Program Needs for Indoor Environments Research (PNIER)

March 2005

www.epa.gov/iaq/pdfs/pnier.pdf

U.S. Environmental Protection Agency
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INTRODUCTION

Overview:

All across our nation, people live, work, and learn in indoor environments. On average, people spend approximately 90% of their time indoors, where many pollutant levels are often two to five times higher than outdoors. The EPA and its Science Advisory Board have ranked indoor air pollution among the top five environmental risks to public health (U.S. EPA, 1987; U.S. EPA, 1990).

The Indoor Environments Division (IED), located within the Office of Radiation and Indoor Air (ORIA) under the Office of Air and Radiation (OAR), is the lead U.S. EPA program office for issues relating to indoor environmental quality. The Indoor Environments Division focuses on several priority areas including: indoor air toxics, asthma, radon, schools, and environmental tobacco smoke. Additionally, there are several other offices within the EPA that have significant responsibilities related to the indoor environment within their programs. These offices include, but are not limited to, EPA Regional Offices, the Office of Research and Development (ORD), the Office of Children's Health Protection, the Office of Pollution Prevention and Toxic Substances, the Office of Solid Waste and Emergency Response, and the ORIA laboratories.

This document, *Program Needs for Indoor Environments Research (PNIER)*, is a strategic document outlining EPA's research needs for the indoor environment. The *PNIER* concept was initiated within the Indoor Environments Division, and the document developed into its present form through strong collaboration with other EPA offices. *PNIER* is considered a 'living document' that can evolve to reflect the changing needs of EPA program offices and researchers through periodic updates and revisions.

PNIER is intended to be a document that captures the indoor environments research needs for all EPA offices with program responsibilities related to indoor environmental quality. It is envisioned that *PNIER* will be a valuable document that can serve several purposes, including:

- articulating EPA's indoor environments research needs, for both internal and external uses;
- identifying where knowledge gaps exist;
- helping to establish a more well-defined presence for an indoor environments research program at EPA;
- facilitating collaboration between EPA program offices and research offices when developing research agendas and awarding research grants;
- fulfilling EPA's *Healthy Buildings, Healthy People (HBHP)* initiative, which calls for the development of a high-level, cross-Agency indoor environments research strategy. *PNIER* could serve as EPA's foundation towards this larger cross-agency research strategy, and could influence research performed by other agencies and organizations (U.S. EPA, 2001).

PNIER is limited to the EPA's indoor environments research needs, and is not intended to be a 'global' document for all possible indoor environments research. While *PNIER* is intended to describe EPA's indoor environments research needs, it is not envisioned that all research contained within *PNIER* be performed directly by EPA's research community. In some cases, it may be appropriate for the research to be performed by other government agencies, private industry, non-profit organizations, or other outside parties. **It is also important to note that while *PNIER* describes research needs, it does not attempt to prioritize the research needs or catalog any ongoing research efforts that may support *PNIER*.**

***PNIER* Development History:**

The *PNIER* development process included close coordination with a wide range of EPA offices and staff. The following *PNIER* development and review sequence was performed:

- The initial *PNIER* concept was presented, with requests for input and comment, to EPA's Indoor Environments Division staff and EPA Regional staff working on indoor air and radon-related issues in a series of meetings held during the spring of 2001. The initial *PNIER* concept was also presented to the EPA's ORD staff, and staff from other EPA offices, at an *Indoor Environments Scientist-to-Scientist* meeting in May 2001.
- Members of the IED Scientific Analysis Team outlined and drafted preliminary sections for the *PNIER* programmatic and technical areas shown in the content outline on page 4. Outlines and preliminary drafts were discussed and revised by the IED Scientific Analysis Team during regular meetings dedicated to *PNIER* (June 2001-February 2002).
- The IED Scientific Analysis Team conducted an internal team-based review of the initial compiled draft of *PNIER*, and developed a revised draft (March 2002 - May 2002).
- *PNIER* was reviewed by the IED Division Director and IED staff. Comments were resolved, resulting in a version of *PNIER* that was considered a suitable starting point for soliciting input and comments from other EPA offices (June 2002 - November 2002).
- The initial *PNIER* draft developed by the Indoor Environments Division was distributed to the following EPA organizations for review and comment in January 2003:

  - Office of Research & Development (ORD)
  - Office of Children's Health Protection (OCHP)
  - Office of Prevention, Pesticides and Toxic Substances (OPPTS)
  - Office of Solid Waste and Emergency Response (OSWER)
  - Office of Air and Radiation, Office of Air Quality Planning and Standards (OAR/OAQPS)
  - Office of Air and Radiation, Office of Atmospheric Programs (OAR/OAP)
  - Office of Air and Radiation, Office of Transportation Air Quality (OAR/OTAQ)
  - EPA Regional Offices (Regional Program Managers for indoor environments)
  - Radiation & Indoor Environments National Laboratory / Las Vegas (RIENL)

- Comments were received from reviewers between late January and late April 2003. IED staff considered the review comments and developed a revised version of *PNIER* that was redistributed to EPA reviewers (April-July 2003).
- Indoor environments research needs, primarily within the context of *PNIER*, were discussed during an *Indoor Environments Scientist-to-Scientist* meeting on September 3-4, 2003, that included staff from several EPA offices. Follow-up actions planned from that meeting include

ORD developing an indoor environments 'research framework' for presentation to ORD's upper management, modifying the EPA's multi-year research plans to incorporate indoor environments research needs, and evaluating ORD's capabilities and identifying research that may be accomplished through organizations external to the EPA.

Indoor Environments Research Criteria:

The following criteria were established for assessing the suitability of research items to be included in *PNIER*:

1. Research must be consistent with the EPA's authorization under Title IV of the Superfund Amendments and Reauthorization Act of 1986 (SARA), which gives the EPA broad authority to conduct research on indoor air quality (IAQ) issues, develop and disseminate information on IAQ, and coordinate IAQ efforts at the federal, State and local levels.

2. Research should be for indoor environmental health risks predominantly due to inhalation exposure, and health risks predominantly associated with indoor sources, or which may be managed by controlling indoor exposures. This also includes managing outdoor sources that impact the indoor environment.

3. Research should focus on indoor environments that the general public frequently accesses (e.g., residences, schools, offices, public buildings, vehicle passenger compartments, etc.). Research should not address specialized indoor environments with established regulations (e.g., industrial work sites, hospitals, and other specialized occupational settings).

4. Research should address perceived high risk areas where there is a practical likelihood to implement corrective actions. Research is expected to provide a reasonable return-on-investment.

5. Research that motivates public action, industry development, and real-world implementation of indoor environmental improvements should be included.

6. Research that builds on the existing knowledge base and that supports current EPA activities and priorities for the indoor environment should be included.

7. Research should be accepted and endorsed by organizations outside the EPA (peer acceptance of the research).

8. Research should focus on areas that are not currently addressed by mature programs (e.g., asbestos, lead).

9. Research should be for efforts that could be initiated within the next five years, and completed within the next ten years. Research may include efforts that are already underway or represent an expansion of those efforts.

10. When research is intended to develop methods to mitigate indoor air problems, an analysis of the efficacy of the methods should be done.

***PNIER* Content Outline**:

Indoor environmental quality is an extremely broad subject, and there are many possible options for presenting research categories. The following content outline was developed as an attempt to meld categories useful for organizing basic research with those that support EPA's program needs. Detailed indoor environments research needs for these outline topics are presented in the following sections, starting on page 5.

A. POLLUTANTS, SOURCES AND HEALTH EFFECTS
   - A.1. Chemicals (Including Indoor Air Toxics)
   - A.2. Biological Contaminants
   - A.3. Sensitization, Allergy and Irritation Health Effects
   - A.4. Particulate Matter

B. HUMAN PERFORMANCE

C. IAQ MEASURES AND INDICES
   - C.1. Building IAQ Indices
   - C.2. Development of Public Health Measures for IAQ

D. BUILDING DESIGN AND OPERATION
   - D.1. Building Characterization and Intervention
   - D.2. Ventilation Systems
   - D.3. Radon Control
   - D.4. Building Design and Implementation

E. HOMELAND SECURITY

F. PRODUCT AND TECHNOLOGY VERIFICATION

References for Introduction:

U.S. Environmental Protection Agency (U.S. EPA). 1987. Unfinished Business: A Comparative Assessment of Environmental Problems. Washington DC: U.S. Environmental Protection Agency.

U.S. Environmental Protection Agency (U.S. EPA). 1990. Reducing Risk: Setting Priorities and Strategies for Environmental Protection. Washington DC: U.S. Environmental Protection Agency. EPA-SAB-EC-90-021.

U.S. Environmental Protection Agency (U.S. EPA). 2001. Healthy Buildings, Healthy People: A Vision for the 21st Century. Washington DC: U.S. Environmental Protection Agency. EPA 402-K-01-003.

A. POLLUTANTS AND SOURCES

A.1. CHEMICALS (INCLUDING INDOOR AIR TOXICS)

Background Information:

In the early 1980's, the relatively high exposures and potential risks from toxic chemicals in the indoor environment became recognized through the EPA Total Exposure Assessment Methodology (TEAM) studies (Wallace, 1987). Since that time, the potential exposures and risks from toxic chemicals in indoor air have been confirmed by a number of studies, both within and outside EPA (U.S. EPA, 1998). However, with the exception of joint programs between ORIA and OPPT in the late 1980's and early 1990's to address emissions from carpet products and wall paint, little effort has been directed at research to evaluate and manage these exposures and risks, in part because there have been no regulatory drivers that require EPA to do so.

Since the enactment of the Clean Air Act Amendments of 1990, work on reducing toxic chemicals in ambient (outdoor) air from stationary emissions sources has focused mainly on developing standards based on technology [i.e., maximum achievable control technology (MACT) and generally available control technology (GACT) standards]. The Agency is now required to address the "residual risk" remaining after promulgation of these standards and, therefore, is moving into a "risk-based" assessment process which requires new and improved assessment tools. In addition, the Agency's mobile source program is required to study the need for, and feasibility of, controlling emissions of toxic air pollutants associated with motor vehicles and fuels, and to set technology-based standards to reduce exposures from these sources. While the Agency is mandated to address toxic air pollutants from outdoor sources only, in some cases indoor exposures to these substances may be greater than those from outdoors. Currently, the Agency does not know enough about the relative exposures and risks resulting from indoor and outdoor sources to fully understand the relative importance of these sources.

In the past few years, the outdoor and indoor air toxics programs have become much more integrated and have started to address the close connections between indoor and outdoor environments and each environment's impact on the other. Although research is needed to address indoor, stationary, and mobile sources of toxic air pollutants, in general, research has focused on outdoor air toxics.

While some research on chemicals and mixtures is useful for determining risks from both indoor and outdoor pollutants (e.g., dose-response assessments, time-activity studies), certain types of unique research activities are needed to address indoor risks. For example, the methods used to determine emissions characteristics, to model the flow of pollutants, to study the fate and transport of pollutants, and to manage risks are substantially different for indoor and outdoor environments. Therefore, in these areas, research directed at studying outdoor pollutants cannot substitute for indoor air research.

The long-term program goals for research on chemicals and their sources are to: (1) develop and refine systems that can be used on an ongoing basis to prioritize and select those chemicals and mixtures, in addition to radon and environmental tobacco smoke, that are of concern in indoor environments, (2) further develop methods to determine how the selected pollutants and mixtures of concern interact with the indoor environment, with each other, and with other chemicals (e.g., ozone), (3) examine the determinants of exposure for, and the potential risks posed by, the chemicals and mixtures of concern, and (4) develop methods and practices that can be used to mitigate any substantial risks of the selected chemicals and mixtures.

Program Needs for Chemicals (Including Indoor Air Toxics) Research:

A.1.a. Determine chemicals and mixtures found in indoor environments.

A.1.a.1. Perform additional baseline analyses to determine the typical levels of chemicals in indoor environments.

EPA recently completed the sampling portion of the Building Assessment, Survey, and Evaluation (BASE) study to determine the typical concentration distributions of a number of chemicals found in a representative sample of U.S. office buildings and to correlate these pollutant levels with building parameters and occupant activities and symptoms. However, similar studies have not been completed in other types of buildings (e.g., homes, schools, day care facilities, retail establishments, etc.) and the number and types of pollutants monitored in the BASE study was not comprehensive (i.e., chemicals to be monitored were selected based on past studies and ease of sampling and analysis). Studies such as BASE need to be expanded to a larger set of building environments and a broader spectrum of pollutants (see section D.1.a. for additional discussion). In addition, the data (existing BASE data and future data collected) need to be analyzed to assist in determining the potential sources of the chemicals indoors.

A.1.a.2. Analyze formulation and emissions data for products and materials used indoors to determine likely chemical exposures indoors.

Another source of information on chemicals that may lead to exposures indoors is formulation and emissions databases for products and materials used indoors. Some data are available on product formulations through voluntary industry disclosure and, in rare cases, have been obtained through required industry disclosure under the ambient air program of the Clean Air Act (CAA). However, most of the available data on product formulations were obtained prior to 1990, which limits their usefulness. Data for some chemical exposures may also be obtained through current programs such as the EPA Voluntary Children's Chemical Evaluation Program (65 FR 81700), which provides data on exposures to 23 chemicals to enable the public to better understand the potential health risks to children, or through work with the Organization of Economic Cooperative Development (OECD) to develop emissions scenario documents for products. Another source of product formulation data is Material Safety Data Sheets (MSDSs); however, these data sheets may not list all the potential chemicals of concern in a product or material used indoors. For a more limited number of products and materials, emissions data are available in the literature through chamber or field studies. Formulation and emissions databases for products and materials are particularly useful where the data have been used in indoor air quality models to assess potential concentrations, and related exposures, indoors.

