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EPA

# Report to Congress on Indoor Air Quality

## Volume III: Indoor Air Pollution Research Needs Statement

Issued under Section 403(e), Title IV of the Superfund Amendments and Reauthorization Act of 1986 (SARA)

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# Indoor Air Quality

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CONTENTS

## TABLES



## FIGURES

NOTE

EPA's Science Advisory Board reviewed this research needs statement on March 29, 1989. The Agency is grateful for the thoughtful comments and suggestions of the SAB. At the time the SAB final report is received by EPA, the Research Needs Statement will be modified and a more detailed research plan will be prepared.

# I. OVERVIEW OF INDOOR AIR POLLUTION RESEARCH NEEDS

## A. PURPOSE OF THE INDOOR AIR RESEARCH PROGRAM

In October 1986, Congress passed the Superfund Amendments and Reauthorization Act (SARA, PL 99-499) which included the Radon Gas and Indoor Air Quality Research Act (Title IV). This act provided for the first time a direct Congressional mandate for a national indoor air research program. While no regulatory program is authorized under this legislation, EPA is directed to undertake a comprehensive research and development effort, including the coordination of government and private efforts, with the ultimate goal of disseminating information to the public regarding indoor air control techniques and mitigation measures.

Title IV of the Superfund legislation directs the Environmental Protection Agency and other federal agencies to establish an indoor air quality research program designed to promote the understanding of health problems associated with indoor air pollutants. SARA directs that EPA coordinate with federal, state, local, and private sector research and development efforts related to improvement of indoor air quality and assess appropriate federal actions to mitigate environmental and health risks associated with indoor air quality problems. The statute encourages federal agencies to disseminate information regarding indoor air pollutant sources and concentrations, high risk building types, measurement instruments, and health effects, as well as to recommend methods for the prevention and abatement of indoor air pollution.

Research program requirements under Section 403 include identification, characterization, and monitoring (measurement) of the sources and levels of indoor air pollution; development of instruments for indoor air quality data collection; and the study of high risk building types. The statute also requires research directed at identifying effects of indoor air pollution on human health. In the area of mitigation and control the following are required: development of mitigation measures to prevent or abate indoor air pollution; demonstration of methods for reducing or eliminating indoor air pollution; development of methods for assessing the potential for radon contamination of new construction, and examination of design measures to avoid indoor air pollution.

## B. THE INDOOR AIR RESEARCH SETTING

The ultimate goal of SARA Title IV is the dissemination of information to the public. Therefore, the central purpose of EPA's Indoor Air Research Program is to provide information useful for identifying and characterizing overall health risks in the indoor environment and for reducing exposures that pose an adverse health risk. The objectives of this research are to both determine the causes of excess risks and to identify those activities and technologies that have the greatest potential for reducing risks in the indoor environment.

Research devoted to indoor pollutants and their sources is responsive to the goal of indoor air quality guidance rather than regulation. A regulatory program requires a multitude of scientifically based outputs that are judged by scientists and interpreted by those who establish the regulations. The public and industrial sector have a relatively passive involvement, although they are involved through public comment opportunities and bear the economic burden. In contrast, the EPA's indoor air research program includes active participation of the public, industry, federal, state and local governments, and many different professional associations.

The information and guidance produced by indoor air research will be judged in terms of its ability to reduce indoor pollutant exposures. Therefore, technology transfer is an important part of the EPA indoor air research program. Information on some indoor air health risks is already sufficiently advanced that public notification of risks and mitigation procedures has begun. An example of this is the issue of environmental tobacco smoke, as discussed in the report of the Surgeon General. The radon situation is another example. Sufficient information is not yet available on many pollutants, such as volatile organic compounds, to warrant the dissemination of the health risk information to the public. The potential health risks of these pollutants is an area of active research.

Neither SARA nor any other legislative provision of EPA authorizes the establishment of a regulatory program to address indoor air quality. Therefore, EPA's indoor air research program is not intended to directly support the special purpose indoor air regulatory programs that have been authorized by Congress (e.g., the Asbestos Hazard Emergency Response Act of 1987, which amends the Toxic Substances Control Act). Indoor air research is directed toward the identification and characterization of serious public health risks in the indoor environment, and the provision of practical information that can be used by the public to avoid or mitigate these risks.

Such information is expected to be of considerable utility to the public, because the costs and benefits associated with indoor risks are largely internalized, unlike the situation with outdoor air. This means that those experiencing effects in indoor environments are likely to have greater control over the pollutant sources and are more likely to incur the costs and enjoy the benefits of any mitigation efforts. Although this relationship does not hold true in all cases, it does mean that, given appropriate and useful information, those responsible for indoor environments are expected to voluntarily take practical steps to reduce their risks from indoor air.

Many of the strategies for controlling indoor exposures involve simple, low cost efforts. For example, awareness of the health risks associated with environmental tobacco smoke can result in lowered exposures as a consequence of voluntary steps to reduce smoking. Also, simple maintenance and cleaning can reduce or eliminate many sources of biological contaminants. In other cases, it is apparent that more can be done to reduce overall exposures and risks by altering building designs and ventilation patterns than by approaching the problem source-by-source or pollutant-by-pollutant. Risks from exposures to many consumer products can be reduced by following label instructions and assuring that ventilation is adequate during use. An important role for EPA's indoor air research program is to bring these low cost control options to the attention of the public.

## C. RADON

A major research effort conducted under SARA Title IV and continuing under the Indoor Radon Abatement Act (TSCA Amendments) involves the assessment and control of radon in indoor environments. The Federal research and development radon program on health effects is the responsibility of the Department of Energy; research on radon mitigation is conducted by EPA. Section 118(K) of SARA requires a separate report to Congress on the EPA radon mitigation research program, therefore this Indoor Air Research Needs Statement includes all aspects of the Federal indoor air quality research program exclusive of radon. While the radon research effort is not covered herein, certain similarities between radon and other indoor pollutants are recognized. Assessment of pesticide vapors entering indoor environments in soil gas and control of particles similar to radon progeny are two examples of where the research efforts are complementary. The reader is encouraged to review the 1988 Report to Congress on the Radon Mitigation Demonstration Program for a full discussion of EPA's radon research needs.

## D. SUMMARY OF RESEARCH NEEDS

Congress requested that EPA undertake a comprehensive indoor air research program, including the coordination of government and private sector efforts. The research needs discussed in this report reflect the coordination of the activities of these organizations. For the purposes of identifying indoor air research needs, the federal agencies involved with indoor air research have identified research activities in the following "need" categories:

- Risk assessment methodology needs, which focus on health and hazard identification, dose-response assessment, exposure assessment, and risk characterization frameworks and methods, especially as they relate to the comparability of results from oral versus respiratory toxicity studies

- Exposure assessment and modeling needs, including methods development and evaluation, measurement studies, development of predictive models and the management of measurement data

- Source-specific needs which emphasize indoor combustion sources, such as tobacco products and indoor combustion appliances; building materials and furnishings; activity sources that emphasize product use and storage; and transportation and ambient sources of urban pollutants

- Building system needs which emphasize studies of infiltration and ventilation in both large and small buildings

- Control techniques aimed at specific sources of indoor pollutants and ventilation strategies

- Crosscutting research needs, including research devoted to the study of the impact of indoor air quality on productivity

- Technology transfer and support to state and local governments and the private sector.

The following table summarizes the major indoor air research needs in these categories, and attempts to give a sense of agency involvement, timing, and priority. Priority is based upon an immediate need to protect public health, the needs of state and local governments and the public, and the needs of the environmental research community to properly assess preliminary research results, especially the health significance of indoor pollutant exposures.

## SUMMARY OF MAJOR INDOOR AIR RESEARCH NEEDS[1]

| RESEARCH AREA AND STUDY DESCRIPTION | AGENCIES AND ORGANIZATIONS INVOLVED | PROJECT TIME (YRS) | PRIORITY[2] |
|---|---|---|---|
| A. RISK ASSESSMENT METHODOLOGY FRAMEWORK | | | |
| 1. Risk Assessment Methods | | | |
| * Develop risk methodology procedures and perform assessments for major indoor air pollution scenarios, and conduct additional toxicological research vis-a-vis evaluation of respiratory hazards | EPA/CPSC/DHHS/ STATES/PRIVATE SECTOR | 4 | PRIMARY |
| 2. Special Reports and Hazard Identification | | | |
| * Prepare special reports evaluating biological contaminants, odors and annoyance levels, and the effects of cleaning and maintenance on indoor air quality | EPA/CPSC/DHHS/ DOE/PRIVATE SECTOR | 5 | SECONDARY |
| 3. Supporting Information for Risk Assessment | | | |
| * Provide support for development and maintenance of data bases | EPA/DHHS/DOE/PRIVATE SECTOR | 5 | PRIMARY |
| B. EXPOSURE ASSESSMENT AND MODELING | | | |
| 1. Monitoring and Measurement | | | |
| * Improve sampling and analytical techniques for volatile and semi-volatile organic compounds | EPA/DHHS/DOE/NIST | 4 | PRIMARY |
| * Develop improved screening protocols, questionnaires, and measurement methods for complaint-building studies | EPA/DHHS/DOE/STATES | 4 | PRIMARY |
| * Develop improved screening protocols, questionnaires, and measurement methods for indoor air quality studies in residences | EPA/CPSC/PRIVATE SECTOR | 4 | SECONDARY |
| * Evaluate and validate new measurement methodologies under field conditions for aerosols, organics, biological species, and air exchange rates | EPA/CPSC/DHHS/DOE/ PRIVATE SECTOR | 4 | PRIMARY |
| * Develop validation procedures to improve accuracy of information collection (such as questionnaires and activity diaries) | EPA/DHHS/DOE/PRIVATE SECTOR | 4 | SECONDARY |
| 2. Modeling | | | |
| * Further develop and validate spatial/temporal models, source models, receptor models, and exposure models for indoor environments including transportation compartments | EPA/CPSC/DHHS/DOE/ STATES/PRIVATE SECTOR | 5 | SECONDARY |

[1]Research needs to be conducted by both the public and private sectors.
[2]Primary research projects are those projects that need to be initiated immediately to provide important information to protect public health or to begin more in-depth research. Secondary status research projects are also necessary projects that will begin after an evaluation of preliminary research results, or as soon as research facilities, staff and funding become available.

