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GAO

Report to the Ranking Minority Member
Committee on Government Reform
House of Representatives

August 1999

INDOOR POLLUTION

Status of Federal Research Activities

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Accountability * Integrity * Reliability

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General Accounting Office
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Resources, Community, and
Economic Development Division

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August 31, 1999

The Honorable Henry A. Waxman
Ranking Minority Member
Committee on Government Reform
House of Representatives

Dear Mr. Waxman:

This report responds to your request for information on the status of federal agencies' research activities on indoor environmental quality.

We are providing copies of this report to other appropriate congressional committees; the Director, Office of Management and Budget; the Administrator, Environmental Protection Agency; the Chairman, Consumer Product Safety Commission; and the Secretaries of the departments of Commerce, Energy, Health and Human Services, Housing and Urban Development, and Labor. We will also make copies available to others upon request.

If you or your staff have any questions regarding this report, please contact me at (202) 512-6111. Key contributors to this assignment are listed in appendix IV.

Sincerely yours,

David G. Wood

David G. Wood
Associate Director, Environmental
Protection Issues

Executive Summary

Purpose

Over the past two decades, particularly since the energy crisis of the 1970s, there has been a growing understanding of the hazards to human health posed by exposures to the pollutants commonly encountered in homes, schools, offices, and other indoor environments —places where most people spend the major portion of their lives. Initially, scientific interest focused on indoor air pollutants, primarily because of suspicions, later confirmed by research, that some of the measures taken to improve the energy efficiency of buildings could increase indoor air concentrations of pollutants, such as carbon monoxide and other by-products of combustion, as well as concentrations of toxic emissions from products and materials widely used in building construction and furnishings. While indoor air quality remains a matter of considerable public and scientific concern, research has also shown that the health risks posed by pollutants present in the indoor environment extend beyond inhaling air contaminants. Many of the products routinely used and stored indoors, such as paints, solvents, cleaning products, and pesticides, as well as contaminants that are frequently tracked indoors from the outside pose potential health risks through other means, such as skin contact and ingestion. Concerned about the pace of progress in understanding and devising effective solutions to the problem of indoor pollution, the Ranking Minority Member of the House Committee on Government Reform asked GAO to (1) characterize the current scientific understanding of the health risks of pollutants commonly found in indoor environments and the sources of exposure to these pollutants; (2) provide information on the federal funding of indoor pollution-related research in recent years and the advances in the scientific understanding of indoor pollution and the ability to control it that have resulted from this spending; and (3) identify the significant gaps in the knowledge and understanding of the problem and the solutions for dealing with it, as well as the implications of these gaps for future research.

Background

Although the Environmental Protection Agency (EPA), the Consumer Product Safety Commission, the Department of Energy, and other federal agencies had conducted limited research related to various aspects of indoor pollution in the 1970s and early 1980s, the first legislation to deal specifically with this problem was not enacted until 1986. Title IV of the Superfund Amendments and Reauthorization Act of 1986 called for EPA to establish a formal program of research with respect to radon, a naturally occurring radioactive gas, and indoor air quality.[1] It also called for EPA to disseminate the results of its research and to establish an advisory

[1]P.L. No. 99-499, 100 Stat. 1613, 1758 (1986) (codified at 42 U.S.C. Sec. 7401 note (1995)).

committee composed of federal agencies to help it carry out its research and information dissemination activities. To meet this latter requirement, EPA relied on an interagency consultative body, the Committee on Indoor Air Quality, composed of agencies, such as the Department of Housing and Urban Development and the Consumer Product Safety Commission, whose missions were in some way related to the healthfulness of indoor environments.[2] In 1989, as required by the 1986 legislation, EPA submitted a report to the Congress on indoor air quality and radon. The report described the research that EPA and others had conducted up to that time and the general understanding of the problem. It also outlined a broad agenda of research that EPA, in consultation with others, had concluded would be needed to increase the scientific understanding of the problem and the ability to devise effective solutions for it.