A.1.a.3. Evaluate levels of pollutants that may result from particular exposure scenarios of concern.

Studies such as BASE, which evaluate the typical concentrations of chemicals and mixtures indoors, do not effectively address the high level exposures that may occur under special circumstances. For example, high level exposures may occur during the use or storage of specific products or materials within the indoor environment; in some cases, these may come from areas external to the living area (e.g., from attached garages or parking areas, or from commercial facilities located within a building). In addition, exposures from external sources may be of concern, including emissions from stationary or mobile sources, particularly those in close proximity to a building, or penetration of chemicals through soil. Monitoring studies, or source characterization studies (see section A.1.d), are needed to more fully address the both the acute and chronic exposures that may result from particular exposure scenarios of concern.

A.1.a.4. Further develop and refine personal monitoring techniques and equipment for use indoors.

Stationary monitors set up at fixed sites in a building may not accurately represent the actual exposures that occur to individuals in the building. For example, a person using a consumer product in a bedroom may receive a much higher exposure to the product than would be indicated by a monitor set up on the other side of the bedroom or in the kitchen. For this reason, personal monitors have been designed to be worn or carried by individuals to more accurately record the their exposures. The development of improved personal monitors that are less cumbersome for users to wear and that can accurately sample for a broader range of chemicals is needed. In addition, the research is needed to develop and establish recommended sampling methods for these devices.

A.1.b. Determine hazards and dose-response indices for chemicals and mixtures found in indoor environments.

Even if we knew the levels of chemicals and mixtures that occur indoors under a broad range of exposure scenarios, we would be at a loss to determine their impact without knowledge of the hazards of the chemicals and mixtures and the doses that may result in health impacts. For several years, concerns about carcinogenicity have dominated discussions about the risks posed by toxic substances. However, the noncarcinogenic effects on organs and organ systems may pose an equal or greater threat to public health. Some of the targets of these effects to consider include the respiratory system, cardiovascular and cardiopulmonary systems, the reproductive system, and the nervous system. Developmental effects may also be of concern. In particular, there is a need to develop toxicity data for chemicals and mixtures that may be relevant to potentially susceptible life stages including pregnant women, infants and children, and the elderly.

Dose-response data are not available for many of the volatile organic chemicals and mixtures found in the indoor environment, although some steps have been taken in recent years to obtain such data through programs like EPA's High Production Volume (HPV) Initiative Program (65 FR 81686), a program to obtain basic screening-level hazard data for chemicals produced or imported in quantities exceeding 1 million pounds per year, and the VCCEP. Even when data are available, they are generally based on a less than comprehensive review of the health effects of the chemicals and mixtures. To help in prioritizing the health effects data needed, an analysis of the available monitoring data should be performed to help target chemicals for evaluation in laboratory or epidemiological studies (e.g., chemicals that are unlikely to be highly toxic, based on structure-activity relationships, and that are found at very low levels indoors would be given lower preference for further toxicological testing).

Several inorganic compounds are not adequately characterized from a health effects perspective including combustion byproducts such as nitrogen dioxide (NO_2) and carbon monoxide (CO). A thorough analysis of the current literature, as well as additional research, is needed to fully assess the respiratory effects of NO_2 at levels expected to occur in the indoor environment and also the potential association between respiratory illnesses and symptoms and elevated NO_2 levels. These respiratory illnesses and symptoms include chronic obstructive pulmonary disease in adults; asthma, the increased occurrence of respiratory infections, and the increased sensitivity to inhaled allergens, particularly in children; and the potential for the development of diarrhea and other non-respiratory symptoms in infants. In addition, more research is needed on the potential morbidity associated with low-level CO exposures, the potential mechanisms of CO toxicity unrelated to hemoglobin binding, and the impact and mechanisms of CO exposure on potential highly-susceptible populations (e.g., the elderly, infants, and persons with heart, lung, or blood disorders).

Further research is also needed to determine if chemical allergens, irritants, fragrances, or odors can potentially cause or trigger asthma.

A.1.c. Prioritize chemicals and mixtures of concern and select a small number for further study.

The purpose of the prioritization should be to select a handful of chemicals or classes of chemicals that will undergo a more extensive analysis, as detailed under sections A.1.d through A.1.h. For some chemicals, the research sequence described by sections A.1.d through A.1.h. may not fully apply, as the initial chemical assessments may reveal that certain steps may be bypassed due to the availability of existing information.

EPA already has programs to address two high-risk components of indoor air, radon and environmental tobacco smoke (ETS). EPA needs to develop a generally acceptable system for prioritization of chemicals of concern, other than radon and ETS. Although the prioritization will focus on potential relative risks of chemicals and mixtures in indoor air, the prioritization scheme may be expanded to include dermal exposures as well as inhalation exposures. One approach is to look at monitored levels of the chemicals in indoor environments. Another approach is to consider the development of prioritization systems based on the formulations or emissions of products and materials used in the indoor environment, in conjunction with modeling to determine potential concentrations. We may also use biomonitoring data to assist in prioritizing chemicals or mixtures of concern. However, although biomonitoring data are useful in determining those chemicals and mixtures that are a concern from the standpoint of cumulative exposures, additional analyses would be needed to determine the contributions to these cumulative exposures occurring through the indoor environment. Biomonitoring data may help us, however, to narrow the list of chemicals and mixtures of concern. EPA must also continue to evaluate and compare the exposures and risks that may occur due to specific scenarios of concern (e.g., 'hot spots' with untypically high exposures), so that we do not neglect high-exposure scenarios of concern and other known risks.

Based on this prioritization, specific chemicals or mixtures would be selected for further study.

A.1.d. Characterize the sources of the chemicals and mixtures selected in A.1.c.

A.1.d.1. Determine potential sources of selected chemicals and mixtures.

Specific research to determine the sources of the chemicals and mixtures selected will vary. For example, if a chemical is chosen based on product formulations or emissions or on specific scenarios of concern, the source(s) of the chemical or mixture will already be known. However, further source characterization studies may be needed to more accurately determine emissions factors for these sources under differing conditions.

If chemicals and mixtures are chosen from a prioritization scheme using monitoring data (Section A.1.c) or because of health concerns at levels in the indoor environment, data needed will depend on the properties of the chemical or mixture. For chemicals that are unlikely to be produced through natural processes or through breakdown of products or materials indoors (e.g., methylene chloride), source information can be obtained through (1) a market analysis of products and materials formulated using that chemical or mixture, (2) a search of databases containing product formulation data, (3) a search of data from indoor air source characterization studies, etc. For chemicals that may have natural sources or that may be formed by the breakdown of products or materials, combustion processes, or chemical interactions (e.g., formaldehyde), source characterization is more complex, and will rely upon both the information sources mentioned above and a further literature review of potential mechanisms of increased indoor concentrations.

A.1.d.2. Develop quantitative emissions factors by source.

In many cases, the data available will provide only an indication of potential sources of exposure; they will not provide the quantitative data on emissions factors that are needed to do an exposure assessment. Therefore, research will be needed using chamber or test house studies, or through the development of emissions models (e.g., based on chemical formulations), to determine emissions factors for exposure scenarios of concern.

A.1.d.3. Determine cumulative exposures.

In addition to the characterization of indoor sources of the chemicals and mixtures, research is also needed to determine the amount of the chemicals and mixtures found indoors that may be from ambient air, track-in from outdoors, food, water, soil, and other potential sources.

A.1.e. Study the indoor fate of the chemicals and mixtures selected in A.1.c.

Research on the fate of the chemicals and mixtures of concern will be highly dependent on the substances themselves (i.e., their likelihood of penetrating the building envelope; of being adsorbed to, and re-emitted from, materials indoors; and of interacting with other chemicals or mixtures in the indoor environment). Research is also needed to better understand the impact of reactive contaminants on the indoor environment. Reactive contaminants have the potential to react with other components of the indoor environment to form 'new' pollutants (usually chemicals or particulate matter) (Weschler and Shields, 1997, 1999). For example, several reports have shown that low levels of ozone react with some volatile organic compounds in the environment to produce chemical pollutants and particulates that are associated with health impacts including respiratory system irritation. Some highly-used chemicals and products are of particular concern because of the reactive nature of the resulting compound produced when ozone reacts with these substances (e.g., limonene or other terpenes, decomposition products of printer/copier toner powder, and building materials that contain an unsaturated carbon-carbon structure). The chemical structures of all the potentially formed species and their impact on health are not yet known and should be evaluated under research needs described in sections A.1.b. and A.1.g.

Although understanding the fate of chemicals in the indoor environment may be important in determining the actual exposures that may occur from chemicals and mixtures indoors, these data are difficult and time-consuming to obtain. It may be necessary, in the short term, to estimate the effects of these processes indoors while we await the results of this research. Therefore, this research should have secondary importance to the research in sections A.1.a through A.1.d, and sections A.1.f through A.1.h.

A.1.f. Perform exposure assessments for the chemicals and mixtures selected in A.1.c.

A.1.f.1. Determine and compare cumulative exposures.

Research will be needed to determine the exposures that may occur with the chemicals and mixtures of concern. If there appear to be scenarios where high levels of the chemical or mixture may occur over short time periods, acute exposures should be assessed, as well as chronic exposures. If not, analyses of chronic exposures alone may be sufficient. Data on sources, estimated concentrations, and time-activity patterns should be combined to estimate these exposures. Where concentration data are not directly available through monitoring, modeling can be used to estimate exposure concentrations if data are available on emissions factors for the chemicals and mixtures. Although the focus of the exposure assessments will be on indoor air exposures, the relative exposures from other media (ambient air, track-in from outdoors, food, water, soil, etc.) should also be estimated; if exposures from other media account for a disproportionate exposure as compared to those from indoor sources, further assessment of exposures from indoor sources may not be required.

The initial exposure assessments will be less detailed, and will be refined as the key pollutant sources and routes of exposure are determined. More detailed, follow-on exposure assessments will only be required if the risks estimated based on the initial exposure assessments warrant further study (see section A.1.g.) and should focus on scenarios that appear to result in the greatest exposures based on the initial assessments.

A.1.f.2. Develop more refined assessments of exposure variations by population.

Although there have been a number of studies looking at time-activity patterns for the general population (Klepeis, Tsang, and Behar, 1996), less is currently known about demographic or geographic variations in product use (e.g., differences in product use by certain cultures or occupations or differences in pesticide use across the country) or variations in product use across building types (e.g., differences in the cleaning products used, or differences in pressed wood use, in homes versus office buildings). Further research on variations in both acute and chronic exposures are needed in these areas. The evaluation of any possible increased exposures, both demographically/geographically and by building type, for particular susceptible populations (e.g., infants and children, pregnant women, the elderly, those with asthma, etc.) is also an area of needed research. In some cases, EPA may be able to work with industry to obtain such infomation on a voluntary basis; in other cases, it may be necessary to survey for this information. Depending on the chemicals and mixtures selected, their sources, and the level of detail needed in the assessments, evaluation of these factors may be more or less important.

A.1.f.3. Further develop and refine exposure modeling tools and assessments.

This exposure assessment work may also require further development and refinement of exposure modeling tools such as indoor air quality models. In addition, the results of these assessments should be transferred, as appropriate, to inform other exposure modeling efforts within the Agency (e.g., the Hazardous Air Pollutant Exposure Model [HAPEM] being used for the National Scale Assessment, and community-based modeling assessments).

A.1.g. Assess risks for the chemicals and mixtures selected in A.1.c.

Risk assessments should be performed by combining data on exposures (section A.1.f.) and dose-response indices (section A.1.b.) for the selected chemicals and mixtures. As with the exposure assessments, initial risk assessments should be less detailed; more detailed assessments should be performed, as warranted, for any significant risk scenarios. In addition, the relative risks from exposures in various media should be assessed; if management of risks due to exposures from other media (ambient air, track-in from outdoors, food, water, soil, etc.) is more effective in reducing risk, further assessment of risks from indoor sources may not be required. When possible, the risks to certain susceptible populations, such as pregnant women, infants and children, and the elderly, should be assessed.

A.1.h. Perform research on methods to manage risks for the chemicals and mixtures selected in A.1.c.

A.1.h.1. Determine the need for development of risk management methods.

This research will be dependent on results from section A.1.g. In many cases, further research will be needed to determine the most efficient and cost-effective methods to reduce risk, however, if the risks from a chemical or mixture found indoors do not appear to be significant or if the risks occur in large part through another mode of exposure (e.g., ambient air or pesticide track-in), research efforts may be better spent elsewhere. Even if the risks from an indoor source(s) are substantial, further research on methods to manage risks may not be warranted (e.g., there are obvious things that can be done to substantially reduce exposures and risks). In addition, for the case in which the chemical or mixture of concern is a HAP, the potential reductions in exposure due to regulatory actions should be taken into account before determining the need for additional voluntary risk management research.

A.1.h.2. Perform research to determine the most effective methods for voluntary reduction of risks.