| RESEARCH AREA AND STUDY DESCRIPTION | AGENCIES AND ORGANIZATIONS INVOLVED | PROJECT TIME (YRS) | PRIORITY[2] |
|---|---|---|---|
| 3. Data Management and Quality Assurance | | | |
| * Implement and maintain a source emissions data base incorporating source characteristics associated with emission factors | EPA/CPSC | 5 | PRIMARY |
| * Develop standard reference materials for measurement of indoor pollutants | NIST/EPA | 5 | PRIMARY |
| * Implement and maintain an indoor air quality data repository | EPA/CPSC/DHHS/DOE/ STATES/PRIVATE SECTOR | 5 | PRIMARY |
| C. <u>SOURCE-SPECIFIC NEEDS</u> | | | |
| 1. Combustion Sources | | | |
| <u>Environmental Tobacco Smoke</u> (ETS) | | | |
| * Characterize and model ETS exposure to children | DHHS/EPA | 2 | PRIMARY |
| * Develop ETS exposure dosimetry methods | DHHS/EPA | 2 | PRIMARY |
| * Evaluate cancer risks from ETS exposure | DHHS/EPA | 3 | PRIMARY |
| * Study the non-cancer effects from ETS exposure | DHHS/EPA | 4 | PRIMARY |
| <u>Indoor Combustion Appliances</u> | | | |
| * Characterize emissions from kerosene heaters | CPSC/EPA/PRIVATE SECTOR | 3 | PRIMARY |
| * Prepare exposure assessment of kerosene heater, gas-space heater, wood stove, and unvented gas stove emissions | CPSC/EPA/PRIVATE SECTOR | 4 | PRIMARY |
| * Dosimetry - Develop physiologically-based dose-response models and biological markers | EPA/DHHS/PRIVATE SECTOR | 4 | SECONDARY |
| * Cancer risks - Conduct epidemiology feasibility study and perform <u>in vitro</u> and <u>in vivo</u> genetic and carcinogenic bioassays | EPA/DHHS/STATES | 4 | SECONDARY |
| * Non-cancer health risks - Prepare screening studies for hazard identification, multidisciplinary assessments, and verify the accuracy of the predictive exposure, dose, and health effects models | EPA/DHHS/STATES PRIVATE SECTOR | 5 | SECONDARY |
| 2. Material Sources | | | |
| * Measure emission rates of organic chemicals from building materials, furnishings, and consumer products | EPA/CPSC/DOE | 3 | PRIMARY |
| * Conduct comparisons of emissions from selected materials in small chambers, large chambers, and test houses | EPA/CPSC/PRIVATE SECTOR | 3 | PRIMARY |
| * Characterize the human response produced by emissions from selected materials | EPA/DHHS/STATES | 5 | PRIMARY |
| * Evaluate health effects of substitute products and materials | EPA/DHHS | 3 | PRIMARY |

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SUMMARY OF MAJOR INDOOR AIR RESEARCH NEEDS[1] (continued)

| RESEARCH AREA AND STUDY DESCRIPTION | AGENCIES AND ORGANIZATIONS INVOLVED | PROJECT TIME (YRS) | PRIORITY[2] |
|---|---|---|---|
| 3. Activity Sources | | | |
| * Develop measurement methods and generate emission factors for activities associated with personal care, maintenance, office work, leisure, and transportation | EPA/CPSC/DHHS | 5 | PRIMARY |
| * Characterize electrical, magnetic, and electromagnetic fields encountered in personal and work-related activities | DOE/DHHS/EPA/PRIVATE SECTOR | 5 | SECONDARY |
| * Determine the health effects and mechanisms of interaction with electromagnetic fields | DOE/DHHS/EPA/PRIVATE SECTOR | 5 | SECONDARY |
| * Characterize indoor exposures to consumer-applied pesticides (and other toxicants) | EPA/PRIVATE SECTOR | 5 | PRIMARY |
| 4. Ambient Sources | | | |
| Outdoor Air | | | |
| * Characterize indoor/outdoor concentration relationships for input to exposure models (e.g., heavy metals, ozone, and biological contaminants) | EPA/DHHS/STATES | 5 | SECONDARY |
| Soil | | | |
| * Characterize the penetration of soil-related pollutants into the indoor environment and perform a risk assessment | EPA/STATES | 3 | SECONDARY |
| Water | | | |
| * Characterize exposures to volatile organic compounds released from water | EPA | 3 | SECONDARY |
| * Investigate contribution of tap water in home humidifiers to indoor pollutant levels | EPA/CPSC | 3 | PRIMARY |
| 5. Biological Contaminants | | | |
| * Prepare report on health effects, state-of-the-art sampling methods, and research needs | EPA/CPSC/DHHS/PRIVATE SECTOR | 2 | PRIMARY |
| * Initiate development of standardized monitoring methods | EPA/CPSC/DHHS/PRIVATE SECTOR | 3 | PRIMARY |
| * Hardware development for biological monitoring methods | EPA/CPSC/DHHS/PRIVATE SECTOR | 2 | SECONDARY |
| * Identify and establish baseline concentrations of major classes of biological contaminants | EPA/CPSC/DHHS/PRIVATE SECTOR | 4 | PRIMARY |
| * Investigate contribution of HVAC equipment to indoor levels of biologicals | EPA/CPSC/DHHS/DOE/STATES/PRIVATE SECTOR | 4 | PRIMARY |

[1]Research needs to be conducted by both the public and private sectors.
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SUMMARY OF MAJOR INDOOR AIR RESEARCH NEEDS[1] (continued)

| RESEARCH AREA AND STUDY DESCRIPTION | AGENCIES AND ORGANIZATIONS INVOLVED | PROJECT TIME (YRS) | PRIORITY[2] |
|---|---|---|---|
| D. CONTROL TECHNIQUES | | | |
| 1. Source-Specific | | | |
| * Evaluate effectiveness of source modifications, including changes in product composition or use, conditioning of building materials before use, and product substitution | EPA/CPSC/DOE/STATES/ PRIVATE SECTOR | 5 | PRIMARY |
| 2. Air Cleaning | | | |
| * Conduct laboratory and field studies to determine the effectiveness of air cleaners for the control of indoor pollutants | EPA/CPSC/DOE/NIST/ PRIVATE SECTOR | 3 | PRIMARY |
| E. BUILDING SYSTEMS | | | |
| 1. Ventilation | | | |
| * Continue research to refine tracer gas techniques for measuring ventilation | DOE/DHHS/EPA/NIST/ PRIVATE SECTOR | 3 | SECONDARY |
| * Develop ventilation measurements that can be widely applied | EPA/DOE/DHHS/NIST/ PRIVATE SECTOR | 4 | PRIMARY |
| * Continue research devoted to laboratory measurements of ventilation | DOE/EPA/PRIVATE SECTOR | 4 | SECONDARY |
| * Develop techniques and protocols to measure ventilation effectiveness | NIST/EPA/DOE/DHHS/ PRIVATE SECTOR | 5 | PRIMARY |
| 2. Field Measurements | | | |
| * Measure ventilation rates and ventilation effectiveness in complaint-building investigations and residences | EPA/CPSC/DHHS/DOE/ NIST/PRIVATE SECTOR | 5 | PRIMARY |
| 3. The Total Building System | | | |
| * Conduct prototype integrated assessments of the combined impacts of source emissions, pollutant levels, ventilation rates, and energy consumption in new building designs and perform follow-up measurements | EPA/CPSC/DHHS/DOE/ NIST/PRIVATE SECTOR | 5 | PRIMARY |

[1]Research needs to be conducted by both the public and private sectors.
[2]Primary research projects are those projects that need to be initiated immediately to provide important information to protect public health or to begin more in-depth research. Secondary status research projects are also necessary projects that will begin after an evaluation of preliminary research results, or as soon as research facilities, staff and funding become available.

SUMMARY OF MAJOR INDOOR AIR RESEARCH NEEDS[1] (continued)

| RESEARCH AREA AND STUDY DESCRIPTION | AGENCIES AND ORGANIZATIONS INVOLVED | PROJECT TIME (YRS) | PRIORITY[2] |
|---|---|---|---|
| F. CROSSCUTTING RESEARCH | | | |
| * Conduct an epidemiologic study of the impact of indoor air quality on productivity | EPA/CPSC/DHHS/DOE/ NIST/STATES/ PRIVATE SECTOR | 3 | PRIMARY |
| * Conduct studies regarding the prevalence of building-occupant symptoms and indoor pollutant levels | DHHS/EPA/STATES/ PRIVATE SECTOR | 4 | SECONDARY |
| * Conduct ergonomic and psychosocial research | DHHS/EPA/PRIVATE | 3 | SECONDARY |
| G. TECHNOLOGY TRANSFER | FEDERAL AGENCIES/STATES/ PRIVATE SECTOR | | PRIMARY |

[1]Research needs to be conducted by both the public and private sectors.

[2]Primary research projects are those projects that need to be initiated immediately to provide important information to protect public health or to begin more in-depth research. Secondary status research projects are also necessary projects that will begin after an evaluation of preliminary research results, or as soon as research facilities, staff and funding become available.

## II. RESEARCH NEEDS

### A. RISK ASSESSMENT

The ultimate goals in addressing indoor air quality problems are to characterize and understand the risks to human health which indoor pollutants pose and reduce those risks by reducing exposures through non-regulatory mitigation approaches.

Indoor air quality has become a concern, because indoor pollutant levels frequently exceed outdoor levels, and individuals may spend 80 to 90% of their time in rèsidences, buildings, and in closed transit. While we have expended much effort over the past 20 years to assess and manage outdoor pollutants, the identification and assessment of hazardous indoor air pollutants have only recently begun.

The major categories of indoor pollutants can be related to mortality, morbidity, and reduced productivity. The most potentially hazardous pollutants are shown below.

INDOOR AIR QUALITY HAZARDS

| Pollutant | Mortality | Morbidity | Productivity |
|---|---|---|---|
| 1. ETS | # | # | $ |
| 2. Radon | # | | |
| 3. Asbestos | # | | |
| 4. Organics | # | # | $ |
| 5. Biologicals | # | # | $ |
| 6. Inorganics | # | # | |
| 7. Non-Ionizing Radiation | # | # | $ |

The characterization of risk from these pollutants varies in relation to understanding their sources, exposures, and dose-response information. The most well known indoor air pollutants originate from a variety of sources. These sources generate wide ranges of the pollutant concentrations over time. Actual human exposure to many of these pollutants is at this time not well understood. Exposure assessment is one of the indoor air research community's most important research activities.

Although far from being complete, our knowledge of concentration-response relationships for some indoor air pollutants, those which are also outdoor or occupational-setting pollutants, is quite extensive. Health consequences of exposures to carbon monoxide, nitrogen dioxide, fine particles (i.e., less than 2.5 μm), radon, and even asbestos are predictable because of the many years of study of these substances in either the ambient environment or occupational settings. However, even for these pollutants, we often lack knowledge of their effects when combined with other pollutants. For example, fine particles in environmental tobacco smoke (ETS) are not toxicologically identical to fine particles from a kerosene heater or a humidifier.

For many indoor air pollutants such as the biological contaminants, individual gas-phase organics (both single compounds and mixtures), and non-ionizing radiation, our knowledge of the health consequences associated with indoor exposures is extremely limited.

Recently, risk characterizations have been made for a very few specific indoor air pollutants. Annual excess mortality in the range of 5,000 to 20,000 cases per year has been estimated for radon. Also, environmental tobacco smoke may be associated with 500 to 5,000 excess cancer deaths for nonsmokers annually.