In October 1991, GAO reported on the progress by EPA and other federal agencies in implementing the 1986 legislation and advancing its objectives.[3] GAO concluded that EPA's emphasis on indoor air pollution, as reflected by the amount of funding for research and related activities, was not commensurate with the health risks posed by the problem—a high comparative risk ranking made by the agency and endorsed by its Science Advisory Board.[4] GAO also concluded that better coordination was needed among federal agencies in their indoor air-related activities, including research. GAO reported that EPA's indoor air-related research had been, and likely would continue to be, constrained by a lack of funding, largely due to an increase in the agency's overall program responsibilities over the years that was not accompanied by a corresponding increase in its budget. Also contributing to this problem was the fact that the indoor air program, unlike other statutorily mandated EPA programs, did not have the kinds of legislatively mandated time frames and goals that tend to drive the resource allocation process and set research funding priorities. With respect to cooperation and coordination among members of the Committee on Indoor Air Quality, GAO found that the limited participation by agencies other than EPA and the lack of a clear charter for the body had inhibited its effectiveness as a means to coordinate federal indoor air pollution efforts and avoid duplication.

[2]The Committee was first set up in 1979, disbanded during the tenure of EPA Administrator Anne Gorsuch, and reinstituted in 1984 in response to an appropriation giving EPA funds to conduct research on indoor air issues. Current members of the Committee on Indoor Air Quality are listed in app. II.

[3]Indoor Air Pollution: Federal Efforts Are Not Effectively Addressing a Growing Problem (GAO/RCED-92-8, Oct. 15, 1991).

[4]A public advisory group established within the Office of the EPA Administrator to provide independent, expert advice on scientific matters related to EPA's mission responsibilities.

In its 1991 report, GAO made several recommendations intended to (1) ensure that the funding of indoor air pollution-related activities, including research, would be commensurate with the high public health risk posed by the problem and (2) enhance the effectiveness of the Committee on Indoor Air Quality as a mechanism for planning and coordinating research. GAO also suggested actions that the Congress might take to enhance the effectiveness of the Committee as it considered proposed legislation to enlarge the federal role in this area. This review provided little evidence that EPA implemented GAO's recommendations in that report. In addition, the proposed Indoor Air Quality Act of 1991 was not enacted by the Congress.

Results in Brief

EPA officials and others have consistently identified indoor pollution as one of the most serious environmental risks to public health. Pollutant exposures encountered indoors, resulting from natural causes, such as radon gas; from commonly used consumer products, such as cleaners, deodorizers, paints, and solvents; or from a variety of indoor activities, such as cooking, showering, and smoking, can result in some of the most serious pollutant exposures people receive as they go about their daily lives. This is explained by the fact that concentrations of pollutants in indoor air can exceed those found in outdoor air by a factor of 2 to 5 (and sometimes much more); by the sheer amount of time most people spend indoors (an average of 80 to 90 percent, even more for certain particularly vulnerable population groups, such as the very young, the infirm elderly, and the chronically ill); and by the peculiarities of the indoor environment, such as the presence of materials and surfaces that can act as emitters and reservoirs of pollutants.

Federal agencies reported that they will have spent a total of almost $1.1 billion on indoor pollution-related research from fiscal years 1987 through 1999 (in 1999 constant dollars).[5] Just over half of the agencies' actual and planned expenditures went for research related to indoor air, while about one-quarter went for research related to the hazard posed by lead in the indoor environment. The remaining spending was for research relating to the hazards presented by radon and asbestos. During this period, about 64 percent of the spending went for research conducted or sponsored by four institutes of the National Institutes of Health to provide a better understanding of the health effects associated with indoor pollution, including allergies, asthma, and infectious diseases. While some

[5]Agencies' spending is expressed in constant dollars to account for inflation and to facilitate interyear comparisons.

of the agencies, such as the National Institute for Environmental Health Sciences,[6] have experienced an increase in indoor pollution-related research funding over this period, funding for such research has declined in other agencies, including the Department of Energy.