If research to manage risks appears warranted, initial research efforts should focus on voluntary actions that might be taken to reduce risks. Risk management research will be dependent on the sources of concern, and may include the following options, among others: (1) assessments of risk reductions through voluntary reformulations of products by industry or the use of alternative products which are judged as "safer," (2) evaluations of the effects of changes in industrial processes on emissions and the related risk reduction, (3) analyses of the effectiveness of the use of "best practices" to reduce risks, (4) analyses of the effectiveness of increasing ventilation or affecting building pressure differentials; (5) voluntary actions taken by consumers and businesses to alter behavior or practices, (6) assessments of the economic benefits of risk management options, (7) evaluations of the effectiveness of market incentive programs, and (8) assessments of the impact of educational and outreach programs, including programs such as "Read the Label." Efforts should be made to set up formal voluntary programs with industry, both to obtain needed data to develop appropriate risk management options and to assist us in achieving risk reductions.

Also, although source modification or substitution may be the "best" option for reducing risks, it may take several years to implement. Therefore, quick and inexpensive options should be investigated in the interim.

Program Applications for Chemicals Research:

Fundamental to reducing risks from exposures to chemicals and mixtures in any environment is the identification of pollutants of concern and the assessment of sources, fate, exposures, and risks. Many EPA program offices are involved in projects to collect data on, and to assess the exposures, risks, and risk management options for chemicals and mixtures that may be emitted from products and materials indoors or that may infiltrate the indoor environment from outdoors. Suitable cross-program strategies for research on chemicals and mixtures in the indoor environment are needed to address a wide array of program interests. For example, ORIA has the general need to respond to public inquiries, and to provide information and training to numerous audiences, about the potential impacts of chemicals and mixtures in the indoor environment and methods that can be used to reduce exposures and risks. In addition, as implementation of the air toxics sections of the Clean Air Act moves towards a more risk-based process, it is important that ORIA works with OAQPS and OTAQ so that indoor sources and exposures are appropriately combined with those outdoors in an integrated strategy. This research would provide information about indoor exposures and risks that are needed to integrate indoor and outdoor air toxics strategies, and design those strategies to minimize total human exposures from both environments. Other offices with a need for research on chemicals and mixtures indoors include OPPTS, which is working to develop guidance for Federal facilities on the selection of products and materials for use indoors; OSWER, which is concerned with the infiltration of hazardous chemicals into buildings through soil; and OCHP, which is concerned with exposures to infants, children, pregnant women, and the elderly in the indoor environment.

References for Chemicals Research:

Kepleis NE, Tsang AM, and Behar JV. 1996. *Analysis of the National Human Activity Pattern Survey (NHAPS) Respondents From the Standpoint of Exposure Assessment: Percentage of Time Spent, Duration, and Frequency of Occurrence for Selected Microenvironments by Gender, Age, Time-of-Day, Day-of-Week, Season, and U.S. Census Region.* Final Report. Washington, DC: Office of Research and Development, U.S. Environmental Protection Agency. EPA/600/R-96/074.

U.S. Environmental Protection Agency (U.S. EPA). 1998. A comparison of indoor and outdoor concentrations of hazardous air pollutants. *Inside EPA*, Spring/Summer 1998. Research Triangle Park, NC: Office of Research and Development, U.S. Environmental Protection Agency. EPA/600/N-98/002.

Wallace LA. 1987. *The Total Exposure Assessment Methodology (TEAM) Study: Summary and Analysis: Volume I.* Washington DC: Office of Acid Deposition, Environmental Monitoring and Quality Assurance, Office of Research and Development, U.S. Environmental Protection Agency.

Weschler CJ, and Shields, HC. 1999. Indoor ozone/terpene reactions as a source of indoor particles. *Atmospheric Environment.* Vol. 33, pp 2301-2312.

Weschler CJ, and Shields, HC. 1997. Potential reactions among indoor air pollutants. *Atmospheric Environment.* Vol. 31 (21), pp 3487-3495.

A.2. BIOLOGICAL CONTAMINANTS

Background Information:

Indoor biological contaminants can have adverse impacts on human health. Bacteria, viruses, fungi/ molds, pets, rodents, cockroaches, and dust mites may all contribute to the contamination of indoor environments. In many cases, the presence of these contaminants is associated with a transient or long standing moisture problem, which supports the growth of fungi, dust mites, and certain bacteria, or they may result from the presence of a pet or pest infestation. To a limited extent, biocontaminants may be blown in from outdoors, or carried in on people's hair or clothing. In addition, biocontaminants may be purposely introduced into a building as an act of terrorism, an issue which has recently emerged as a national priority.

Biocontaminants can cause a variety of allergic or infectious diseases. Fungi also produce irritants and in some cases potentially toxic substances (mycotoxins). Pets, rodents, cockroaches, mold, and dust mites are known to be asthma triggers. Some of the most serious and potentially fatal building related illnesses are caused from exposure to indoor biological contaminants. These include Legionnaires disease, hypersensitivity pneumonitis, and allergic asthma. The extent to which exposure to these contaminants indoors can be or should be reduced, and under what circumstances, has great consequences for public health.

Over the past few decades, we have seen an unprecedented rise in asthma, allergic rhinitis, and other allergic diseases. However, the reasons or causes for this rise are unknown. Millions of dollars are spent yearly on medications, devices, and doctors appointments to address indoor allergy issues. It is estimated that more than 50 million Americans have allergic diseases (AAAAI, 1996-2001) and that in 1996 chronic sinusitis affected more that 38 million Americans (CDC, 2002). In fact, allergic diseases are the 6th leading cause of chronic disease in the U.S. and allergies cost health care systems more than18 billion dollars per year (AAAAI, 1996-2001). Economic costs for allergic rhinitis alone, estimated for 1993, were 3.4 billion dollars (Storms, Meltzer, Nathan *et al.*, 1997).

In addition, buildings have changed over the years - with the advent of new construction techniques, new building materials, tighter building envelopes, and reduced outside air ventilation, the incubation and transmission of infectious diseases through the indoor environment is of growing concern. This is of particular concern in buildings with high occupant density such as schools.

Unfortunately, our knowledge of the relationships between building conditions, occupant exposures, and health consequences is limited, as is our knowledge of viable means to effectively mitigate exposures and health impacts. Nevertheless, because of the public health impact of biocontaminants, there is considerable interest in producing information and guidelines to the public, the building industry, and to public health authorities. In response, the EPA has provided some limited guidance, mostly under the premise that reducing exposure is an appropriate response. But while there are little hard data and the true efficacy of such an approach is not known, organizations such as the National Academy of Sciences recommend proceeding with exposure reduction measures for indoor asthma triggers rather than waiting until all desirable research is performed (NAS, 2000). Asthma and allergy sensitization and exposure reduction measures are discussed in additional detail in section A.3.

Program Needs for Biological Contaminants Research:

A.2.a. Conduct research for specific biocontaminants.

A.2.a.1. Conduct studies on mold allergens and mycotoxins.

Mold allergens

Mold allergens are important asthma and allergy triggers. Research is needed to obtain more information on the characteristics and health-related issues associated with mold allergens. Research should identify the specific fungal proteins that cause allergic response. Standardized and quantitative methods to assess mold exposure are important efforts, which should include studies to establish biomarkers of exposure to mold in humans (or surrogate biomarkers) in order to assist researchers and medical personnel in assessing mold exposures. Research should identify patterns of cross-reactivity among fungal allergens and the relative potency of different antigens.

Mycotoxins

Research is needed to obtain more information on the characteristics and health-related issues associated with mycotoxins, including work which directly correlates mycotoxin exposure by the inhalation route with human health effects. The health effects resulting from inhalation exposure to mycotoxins are largely unknown; ongoing research on these health effects is important, and should continue.

A.2.a.2. Conduct studies on allergens from rodents and rabbits.

Research is needed to develop a better understanding of biological contaminants that originate from rodents (e.g., rats and mice) and rabbits. Studies should assess the degree to which rodent/rabbit exposures in the home exacerbate and/or cause asthma in sensitized asthmatics.

A.2.b. Assess the effects of early-life exposures on the development of the immune system.

One theory regarding the development of asthma from an environmental exposure involves the developing immune system. During early life, an environmental exposure (or exposures) may push the immune system to develop in such a way that the risk of developing asthma is increased. Some studies, however, indicate that early childhood exposure to some contaminants (e.g., allergens, microbes, and their products such as endotoxin) can be protective, and may reduce the chances of developing asthma.

It is theoretically possible that EPA's guidance for reducing exposure to biological contaminants, particularly during infancy/early childhood while the immune system is developing, could be counterproductive for some indoor biological pollutants. More information is needed regarding the effects of early-life exposures on the immune system and the potential that the lack of exposure during infancy can increase atopy in some individuals. This is especially critical because it may help explain the rapid rise in allergic diseases, and it has the potential to strongly influence the EPA's outreach messages related to asthma and other allergic diseases. The role of breast milk in this process should also be considered.

A.2.b.1. Conduct early-life exposure studies for endotoxin.

Endotoxin comes from the outer membrane of gram-negative bacteria. Endotoxin can be found in household dust in both urban and rural settings. People are exposed to low levels of endotoxin on a continuing basis since gram-negative bacteria are ubiquitous. Endotoxin is a potent stimulant of the immune system, and it is possible that endotoxin exposure has both positive and negative effects, depending upon age of exposure and other factors. Some studies suggest that early exposure to endotoxin can be protective against asthma, but that later life exposure can exacerbate existing asthma. In the case of dust mite exposure, early life exposure can clearly cause asthma, but for other biological pollutants such as endotoxin, we do not have enough information to make a determination on the effects of early exposure. Studies are needed to determine what effects, if any, that early-life exposure to endotoxin has on the developing immune system.

A.2.b.2. Conduct early-life exposure studies for other environmental factors.

Other exposures which may affect a developing immune system during early-life include infectious diseases, parasites, and other biological contaminants such as dog/cat allergens. Research should include single pollutants as well as mixtures of chemical and biological contaminants. A first step in this research area could be to convene an expert panel to identify and prioritize the environmental factors and contaminants that should be considered, followed by appropriate research to evaluate the potential health impacts such as allergic and asthma-like conditions.

Program Applications for Biological Contaminants Research:

The rapid rise in the incidence of asthma and other allergic diseases is yet unexplained. We know that some common allergens are biological, and that exposure to some of these allergens occurs primarily indoors. This makes allergic diseases both medical and indoor environmental problems. On the specific issue of mold, there is some epidemiological evidence that the existence of mold and/or dampness in the home increases the risk of respiratory symptoms - this ongoing research is important and should continue. The balance between humidification and dehumidification of indoor environments needs to be assessed in conjunction with appropriate control of mold growth (see section D, "Building Design and Operation). The ability to understand the relationship between mold exposure and health is a foundational issue and requires that techniques to reliably and accurately assess mold exposure be developed.

References for Biological Contaminants Research:

American Academy of Allergy, Asthma and Immunology (AAAAI). 1996-2001. *The Allergy Report: Science Based Findings on the Diagnosis and Treatment of Allergic Disorders.*

Centers for Disease Control (CDC). 2002. Fast Stats A-Z, *Vital and Health Statistics*, Series 10, No. 200, Table 57. 1996 as cited in NIAID (National Institute of Allergy and Infectious Diseases). January 2002. Allergy Statistics, Fact Sheet.

National Academy of Sciences (NAS), Institute of Medicine. 2000. *Clearing the Air, Asthma and Indoor Air Exposures*. Washington DC: National Academy Press.

Storms W, Meltzer E, Nathan R, and Selner J. 1997. The Economic Impact of Allergic Rhinitis. *Journal of Allergy and Clinical Immunology*. 99:S820-4.

A.3. SENSITIZATION, ALLERGY AND IRRITATION HEALTH EFFECTS

Background Information:

Exposure to certain levels of specific pollutants may cause an individual to become increasingly susceptible to respiratory reactions upon further exposure to those or other pollutants. This applies to a broad spectrum of pollutants, including chemicals (see also A.1), biocontaminants (see also A.2) and particulate matter (see also A.4). This enhanced susceptibility is referred to as sensitization and may be reported as a positive allergen test response. For example, most studies have shown an association between exposure to dust mite and cockroach allergens above certain levels and an increased prevalence of sensitization. Some studies have reported this association for cat and dog allergens, whereas others have not found an association for these allergens. Several studies have reported clear dose-response relationships between the allergen levels and sensitization. Atopy or genetic disposition has also been strongly associated with sensitization potential. In contrast to sensitization, there is a "hygiene hypothesis" or "dirt hypothesis" that suggests that the human immune system development is affected by reduced exposure at birth and in early life to certain contaminants (see A.2.b).

There is a large and ever growing body of current literature related to the influence of indoor pollutants such as dust mites, pet dander, molds, cockroaches, and environmental tobacco smoke on asthma or allergy symptoms. The association between these indoor contaminants and the exacerbation of allergies and asthma is well-established. For dust mites and environmental tobacco smoke, there is also strong data to support an association between exposure to the contaminant and initiation of asthma or allergy symptoms. Several primarily outdoor air pollutants have also been linked to asthma and other adverse respiratory conditions, including sulfur dioxide, nitrogen dioxide, ozone and particulate matter including acid aerosols. Although there is a large body of current data on the impact of environmental exposures on asthma and allergies, the results of many of the studies are limited by problems with inconsistencies in disease diagnosis, design of study, or inappropriate consideration of confounders. In addition, there are potentially several different variations (phenotypes) of asthma and allergies, and different treatments or mitigation methods may be required.