Though it is difficult to adequately quantify the risks of many indoor air pollutants, it is expected that more risk occurs indoors simply because more time is spent indoors. This is especially true for many of the "hazardous air pollutants" for which much attention has been directed in the ambient environment over the past decade.

One of the biggest deficiencies highlighted in the EPA's preliminary assessment of indoor environments is the inability to properly assess human risk from indoor air pollution. This shortcoming is the result of limited data on human exposure to the many different pollutants found indoors and the inability to distinguish among multiple health endpoints. Consequently, one of the highest research objectives is to develop data and information with which to better characterize exposure and health effects to determine risk.

Risk characterization is a primary objective of Title IV. The following are basic research needs that are intended to respond to this Congressional requirement.

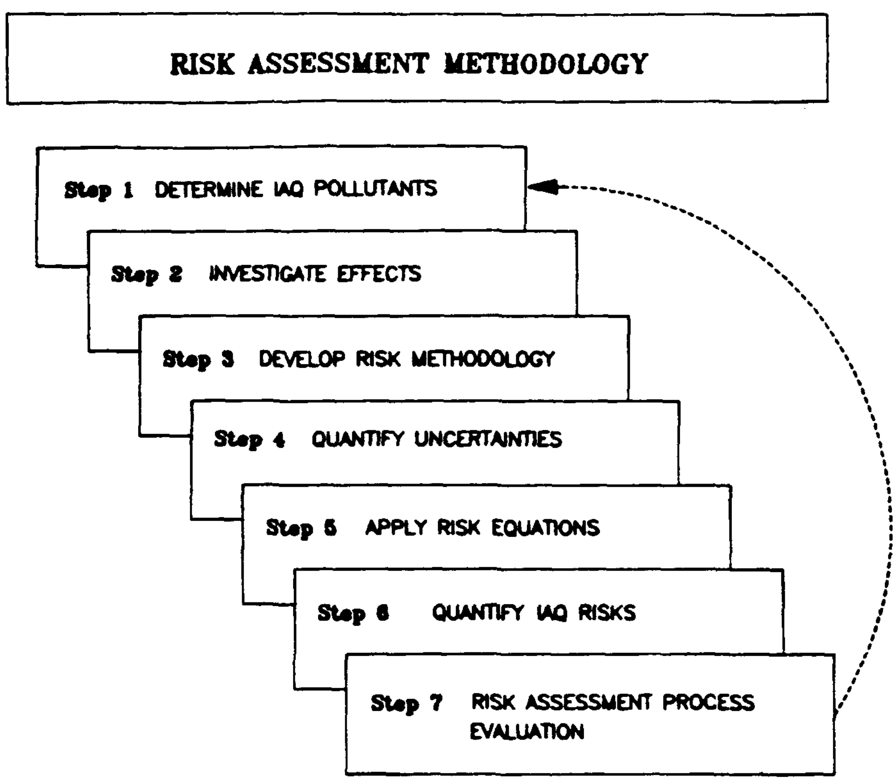
1. Framework for Assessing Risk

The process of estimating the harmful effects of indoor air pollution is accomplished through risk assessment. The assessment of risk entails: (1) hazard identification, (2) exposure assessment, and (3) dose-response assessment. Risk characterization involves pulling together all relevant health information to quantify or qualify the risks associated with various indoor air scenarios.

The majority of research needs mentioned in this report are intended to be applied in the risk assessment process. The risk assessment process is well-defined and is driven by widely accepted scientifically-based guidelines. One essential research need is the application of the risk assessment guidelines to different indoor air pollution scenarios and situations.

Risk assessment fully utilizes the data collected in indoor studies. To achieve the best results, the risk assessment framework should embody the traditional risk model chain: sources, transport and fate, exposure, dose, and effect. This framework would be best applied in multiple iterations rather than in a "single pass" to take full advantage of new data. To fill this need quantitatively, a seven step methodology is being designed and will be used with a number of indoor air pollution scenarios.

As shown graphically below, the purpose of step one is to survey what is known about a pollutant and its sources. Step 2 investigates possible health or welfare effects, while step 3 identifies a number of components including source factors, concentration distributions, exposure times, and populations at risk. Step 4 quantifies these components and their uncertainties, and step 5 involves the derivation of a deterministic risk equation. Step 6 tests the risk equation under varying assumptions and situations, and the final step examines the risk assessment and identifies ways to better integrate research results so that the risks can be more readily compared and better estimated in another iteration of the process.




Seven-step risk characterization methodology

Since the goal of the EPA indoor air research effort is to support non-regulatory approaches to mitigating potential indoor health risks, the quantification requirements of risk assessment are somewhat relaxed. While it is important to quantify the relative risks both among indoor pollutant exposures and as compared with those associated with ambient pollutant exposures, the calculation of risk need only be sufficient to estimate the benefits from different risk management approaches.

2. Special Topics for Assessing Risk

An adequate assessment of risk is a complex and far reaching process. There are many unstudied sources of pollutants found indoors which may contribute to the human health risk and need to be better understood so they can be factored into the the risk assessment process. Some of these include cleaning methods and practices, biological organisms originating from humans and animals and from excess moisture situations, and sources of odors. EPA is currently preparing a series of reports to provide information on these special topics.

3. Supporting Information for Risk Assessment

Data and information that support the assessment of risk must be properly maintained, updated, and distributed. This type of support includes the establishment of a clearinghouse for scientific information and maintenance of a bibliographic data base.

## B. EXPOSURE ASSESSMENT AND MODELING NEEDS

An integral step in assessing risk in the indoor environment is the determination of the exposure distributions of pollutants. This can be accomplished by making microenvironmental and exposure measurements using fixed location and personal exposure monitors, or by estimating these exposures using limited empirical data sets and predictive models. A direct link to sources and mitigation can then be made through indoor receptor models.

Indoor air quality models and supportive data bases are essential in understanding the nature and magnitude of indoor air quality. Reliance on monitoring efforts alone to provide information on the number of pollutants and building types is prohibitively expensive. The research community must continue to develop models that will simulate pollutant sources and building factors affecting indoor air quality. These models can then be used to quantify exposure reductions expected from different mitigation options, and serve as an important tool for public and private building investigators to use in identifying and solving problems.

The following is a list of assessment tools which must be refined if characterization and control of indoor pollutants are to be achieved.

- Evaluation of sampling and analysis for organic pollutants
- Improvement of measurement methodologies for polar organic compounds
- Improvement of measurement methodologies for biological pollutants
- Development of versatile and unobtrusive indoor air quality samplers
- Development of protocols for measuring and reporting source emission rates for selected indoor materials and consumer products
- Development and testing of screening and source use questionnaires
- Evaluation of methods to estimate indoor pollutant exposures in epidemiological studies
- Investigation of the composition and size distribution of indoor particles
- Measurement of indoor spatial and temporal concentration gradients
- Development of receptor models for using field data to estimate the contributions of various pollutant sources
- Maintenance of the indoor source emissions data base

## 1. Monitoring and Measurement

One way to assess an individual's exposure to indoor air pollution is the direct measurement of pollutants in indoor microenvironments. The accuracy and representativeness of these measurements depend on the measurement and monitoring methods used. Indoor monitoring methodologies must consider the obtrusiveness of the samplers and their ability to sample without altering the microenvironmental situation. Current monitoring needs include evaluating the ability to extend existing monitoring methods for analyzing indoor levels of organics to an expanding list of potential contaminants, developing better methods for measuring polar organic compounds, and developing smaller, less obtrusive samplers for semivolatile organics and analytical techniques to separate organic vapor and particle phases. Miniature, real-time analyzers are needed to provide exposure distribution information for pollutants such as nitrogen dioxide ($NO_2$) and gas-phase organic compounds or volatile organic compounds (VOCs). Low cost monitors must be developed so that large scale studies can be undertaken and individual homeowners can afford testing. Such monitors are often small, passive devices that can be worn on the person.

Health and comfort complaints among building occupants have become more prevalent as the public becomes better informed about indoor air pollution. Better screening techniques are needed to provide rapid response and broad-scale coverage of pollutant classes. Standardized protocols for resolving SBS complaints must be developed and tested for use by local agencies and private contractors. To standardize procedures, a compendium of methods must be developed and maintained so that measurements made by various investigators are accurate, consistent, and comparable.

After monitoring methods are developed, they must be field tested. Research needs include evaluation of new monitoring methods for semivolatile organic compounds (SVOCs) and study of their chemical identity and fate indoors. Data bases must be examined to relate sources to marker elements and compounds through receptor models. Measurement methods for biological contaminants are needed. New indoor aerosol monitoring methods must be evaluated to determine their consistency with ambient methods.

Measurements are needed to determine the exposure distributions of selected SVOCs to better estimate risk for the more toxic pollutants found indoors. Sources of SVOCs include combustion appliances, ETS, and furnishings. SBS protocols and measurement techniques must be applied to selected situations to better understand the nature and magnitude of SBS complaint situations. Special studies are also needed to delineate the risk of using humidifiers and their dissemination of minerals and biological species. Monitoring studies are needed to better understand the gas-phase organic compound contributions of solvents used in personal hobbies, offices, and maintenance activities.

A multi-purpose indoor air questionnaire must be developed for use in future indoor air investigations. This questionnaire must be validated for accuracy and completeness, easy to administer, machine readable, and must provide responses and summaries that are directly relatable to corresponding exposure, source, and analytical data. Uniform activity diaries (personal and source) must also be made available to the scientific community to facilitate comparability of study data.

2. Modeling

Models can be used to rapidly and economically assess indoor problems. Once validated, models often provide acceptably accurate estimates of indoor pollutant levels. EPA has developed an IAQ model for personal computers that couples indoor sources with building air exchange, room-to-room transport, HVAC operation, and air cleaners to predict indoor concentrations of specific pollutants. Another promising indoor model under development is the CONTAM model developed by the National Institute of Standards and Technology for EPA, DOE, and CPSC. CONTAM is a full-scale, multi-zone building contaminant dispersal model that simulates flow processes (e.g., infiltration, dilution, and exfiltration) and contaminant generation, reaction, and removal processes. In addition macromodeling research sponsored by CPSC and DOE may provide generalized population exposure distributions. Research is needed to validate these models using actual measurements under controlled situations. User-friendly computer programs are needed to facilitate their use beyond the research setting.

Exposure estimation involves the use of predictive models. Research needs include better information on activity patterns and the development of colocated exposure and microenvironmental data bases to permit validation of the models and linking them to sources and mitigation strategies. The incorporation of biomarkers within exposure models must be pursued to permit more accurate assessments of potential health risks from indoor pollutants. Additional information is needed on the distribution of pollutant exposures to help develop selection criteria for sampling.