As a result of research funded by the federal government, a few state governments, and others since the early 1970s, notable progress has been made in understanding the problem of indoor pollution and in devising strategies for mitigating pollutant exposures. Consumer products have been reformulated, and building materials and practices have been altered. Guidance documents have also been developed for use by building managers, homeowners, and consumers to help them better understand the causes and the sources of indoor pollution and enable them to take steps to prevent pollution problems or remedy them when they occur.

Notwithstanding the progress that has been made in understanding and managing the problem of indoor pollution, GAO's review of the scientific literature as well as comments provided by agency officials and other experts clearly showed that many gaps in knowledge and understanding of the problem remain. These include gaps and uncertainties with respect to (1) the identity and the sources of pollutants; (2) the mechanisms by which people are exposed to them; (3) the health effects resulting from prolonged and intermittent exposure to low-level concentrations of chemical and biological pollutants as well as complex pollutant mixtures; and (4) the most cost-effective strategies for reducing pollutant sources, exposures, and consequent health effects. The consensus of experts GAO consulted is that significant progress in filling these gaps and resolving these uncertainties will require a comprehensive and coordinated research effort involving multidisciplinary research teams composed of experts in such areas as epidemiology, exposure assessment, medicine, chemistry, microbiology, and building systems.

Principal Findings

Current Understanding of the Risks of Indoor Pollution

In 1987, EPA officials ranked indoor radon and other indoor air pollution among the top 5 of 31 enumerated environmental risks. This comparative risk ranking was based, in large part, on an understanding of (1) the health

[6] The National Institute for Environmental Health Sciences engages primarily in basic research designed to increase the scientific understanding of the toxic, mutagenic, and other effects of a broad range of chemical and other substances found in the outdoor as well as indoor environments. Thus, its research efforts are often less specific to the indoor environment than those of other agencies.

risks posed by radon and such other indoor air pollutants as asbestos fibers and environmental tobacco smoke (secondhand smoke) and (2) how some of the measures taken to conserve energy use in homes and other buildings might increase concentrations of indoor pollutants and result in other indoor conditions threatening to the health of the occupants. Since 1987, research has broadened scientific understanding of the indoor environment and provided strong additional evidence that pollutant exposures encountered indoors can, by virtue of peculiarities of the indoor environment and the sheer amount of time spent there, constitute some of the most serious environmental exposures people receive. The sources of these exposures include not just those that commonly come to mind, such as radon gas seeping into a house through cracks in its foundation, or by-products of combustion, such as carbon monoxide and nitrogen oxides from cooking on gas stoves or burning wood in fireplaces. They also include inhalation, skin contact, and ingestion exposures to toxic substances contained in cleaning and disinfecting products, pesticides, paints, solvents, air fresheners, moth repellants, arts and crafts materials, and a variety of other substances widely used and stored in homes, schools, offices, and other buildings.

Health-threatening indoor exposures can also result from a variety of biological contaminants that often occur indoors. Such exposures often result from poor building maintenance and housekeeping practices; excessive moisture resulting from the tightening of buildings to make them more energy efficient; the inadequate venting of humidity sources, such as bathrooms, kitchens, and laundry rooms; or water leaks through a building's exterior shell into the interior. Biological contaminants include allergens from such sources as dust mites, cockroaches, and pets;[7] bacteria and other infectious disease agents; fungi and their products, including volatile organic compounds; and other toxins. The mixtures of toxic chemicals and other contaminants often found in house dust that becomes embedded in carpets, upholstery, and other indoor surfaces also present serious hazards. These exposures, which can result from disturbing dust on indoor surfaces, may occur by inhaling fine particles, having skin contact with them, ingesting them, or any combination of these means. Exposures to pollutant-laden house dust are believed to be particularly problematic for toddlers and small children who spend a large amount of time on or near the floors of their homes, day care centers, and schools and often put things in their mouths.

[7]Allergens are foreign substances, often plant and animal proteins, such as pollens, excretions from cockroaches and dust mites, and dander from household pets. In susceptible individuals, allergens induce a specific type of immune response that produces allergic, or IgE, antibodies. The production of allergic antibodies can result in the symptoms of allergies.