Several contaminants found in the indoor environment can directly or indirectly induce allergic respiratory reactions, while other contaminants cause respiratory symptoms through non-allergic mechanisms such as irritation. Most allergens stimulate production of immunoglobulin E (IgE) antibodies that can result in various hypersensitivity reactions. There also appear to be chemical compounds with a capacity to trigger inflammation without involving IgE.

Program Needs for Sensitization, Allergy and Irritation Health Effects Research:

A.3.a. Investigate relationships for pollutant exposure levels and sensitization.

Although there is strong support for a relationship between some pollutant exposures above certain levels and sensitization in particular populations, research is needed to more fully assess the exact relationships between exposure, sensitization, asthma, and/or other respiratory morbidity variables. The sensitization process, as well as the thresholds of exposure and other potentiating conditions that can trigger a response, exacerbate an existing disease, or induce a new or unidentified disease state are of critical interest. Research should also investigate whether combinations of allergens affect sensitization.

A.3.a.1. Characterize exposure thresholds that sensitize individuals and those that trigger allergic reactions to pet and cockroach allergens.

Pet allergens and cockroach allergens are difficult to control because of their adhesive and aerodynamic properties. In addition, pet allergens tend to be ubiquitous and travel readily between environments on people's clothing, and cockroaches can infest a dwelling from an adjacent dwelling or building. Thus, significant exposure reduction for these allergens is difficult to achieve. Knowledge of the thresholds for sensitization and for triggering responses would help determine the degree of avoidance and mitigation that is critical so that proper guidelines can be established.

A.3.b. Conduct characterization studies of allergens and chemical irritants.

Although the literature concerning allergic reactions and allergens has greatly advanced in recent years, research is needed to address data gaps with regard to the mechanisms of action of various allergens on the respiratory system. Research is also needed to address limitations and gaps in available information regarding specific actions of irritants on the respiratory system. Some of the major data gaps in the available literature for both allergens and irritants involve the specific characteristics of inflammatory processes; the exact mechanism of action of contaminants on the respiratory system; the long-term role of continued exposure to contaminants on persistent lung conditions; the possibility of differential impacts of exposure on potentially sensitive populations such as children and the elderly; efficacy and effectiveness of mitigation methods; and, the role of avoidance or mitigation to symptom or disease improvement. Research is also needed to further investigate the concept of total allergic burden, and whether exposure to low-levels of multiple allergens simultaneously (or within a short time period) affect health endpoints.

A.3.b.1. Investigate allergy and irritancy issues for occupational contaminants in other indoor environments.

Several allergens and chemicals that have been shown to cause allergy or asthma in occupational settings have not been well-studied in other typical indoor environments (e.g., residences and schools). For example, mouse allergen is a well-defined cause of IgE-mediated hypersensitivity in occupational settings, but although it is known that mouse allergen is widely distributed in inner-city homes where allergy and asthma prevalence is high, little information is available on the impact of the level of mouse allergen found in homes on the respiratory system of susceptible individuals. Further study is needed to assess the clinical importance of this potentially significant and under-recognized indoor allergen. Similarly, rat and rabbit allergens are known to cause allergies and asthma in occupational environments, but further research is needed to assess these contaminants in other indoor environments.

A.3.c. Determine the efficacy of exposure reduction measures recommended in existing EPA guidance.

The EPA currently recommends reducing or eliminating exposure to indoor asthma triggers to reduce the likelihood of asthma symptoms indoors. There is insufficient data to support the effectiveness of this approach. Research is needed to fill this data gap, and to assess critical issues such as whether reducing exposure to indoor contaminants reduces the potential for sensitization, and whether occupant age or other population characteristics are significant factors. One example of research that could be performed in this area includes assessing whether the removal of a dog or cat from a home results in a sufficient decrease in overall allergen exposure to decrease allergic symptoms in sensitized individuals. Similar research could be performed for other exposure reduction measures.

A.3.d. Conduct studies to determine the most effective mitigation techniques to achieve sub-threshold levels for allergens and irritants.

Studies are needed to evaluate potential mitigation strategies for reducing exposures to allergens and irritants. For each strategy, research should evaluate the effectiveness in reducing exposure, the net improvement in health conditions, cost-effectiveness, ease-of-implementation, and applicability to various indoor environments. Given the variable nature of human immune systems, occupants will likely have varied responses to indoor allergens and irritants, and a sufficiently 'clean' or 'mitigated' room may not be the same for all occupants. Studies would need to determine whether there are practical ways of reducing exposures in various contaminated environments below the required thresholds, or whether a complete change in environment may be necessary.

Program Applications for Sensitization, Allergy and Irritation Health Effects Research:

The EPA seeks to educate health care providers and the public about the importance of having a balanced approach to asthma management involving both medication and environmental controls (trigger avoidance). Many of the trigger avoidance strategies currently used are based on the concept that exposure reduction will alter symptoms, even though additional scientific evidence as to the efficacy of such strategies is needed. Furthermore, the National Academy of Sciences recommended that, although more research is needed, these exposure reduction measures should be implemented rather than waiting until all desirable research is performed (NAS, 2000).
In addition, a troubling question is the issue of whether some exposures may be needed to prevent sensitization and allergic response. And for those exposures for which it truly is advisable to mitigate, how much mitigation is necessary or feasible are open questions. Knowledge as to how exposure to certain allergens affects human responses, and what threshold levels must be achieved to avoid an allergic response is of critical concern. The proposed research is designed to provide information needed to identify and promote effective environmental control strategies.

References for Sensitization, Allergy and Irritation Health Effects Research:

National Academy of Sciences (NAS), Institute of Medicine. 2000. *Clearing the Air, Asthma and Indoor Air Exposures*. Washington DC: National Academy Press.

A.4. PARTICULATE MATTER

Background Information:

Airborne particulate matter (PM) refers to a large group of materials of diverse sizes and chemical characteristics which share the ability to be transported in the air as discrete solid particles or liquid droplets. These particles originate from a number of natural processes as well as from some human activities, both indoors and outdoors. A large number of inorganic and organic materials may be contained within these particles, including biological contaminants.

Epidemiological studies document a number of associations linking outdoor particulate matter concentrations to adverse health effects such as decreased lung function, exacerbation of respiratory diseases, and premature death. Studies on indoor air have also shown that particulate matter is a significant indoor pollutant (e.g., EPA's Particle TEAM study, and EPA's Building Assessment and Survey Evaluation [BASE] study). Indoor exposures to particulate matter can be significant, and there is inadequate information as to whether indoor particles originate outdoors, thus reflecting the epidemiological results above, or whether there is a substantial component from indoor sources that would add to the health impacts from particle exposure. Of particular concern are the growth of biological contaminants indoors, particulate matter from indoor combustion appliances, and other potential indoor sources including printers and copiers. Furthermore, there is little known about the particle dynamics that could affect particulate matter exposure. For example, there is believed to be a 'personal cloud' in which an individual's exposure to particles is not influenced solely by ambient contaminant levels, but also by particles that become airborne due to one's own physical activity. Information on these issues is needed for the EPA to develop an effective program to mitigate exposure and risks from indoor particulate matter.

An EPA program has been established to conduct particulate matter research, primarily from an outdoor air perspective, to support review and implementation of EPA's National Ambient Air Quality Standards (NAAQS) for PM. Congress directed the EPA to arrange for an independent study by the National Research Council (NRC). This study was intended to identify the most important research priorities, develop a conceptual plan for particulate matter research, and monitor and evaluate the research progress. NRC established the Committee on Research Priorities for Airborne Particulate Matter in January 1998. This committee identified ten high priority research topics and developed a 13-year integrated strategic plan (from 1998 to 2010) of recommended research.

While some of the indoor environments research needs for particulate matter may be addressed by the NRC plan and EPA's existing program for outdoor particulate matter research, there are several key areas that require research specifically for advancing the EPA's indoor environments program.

Program Needs for Indoor Particulate Matter Research:

A.4.a. Conduct research for particulate matter measurement techniques.

Particulate matter concentrations can be measured using different techniques and measurement units. For example, one approach is to measure the particulate matter concentration in particle counts per unit volume, while another approach entails measuring the particle mass. Research may be needed to reconcile different methods to ensure proper interpretation of data and inter-comparison of results. Some measurement research is being conducted under the outdoor air particulate matter research program. Specific research is needed to develop appropriate measurement techniques for indoor environments, which may have unique measurement error and other technical considerations. Research is needed to determine the factors for the conversion from particle number to mass for uncharacterized indoor aerosols. Specific research is also needed on the development and verification of improved personal monitoring devices.

A.4.b. Develop particulate matter cumulative exposure models derived from specific indoor particle source parameters, indoor transport mechanisms, indoor contributions of outdoor sources, outdoor exposures, and human activity.

Outdoor air quality particulate matter exposure models are being developed, however these models typically fail to account for indoor sources of particulate matter and many of the issues identified in subsequent sections A.4.c.1 through A.4.c.3. Efforts are needed to develop improved exposure models that accurately predict cumulative particulate matter exposure by integrating outdoor exposures with indoor exposures, i.e., indoor exposures that are based on both outdoor and indoor sources of particulate matter within the indoor environment. Research could investigate linking/adapting existing indoor and outdoor exposure models. There may be existing indoor air quality exposure models, such as the CONTAM model developed by the National Institute for Standards and Technology (NIST), which may be adapted or modified for particulate matter exposure modeling.

A.4.c. Identify major indoor particulate sources for different indoor environments.

There is a need to understand the major indoor sources of particulate matter for homes, schools and offices, and to identify other critical indoor environments where particulate matter requires further investigation. A comprehensive study is needed of how sources impact each other.

A.4.c.1. Quantify the contribution of indoor sources and outdoor sources to particulate matter found indoors.

Particulate matter in the indoor environment can result from indoor sources, and outdoor sources from which the particles are able to migrate indoors. Where possible, this research should identify and characterize the predominant indoor and outdoor sources of particulate matter, determine how sources impact each other, and assess the relative contribution of the indoor and outdoor sources to total PM exposure, as well as to total indoor PM exposure and total outdoor PM exposure. Research should also identify reactive contaminants, mechanisms, and devices (such as ozone generators) that lead to the existence of secondary particles in the indoor environment. The resulting compounds and their toxicities need to be fully characterized.

A.4.c.2. Investigate the 'personal dust cloud' phenomena.

The implications of the 'personal dust cloud' phenomena are largely unknown. Research is needed to evaluate how much an individual's particulate matter exposure is affected by localized personal activities that may either generate particulate matter or increase particulate matter exposure by re-entrainment of settled-out particulate matter, and evaluate the impact of other individuals''personal dust clouds' on exposure. Research is also needed to assess the impact of the 'personal dust cloud' on health and to identify/develop low cost ways to mitigate any such effect.

A.4.c.3. Investigate the chemical composition and size distribution of indoor particulate matter.

In order to adequately assess particulate matter health risks and mitigation techniques of indoor particles from both indoor and outdoor sources, information is needed regarding the chemical composition and how it relates to particle size and particle source. This research should differentiate between coarse, fine, and ultra-fine particles. The differentiation between fine particles (less than 2.5um) and ultra-fine particles (less than 0.1um) is required to infer the aerodynamic properties of the particles in the distribution and ascertain the appropriate effective disposition rate constant.

A.4.d. Determine the health effects and risks of indoor particulate matter.

Many studies have associated particulate air pollution with asthma exacerbations, increased respiratory symptoms, decreased lung function, increased medication use, and increased respiratory-related hospital admissions, among other health endpoints. Although there is a strong association between particulate matter exposure and respiratory symptoms, there are several areas that have not been fully evaluated, including the mechanisms of action (i.e., direct impact of the particulate on respiratory tissues, transport of allergen or irritant to tissues where it causes an effect, or receptor modulation causing an inflammatory response), composition of particles or particle complexes, concentrations of concern, and impacts of co-pollutants. Particulate matter has also been strongly been associated with excess cardiopulmonary death; however, mechanisms of action for this effect are debated in literature. Further information on these mechanisms of action and the biological basis of these adverse health effects may help establish levels of concern and health-based risk management options, especially for sensitive populations. In addition, the populations that have been reported to be at increased risk (e.g., the elderly, persons with pneumonia, heart diseases, and respiratory diseases) may spend greater amounts of time indoors and may have an even larger component of their total particulate matter exposure due to indoor particulate sources.

The majority of available health effects information on particulate matter exposure is based on studies of outdoor air. While considerable particulate matter health effects research is being conducted under the auspices of the outdoor air particulate matter research program, this research will likely need to be expanded to consider the particulate matter that is determined to be most-characteristic of the indoor environment, particularly from indoor sources (see sections A.4.c.1. and A.4.c.3). Additional research items include:

1. identifying the most-toxic indoor particulate matter contaminants;
2. investigating indoor particulate matter health effects for the general population and for susceptible sub-populations;
3. investigating the deposition and fate of particles in the respiratory tract, particularly for indoor biological contaminants (e.g., cockroach parts);
4. evaluating the health effects when particulate matter is combined with other indoor pollutants.

A.4.e. Assess particulate matter mitigation strategies.