3. Data Management and Quality Assurance

The development of centralized repositories of indoor data is needed to better analyze data from various researchers. Personal exposure, microenvironmental, ambient, source emission, and analytical results should be uniformly maintained in central repository. These systems must be easily accessible by federal, state, and local agencies, and must include precise and accurate information. The indoor air quality field studies data base maintained for the Gas Research Institute, the Electric Power Research Institute, and DOE is an example of such a data base.

Quality assurance efforts specific to indoor measurements are needed to provide standard methodologies for use by researchers. Examples include the development of standard VOC mixtures and standards for SVOC, ETS, and biological contaminant analyses.

## C. SOURCE-SPECIFIC NEEDS

To properly characterize the indoor air environment, it is important to understand the primary sources of indoor pollutants. Indoor sources produce the pollutants that cause health effects, and control of these sources is the most direct mitigation approach. There is a large variety of potential pollutant sources in the ordinary American household and office building. Common sources include heating and air conditioning systems, cooking and heating appliances, building materials, biological contaminants, household products, electric and magnetic fields, and infiltration of outdoor pollutants.

Indoor air quality is influenced by the nature and strength of pollutant sources and sinks. In turn these sources and sinks are influenced by a number of factors. Sources may emit pollutants at a single point or over a wide area either continuously or episodically. Source strength may depend on human activity such as smoking or cooking or meteorological conditions such as temperature, humidity, wind speed, or season. The type and age of the building, building materials, and furnishings may also be contributing factors. Many of the above considerations also apply to sinks. Typical sinks include sorption on interior surfaces, chemical reaction, and replacement with outside air.

Research oriented toward specific sources of exposure and individual pollutants is a central focus of the federal indoor air research program. This research is necessary to assure that important indoor air risks are not overlooked, and to focus continued emphasis on known risks. This research will provide a vehicle for the assessment of known high-risk categories, such as ETS, as well as suspected high risk categories such as biological contaminants, combustion appliances, and building materials and products.

For purposes of organizing research and assuring that all indoor air risks are considered in a methodical manner, the following source categories have been established.

1. Combustion Sources - environmental tobacco smoke, indoor combustion appliances

2. Material Sources - building materials, furnishings, work and leisure materials, replacement materials, product storage

3. Activity Sources - maintenance and cleaning supplies, domestic water, pesticides, transportation

4. Ambient Sources - air, soil, water

5. Sources of Biological Contaminants - animal and human sources of bacteria, viruses, and allergens.

### 1. Combustion Sources

Prominent among the concerns of indoor combustion sources are environmental tobacco smoke, unvented gas stoves and heaters, kerosene heaters, and wood burning stoves, furnaces, and fireplaces.

Although cigarette smoking is well established as the largest single preventable cause of premature death and disability in the United States, the 1986 Surgeon General's report, "The Health Consequences of Involuntary Smoking" was the first U.S. Government report to establish a significant health risk from exposure to ETS. The quantitative estimates of the cancer risk alone as reviewed by this and the National Academy of Sciences, 1986 report suggest that ETS poses a very significant risk to the U.S. population. Consideration of the magnitude of the exposure to ETS indoors and the time individuals spend indoors has led scientists to suggest that it is a major and possibly the single largest source of exposure to particles, organics, and mutagens. Several studies are underway to determine the human exposure and potential cancer risk from exposure to ETS. Overall, research is providing information so that the public, local, state, and federal government agencies, the building industry, employers, and others can make well informed choices regarding the control of exposure to ETS.

Some of the pollutants associated with wood stoves, furnaces, and fireplaces, and unvented heating and cooking appliances are regulated under the Clean Air Act. These pollutants include $NO_2$, sulfur dioxide ($SO_2$), carbon monoxide (CO), and particulate matter. While EPA has the authority to regulate "ambient air," CPSC has the authority to regulate emissions from appliances that contribute to poor indoor air quality.

Considerable progress has been made in developing personal monitors and characterizing exposures to combustion pollutants in indoor microenvironments (notably for $NO_2$ and CO). There has also been considerable research to assess the health effects associated with these pollutants and of some polycyclic aromatic hydrocarbons (PAHs). However, there is very little knowledge about the comparative (or actual) health risks of commonly used combustion appliances. Thus, further research is necessary to determine the magnitude of the health risks from those sources. Recent data from studies of kerosene and unvented gas space heaters indicate the need for continued examination of potential exposures from these products. The implications of acute and chronic respiratory health effects are potentially very important.

Studies are needed to evaluate the non-cancer health effects of combustion appliance emissions indoors. This issue is important because approximately 7 million homes have kerosene appliances, 4.2 million homes use unvented gas space heaters, and 20 million homes have gas stoves. Studies are needed to investigate the health effects associated with the acute and intermittent inhalation of the whole and fractionated effluents generated from home heating units and other combustion appliances.

### Environmental tobacco smoke

Environmental tobacco smoke consists of at least four thousand compounds, some of which have toxic or carcinogenic properties. The large emission rate of fine mode particles from tobacco smoke has led researchers to conclude that ETS is the dominant source of these particles indoors. Although not well characterized, ETS may also pose a significant risk of non-cancer effects ranging from irritation to chronic lung disease, especially for children.

Evaluations from the National Academy of Sciences and the Surgeon General's Office of Smoking and Health conclude that exposure to ETS increases the incidence of lung cancer in nonsmokers. Studies devoted to ETS consistently show a 30% increased risk (within 95% confidence intervals) for nonsmoking spouses of smokers.

There is enough known about the health effects of ETS to demonstrate the need for quantitative risk assessments for cancer and non-cancer effects. The specific research needs identified below are drawn heavily from the research recommendations made by the NAS and the Surgeon General.

One important research need is the development and standardization of better sampling and analytical methods to both collect and measure ETS and to characterize the toxicologically significant components of ETS. Research is planned to determine the distribution of constituents in the particulate and vapor phases of ETS and to identify and evaluate marker compounds for these phases. Short-term genetic microbioassay methods will be used in conjunction with chemical characterization to identify mutagenic components and to continue research to measure mutagenic emission rates and exposures. Monitoring and modeling studies will continue to quantify emissions, transport, and fate of ETS in indoor air environments. Chambers and test homes will be used to determine the relationship between various factors (e.g., room size, humidity, air exchange rate, wall coverings) on ETS exposure concentrations.

The highest priority research recommended by both the NAS and the Surgeon General is in the area of understanding the relationship between ETS exposure and dosimetry. This area of research is central to proposed research in pollutant characterization and modeling. The strategy relies on the development and use of biological markers together with personal exposure monitoring and health effects studies. Studies are needed to improve use of cotinine (a nicotine metabolite) as a biological marker of exposure to ETS. New highly sensitive methods for measuring DNA and protein adducts of tobacco-specific chemicals will be further developed and applied in pilot studies of human fluids and tissues. These methods will also be tested in chamber and field studies.

Research devoted to the non-cancer effects of ETS includes examination of exposure-effects relationships for both short-term acute effects (e.g., irritation and allergic responses) and chronic effects that can lead to respiratory or cardiovascular effects. Initial attention should be given to susceptible populations such as children and people with preexisting cardiopulmonary diseases.

Indoor combustion appliances

Indoor combustion appliances are known to be significant sources of indoor pollutants including $NO_2$, CO, $CO_2$, $SO_2$, fine particles, polycyclic organic matter (POM), VOCs, and SVOCs. Incomplete combustion products have been associated with human cancers at many sites, particularly the lung. Combustion products of coal, wood, and diesel fuel are mutagenic in bacteria and tumorigenic in animal studies. Polycyclic aromatic hydrocarbons are known animal carcinogens. The criteria pollutants, $NO_2$, CO, particles and $SO_2$, have health effects demonstrated in humans which include pulmonary toxicity and dysfunction, especially in sensitive populations such as asthmatics.

Gas stove usage has been associated with respiratory effects, especially in children, including increases in pulmonary illnesses. Elevated levels of $NO_2$ in homes can exceed the levels that cause pulmonary function changes in some asthmatics studied under controlled conditions. The short-term and long-term health effects on humans from exposure to the combination of pollutants in combustion emissions in the indoor environment are not well understood. For example, information on unvented combustion appliances indicates that combustion emissions can cause pulmonary function changes in asthmatics (short-term exposure) and irreversible lung changes in animals (long-term exposure). Preliminary studies also indicate that emissions from some kerosene heaters may be potentially genotoxic and carcinogenic.

Limited information is available on the contribution of vented appliances to indoor air pollution. Problems often associated with vented appliances and poor indoor air quality include blocked flues, down drafting, corroded heat exchange units, and maladjusted appliances. These problems can result in severe exposures. Research is needed to determine the prevalence of these problems and their contribution to indoor pollutant exposures.

To characterize the risks from combustion appliances, it is necessary to know what appliance types and models are in use and how they are operated and maintained. This information provides data for exposure assessment and gives guidance as to which appliances should be studied as a higher priority. Exposure assessment and health risk characterization studies are needed. Studies of specific gases, such as $NO_2$ and CO from gas stoves, have shown that when properly adjusted and used (e.g., not for heating), these devices operate within a level which does not pose a serious health risk. Although significant uncertainties exist for risk assessment of gas stoves, much is known and major epidemiology studies are underway. Therefore, the priority for research is on unvented combustion appliances where there is a potential concern for acute effects, chronic lung disease, and possibly cancer, but minimal supporting data. Other major classes of combustion (i.e., coal and wood stoves, fireplaces, and furnaces) have been studied, and do not seem to pose comparable risk to unvented appliances.

Research is needed to characterize the chemical and physical emissions from various indoor combustion sources. Previous studies have shown that the use of gas stoves, kerosene heaters, and unvented gas space heaters can significantly increase indoor $NO_2$ levels under certain use conditions. Organic emissions (particle-bound, semivolatile organics and VOCs) have not been characterized or monitored. Research devoted to combustion appliances should initially emphasize unvented appliances. Research is being conducted to survey information on appliance types and models and maintenance and usage patterns in U.S. homes. Results from the survey will provide guidance on designing future monitoring and health studies that are most representative of home use scenarios. The major portion of this research will involve characterization of the combustion emissions in chambers and test homes and modeling of human exposures under various conditions. This research will both assist in estimating potential risks and provide information to mitigate exposures from these sources.

Studies are also needed to determine the profile of the population at risk (age, sex, and health status), and the magnitude, frequency, and duration of inhalation exposure to pollutants from indoor combustion. Human exposures can be estimated by measuring existing exposures and modeling future exposures.

Dosimetry is the quantitative relationship between exposure and dose delivered to the target site, and thus is a critical component of quantitative risk assessment. Dosimetry models need to relate inhaled concentrations of combustion emissions to dose in children and people with preexisting lung disease to determine which subpopulations are likely to be at increased risk. Biomarkers also need to be developed to assess biologically effective doses, for example to DNA, since combustion emissions may have carcinogenic potential. Biomarker methods will be valuable in future epidemiology studies.

