies. Those methods become extremely important in terms of bringing new devices and processes on the market and putting them into use.

We can identify at least four major trends in the area of indoor air source contamination and mitigation: developing information on "clean" materials and products; elaborating the role of pollutant sinks as emitters; developing desiqn information; and emphasizing more field work. For example, information may be developed on "clean" materials and products. An example of this was discussed earlier at this workshop concerning state regulations on emissions from plywood and the decrease in complaints about it. There are some of us that would emphasize that claim in regard to plywood. Such examples give you a sense that the consumer has an idea of what is in the material and at what levels, and if he chooses to buy products with the lower levels of emission he is making an attempt to control his exposure.

An issue that I think is going to be extremely important and one that we need to look at more is the idea of pollutant sinks as emitters. Pollutant sinks are not necessarily the primary emitters, but something that has the ability to collect and release complex mixtures of materials that may not exist in the environment to be characterized on their own, but may be important exposures within the indoor environment simply as pollutant sinks and re-emitters.

A number of studies have suggested that sensitive subpopulations may be at greater potential risk to the adverse effects associated with indoor air exposure. We have heard at this workshop that "mind set changes" are needed with regard to how we build our homes and offices and whether there are special issues that we need to be aware of for certain sensitive populations such as infants, children, the elderly, or infirm (particularly individuals suffering from respiratory disease).

Emphasis on more field work is particularly important. How do we continue our surveillance activities? Some of the National Institute of Occupational Safety and Health (NIOSH) and Agency for Toxic Substances and Diseases Registry (ATSDR) activities might be examples of the types of surveillance to be considered. This can provide us with an early alert to some of the problems that are particularly going to plague us in the future with regard to our indoor environment.

This morning T. K. Pierson addressed the question of the health impact on risk assessment for indoor air and how one characterizes that information. Clearly, we are going to have to deal with multiple chemical pollutants and multiple health end points in terms of the indoor air environment. At EPA we feel that it is important to develop and evaluate common indoor air quality scenarios. We are going to find very unique combinations of both pollutants, end points, and scenarios that are difficult for us to characterize and that are going to take a fair amount of judgment and work by risk assessors.

In terms of the trends, we believe that the emphasis will be on noncancer effects and multiple pollutants at low levels. Some of the other issues that we have heard about in this conference have to do with our ability to characterize the types of exposrues and effects that are associated in the indoor air environment.

Well-documented and defined uncertainty analyses are needed with approaches such as the reference dose methodology and cancer risk assessment that uses upper bounds on plausible cancer risks. This is going to present us with quite a challenge.

Program Management and Technology Transfer

Finally, to effectively translate science from this area to support decision making will involve program management and technology transfer. Our principal goal is to have effective coordination within EPA, with other agencies, and to extend beyond the Federal agencies into the scientific community. This goal has been highlighted by the types of discussions that have gone on at this conference. We really must focus on multidisciplinary involvement in research projects and assessments as we try to characterize the particular environment that we have called indoor air.

We need to focus on management systems that will allow us to coordinate across a variety of different scenarios and track the programs that are being worked on so that we will have some sense of what answers will be available for the decision-making process. We cannot neglect the idea of technology transfer, as illustrated in the earlier discussion relating to home builders and architects trying to understand indoor air issues as they work through their processes. P. Lioy's discussion of building design and the maintenance issues clearly points to ways that will enable us in the future to prevent some of the exposures that we are so concerned about right now.

I would like to add my thanks to the conference orgainzers and suggest that from all the comments that I have heard so far, this has been an extremely successful conference. We have identified critical issues and research needs that are a challenge to scientific community as well as a challenge to the funding agencies. Indoor air is part of our environment that we need to address now and in the future.

REFERENCES

1. National Research Council. Risk Assessment in the Federal Government: *Managing the Process*. National Academy Press, Washington, DC, 1983.
2. U.S. Environmental Protection Agency. Report to Congress on Air Quality, Vol. 2, Assessment and Control of Indoor Air Pollution. EPA/400/1-89001C, U.S. EPA, Washington, DC, August, 1989.