Recommended mitigation strategies will likely be dependent on the particulate matter sources (physical characteristics and health impacts), the building design and operating characteristics, and the occupants. For example, ventilation with outdoor air may be considered a mitigation strategy for indoor particulate matter; however, there may be many situations where the indoor particulate matter results predominantly from outdoor sources or where the outdoor ambient air may require filtration or other treatment.

There ultimately needs to be simple and cost-effective actions that the EPA can recommend for the general population, and for sensitive and susceptible individuals, to reduce particulate matter exposure in the indoor environment. In evaluating particulate matter mitigation strategies, the research should consider the effectiveness in reducing particulate matter exposure, the net improvement in health conditions, cost-effectiveness, ease-of-implementation, and applicability to other indoor environments. Existing mitigation techniques that should be investigated can be divided into strategies which are continuous (such as building design, building construction features that limit the entry of outdoor particles, air filtration, and ventilation), intermittent activities primarily involved with clean-up (such as high-efficiency vacuum cleaners, wet mopping, hazardous particle removal, and changes in cleaning and maintenance practices), and lifestyle changes (such as eliminating indoor smoking or getting rid of house pets). Additional particulate matter mitigation strategies should also be investigated after the research described in sections A.4.c.1 through A.4.c.3 yields information regarding specific indoor particulate matter sources and exposure routes.

Program Applications for Indoor Particulate Matter Research:

Particles are ubiquitous contaminants, but unlike chemical contaminants, outdoor and indoor particles vary in size, shape, and chemical make-up. As a result, conclusions reached relative to particles outdoors do not necessarily apply to particles indoors. In addition to the outdoors, indoor sources of particles include material sources, biological sources, combustion sources, and activity sources, such as vacuuming. While particles are a known health hazard, the extent of that hazard indoors, or the types or sources of indoor particles creating that hazard remain unknown. This research will enable EPA to provide substantive and detailed guidance for controlling indoor particle exposures in ways that are effective in reducing risk. Research to investigate particulate matter from indoor combustion appliances would directly support EPA's role in the international Partnership for Clean Indoor Air, particularly if the assessments include exposures from indoor cooking fires, biomass stoves, kerosene, and liquefied propane gas.

B. HUMAN PERFORMANCE

Background Information:

Human performance refers to our ability to perform various generic mental and physical functions such as reading/comprehending, calculating, remembering, typing, or driving. These tasks are inherent to how well we perform life's functions at home, at school or at work. They have important social and economic value, and understanding how the quality of the indoor environment enhances or inhibits our ability to perform life's tasks is the subject of this programmatic research need.

Evidence is accumulating that indoor air quality can have a measurable impact on human performance. Early studies using survey data in which respondents estimate the effect of indoor air on their productivity suggest that current conditions reduce productivity by 3%-4% on average, or that personal controls of ventilation and temperature could improve productivity by up to 6% and 10% respectively (U.S. EPA, 1989; Raw, Roys and Leaman, 1990). More recent controlled field studies measuring performance of specific tasks suggest that increased pollution sources or reduced ventilation can reduce human performance measures by 2%-6% (Wargocki, Wyon, Baik *et al.*, 1999). Further, a major cross sectional study of offices of a large U.S. corporation found that 35% of short term sick absences could be attributed to low ventilation conditions. The economic value of losses in human performance has been estimated to be in the "tens of billions" of dollars (U.S. EPA, 1989) or $20 to $160 billion dollars per year (Fisk and Rosenfeld, 1997).

While the potential value for improved human performance from improved indoor air quality appears to be substantial, many methodological uncertainties make research in this field difficult. First, it is important to determine if the impact on human performance is biologically dependent or independent of other health symptoms such as headaches or lethargy (i.e., is it the headache or other health condition that causes performance to be effected?). Second, there is no generally accepted method of measuring human performance in ways that are appropriate to different indoor environments. Self assessed productivity through surveys is a convenient measure, but there is only scant evidence that such measures accurately reflect true productivity. Various test methods have been used to measure different aspects of mental and physical acuity (e.g., typing test, memory test, arithmetic test), but without standardization, and it is difficult to compare results across studies or to relate how such measures represent human performance in real world conditions of different indoor environments. Research on the attributes of indoor air quality parameters that impact human performance is needed before prescriptive guidance can be formulated.

The long term program goals for research in human performance are to (1) understand the biological mechanism by which indoor air quality affects human performance, and the relationship (or lack thereof) between indoor air quality health symptoms and human performance; (2) develop a general consensus on the metrics for measuring human performance in various settings, and develop continuing research to improve those metrics over time; (3) develop a database of information sufficient for statistically reliable inferences to support guidelines or standards affecting indoor environmental parameters in homes, schools, offices, hospitals, and other environments.

Program Needs for Human Performance Research:

B.1.a. Evaluate methods and define research agenda for measuring human performance.

Knowledge on the relationship between indoor environment parameters and human performance are hindered by the lack of standardized measures. Establish a panel of renowned scientists with expertise in the field of human performance measurements, convened under the auspices of the National Academy of Sciences, the World Health Organization, or similar body. The panel should review current theory and practice in the measurement of human performance, recommend specific protocols for measuring human performance in a variety of settings (e.g., short term memory, motor ability, cognitive abilities), and recommend a research agenda using these protocols.

B.1.b. Develop dose-effect relationships for key contaminants on human performance measures.

Ethical considerations inhibit experiments in which human subjects are exposed to harmful contaminants, while animal studies that shows definitive performance decrements in rats due to exposure to specific contaminants only provide indirect evidence. However, some research suggests promising methods for extrapolation of dose-effect relationships in animals to estimate the corresponding relationships in humans (e.g., Benignus, 2001). The ability for cross-species extrapolation would greatly enhance our ability to document and quantify the decrements in human performance associated with indoor air pollution.

B.1.c. Quantify the relationship between health symptoms and human performance.

There are many studies relating occupant symptoms to building or air quality attributes and this literature has been critically reviewed (Mendell, 1993; Seppänen, Fisk and Mendell, 1999). However, there is little information about the relationship between health symptoms and human performance, though there is some suggestion that decreases in human performance do not take place until certain health symptoms such as headache become evident (Wargocki, Wyon, Baik *et al.*, 1999). This suggests that information on the relationship between health symptoms and human performance combined with available data on the relationship between building attributes and health symptoms could be used to estimate human performance effects of building attributes. Quantifying the relationship between building performance and health would provide a missing link in our ability to quantify how building or air quality attributes affect human performance.

B.1.d. Quantify the relationship between building attributes and human performance using both laboratory and field studies.

B.1.d.1. Conduct cross sectional studies to identify possible indoor parameters that affect human performance.

Conduct cross sectional studies in which data from many buildings are systematically compared in an attempt to derive statistical relationships between IAQ relevant building parameters and performance/productivity variables. Such studies would suggest relevant variables that could be more rigorously tested through controlled studies.

B.1.d.2. Conduct controlled studies to determine key indoor parameters that affect human performance.

Conduct controlled studies in laboratories and in actual environments in which building or air quality parameters are systematically changed and human performance measured to identify specific indoor air quality parameters that affect human performance. Attempt to derive cause-effect relationships and dose-response functions. Parameters of interest would include such things as variations in specific source emissions, type and rate of ventilation air, personal controls of their microenvironment, air cleaning, intensity of housekeeping, humidity/moisture controls, and thermal controls. Light (including daylight), noise and ergonomic effects could also be studied.

B.1.d.3. Conduct studies to determine the efficacy of using self assessed performance as a true measure of actual performance.

Since data on subjective measures are easier and more feasible to obtain, knowledge of the relationship between subjective and objective measures can greatly facilitate the use and interpretation of available data for guidance development and decision-making.

B.1.e. Conduct research to examine the potential for improving productivity in schools and offices through actions designed to improve human performance

B.1.e.1 Quantify the relationship between measures of human performance and productivity in real world environments.

Human activity in the office or in school involve a complex combination of mental and physical functions and tasks (e.g., reading, writing, calculating, interpreting, reacting, communicating, typing), each of which may or may not be affected by indoor air quality. Thus, while research on the relationship between indoor air quality and specific elements of human performance (e.g., reading comprehension) is important, it does not, in itself, capture the economic or social value of performance changes in various indoor settings. Rather, the value of performance changes is reflected through its impact on productivity. For example, how much is productivity improved by a 10% decrease in typing errors in an office setting, or how does a 10% improvement in short-term memory affect a student's performance in school? A set of experiments would be undertaken to establish the relationships between changes in human performance and changes in productivity in office, school, and home environments.

B.1.e.2 Conduct intervention and cross sectional studies to measure productivity changes in schools and offices

The EPA and other organizations provide and promote guidance on good indoor air quality practices that are expected to improve occupant health and performance. This research would test the hypothesis that following good IAQ practices in schools or office buildings will result in measurably higher productivity, taking into account the need to reduce exposures from both indoor and outdoor sources.

Program Applications for Human Performance Research:

The indoor air quality program is a non-regulatory program that depends on its ability to motivate people to take actions that improve indoor air quality in their environments. Currently, however, motivational messages must be related to improvements in health because this is where data are. This is very limiting. The general public may be sensitive to health issues related to their homes, but for other audiences such as office building managers, corporate executives, or school administrators, improved health may be only a secondary concern to human performance and productivity. To businesses, improved performance and productivity implies increased profits or growth. To schools, student performance is a measure of educational system success. Thus, developing information on how indoor air quality impacts human performance in offices, schools, and other environments greatly expands the potential for indoor air quality programs to effectively motivate the public to take action. The information from this research could substantially energize the motivational potential of program material in virtually every program area.

References for Human Performance Research:

Benignus, VA. 2001. Quantitative cross-species extrapolation in noncancer risk assessment. *Regul Toxicol Pharmacol*. 34(1):62-8.

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C. IAQ MEASURES AND INDICES

C.1. BUILDING IAQ INDICES

Background Information:

Current market forces and legal incentives for improving IAQ are absent largely because of our inability to define IAQ by a simple measuring system, similar to the way energy can be measured. In the absence of a convenient measure for IAQ, buildings can not be labeled or categorized by their IAQ performance. IAQ is not easily marketed by owners, nor can tenants conveniently negotiate for an IAQ upgrade during lease negotiations. In addition, insurers can not conveniently adjust the insurance rates or mortgage companies adjust their finance rates on the basis of IAQ. Nor does the research community have a convenient measure of IAQ that can be related to health, property value, or productivity. For any market or program transaction to incorporate IAQ, a convenient measure or measures are needed. This was recognized by the *Healthy Buildings Healthy People (HBHP)* project that called for the development of an IAQ index.

The pollution standards index (PSI) for outdoor air, or the UV index for sunlight are examples of indices that greatly facilitate the valuation of risk conditions so that they may be easily incorporated into decision and transactions. A variety of methods for constructing an index are available and they vary from a simply linear weighting of input variables to more complex structures.

A building IAQ index can be designed to incorporate readily available information on IAQ related building parameters such as ventilation, the presence of sources, and thermal parameters. An index may require some measures of air contaminants, though comprehensive sampling for all buildings to be indexed may prove impractical. In addition, an IAQ index could incorporate measures of the ability of building management to maintain good IAQ conditions over time, and thus incorporate ratings operations and maintenance protocols along with ratings of IAQ management practices. Separate specific indices may ultimately be needed for homes, schools, offices, and other indoor environments.

The long term goals for this program initiative are to (1) develop a generally accepted set of indices that would reasonably represent indoor air quality in buildings, (2) provide for the quick development of trial indices based on current knowledge, with index structures that can accommodate easy refinement and expansion over time, (3) energize markets and other institutional mechanisms to incorporate IAQ into decision-making based on its measurability through such indices, and (4) establish an active area of research interest in the IAQ community and the building community for continuous refinement of the indices.

Program Needs for Building IAQ Index Development Research:

C.1.a. Review and evaluate indexing methodologies.

Establish a panel of renowned scientists with expertise in the field of index development in the health or environmental sciences convened under the auspices of the National Academy of Sciences, the World Health Organization, or similar body. The panel will review current theory and practice in the development of indices to measure environmental conditions, and make recommendations as to (1) the criteria that should be used as the basis for the indices (2) the methods that would be useful for constructing one or more building indoor air quality indices, and (3) the databases that are available or could easily be developed for use in these indices.

C.1.b. Construct and characterize different indices.

Identify several individuals or organization, each of which will develop one or more IAQ indices for buildings, and will characterize the indices (e.g., how does the index of IAQ building parameters track occupant symptoms, or how does the index change as building conditions change) using available data such as that from comprehensive building surveys (e.g. BASE), as well as individual buildings, and hypothetical buildings designed to evaluate the indices.

C.1.c. Evaluate different indices and provide recommendations for selection.

Convene one or more workshops or similar forums in which the indices developed are presented and critiqued and recommendations made for further development or selection.

Program Applications for Building IAQ Index Development Research:

With the development of IAQ indices, IAQ would become more quantifiable, enabling a host of new program initiatives. Measurable indices would make it possible to integrate IAQ into normal market transactions for buildings, rental space, liability insurance, health insurance, and finance. Once institutionalized in these markets, good IAQ practices could become important in the marketplace. Initially, the program office would promote the adoption of building IAQ indices by appropriate national and international standard setting organizations, and then help institutionalize these indices through cooperative programs with public and private institutions.