Research is also needed to study the non-cancer risks associated with combustion appliance emissions. Given the range of sources and potential health effects, this research must be conducted stepwise, with each step providing guidance in the design of the next step. Research will begin with unvented heaters because preliminary data suggests that emissions from some unvented heaters may present adverse health risks.

Based on the results from these preliminary characterization studies, the range of appliances examined and the type of test conditions may be expanded. The basic approach used in this effort will be to begin with hazard identification and proceed to dosimetry and dose-response assessment. Prior animal inhalation (and controlled-human) studies have concentrated on individual pollutants. Research devoted to mixtures of combustion pollutants is needed. As more knowledge is gained, epidemiological studies will be designed.

Results from characterization studies will also allow selection of the appliances of concern for cancer risk assessment. Dose-response assessment is crucial to determine the quantitative relationship between exposure and dose to combustion pollutants and the incidence of cancers. Dose-response relationships associated with indoor combustion emissions need to be obtained through epidemiological studies in highly exposed human populations and through in vitro and in vivo cancer bioassays.

Other studies will use emissions data to develop models for predicting combustion appliance-related hazards. Controlled studies in chambers and test buildings will be conducted on selected combustion appliances (probably kerosene heaters and wood burners). Avenues of health research initiated during the screening stage will then be expanded (i.e., lung irritancy, lung immunotoxicity, neurobehavioral impacts, and mutagenicity). Controlled studies in chambers and test buildings will be conducted to evaluate selected appliances under varied conditions of use and physical environments. Appliance design and use factors will be investigated.

The primary focus of each study in this area is dosimetry and identification of the factors that contribute to the potential for increased exposure, uptake and distribution, and disposition of the inhaled emission components. While every emission component cannot be evaluated, studies will be conducted to identify suspect toxicants and/or tracer elements within whole emissions, which will contribute to both the health effects research effort and dosimetry models.

2. Material Sources

Building materials, furnishings, and household chemicals can be significant sources of indoor air pollution. These sources are frequently included under the heading of "material sources." Research is needed to study the emission characteristics of material sources and the factors which affect these emissions. Material sources to be studied include pressed wood products, insulation, ceiling tiles, wall coverings, adhesives, caulks, paints, and stains; furniture, draperies, carpeting, and office partitions; and pesticides, waxes, polishes, cleansers, room fresheners, and stored materials.

Building materials and furnishings are known to be sources of toxic substances. For example, asbestos fibers from insulation and ceiling tiles are widely recognized as important indoor air pollutants in schools, office buildings, and many private residences. Formaldehyde emissions from pressed wood products and urea formaldehyde foam insulation (UFFI) have been extensively studied. Numerous field investigations in new and complaint buildings have shown levels of organics well in excess of outdoor concentrations. Except for formaldehyde, however, limited data are available on the sources and health effects of organic compounds found in the indoor environment. A comprehensive research program is needed to develop an understanding of the health risks associated with organic emissions from materials and products commonly found in residential and commercial buildings.

Sources of indoor air pollution from stored materials include solvents and household and commercial products. Data are available on the classes of compounds emitted from common solvents and on many of the specific compounds emitted from petroleum based solvents. Limited data on household solvent usage are available from the EPA Office of Toxic Substances which emphasizes chlorinated solvents.

Information is needed on the stored material (solvent) composition, the classes of compounds emitted, and the specific compounds emitted. Data on emission factors are required for both total organics and targeted individual compounds, based on the type, age, and condition of the storage container (including type and condition of the container cap or seal). Information is needed on: (1) the effect of container type, condition, and age on emission rates, (2) the effect of container seal or cap type and condition on emission rates, (3) the impact of temperature, humidity, air exchange, product use, and product age on emission factors, and (4) source characteristics (e.g., composition, compound vapor pressure, reactivity) that affect emission factors. Data are also needed on the amount of material manufactured, sold, used, and stored, storage location, and storage time.

The exposures of interest from these materials are those which continuously occur during day-to-day occupancy, as opposed to the exposures experienced during use or application. (The latter exposures are addressed later under "Activity Sources.") Many products, such as adhesives, caulks, paints, waxes, and polishes, have large initial emission rates of highly volatile compounds followed by lower rates for the less volatile organic species.

The evaluation of the health effects from material sources is important, but the direct approach of examining the health effects of every potential major source is not feasible due to the costs involved. Rather, it is necessary to take a more generic approach with limited evaluations of specific chemicals or specific sources. Priority should be given to those sources identified as causative factors of complaint buildings and longer-term health effects.

Monitoring surveys of homes and public buildings worldwide indicate that an assortment of volatile organic compounds is present in indoor environments. Although the levels of individual VOCs found are generally orders of magnitude below the Threshold Limit Values or levels considered to be harmful for any individual compound in occupational settings, complaints associated with VOCs do occur and little is known about the toxicity of complex mixtures. Among the VOCs found are acetone, formaldehyde, methylethylketone, hexane, toluene, and xylene (used in building materials, furnishings, and adhesives) and benzene (emitted from gasoline). Chlorinated hydrocarbons frequently found include methylene chloride (paint strippers), trichloroethane (paint), perchloroethylene (dry-cleaned clothes), trichloroethylene (type correction fluid and degreasing agents) and paradichlorobenzene (deodorizers and insect repellents). Some of these VOCs (e.g., benzene) are known to be carcinogenic. Many of the individual VOCs such as n-hexane and toluene are known to be neurotoxic, but at levels much higher than those found typically indoors. Complaints of irritating air quality in homes and office buildings have given rise to the term sick building syndrome. This syndrome includes a large number of neurobehavioral and respiratory complaints, including mental fatigue, headache, dizziness, nausea, irritation of eye, nose and throat, hoarseness of voice, wheezing, dry mucous membranes and skin, erythema, airway infections, cough, and nonspecific airway hyperreactivity reactions.

Research emphasis needs to be placed on developing and conducting appropriate tests to objectively assess the health effects associated with these exposures. Monitoring methods and instruments need to be designed to measure organic species at low levels. Source emission rates need to be determined, and source models developed to evaluate the effect of air temperature, humidity, and air exchange rate on emissions. Other source characteristics that affect emission rates (e.g., composition, compound vapor pressures, reactivity, etc.) also need to be evaluated. Control strategies which need to be investigated include product modification, material substitution, and modification of the ventilation system. For example, the effectiveness of increased temperature (during unoccupied hours) and increased ventilation following initial building construction needs to be studied. Health effects and source characterization studies need to be performed using exposure chambers. Field measurements in a test home need to be conducted to evaluate monitoring instruments and to integrate health effects, monitoring, and source characterization studies. Ultimate verification of findings will rely on field studies in residences, offices, and public access buildings.

The information developed in this research program is needed by builders, architects, engineers, contractors, manufacturers, homeowners, building owners and managers, public officials, researchers, and the general public. The following outputs are anticipated:

- Emission testing procedures useful for developing emission rate and organic vapor composition data for building materials and consumer products. Such procedures would be useful to manufacturers for determining the emission characteristics of their products and passing such information on to their customers.

- Monitoring methods for organics applicable to the low concentrations encountered in buildings. These methods would be useful to those investigating indoor air quality problems, including complaint buildings.

- Health effects testing methods for evaluating acute and chronic health end points. Such methods would be used by researchers and the medical community to determine the health hazard associated with materials, furnishings, and consumer products.

- Emission factors for a variety of materials and consumer products. This information would allow architects and builders to design and construct buildings with inherently low organic emission characteristics. Homeowners, landlords, and the general public would be able to select products with low emission characteristics.

- Relative health hazard rankings of materials and consumer products. All parties would use such information to select and use products with minimum health hazard. Public officials might use these rankings to develop product standards (e.g., HUD requirements for particleboard formaldehyde emissions in mobile homes) or influence local building codes (e.g., prohibition of asbestos or UFFI).

- Emission models for indoor material sources. Simple models for predicting the emission rates from sources as a function of environmental variables (e.g., temperature, relative humidity, air exchange rate) would be used in "whole building" models to calculate the expected concentration of various pollutants in the indoor environment. Data on the "sink effect" of materials and furnishings is also required.

- Information on emission control strategies and alternatives. Architects and builders would use indoor air quality controls to ameliorate complaint building problems and to design and construct buildings to minimize indoor air quality problems. Homeowners and landlords could use indoor air quality control information to solve existing problems in residences.

<u>Chamber studies</u>

Initial health hazard comparisons of selected building materials, furnishings, and consumer products will produce health assessments and source characterizations that will provide an indication of the relative rankings of indoor materials. Environmental test chambers provide a convenient means of evaluating a variety of materials under controlled conditions. Available sampling and analysis tools (sample adsorption and concentration followed by gas chromatography) can provide information on organic species at low levels. In addition, vapor phase bioassays can be performed on test chamber emissions.

Environmental test chamber research is needed to determine potential exposures to organic mixtures emitted from selected materials. This research should include developing emission rate data; predicting indoor concentrations expected in buildings; conducting interlaboratory comparisons of small chamber studies used by U.S., European, and Canadian investigators; and evaluating and developing monitoring methods applicable to organic species and concentrations occurring in chambers and expected in buildings. In addition, research is needed to study interactions between pollutants and source and sink effects. Research outputs needed include emission testing procedures, monitoring methods, emission factors, and emission source models.

Exposure chamber studies

Exposure chamber studies provide opportunities to determine the impact of indoor air pollutants on humans, animals, and other biological organisms. In order to identify the hazards associated with exposure, the constituents of the exposure must be determined and simple screening tests conducted to indicate biological activity of the constituents at relevant concentrations. The focus of the health effects testing should initially be on neurotoxicity and genotoxicity.

Research will include genotoxicity studies, including short term vapor phase bioassays, chemical analysis of active mixtures, and testing of reconstituted mixtures determined to have biological activity based on previous studies. Included should be the conduct of controlled human exposure to relevant volatile organic compounds and mixtures to determine the replicability of previously reported psychological disturbances and the potential role of trigeminal nerve activity in producing discomfort and dysfunction in sick building syndrome. In addition, research is needed which will expose animals, via inhalation, to relevant simple and complex VOC mixtures to screen for lung irritancy and neurotoxicity.

Test home studies

Health assessments, source characterizations, and organic measurement development will provide relative rankings of indoor materials in terms of emissions and biological activity. Test-house evaluations allow the investigation of specific sources of indoor air pollutants without the confounding influence of multiple (and often unknown) sources found in occupied buildings. Test-house evaluations are necessary to provide "scale-up" and validation of test chamber results.

Materials which indicate high relative health risk from the chamber testing studies will be placed in the test-house. Organic monitoring will be conducted concurrently and measurement methods validated. Emission factors will be calculated and compared to those developed in the small chambers. Source emission models will be calibrated and verified. Research applicable to assessing health effects (e.g., bioassays) will also be conducted.

Characterization and dose-response

Characterization and dose-response of health hazards produced by emissions from selected building materials and consumer products will accomplish several objectives: aid in understanding the relationship between exposure to emissions from indoor materials and internal dose; help determine the spectrum of biological activity produced by these pollutants; and establish the relationship between dose and the magnitude and nature of the biological effect.

The potential bioactivity of constituents of emissions from building materials and consumer products to the indoor environment will be identified. Once specific constituents and mixtures of VOCs are shown to have biological activity, the risk assessment process demands knowledge of the nature of the adverse effect as well as its dose dependence, so that extrapolation from high to low dose and from animal to man may be accomplished.

Using data obtained from the hazard identification and screening studies, dosimetry studies will be performed, including model development, studies of respiratory tract removal of VOCs, and genotoxicity. Animal toxicology studies will include whole animal studies of carcinogenesis and neurotoxicity, and evaluation of pulmonary, developmental, and immunological consequences of inhalation exposure to relevant simple and complex VOC mixtures. Controlled human exposures will be used to evaluate potential neurobehavioral dysfunction produced by constituents and mixtures of constituents identified and relevant from hazard identification/screening studies.

Sink effect studies

The "sink effect" of building materials and furnishings on indoor organic concentrations needs to be examined. Data are available on sink rates for $NO_2$ from combustion sources, and the goal of this research is to extend the limited data available on the adsorptive capacity of building materials and furnishings for organic compounds in indoor environments. An understanding of the adsorption (and subsequent re-emission) of indoor organic vapors is required because organic sinks have the potential to reduce maximum indoor concentrations, or they can act as sources which re-emit the compound.

A three stage research effort is proposed. The first stage will employ small environmental test chambers to evaluate a variety of potential organic sinks (e.g., gypsum wallboard, acoustical ceiling tiles, and carpets). The potential sink effect of each material will be determined as a function of chamber conditions (e.g., temperature, relative humidity, and air exchange rate) for a variety of common indoor organic vapors. The role of building materials as sinks for SOx, NOx, and particles will also be studied. The second stage will involve validation of the test data in the test house, and the third stage will be the initiation of field evaluations.

Material and product substitution

Evaluation of indoor air quality control via material or product modification or substitution will determine the health risk effects associated with these changes. Material and product selection provides builders and occupants the opportunity to control the indoor environment. Avoidance of materials and products known or suspected to cause adverse health effects relies on knowledge of the relative risks.

Initial emphasis will be given to materials determined to potentially pose relatively high health risks. Studies will be conducted to determine the reduction in risk caused by material substitution or modification. For example, changing from urea formaldehyde pressed wood products to those using phenol formaldehyde will reduce formaldehyde emissions. Well defined screening tests can be developed to define the potential toxicity of proposed replacement materials. Initial evaluations will be conducted in chambers, with follow-up studies in the test house. The health effects work will be supported by source characterization and monitoring.

Field studies

Field studies of indoor air pollutant concentrations, sources, and health effects in residential and commercial buildings will be conducted to validate and extend research findings. Field studies are a means by which to validate and verify data, methods, and models developed under controlled conditions (e.g., in environmental chambers and test houses). Such studies provide a means for combining the health effects, monitoring, and source characterization techniques into integrated evaluation protocols applicable to the investigation of a variety of indoor air quality problems.

A five stage field study approach is proposed. This project will integrate the indoor air quality research programs for all indoor pollutant source categories. The first stage will be the identification of target populations of human subjects (including responders and nonresponders to the sick building syndrome), development of methods required to study specific subsets of this population (e.g., children), and evaluation of the health status (e.g., neurobehavioral function, trigeminal sensitivity) of participants. The second stage will involve a small sample of buildings (3-6) and will refine and test the evaluation capabilities of the laboratories involved. The third stage will be conducted on a larger sample (~10 buildings) and will validate the methods and models developed by the indoor air research teams. The fourth stage will include complaint buildings, including residences, and will develop and test diagnostic and control procedures. Finally, the fifth stage will be an evaluation of indoor air quality control techniques and strategies.

3. Activity Sources

Normal day-to-day activities involve the use of a broad range of consumer products, devices, and tools which can result in emissions of air pollutants. Outdoors, with the possible exception of occupational activities, such exposures are generally believed to be of only limited health consequence, largely because of the diluting effect of the ambient air. Indoors, however, the health implications may be more consequential, depending on the exposure received in a given microenvironment. Even if indoor air pollutant concentrations are low, they may make a substantial contribution to time-weighted exposures due to the large amount of time spent indoors. If indoor personal exposures are not taken into consideration in epidemiologic investigations, spurious conclusions may be reached.

This section identifies a limited number of personal activities for research. The object of the research is to identify exposures of concern to the public and evaluate mitigation efforts.

Maintenance, work, and leisure activities

Within this grouping are the following sources:

- Maintenance Activities: cleansers, waxes, polishes, paints, vacuuming, room fresheners.

- Work and Leisure Activities: glues, office machines, inks, hobby materials, aerosol products, cleaning solvents.

Available data on organic compounds emitted from these sources are limited to compound classes from solvent based materials and specific compounds and product composition for a few specific products. Data on non-occupational exposure to particles from activities which generate aerosols (e.g., spray paints and waxes) or reentrained dust are nearly non-existent. Known information on emission factors is limited to a few materials (e.g., emissions from some waxes, paints and finishes). Limited data also exists for mass emissions from aerosol products and anecdotal information on office machine emissions.

Information is required on the wide variety of indoor air pollutants emitted from these products and materials, especially those associated with maintenance, work, and leisure activities. Data are needed on material composition, compound classes emitted, and organic emissions. Particulate data, including particle size distribution, are needed for vacuum cleaning and aerosol products. Information is required to determine the impact of temperature, humidity, air exchange, source characteristics (e.g., composition, compound vapor pressure, reactivity), product use, and product age on emission factors. Also, data are needed on: (a) vacuum cleaner characteristics and their relationship to particulate emission rates, (b) the effect of can pressure, percent product remaining in can, and application time on emissions from aerosol spray products, and (c) the effect of office machine operating parameters on emission rates.

Pesticides--home use

Significant exposures can occur from homeowner application of pesticides. Sources include sprays, powders, moth cakes, and pest strips. The EPA Non-Occupational Pesticide Exposure Study (NOPES) is gathering information in this area.

Chemical pesticides have a wide range of toxicities and potencies, and some, at sufficient exposure levels, can cause neurotoxicity, teratogenicity, liver effects, cancer, and other serious effects. Because of existing regulations (Federal Insecticide, Fungicide, and Rodenticide Act) there is some health data on all pesticides. The information is especially inadequate, however, on the distribution of indoor personal exposures to different chemicals. Whenever the data base is found to be inadequate, EPA will require the necessary data pursuant to its authority under the Federal Insecticide, Fungicide, and Rodenticide Act.

Information is needed on the composition of pesticide emissions as well as data on emission factors for pesticides in various forms (e.g., solid, spray, powder). For determining emission factors, information is required on the impact of temperature, humidity, air exchange, product use, and product age, source characteristics (e.g., composition, compound vapor pressure, reactivity) that affect emission factors, and the effect of can pressure, percent product remaining in can, and application time.

Transportation

Personal exposures to organics and particles occur during the use of private and public transportation (ground and air). Limited data on compounds emitted are available on automobile interior emissions and commercial airliner interiors.

Information is needed on material composition and on the compounds emitted from interior materials (e.g., plastics, carpeting, fabrics, adhesives). Data are required on emission factors for total organics and individual compounds. Information is also needed on source characteristics (e.g., composition, compound vapor pressure, reactivity) that affect emission factors, the impact of temperature, humidity, air exchange, vehicle use, and vehicle age on emission factors, and the effect of "sinks" on emission rates.

Non-ionizing radiation: extremely low frequency electric and magnetic fields

The high voltages and currents associated with electric power generation result in electric and magnetic fields (typically at 60 Hz) in or near dwellings, offices, and factories. In addition, the use of appliances with electric motors or electric heating elements and the use of electric light bulbs produce 60 Hz fields. Many of these sources also generate electromagnetic fields at other frequencies. Although data on indoor exposure characteristics are sparse, exposure does occur, sometimes for long periods of time (i.e., children in front of a TV set, people sleeping under an electric blanket or on a heated waterbed).

Exposures to electromagnetic fields from the use of electric power have been associated with numerous effects, most notably, carcinogenesis, reproductive effects, and nervous system effects. The epidemiological data base on cancer is based on exposure to power distribution lines, which are located outside virtually every house in the United States. Most of the effects observed have been in laboratory studies which utilized exposure characteristics very different from indoor exposures. In those few laboratory studies that have employed indoor exposure levels, unusual biological perturbations (e.g., impaired immune defense systems) were observed due to the exposures. The limited epidemiological work on home appliances (use of electric blankets and electrically heated water beds) suggests increased spontaneous abortions for mothers exposed during the first trimester, a lengthening of gestation, and a reduction in birthweight. Much additional health effects information is available, but its extrapolation to the indoor environment is qualitative, at best, until more is known about indoor exposure characteristics and factors influencing the dose-response.

The literature on the health effects of electromagnetic fields, especially 60 Hz fields, indicates several areas of major concern, namely, cancer, reproductive effects, and effects on the central nervous system. To aid in extrapolation of the existing (and future) data to the population in general,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indoor exposures must be better characterized and validation and dose-response studies are needed. Furthermore, to devise and conduct appropriate experimental studies of the biological effects of electromagnetic pollution inside man-made environments, the present electromagnetic environments must be characterized and reconstructed inside the laboratory. Knowledge of these parameters will enable a strategy to be developed to alleviate biological hazards in the short-term, and possibly to eliminate them in the long-term. Primary research needs include the validation of the potentially detrimental biological changes caused by exposure to electric and magnetic fields associated with electric power distribution and utilization, and the investigation of the mechanisms of action of these effects. The focus of the validation studies will be the establishment of dose-response relationships. A key element of the mechanistic studies will be the definition of the critical electromagnetic parameters that are associated with the field-induced health effects. The information obtained from these studies will used to design epidemiological studies that explicitly focus on the radiobiological parameters that the laboratory investigations have shown to be critical factors in inducing biological effects.

## 4. Ambient Sources

The intrusion of environmental pollutants indoors has received increasing attention since the late 1970s. While considerable research has been devoted to understanding and predicting the movement, persistence, and degradation of pollutants in the ambient environment, little information exists on the entry of these substances into our homes, offices, and schools. Several studies have been undertaken to assess the exposures indoors to the more common criteria pollutants and, to a limited degree, to volatile organic compounds. More recently, limited research has begun on indoor air exposures to pesticides. Pesticides are introduced into the indoor environment through their normal application, both indoors and out. The persistency of pesticides may lead to buildups in the indoor environment with measurable amounts being found in the air, on dust particles, on the walls, and on particles in the room for as long as 35 days after the initial application of some types of pesticides. The termiticide chlordane has been detected in the air of some treated homes 14 years after application. Organic vapors may enter the indoor environment via infiltration from the soil and compounds contained in contaminated groundwater may volatilize and enter structures via the same pathways as discussed above for radon and pesticides. Also, seepage of groundwater or leachate from land fills can enter substructures and organics contained in such seepage can vaporize once indoors.