C.2. DEVELOPMENT OF PUBLIC HEALTH MEASURES FOR IAQ

Background Information:

Poor or inadequate indoor air quality in the nation's building stock may increase the prevalence of many diseases such as lung cancer and asthma, as well as the spread of infectious diseases. Yet, to date, there are no mechanisms to establish the proportion of these diseases that are directly or indirectly attributable to poor IAQ. Research is needed to establish the attributable risk of selected health endpoints to indoor air parameters that can be measured and tracked over time as a means to measure health gains or losses from changes in the indoor air quality of the nation's building stock. Such a need was recognized by the EPA's *Healthy Buildings Healthy People (HBHP)* project.

By way of example, consider recent research that estimates the incidence of asthma, otitis media, bronchitis, and pneumonia in children attributable environmental tobacco smoke (ETS) exposure. The estimates are based on a review of the literature that report on the relative risk or odds ratios of these diseases associated with ETS exposures (DiFranza and Lew, 1996), from which attributable risk is then calculated. From information on attributable risk, the proportion of the national incidence of each of these diseases attributable to ETS exposure has been estimated, along with national medical expenditures for physicians, emergency care, hospitalizations, and medications (Cunningham, Houle and Mudarri, 2002). From this information, estimates of the reductions in the national incidence in these diseases, and the reductions in associated national medical expenditures resulting from programs to reduce exposure of children to ETS can also be made. Similar efforts could be initiated for other exposures, and other building conditions, and other health endpoints. This type of data would provide a significant opportunity to establish health-based goals under the Government Performance Results Act (GPRA), and then track progress over time in achieving those goals.

One should harbor no illusions that a small amount of research in a short period of time will provide comprehensive data on all the diseases attributable to indoor air that may be of interest. But a case can be made for providing estimates for those diseases based on existing research that have reported relative risks or odds ratios, and then starting on a long term path to provide a comprehensive database. The research should tie into and complement CDC's National Report(s) on Human Exposure to Environmental Chemicals. Considering all potential health outcomes, the long term goals of this program need for research are to: (a) develop estimates of the incidence of all diseases attributable to poor indoor air quality; and (b) relate progress made in improving indoor air to the improvement in public health through the quantifiable reduction in disease incidence.

Program Needs for Research on Public Health Measures for IAQ:

C.2.a. Select target diseases and indoor air parameters.

C.2.a.1. Establish candidate diseases associated with specific indoor air quality attributes.

Conduct a comprehensive literature review and evaluation of diseases (or other health effects) for which national statistics are collected and for which studies are available that provide estimates of relative risk/odds ratio, dose-response, or similar statistical association to indoor air quality attributes. Identify candidate diseases and attributes for further investigation.

C.2.a.2. Identify available data and data needs to determine population exposures to candidate indoor air quality attributes.

Conduct a comprehensive review of available data and/or data collection efforts needed to establish the proportion of the population exposed to the indoor air quality attributes identified in C.2.a.1.

C.2.a.3. Select two or three diseases and associated indoor air quality attributes for development of national impact estimates.

Based on C.2.a.1 and C.2.a.2, select two or three candidate diseases and their associated indoor air quality attributes for a concerted effort to estimate the attributable risk and national incidence of the selected disease attributable to indoor air quality. An important criteria for choice should be the availability of data for appropriate estimates of attributable risk.

C.2.b. Estimate the proportion of selected diseases attributable to indoor air quality.

Data gaps on the national incidence of the selected diseases and the attributable risk associated with indoor air quality attributes for those diseases will have to be assessed, and, if necessary, additional studies and data collection efforts instituted. Once the data are established, estimates of the attributable risk and the national incidence of the selected diseases attributable to indoor air quality should be made.

C.2.c. Publish estimates of attributable risk and national incidence of selected diseases attributable to indoor air quality.

These estimates should be thoroughly peer reviewed and published. Solicitation of interest from a wider research community to continue these studies, selecting other disease endpoints would be part of an overall strategy to elevate indoor air quality as a public health concern.

Program Applications for Research on Public Health Measures for IAQ:

The health research budget in the United States is substantial, much of it is focused on research directly related to specific diseases. Developing estimates of attributable risk to indoor air may provide an avenue by which indoor air could be promoted as a more significant topic of interest to the health research community. Further, these studies would allow EPA to develop quantitative health-based GPRA goals for indoor air, establish a data collection program to track the critical indoor air and building attributes over time, and thereby report on progress in reducing disease incidence through improved indoor air quality.

References for Research on Public Health Measures for IAQ:

Cunningham K, Houle C, and Mudarri D. 2002. Medical Cost of Childhood Illnesses Attributable to Environmental Tobacco Smoke: Total National Costs and Costs to Managed Care Organizations. Draft Contractor Report prepared for the Indoor Environments Division. U.S. Environmental Protection Agency, Washington, D.C.

DiFranza J and Lew R. 1996. Morbidity and Mortality in Children Associated with the Use of Tobacco Products by Other People. *Pediatrics.* 97(4): 560-568.

D. BUILDING DESIGN AND OPERATION

Background Information:

Building design and operation play an important role in maintaining a healthy and productive indoor environment. There are several factors driving building professionals to review current products and practices, and to search for practical and effective alternatives, associated with building design and operation. Examples of these driving forces include the green building movement, the progression towards more energy-efficient buildings, and growing concerns over liability due to poor indoor air quality. Other motivations include reduced costs from medical expenses and lost work performance due to illnesses, allergies, and irritations arising from poor indoor air quality. Although much is known or suspected regarding health risks and performance impacts in the indoor environment, a comprehensive, integrated effort to conduct research on the effects of building design and operation is needed.

While the potential value for improved building design and operation appears to be substantial, significant gaps still exist in the current state of knowledge. Building professionals are generally unaware or lack sufficient data to know what they can do to reduce the risk of asthma, cancer, and other serious diseases caused by indoor pollutant exposure. Best practices and products will vary according to the diverse types, locations, and planned uses of buildings.

It is in the proper application of best practices and products that the benefits of a healthy indoor environment that enhances human performance can be realized. The overall program goal for research in building design and operation is to collect and develop data that can be used to create guidelines for building professionals to use in selecting best practices and products based on quantifiable bottom-line costs, as well as health, performance, and other related environmental impacts (e.g., climate change, sustainable building practices, contributing to outdoor air toxics, etc.).

Program Needs for Building Design and Operation Research:

D.1. BUILDING CHARACTERIZATION AND INTERVENTION

D.1.a. Characterize the IAQ of US building stock.

During the 1990's, the EPA conducted the Building Survey and Assessment Evaluation (BASE) program for office buildings, which characterized the baseline levels of indoor environmental parameters, occupant symptoms, and responses within 100 randomly selected office buildings (Burton, Baker, Hanson *et al*., 2000; Girman, Baker and Burton, 2002). The BASE study results are being used by the EPA to assist with the development of national policy related to office building design and operation. A logical continuation would be to characterize the IAQ of other building types, such as schools, homes, and elderly care facilities. These studies would likely be structured differently from the BASE study, and would be more limited in scope and complexity.

This research would identify and prioritize the building types to be investigated. A major outcome of the studies would be the correlation of occupant symptoms and responses to building parameters including indoor and outdoor pollutant sources, outdoor air ventilation rates, humidity control systems, and operation and maintenance practices.

This research would also include efforts to: (1) establish panels of national experts to develop the study protocols for each building type; (2) develop and test appropriate sampling and measurement techniques, as needed; and (3) collect, analyze, and report on the data.

Pilot studies may prove to be useful in developing and refining the protocols and measurement techniques. The data review and analysis could include further consideration of the existing BASE data, and new data that are collected for other building types. Data obtained from the studies of various building types should then be combined to assess the relative contributions of these different indoor environments to total indoor exposure. Improved exposure models could then be developed and validated. An example would be a study on the impacts of sources in attached garages emanating into adjacent living spaces.

D.1.b. Conduct intervention studies of cost, health, and performance benefits resulting from best practices in building operation and design, and other best practices for voluntary risk reduction activities.

This research includes conducting intervention studies to determine whether the benefits resulting from application of building design and operation guidelines (best practices) outweigh the cost of implementing those guidelines. The research would initially be targeted to office buildings, schools, and residences. Given that the resources for applying the full range of building design and operation guidelines are often limited, the data from the field studies could be collected and reported in a manner that would assist building professionals in deciding which specific best practices provide the highest return on investment. Best practices for which there is the potential for significant application costs as well as substantial quantifiable benefits include:

- control of pollutant sources;
- moisture control;
- biocontamination prevention, clean-up and remediation;
- quantity and quality of outdoor ventilation air,
- operation, maintenance, and housekeeping practices;
- design, construction, and commissioning practices; and
- other recommendations in EPA's *Tools for Schools* kit and EPA's *Design Tools for Schools* website

This research could also include intervention studies to determine the benefits resulting from EPA's indoor air quality programs, specifically actions specified to reduce risk from indoor air toxics (e.g., the actions specified by the ETS and radon programs). Additionally, research is needed to determine the most effective voluntary risk reduction methods for chemicals that are known health hazards.

D.2. VENTILATION SYSTEMS

D.2.a. Analyze advanced ventilation system approaches.

Ventilation plays a major role in the health, comfort, and performance of building occupants, and in the initial cost, operating costs, and liability costs of buildings. Research should be performed to determine the value of the following promising ventilation technologies:

- Vertical displacement ventilation systems: This is an approach often used in European commercial buildings and schools to save energy and improve indoor air quality (Seppänen, Fisk, Eto *et al.,* 1989). The principle behind vertical displacement ventilation is a laminar flow of low pressure air that originates at the floor level and exhausts at the ceiling level, which 'lifts' pollutants away from occupants and reduces the transport and mixing of pollutants within the occupant breathing zone. There have been only a few demonstrations of this technology in the U.S. (Belida, Turner, Martel *et al.,* 1997). Research is needed to evaluate the European and U.S. results, assess the differences between European and U.S. applications (e.g., climatic variations, HVAC system influences, and energy prices), and identify the most appropriate applications of this technology in the U.S.

- Decoupled ventilation approaches: This approach involves separating the outdoor ventilation air from the air flow that is provided for space heating and cooling. The potential advantages of this approach include better control of indoor humidity, reduced capital costs, reduced energy costs and easier maintenance (Harriman, Brundrett and Kittler, 2001). Research should focus on how this technology could apply in different climatic regions, and how it would interface with commonly-used HVAC system designs.

- Automation of Heating, Ventilating and Air Conditioning (HVAC) controls: The primary purposes of HVAC controls are thermal comfort, energy-efficiency, and regulation of outdoor ventilation air flow into the building. Currently-available HVAC control systems often fail to perform as intended due to improper installation, adjustment and operation. Research is needed to prioritize equipment malfunctions and indoor contaminant levels that have the potential to affect indoor air quality, and to determine the value that improved controls, including new sensor technologies, would provide though self-diagnostics and automated corrective actions.

- Residential ventilation: Traditional heating and cooling systems in U.S. homes have not addressed the fresh air ventilation needs for home occupants. Homes experience inadequate ventilation because they rely on infiltration and natural ventilation with outdoor air rather than controlled mechanical ventilation systems. Energy-efficient home construction often results in 'tight' buildings with very low leakage (infiltration).

Over the past two decades, materials and techniques available to home builders have resulted in typical new homes having natural ventilation rates less than what is specified by the American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) for residences, a minimum of 0.35 air changes per hour (Howard, 2000; FSEC, undated). The result is stale air, moisture problems, and elevated pollutant levels indoors.

Positive mechanical ventilation with clean outdoor air is needed to dilute indoor contaminants. Mechanical ventilation is a relatively new practice for new home construction, and research is needed to determine the most practical and appropriate approaches which may, in fact, be climate-dependent. Research should include a survey to investigate the natural ventilation rate in homes via blower door testing; and studies intended to evaluate and improve the cost-effectiveness of controlled mechanical ventilation so that these systems are more-readily accepted by builders and homeowners.

Many Americans have residences in apartment buildings, with designs that range from small buildings with a few apartments to large, multistory buildings with hundreds of apartments units. Research is also needed to assess current ventilation approaches for apartment buildings, and to develop recommendations for advanced ventilation approaches that promote good indoor air quality.

- <u>Air filter efficiency</u>: Every type of building requires some degree of air filtration. Filtration is needed for several reasons, including protection of equipment, energy-efficient operation, and protection of occupant health and performance. The selection of an appropriate filtration system depends on several factors including the HVAC system design, the building design characteristics, occupancy requirements, and financial considerations (including life cycle costs and impacts on performance and productivity). A study is needed to determine the appropriate filtration approach for various building types and applications for these design parameters.

D.2.b. Develop recommendations for improving existing building ventilation systems.

Given that the proper quantity and quality of ventilation is a critical component of good IAQ, utilize a literature survey, field surveys, and field studies to identify the typical failure modes and operating problems for ventilation systems. Typical failure modes result from design and construction errors (such as selection of noisy equipment that is turned off by occupants, variable-air-volume (VAV) systems with fixed outdoor air dampers and/or no minimum settings to ensure adequate ventilation at reduced load); operation and maintenance errors (such as neglect, turning off ventilation systems due to noise or comfort, not performing a periodic check to measure the outdoor air flow rate); and simple deterioration of equipment. Based on this data, develop maintenance and operation procedures, and practical upgrades for existing ventilation systems, to help ensure a proper supply of outdoor air in existing buildings; and to stimulate the production of better ventilation equipment. Examples of potential research areas include optimizing the performance of unit ventilators in existing school classrooms, assessing and recommending ventilation approaches for multi-family (apartment) dwellings, and developing ventilation recommendations for urban areas with potentially large sources of outdoor pollution.

D.2.c. Characterize the impact of ventilation systems and occupant density on the rate of transmission of infectious diseases in indoor environments.

There is suggestive evidence that low outdoor air ventilation rates and high occupant density increase the transmission of common respiratory diseases such as the common cold and the flu virus (Wheeler, 1997). However, it is not clear the extent to which this occurs, and the extent to which increased ventilation rates mitigate the impacts of occupant density. In addition, vertical displacement ventilation systems may serve to reduce disease transmission from infected individuals by virtue of the air flow patterns that are established. Since respiratory disease impacts have a significant public health implication, and since sick absences are a significant cost factor to the economy, quantitative data on the impacts would go a long way to resolving the controversy surrounding the rate of ventilation that is considered adequate, and for identifying superior ventilation designs. Initial studies should be performed for high-occupant density environments, such as classrooms or auditoriums, to determine if there is a measurable effect and whether further investigations are warranted.

D.3. CONTROL OF RADON AND OTHER SOIL GASES

D.3.a. Conduct studies on potential humidity control benefits of radon mitigation systems.

The most commonly used approach for reducing radon levels in residential applications involves active soil depressurization (ASD). Radon mitigation systems based on this approach typically use one or more vent pipes with a fan to remove soil gases from beneath a home's foundation and vent the soil gases to a location away from the home's living space (U.S. EPA, 1993; ASTM, 2001). It is estimated that approximately 500,000 homes in the United States have had elevated radon levels reduced using ASD radon mitigation systems over the last 15 years (Jalbert and Gregory, 2002). There have been anecdotal reports that homeowners often perceive additional improvements in the IAQ in their homes after an ASD radon mitigation system has been installed. Common perceptions are that the home feels drier, there are fewer problems related to high indoor humidity, and musty odors in basements are reduced. Research is needed to investigate whether ASD radon mitigation provides additional IAQ benefits, particularly with respect to reducing indoor moisture and humidity problems, and which also could result in reduced indoor mold and mildew. Pending the results for ASD radon mitigation systems, follow-on investigations may be appropriate for passive radon control systems (passive systems do not incorporate a fan) that are commonly used in new home construction. Information to support this research need may be provided by ongoing programs such as that described in section D.3.c. for evaluating methods to control migration of volatile contaminants in soil gases into the indoor environment. Research should also investigate the effectiveness of radon mitigation systems over time (in reducing radon levels and potentially providing humidity control benefits).

D.3.b. Conduct studies to evaluate radon-resistant construction techniques for new homes.

Radon-resistant new construction (RRNC) techniques reduce indoor concentrations of radon by blocking radon entry points through the use of sealing techniques, and by using the natural upward thermal draft in a passive vent pipe to slightly depressurize the area under the home's foundation (U.S. EPA, 1994). The passive vent pipe is typically run through the conditioned portion of the home (usually hidden in an interior wall or pipe chase), and relies on the natural upward draft of gases in the pipe caused by the difference between indoor and outdoor temperatures. Research is needed in the following areas to support the EPA's Radon Program:

- Effectiveness of RRNC for reducing radon levels: Research conducted to date shows that RRNC techniques typically reduce radon levels by approximately 50%, on average, however there is a range in the reported results (NAHB Research Center, 1994; NAHB Research Center, 1996; LaFollette and Dickey, 2001). More research is needed to further investigate the effectiveness of RRNC techniques, which includes assessing the effect of builder installation techniques and quality control, and the effects of seasonal weather variations. Research should also investigate the effectiveness of RRNC over time. Research could also investigate the potential energy benefits and the Integrated Pest Management (IPM) benefits that may result from the improved home sealing associated with RRNC.

- Installation costs of RRNC: An often significant barrier towards getting builders to incorporate RRNC techniques into new homes is the incremental added cost for the features. Some studies were conducted in the early 1990s (ICF, Inc. & Camroden Associates, Inc., 1992), however research is needed to assess the current RRNC installation costs experienced by home builders. The research should consider situations where some of RRNC techniques are already implemented as part of the normal home building process (e.g., gravel layer, polyethylene sheeting, weatherization). The research should also investigate the additional costs associated with activating passive RRNC systems, which is accomplished by installing a fan and system operating indicator.

D.3.c. Conduct studies to evaluate methods to control migration of volatile contaminants in soil gases.

Another source of toxic contaminants indoors relates to contaminated soil gas resulting from contaminated ground water, leaking storage tanks, toxic dumps, and landfills. There are tens of thousands of Superfund and RCRA sites that are known and probably many that are still unknown. Volatile contaminants in soil gas can enter buildings in a manner similar to radon. Consequently, mitigation methods similar to those effective with radon may be used. However, current health-based risk reductions often requires much higher performance of the mitigation methods (such as sub-surface depressurization) than is required by the corresponding radon action level. Additional research and development may be required to optimize the performance of these systems.

The government currently has an emphasis on the development of Brownfields, many of which have contaminated ground water and vadose zones. Buildings constructed over these areas will be prone to indoor air toxic problems. This is a circumstance in which the methods for radon reduction in new construction should be revisited to ascertain their applicability to control these new soil gas contaminants. While many of the construction methods will be directly applicable to other toxic soil gases, some research issues exist. First of all, the required level of protection may be significantly higher than in the corresponding case for radon. Consequently, the level of performance of the proposed construction methods must be tested and demonstrated to provide adequate protection by reducing the risk levels appropriately.

There may be some implications for both active (fan-driven) and passive (natural draft) mitigation strategies for the toxic gases associated with volatile contaminants in the soil and groundwater. These gases may diffuse through concrete slabs more effectively than radon. Consequently, prevention of advective transport into buildings may not result in sufficient protection of the indoor environment. In the case of radon, it was observed that reversing the direction of air flow through the building foundation from inward to outward almost always reduced the indoor radon concentrations below the action level. This appeared to be true even when the sub-slab concentration of radon was only nominally reduced. This result agreed with measurements of diffusion rates through concrete slabs. If the effective diffusion rates through the slab are significantly higher for these other gaseous contaminants, then there may be potential for elevated indoor contaminant levels even when a negative pressure is maintained beneath the slab. Effective mitigation methods may be required, not only to reverse the direction of advective flow through the building foundation, but also to reduce the sub-slab concentration to quite low values. Some new research and development work may be required to extend the capabilities of current radon reduction methods to be effective against these new soil gas contaminants. Research should also investigate the effectiveness of these systems over time (in reducing radon levels and indoor concentrations of volatile contaminants from the soil and ground water). Research could also investigate the potential impacts of contractor qualifications and installation techniques on the effectiveness and durability of these systems.

D.3.c.1. Conduct studies to investigate relationships between subsurface concentrations and indoor concentrations of volatile contaminants.

A vapor intrusion-focused research topic that has recently been initiated by the EPA's Office of Solid Waste & Emergency Response (OSWER) and Office of Research & Development (ORD) involves efforts to collect evidence from investigations of vapor intrusion cases from across the United States for incorporation into the Indoor Air Vapor Intrusion (IAVI) database. This research effort is initially focusing on defensible evidence of the relationship between the subsurface concentrations and the associated indoor air concentrations (i.e., amount of attenuation in vapor concentrations), see: http://iavi.rti.org. Anticipated future efforts include working to identify the site-specific characteristics that influence the observed attenuation factors. This information could be used to help improve the accuracy of predictions and prevent the over- and/or under-regulation of these exposures.

D.4. BUILDING DESIGN AND IMPLEMENTATION

D.4.a. Conduct research to support building materials selection and installation procedures.

D.4.a.1. Compare and evaluate product emission methods and standards.

As part of the green building movement, a number of organizations have established mechanisms for evaluating or rating products with respect to their impact on indoor pollution and health. For example, Green Seal, a non-profit institution, provides product standards based on product formulations, while Green Guard, another non-profit organization uses an emission measurement method along with a set of health criteria. As the Green Building movement is rapidly expanding, and includes the encouragement and support of EPA, a host of institutions are using these or similar standards. However, there is a growing concern that many of these standards are not protective of health and may have little scientific foundation. The State of California has developed emission-based standards using California's acute and chronic exposure levels as it's health basis and appears to be the most scientifically supportable, but it has not received independent scrutiny or wide public acceptance. EPA is developing green building guidance for federal facilities but has yet to address the indoor pollution issues involved in the selection of products. Research is needed to provide a systematic comparison and evaluation of the major methodologies and standards used for evaluating products based on the extent to which they limit indoor air pollution and protect public health. Such research would inform the green building community and guide EPA as it develops and refines its guidelines.

D.4.a.2. Develop a building materials selection and installation protocol.

The materials, finishes, furnishings, maintenance supplies, and housekeeping supplies that go into new or existing buildings can have a major impact of the quality of the indoor air. Building professionals responsible for the materials acquisition are becoming more aware that proper selection is important to the health and performance of occupants. Comprehensive yet easy to follow guidelines on how to best select products are urgently needed, yet the development of such guidelines is not possible without emissions and health effects data on key building sources and products. Research should identify the sources and products with the greatest impact on IAQ, and characterize their emissions and health effects. This research interrelates with the *Chemicals and*

Sources program needs in this document, which describe developing quantitative emissions factors for various sources (section A.1.d.2).

With this information, a set of quick and easy materials selection guidelines, providing objective criteria to building designers, could be developed. Criteria could then be developed for determining what constitutes 'best' materials, including effects on occupant health and performance (as information is available), initial capital costs, operating costs, materials performance, life-cycle costs, outdoor environmental impacts, and other impacts on indoor quality through activities such as materials maintenance and replacement.

In addition to materials selection, it is also important to determine appropriate recommendations for installation, for example, scheduling sequence and minimal use of problematic emitting materials.

D.4.b. Conduct studies on the relationship between IAQ, energy efficiency, and moisture management.

Current market trends include designing and constructing energy-efficient buildings, which often results in practices that can adversely affect the quality of the indoor environment. Energy-efficiency and IAQ are strongly interdependent. Proper implementation of energy-efficiency measures requires a thorough consideration of IAQ impacts. Similarly, IAQ measures must be implemented in a manner that is consistent with energy-efficiency goals. For example, there is often a perceived conflict between ventilating with an adequate quantity of outdoor air and the need to minimize energy costs. Research is needed to investigate energy-efficient heating, cooling and ventilation techniques which promote good IAQ.

Energy-efficient buildings can have IAQ problems when moisture management is not properly addressed during the design and construction. Moisture management is often a climate-specific issue. Improperly designed and constructed buildings and mechanical systems can cause indoor moisture problems due to air-flow-induced moisture transfer through the building shell, condensation, outdoor air ventilation, and improper surface water drainage. Research is needed to develop design guidelines that will minimize the potential for mold and comfort problems resulting from excessive indoor moisture.

D.4.c. Evaluate current and popular building practices.

Several practices in building design and operation can have a substantial impact on indoor air quality, thus affecting health and performance. Many of these practices result from current trends in 'green building' and sustainable development. Following are examples of building practices that should be evaluated for indoor air quality, economic, and performance impacts:

- Use of recycled content materials in new and existing buildings;
- Siting new buildings on brownfields, landfills, and other contaminated sites (e.g., evaluating soil gas intrusion and its contribution to indoor contaminant levels, and evaluating the effectiveness of mitigation techniques such as sub-slab depressurization);
- Siting new buildings in areas with high moisture load potentials, such as filled-in wetlands and flood zones;
- Use of air purification such as germicidal ultraviolet lights, carbon air filters, and ion and ozone generators (see also sections F.1 and F.2);
- Use of biocides in building materials, maintenance supplies, and air filters (see also section F.1);
- Duct cleaning (determining whether it is needed, what methods are most effective, and the relative value of duct cleaning versus air handling unit cleaning);
- Floor type and materials selection;
- Floor care focused on particle control via high-efficiency vacuums, central vacuums, entry mats, floor maintenance materials and procedures;
- Sloped roofs as an alternative to the flat roof systems that are typically used in non-residential buildings, to provide better moisture management;
- Attached garages (e.g., evaluating contaminant levels and exposures in adjacent occupied spaces, assessing building design impacts and mitigation strategies);
- Building and HVAC system commissioning and periodic re-commissioning (commissioning is a formal process intended to verify and document that a building and/or HVAC system is constructed, adjusted, and performing in a manner consistent with its intended design);
- Building flush out to remove built-up contaminants prior to occupancy.

Program Applications for Building Design and Operation Research:

Historically, risk evaluations of environmental exposures have focused on long term exposures leading to chronic diseases such as cancer. Exposures are often modeled based on limited field data. With the development of the Building Assessment Survey and Evaluation Study (BASE), the EPA is making data available, specific for commercial office buildings, for rigorous assessments of both chronic and short term exposures and risks. With BASE data, researchers are now beginning to examine exposures leading to other health endpoints such as respiratory diseases, as well as health symptoms such as headache and mucous membrane irritation. Examination of the building conditions and practices that lead to these health effects can also be examined. The proposed research for the development of similar data on other building types, using compatible data collection protocols, would lead to a broad set of analyses to identify the full impact of indoor air on health, comfort, and productivity of occupants; the attributable risk associated with specific building contaminants, sources, and practices; and the mitigation steps required to minimize risk.