### Outdoor Air

Pollutants in indoor air that originate from outdoor sources include air quality criteria pollutants, hazardous pollutants, automobile exhaust, and wood smoke. Some viable and nonviable biological contaminants, such as certain bacteria, molds, and pollens can also enter indoor spaces and may grow and multiply indoors. Information available on penetration of these pollutants into indoor environments is very limited. Little is known about the prevalence of outdoor source types that affect indoor air quality. Some information is known about the effects of infiltration (both above and below grade), relative humidity, and temperature on indoor pollutant concentrations.

Information is required on the penetration of particles to determine the contribution to exposures indoors. The effect of outdoor concentration on indoor concentration needs to be determined as does the diagnosis of points of entry and analysis of the factors that affect the amount of entry into buildings.

## Soil

Pollutants known to enter residences from soil are radon, pesticides, heavy metals such as lead, toxic substances from waste sites, and some biological contaminants. Because it has become common practice to treat the soil beneath new construction with a termiticide, exposure is thought to be increasing for pesticides. Wet areas and areas with high humidity are a prime factor for increased mold growth.

Additional information which may be needed includes:

- Identification and characterization of pesticides.
- Development of measurement methods for detecting pesticides that could enter homes from substructure soil.
- A better understanding of the effects of vapor pressure, soil composition, and soil porosity on pesticides entry rates in individual homes. Development of pesticide emission factors and source models. Investigation of effect of ventilation rates on pesticide emission rates from soil.
- Information on pesticide application practices and indoor residuals from such use.
- Characterization of the magnitude of the lead exposure problem for residences where lead-based paint fragments have entered the soil near the foundation.

## Water

Domestic water supplies can be a source for releasing pollutants into the indoor environment. Sources for organic compounds may include showers, dishwashers, and clothes washers and their associated products. In addition, metals, radon, and waterborne bacteria such as *Legionella* can also be released from domestic water supplies into the indoor environment. This can occur from vaporization at the tap or by using a home humidifier. Preliminary research indicates that some humidifiers can release dissolved minerals and metals into the air in the form of particles of submicron size. The most significant releases by vaporization at the tap occur from showers. Temperature, surface area exposed (degree of agitation, droplet size), and relative concentrations in water and air affect the rate of pollutant release from domestic water. If a primary source of radon is from well water, mitigation techniques are known, but further research is needed to evaluate the long-term effectiveness of these techniques.

Information is needed on the classes of compounds and specific organics emitted. Information is also needed on emission factors (mg/kg) for total and individual organics. For showers, data are needed to determine the effect of organic content, temperature, humidity, and shower spray characteristics on emission rates. Additionally, for laundry machines and dishwashers, information is required on the effect of organic composition, vapor pressure, and reactivity on emission rates (including the influence of detergents, bleaches and other additives). Information is needed to determine emission factors, ventilation parameters for various building types (including the effect of bathroom and kitchen ventilation fans), water use patterns, and use of laundry/dishwashing detergent and additives.

Information is also needed to better characterize the emission process for dissolved constituents, especially heavy metals such as lead, when using humidifiers.

5. Sources of Biological Contaminants

Microorganisms and other antigenic biological material are of particular concern in indoor environments, because various sources and conditions found indoors provide the opportunity for organisms to grow and for microbes and other materials to become airborne. Indoor exposures to these organisms (e.g., molds, spores, bacteria, and viruses) and animal excreta are associated with a broad spectrum of health effects, ranging from life-threatening diseases (e.g., Legionnaires disease) to nonspecific health complaints (e.g., sick building syndrome). Prominent among known indoor sources of biological contaminants are water reservoirs, including humidifiers, air conditioning systems, and shower heads. HVAC systems, carpets, upholstery, and dander from pets are other sources.

Despite growing public health concerns about this biological contamination indoors, little is known about the sources, human exposures, and health effects. Most research to date has been conducted on acute episodes at individual locations. There is a need to continue research devoted to establishing "normal baseline" concentrations for the more important biological contaminants, and to develop standardized monitoring and measurement techniques. Due to a lack of such techniques, relatively little has been done to document the level or extent of exposures to these contaminants. Very little information exists relating individual biological contaminants to particular health effects. Even where such effects have been identified (e.g., Legionella and allergic reactions), dose-response relationships have not been established and the potential range of adverse health effects is unknown. For example, some mycotoxins are carcinogenic, but it is not known whether indoor levels pose a significant carcinogenic risk. There is reason to hypothesize that biological contaminants can have significant involvement in sick building syndrome, but this is a relatively unexplored issue. Sensitive subpopulations have not been fully identified or characterized.

The development of standardized monitoring and measurement techniques is necessary to provide the foundation for subsequent research on biological contaminants. The techniques must take into account differences in indoor spaces such as for rooms as opposed to whole buildings, residences as opposed to office buildings.

Research has been initiated to characterize baseline levels of biological contamination. The continued development of baseline concentrations will involve monitoring of indoor background levels and major classes of biological contaminants. It will include a survey of levels of mycoflora and other biological types found in varying indoor environments in order to establish a baseline for study of concentrations of concern to human health. The influence of season, geography, building type, mechanical systems, and furnishings on background levels of fungi, bacteria, and other biological contaminants will be studied, and indoor/outdoor ratios will be established. Identification of exposure levels associated with particular infections, diseases, or allergic reactions is also needed.

Humidity is known to be a prime factor affecting the growth of various bacteria, molds, and other contaminants (e.g., dust mites) on common indoor surfaces (e.g., curtains, upholstery, carpeting, leather, wood, and fiberglass). Research should identify optimum humidity conditions for growth and control of biological contaminants, and assess the relationship between humidity levels and the onset of or susceptibility to infectious diseases and allergies.

Exposures to biological contaminants from systems which condition air are believed to be both widespread and frequently intensive; however, little is known about the significance to health of these exposures. Air conditioning systems (e.g., cooling coils, water reservoirs, and ventilation ducts) are known to be prime breeding grounds for a range of biological contaminants, including molds and infectious agents. Once established, these contaminants are easily distributed throughout indoor environments by the forced ventilation components of these systems. A need exists to identify the nature and extent of biological contaminants commonly found in these systems.

Research is necessary to identify sources of biological toxins in the indoor environment, quantify exposures, and relate exposures to the occurrence of human health effects. Soil bacteria and other biological contaminants may also result in indoor pollutant exposures. Preliminary research has already been undertaken to assess the growth of Legionella in air conditioning systems and humidifiers. Additional research should also investigate approaches for controlling these bacteria and allergenic materials in known and newly identified sources.

A survey of geographic patterns of infection and allergy is also necessary, although this research would be both complex and difficult. This project will use physician reports to identify patterns of infection and allergy, followed by on-site sampling to identify causative indoor biological organisms. The work will eventually be useful in diagnosing buildings.

## D. CONTROL TECHNIQUES

Research is needed on the effectiveness, reliability, energy implications, and cost of many existing techniques of controlling indoor air quality so that the best options can be selected. In addition, existing control techniques are not fully satisfactory for many pollutants. Thus, research that will lead to entirely new or improved control techniques is needed.

### 1. Source-Specific Controls

Presently, there a few satisfactory options for reducing pollutant concentrations in existing buildings once sources are in place. Removal of sources is often prohibitively expensive. One alternative that seems to be promising is the application of coatings on building materials. Researchers have demonstrated that vinyl linoleum flooring or polyethylene vapor barriers over particle board underlayment may significantly reduce formaldehyde emissions. Additional research is needed on the effectiveness of such coatings, especially for VOCs other than formaldehyde, and other methods of reducing emission rates in existing buildings.

Research needed includes: a) chamber studies to evaluate emission characteristics of modified or coated materials, b) IAQ model studies to evaluate source control strategies, including verifications, and c) field studies to evaluate source control strategies used in occupied buildings. The research would benefit by cooperative ventures with manufacturers of materials and products in the areas of product modification and coatings. Cooperation with builders and architects in the areas of changing use patterns and material/ product substitution would also be beneficial.

#### Environmental tobacco smoke

Smoking restrictions, public education, voluntary isolation of smokers from nonsmokers, ventilation, and filtration will continue to be examined as the primary methods of reducing exposure to ETS. These same measures are appropriate for residential buildings. Research on "physical" tobacco smoke control techniques (in contrast to regulatory measures) should include investigations of: (a) methods of ventilation that reduce the spread of tobacco smoke throughout buildings, (b) the impact of the existing filter systems in commercial buildings on indoor tobacco smoke concentrations, and (c) the potential of air-cleaning equipment to remove the most important gaseous components and odors of tobacco smoke. The research for these topics is covered under the air cleaner and ventilation control sections of this report.

#### Combustion products emitted by appliances

Combustion appliances can emit nitrogen oxides, sulfur oxides, carbon monoxide, particulate matter, and organic compounds. Although product substitutions are often an effective method of control, such substitution may be limited by economic and other factors. It is known, for example, that range hoods and electronic ignition systems may be effective in reducing pollutant emissions from gas ranges. While it is also known that effective maintenance is important in reducing emissions, the elements of such a maintenance program need to be identified.

The effect of design and operation modifications on pollutant emissions must be determined for all combustion appliances. Performance standards need to be developed for these appliances. Research on effective, low-cost air cleaning elements for existing range hoods is needed, as well as research on the economics of modifying sources to reduce emissions. However, as a general practice, combustion appliances should be vented to the outdoors.

Asbestos

Techniques of asbestos removal are well developed and routinely utilized by the private sector. Research is needed that can lead to improved and less costly methods of determining the need for asbestos removal in specific buildings. Such research should include investigations of the relationships between asbestos sources and location, conditions of the building, and the potential for release of asbestos fibers.

Microbiological agents

Microbiological agents are a major cause of poor indoor air quality. As is discussed in previous sections, the information on microbiological agents is limited. However, research should begin to study the methods of controlling the indoor concentrations.

Research on environmental factors (temperature, humidity, presence of other materials) that affect growth of microbiological agents supports development of control techniques by defining regions of building operation that will prevent or limit microbiological contamination. The above research will also allow development of operation and maintenance procedures that can reduce or eliminate risk from microbiological contaminants. Research on the use of biocides is needed.

2. Ventilation Strategies

Some indoor air quality problems can be solved by increasing ventilation rates and/or ventilation effectiveness. These increases may be applied locally or to the entire building. The selection of an appropriate ventilation strategy depends on the effectiveness and economics of various strategies, and requires knowledge of the effect of the strategy on pollutant concentrations. Ventilation research needs are discussed in the Building System Needs section. One of the key unknown variables is the effects of ventilation on source emission rates and pollutant sinks. Another important unknown is the effect of local ventilation on overall building ventilation.