New ventilation technologies and systems, such as displacement ventilation, decoupled ventilation, as well as energy recovery ventilation systems have the potential to greatly improve indoor air quality at significantly reduced energy costs. In addition, new controls and automation systems stand to greatly improve system efficiencies. The proposed research is designed to accelerate the demonstration and adoption of these technologies.

In addition, the EPA has provided the most comprehensive and up to date IAQ guidance for commercial buildings, schools, and radon in residences. However, while the guidance is comprehensive, it is generic, and not necessarily tailored to the actual building stock. The next steps in the evolution of this guidance await further research. The proposed research would evaluate the effectiveness of mitigation practices that are recommended, identify and assess the most common failures of building systems and controls that lead to indoor air quality risks, and evaluate new technologies and products that could improve or degrade progress toward improved indoor environments.

Further, the proposed research is designed to provide information needed to guide ever-growing constituencies for indoor air, such as those constituencies dealing with energy efficiency, green building design and construction, and homeland security.

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E. HOMELAND SECURITY

Background Information:

Recent events and the increased threat of terrorist activities in the U.S. have heightened the need for measures to prevent and clean-up potential releases of chemical, biological, and radiological warfare agents into buildings. There are also instances when remedial measures are needed to address accidental and unintentional releases of toxic substances and other potentially hazardous conditions within the indoor environment. This section presents a simple overview of potential research initiatives in these program areas, which are rapidly emerging. The EPA will likely be receiving major funding increases in FY03 and outyears for research initiatives related to homeland security, planned for execution within several offices including the Office of Research & Development (ORD); the Office of Solid Waste & Emergency Response (OSWER); the Office of Water (OW); the Office of Prevention, Pesticides and Toxics (OPPT); and the Office of Air and Radiation (OAR).

Because this is a rapidly emerging area, the present version of *PNIER* does not attempt to capture all of the detailed indoor environments research initiatives that can and should be pursued by the EPA for homeland security. The broad research initiatives identified in this section of *PNIER* will be further developed, shaped and refined as the larger EPA initiatives and programs become established. In September 2002, the EPA published a high-level strategy for homeland security (U.S. EPA, 2002), and efforts will be made to ensure that the indoor environments research needs contained in *PNIER* are consistent with that strategy. The EPA's Office of Research & Development has established a National Homeland Security Research Center (NHSRC), and a Safe Buildings research program for addressing detection/sampling and analysis; containment; decontamination; and disposal. All homeland security research outlined in this document will be closely coordinated across these Agency programs.

There are several chemical agents (e.g., nerve agents, blister agents, choking agents) and biological agents (e.g., anthrax, botulinum toxin, ebola, ricin, etc.) which could be employed under terrorist or wartime activities because of their direct toxic effects. Although there are several thousand poisonous agents known, only a limited number are generally considered suitable for warfare due to their nature and ability for storage and resistance to climate.
While some treatments and antidotes are known for a portion of these agents, there is a great deal of research that needs to be done. However, due to the varied nature of the agents and the multitude of ways to expose a population (i.e., in the water supply, as a plume in the outside air, through the ventilation system in a building, or as a direct contaminant release inside a building), it is not reasonable to expect that the most effective immediate reaction to these threats will or should be medical in nature. Therefore, it is important to establish ways to limit the ability of these agents to reach the population at large, particularly in the indoor environment.
Any products or technologies developed for homeland security should be objectively evaluated, with thorough performance verification.

Program Needs for Homeland Security Research:

E.1. Conduct simulation modeling studies of contaminant releases to determine critical pathways and control variables.

Releases of chemical, biological, and radiological agents should be simulated under a variety of conditions and assumptions of survival potential, using available building air flow models (research may reveal that modifications are needed for existing models). Studies are needed to characterize the fate and transport of chemical, biological, and radiological agents in indoor environments under a variety of conditions, including: outdoor releases, indoor releases, and point sources which could include individuals. The information obtained during this research will serve as a foundation for prevention, mitigation and clean-up guidelines for the indoor environment.

E.2. Conduct research to support the development of EPA guidance to ensure emergency preparedness in building types through operation and maintenance practices.

In its role as the lead government agency for building emergency preparedness, the EPA needs to develop credible and practical guidance for building owners and operators to ensure adequate protection in the event of a chemical, biological or radiological contamination incident. Research is needed to develop, demonstrate, and verify building operation and maintenance practices which help prevent indoor air contamination, and ensure suitable building emergency preparedness. This should include development of building ventilation system operation and maintenance recommendations, considering both outdoor and indoor sources of the contaminants, and identifying the key variables that can be controlled to prevent and mitigate contaminant transmission. Once developed, these recommendations could be added to existing educational and support materials used by building operators (e.g., maintenance and operation checklists).

E.3. Conduct research to support the development of EPA guidance to ensure emergency preparedness in building types through new technologies and materials.

Research is needed to identify and develop suitable detection methods for chemical, biological, and radiological contaminants. Special considerations should be given to the development of practical sensor and control system technologies that will allow immediate identification and automated building response to a potential threat. Other technologies that warrant research include improved air filtration and cleaning system designs, and alternative air distribution system designs. New technologies and materials must have the capability to be applied cost-effectively to a broad range of contaminants and building types.

E.4. Conduct research to support building clean-up and re-occupancy.

After emergency response, the issue of clean-up after a chemical, biological, or radiological warfare incident or an accidental toxic release is a matter of continued concern. There is insufficient information available to support the use of existing building clean-up protocols with a high degree of confidence. Highly-controlled laboratory studies should be conducted to establish with confidence appropriate cleaning agents and processes to ensure that clean-up is successful, and that workers are sufficiently protected. Information from these studies will be used to establish guidelines for EPA and other public health entities engaged in clean-up efforts. Specific research areas include:

- reviewing currently available threat analyses (including NHSRC's efforts)
- developing lists of contaminants of concern (e.g., from terrorism, criminal activities, or accidental incidents),
- conducting baseline contamination and decontamination studies,
- developing standards for appropriate levels of clean-up, which could be dependent on the specific contaminant(s) and other building-related factors. This would be closely coordinated with NHSRC's Rapid Risk Assessment Program.

E.5. Verify the performance of products and technologies developed to address homeland security.

Verification is needed to validate claims for products and technologies that have been and are being developed to address homeland security concerns. For example, in response to recent terrorist incidents there is an increasing number of products being developed and marketed to address issues such as biological warfare (e.g., the release of anthrax from intentionally contaminated mail in office buildings), and exposure and clean-up after terrorist incidents. The protection of the American citizens is of utmost concern, and there needs to be objective research performed to ensure that only safe, credible and reliable products are introduced into the public marketplace. These research efforts will be closely coordinated with the NHSRC's Environmental Technology Verification (ETV) efforts.

An example would be to investigate the effectiveness of sheltering-in-place actions for schools, office buildings, and other public facilities. This has already been demonstrated for residential applications under the Chemical Stockpile Emergency Preparedness Program (Sorensen and Vogt, 2001).

Program Applications for Homeland Security Research:

The vulnerability of building occupants to a chemical or biological attack depends on the location of the release, characteristics of a building that affect air flow patterns, the location of occupants, and the preparedness of the building management to recognize an attack, and to subsequently be able to isolate and contain the contaminants. The proposed research would provide the basis for the EPA to develop guidelines for building and governmental officials to prepare for and react appropriately to an attack. In addition, further proposed research is needed to prepare for effective clean up of the attack agents and other related contaminants after the attack, so that buildings can be re-occupied.

References for Homeland Security Research:

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F. PRODUCT AND TECHNOLOGY VERIFICATION

Background Information:

There are several products and technologies available in the public and commercial marketplaces that are promoted for their contribution to a healthy indoor environment. In many cases, the effectiveness and net health impacts of these products and technologies have not been fully evaluated. The research needs described in this section are intended to address some of these information gaps, however it is expected that the scope of the research will likely exceed what is captured in this document as new products and technologies evolve.

Program Needs for Product and Technology Verification Research:

F.1. Conduct research on source control products and technologies.

Often the most effective approach to reducing indoor air contaminant exposure is source control. Source control involves both removal and control of contaminant levels. There are several products and appliances marketed for use on surfaces and in ventilation systems (e.g., anti-microbial cleaners and sealants, air fresheners, vacuum cleaners, etc.) which are marketed for this purpose. Many of these products have not been fully assessed for their net effectiveness in improving indoor air quality, and some of these products can themselves be sources of indoor air pollution. In addition, the impact on human health especially from inhalation exposure to these products or by-products produced during use of some of these products has not been fully investigated. One major concern from a health standpoint is the increased incorporation of anti-microbial agents and fragrances in some of these products. There are also concerns expressed in literature about the potential impact of high-level use of these products on human immune system development and biological organism resistance as well as the unknown potential for health impacts from long-term, low-level exposures, which have not been investigated. Further research is needed on each of these issues and data gaps.

F.2. Investigate the performance of air treatment systems.

The performance of air cleaning systems (e.g., ionizers, electrostatic precipitators, ultraviolet germicidal lights, photocatalytic cleaners, activated carbon filters, and alumina coated filters), and filter efficiencies need to be investigated to compare the results with vendor claims. These devices are widely advertised as effective methods for cleaning up the air and providing symptomatic relief for individuals with indoor air health and comfort concerns. However, air cleaning devices and air filters are not generally sufficient by themselves to reduce indoor air contaminant exposures especially when there are large pollutant sources, or the pollutants themselves settle-out on surfaces. In general, the health benefits of air filters and air cleaning devices are not objectively clear and most claims are based on the very limited scientific evidence. In addition, there are several questions about the potential for adverse impacts on respiratory tissues and chronic or latent health effects due to contaminants (e.g., ozone, hydroxyl radicals and other oxidizing agents, ionized particles, formaldehyde, etc.) emitted by some air cleaning devices that have not been thoroughly investigated. As part of this work there is a need to assess and input into the test standards presently used by the industry for various categories of equipment.

F.3. Investigate risk management controls for indoor fuel-fired heating and cooking devices.

Billions of people around the world are exposed to high levels of combustion byproducts from indoor use of propane, methane, kerosene, natural gas, traditional biomass (e.g., wood, dung, and crop residues), and other fuels during heating and cooking. The specific pollutants of concern and the potential health risks from these indoor exposures are dependent on several factors including fuel types, appliance designs, building factors (i.e., ventilation levels, building design, room dimensions, etc.), use patterns, and individual susceptibilities and vulnerabilities with potentially greater impact on highly vulnerable populations such as the elderly, women, children, the chronically ill, and the economically disadvantaged. In addition, the choice of appliance and fuel-type is often associated with societal and cultural issues or beliefs. Biomass burning is associated with 1.6 million deaths per year, adverse pregnancy outcomes, and increased risk of serious respiratory infections worldwide (WHO 2002).

In the United States and several other industrialized countries, there is a body of literature and research on the performance of indoor fuel-fired heating and cooking devices, potential levels of indoor contaminants resulting from these devices, potential health impacts of these contaminants at higher levels, and performance certification programs for some appliances and fuel types. A large portion of the global population is exposed to high levels of contaminants from a wide variety of device designs, particularly in non-industrialized nations. There are also several unknowns related to the specific health impacts of exposure to lower levels of contaminants and exposures experienced by certain susceptible populations, use patterns, and risk reducing technology modifications that need to be addressed (see also A.1.b and A.1.h.2). Several studies in developing countries have documents the health impacts of burning traditional biomass and coal fuels indoors for home cooking and heating. Assistance is needed with evaluating risk control options that are being employed and building local/regional capacity for monitoring indoor air pollution in homes with improved technologies.

Research is needed to investigate and develop self-sustaining and viable risk control and risk management options. Research should consider social, cultural, and economic barriers related to the use of fuel-fired heating and cooking devices and fuel choices in a variety of industrialized and non-industrialized settings. These investigations should include consideration of new risk reduction technologies and development of design guidance or standards. Specifically, research is needed to investigate the performance of improved cook stoves, as more information is needed on the emissions, efficiency and reliability of improved technologies and fuels that are being developed and promoted. Research is also needed to investigate the performance of new personal monitoring devices that have been developed to measure PM and CO, and to develop and establish recommended sampling methods for these devices.

Program Applications for Product and Technology Verification Research:

As good indoor air quality becomes more widely appreciated and desired by consumers, a host of products are being increasingly developed and marketed to solve or protect against indoor air quality problems. These products include new air cleaning technologies, anti-microbial agents, air fresheners, and air quality sensors. With this increased presence in the marketplace there have been increased inquiries concerning the efficacy, effectiveness, and benefits of these products. However, whether many of these products work, how they work, and what possible secondary contaminants or health effects may be created or enhanced from use of some of these products is often unknown and is of utmost concern to the indoor air quality community.
The research proposed in this section addresses the need for further evaluation of the performance, effectiveness, and potential positive and/or negative impacts on indoor air quality and human health from these types of products. This information will help EPA and other concerned federal, state and local organizations to subsequently issue information reports and guidelines to potential users.

References for Product and Technology Verification Research:

World Health Organization (WHO). 2002. Reducing Risks, Promoting Healthy Life. Geneva, Switzerland: World Health Organization.