3. Air Cleaners

Ideally, adequate indoor air quality could be maintained by control of pollutant source strengths together with ventilation. In real-life situations, however, the indoor concentrations of one or a few pollutants may be elevated and pollutant source control can be difficult and costly. Research is need to develop effective and practical air-cleaning technologies.

## Particles

Data on the overall mass collection efficiency of filters for dust are available, but these data do not allow analysis of the effectiveness of air filters for control of many of the particles found indoors. The evaluation of the effectiveness of particulate air cleaners starts with the determination of the efficiency of various cleaners as function of particle diameter. Then data on the effects of circulation rates on effectiveness must be known. Evaluation of the long-term effectiveness of air cleaners requires information on the effects of collected dust, pollutant interactions, and organics on cleaner effectiveness. Data on possible sink/re-emissions are also required. Data on the effects of particulate air cleaners on biological pollutants are required. The development of simple air cleaner evaluation procedures is required, and models and small scale experiments should be verified with field studies.

## Organics

Data on the performance of activated carbon on individual compounds indicate that carbon is not generally useful for controlling organics at the low concentrations found indoors. Rather, data on the performance and economics of effective organic air cleaners are needed. The collection of organics in indoor air is a complicated problem because in some cases the pollutants may be a single compound or a complex mixture of numerous compounds. Information is required on pollutant generation by air cleaners and the effects of particles and building conditions (temperature, RH, etc.) on organic air cleaner efficiency. The control of low concentration levels of organics will probably require new technological developments.

## Biologicals

Research on the effectiveness of air cleaners in removing microbiological agents and on the growth of microbiological agents in air cleaners is needed and is covered in the air cleaner research program.

## Pesticides

The effectiveness of air cleaners for removing or destroying indoor pesticides needs to be determined, as well as the usefulness of radon control measures for simultaneously reducing chlordane or other termiticide vapors. Evaluation of both passive and active control methods for pesticide vapor is also needed.

## E. BUILDING SYSTEM NEEDS

Indoor air pollution problems are caused by the complex interactions of sources, sinks, and ventilation. Indoor air quality problems and solutions must thus be approached from the building system standpoint, which takes all of these interactions into account. The first step, however, is to determine the performance of the various components of the building system. Once the performance of the components is understood, it will be possible to define their interactions.

The building system, especially the heating, ventilating and air conditioning system (HVAC), plays a major role in determining indoor air quality. In addition to conditioning the indoor air, the primary purpose of a building HVAC system is to distribute ventilation air throughout the building and to remove and dilute indoor pollution. However, an ineffective HVAC system (improperly designed, constructed, operated, and/or maintained) can be not only ineffective at controlling indoor pollutant levels, but can also be a significant source of pollutants, especially biological contaminants and fine particles.

Ventilation is therefore a key determinant of indoor air quality. Ventilation includes the flow of outdoor air into and out of the building and inter-room air flows. In addition, the term ventilation effectiveness is used to characterize the distribution of air within a room. A quantitative understanding of all these flows and how they affect pollutant levels is essential to understanding indoor air quality.

Inadequate ventilation has been identified as a major contributing factor to sick building syndrome, and since the causes of sick building syndrome are as yet poorly defined, most mitigation procedures typically focus on the general increase of air flow and ventilation. More information is needed about the causes of SBS in order to identify specific mitigation procedures for source control which could be coupled with ventilation to achieve the most cost-effective prevention strategy.

### Ventilation

In response to the need to conserve energy, considerable research has been devoted to studying both ventilation and infiltration (the uncontrolled introduction of outside air through the building shell) in buildings. This research has developed techniques for measuring and modeling these flows in both residential and large buildings. The results of this research are being incorporated into the modeling efforts described earlier. Additional research is needed to refine these techniques, e.g., the continued development of multi-tracer gas systems for measuring interzonal flows and pulsed tracer gas techniques for measuring ventilation rates.

In addition, research is needed to develop measurement techniques and protocols for measuring ventilation that can be widely applied by non-researchers. These techniques are needed to assist in both the diagnostic and subsequent evaluation of complaint buildings. One such technique is the measurement of carbon dioxide as a surrogate of acceptable ventilation and/or indoor air quality. The validity of this and similar techniques requires additional research.

Research is also needed devoted to continuing laboratory measurements of ventilation flows. This research provides a necessary link between modelled air flows and those measured in the field. This research includes both scale model studies of ventilation flows and laboratory mock-ups of novel ventilation systems.

Finally, techniques and protocols are needed to measure ventilation effectiveness under both laboratory and field conditions. These techniques should quantify how much ventilation air is actually provided from central air handling units to occupied building spaces, how well this air is distributed within the breathing zone of the occupants, and how effective the air flow is for removing and diluting indoor pollutant levels. This research will greatly assist in evaluating the effects of supply diffuser and return grille locations, open windows and doors, appliances, local fans, and human activities on ventilation performance.

Field measurements

The existing data on field measurements of ventilation rates and ventilation effectiveness in buildings is very limited. Because the impact of ventilation on indoor air quality is so important, research devoted to performing indoor air quality studies in buildings must include measurements of both ventilation rates and effectiveness. These measurements are needed to properly evaluate appropriate mitigation approaches (if needed), validate and compare different measurement techniques for assessing ventilation performance, and expand our data base of such measurements.

The total building system

The total building system extends beyond just the building's HVAC system. It also includes all of the (other) sources of and sinks for indoor pollutants within the building including people, furnishings, building materials, and the soil system influenced by the operation and/or construction of the building. Research is needed to assess the combined effects of the factors which determine indoor air quality, emphasizing both the relative importance of specific pollutant sources and the capabilities of the HVAC system to handle them.

This research is particularly applicable to new building design. It would address how to design buildings which provide acceptable indoor air quality, rather than how to mitigate complaint buildings. Multiple buildings should be studied from the selection of materials and HVAC systems at the design stage through construction to ongoing operation and maintenance.

## F. CROSSCUTTING RESEARCH

### Indoor Air Quality and Productivity

Research is needed to quantify the impact of maintaining acceptable indoor air quality on worker productivity. For example, it has been estimated that if reducing ventilation rates by 25% reduces the productivity of an employee by 5 minutes a day, then "bottom line" costs will be increased. Research is needed to quantify the relationship between worker productivity and indoor air quality parameters such as pollutant concentrations and ventilation rates. Although it will be difficult to distinguish the indoor air quality component on productivity, such a study would provide a quantification of the economic benefit associated with maintaining acceptable indoor air quality.

### Epidemiology and Demographics Regarding the Effects Due to Chemical and Physical Agents

Careful epidemiological and medical studies need to be done in buildings to determine the prevalence and incidence of symptoms and other medical conditions in relationship to chemical and physical agents (and as needed to evaluate effects of ergonomic and stress problems). Even though NIOSH has evaluated hundreds of indoor air quality problems, there is still a lack of information on the real differences between problem buildings and non-problem buildings. Research is needed to develop a protocol that would first be used in non-problem buildings so that comparisons of the various study parameters might lead to a better understanding of important differences with respect to worker complaints (frequency and type), building type, ventilation, chemical, phyical, biological, environmental, and ergonomic and psychosocial parameters. The baseline data would then be used to evaluate indoor air quality problems in a more comprehensive manner. This research would include studying 8-10 problem office buildings. Study parameters would include a general characterization of the building (e.g., design, employee activities, smoking policy), employee questionnaires, an assessment of building ventilation, and industrial hygiene sampling.

### Ergonomic and Psychosocial Research

In coordination with the evaluation of the problems associated with physical and chemical agents, the contribution of psychosocial and ergonomic stress factors associated with indoor air quality problems needs to be studied. Ergonomic factors to be examined include the physical design of workstations (e.g., worktables, chairs, and tools), aspects of the ambient environment, interior design of the workplace (e.g., noise and lighting conditions), and task characteristics (e.g., repetitious tasks, constrained or awkward postures). Relevant psychosocial factors would include task and organizational factors such as task complexity, skill utilization, control, social support, workload demands, and role demands. These factors could be objectively measured or assessed via survey techniques, and their effects determined by multivariate statistical methods. Since many of these variables are readily manipulated, opportunities exist for controlled field (workplace) experiments, and for interventions to test control measures. This effort would be the refinement of existing survey instruments so they can be readily applied in the context of indoor air quality studies.

## G. TECHNOLOGY TRANSFER

The ultimate goal of the Federal indoor air research program is the dissemination of information to the public, useful for both characterizing and mitigating the potential risks associated with indoor air pollution. Therefore, technology transfer is an essential part of the indoor air research program.

The Federal government, State and local government agencies, and the private sector are all responsible for effectively sharing information both with each other and the general public. This transfer of information must occur in both directions -- both from the agencies conducting research to potential users and from users to the research community to establish meaningful research needs.

Mechanisms for transferring the results of indoor air research include publishing public information materials, co-sponsoring technical conferences and workshops, and enhancing communication among Federal and State agencies and the private sector. One very successful technology transfer mechanism has been the performance of health hazard evaluations in office buildings in response to reported health complaints or illnesses. Over 500 evaluations have been completed to date. In addition, an indoor air quality clearinghouse is also needed that serves the different information needs of researchers, health officials, and consumers.

For example, State and local governments are approached first by the public for help in assessing and solving immediate indoor air quality problems. Information to support the needs of state and local officials is important to the indoor air pollution research plan.

Technology transfer is a high priority for state and local officials, who stress the need for federally developed materials intended for the general public, such as the radon citizen guides. However, care should be taken in disseminating preliminary research results, so as not to alarm or desensitize the public. Public information should first and foremost characterize the risk presented by indoor air pollution and should present the available mitigation methods. Information materials should be developed with consideration of the regional differences that can affect the appropriateness of the information contained.

State agencies have proposed that EPA designate one official in every Regional Office to serve as an indoor air expert to assist in technology transfer. The regional EPA official would serve as a contact for information regarding Federal indoor air research activities. Specifically, this person should work actively with state personnel and gain intimate knowledge of their indoor air needs and activities. The EPA Regional Offices should also pursue personnel exchanges between state and EPA programs.

Increased participation in the activities of technical and professional organizations (e.g., the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, the Air Pollution Control Association, the American Industrial Hygiene Association, and the American Society of Testing and Materials) can facilitate the transfer of information among Federal agencies, states, and the private sector. These interactions can promote cooperative research and minimize unnecessary duplication of effort. In fact, more joint activities among these organizations, especially conferences and workshops, are needed to exchange indoor quality information of multidisciplinary interest.

In addition, consumer groups such as the Consumer Federation of America have recommended the establishment of an indoor air quality clearinghouse. Such a clearinghouse could serve to compile and distribute information ranging from technical publications to informational pamphlets generated by both the public and private sectors.

## III. ADDITIONAL READING


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