Funding of Research Related to Indoor Pollution by Federal Agencies

From fiscal year 1987 through fiscal year 1999, the federal agencies covered by our review will have spent a total of almost $1.1 billion for research designed to improve the understanding and the control of pollution in the indoor environment.[8] The major portion of these research expenditures, about 78 percent, has been for research related to a wide range of indoor air quality issues as well as the health risks posed by lead in the indoor environment. The remaining 22 percent of spending has been devoted to research related to the hazards presented by radon and asbestos indoors. Total annual spending for indoor pollution-related research peaked in fiscal year 1995 at about $103 million and then declined somewhat in the 3 succeeding fiscal years, averaging about $87 million per year. However, total planned spending for fiscal year 1999 represents, essentially, a return to the fiscal year 1995 level. The National Institute for Environmental Health Sciences, a component of the National Institutes of Health, accounted for about 37 percent of the nearly $1.1 billion in total federal spending since 1987. Four institutes within the National Institutes of Health together accounted for about 64 percent of the total federal spending for that 13-year period. EPA, the Department of Energy, and the Department of Housing and Urban Development were the next largest spenders, each accounting for 7 to 13 percent of the total spending. The Consumer Product Safety Commission, the National Institute for Occupational Safety and Health, and the National Institute of Standards and Technology each accounted for 2 percent or less of the total federal spending for that period.

Progress Resulting From Research Related to Indoor Pollution

During the past two decades, notable progress has been made through federally funded research to understand the sources, the exposure mechanisms, and the potential health risks of pollutants in the indoor environment; to devise strategies for controlling pollutant sources and mitigating exposures; and to disseminate information to the public on actions to provide protection from the hazards of indoor pollution. As a result of research on the sources and the dangers of indoor exposure to radon, mitigation techniques were developed to reduce that threat. Thousands of homes have been tested for radon and modified, as necessary, to prevent high indoor air concentrations of this pollutant. As a result of research demonstrating the health risks of exposure to environmental tobacco smoke, policies have been adopted by federal, state, and local governments and by businesses to greatly reduce involuntary exposure to secondhand smoke in offices, theaters, arenas, and other public spaces and in public transportation. With public

[8] See app. I for a list of agencies.

education and changes in attitudes regarding smoking, experts believe (although there is not yet good empirical data for confirmation) that there has also been a reduction in involuntary exposures to secondhand smoke in private homes, particularly exposures of children.[9]

As a result of research to measure indoor exposures to pollutants and to identify and quantify sources, many important indoor pollutants and their major sources have been identified, and measures have been taken to reduce human exposures through source reduction and control. One important example is formaldehyde, an acute irritant and suspected human carcinogen, which was found to be emitted by a number of indoor sources. Research has led to changes in the manufacturing practices for many indoor products and materials, including paints, insulation, carpeting, and pressed wood products that had been identified as major sources of this pollutant. As a result, highly elevated indoor concentrations of formaldehyde are now less common than in the past.

Federally funded research has also resulted in the development of measuring and modeling tools to diagnose and solve indoor pollution problems and design healthier buildings. For example, research has advanced the basic understanding of the process by which outside air infiltrates through cracks in the exterior shells of single-family residential structures. Currently, this infiltration is the major means of ventilation for these buildings and strongly influences pollutant removal as well as the energy needed to heat or cool them. Similarly, many findings from research on the relationship of indoor air quality to heating, ventilating, and air conditioning technologies and practices have been incorporated in industry-developed guidelines, standards, and handbooks. Educational and guidance materials for building operators have also been developed and widely used.

Additional Research Is Needed to Fill Gaps in Knowledge and Resolve Uncertainties

Despite the progress in understanding and managing the problem of indoor pollution that has been achieved through research over the past two decades, many important gaps in knowledge of the problem remain, including significant uncertainties related to exposures and health effects. Many of the agency officials and other experts GAO contacted commented that the progress made to date in understanding this problem has only enhanced the appreciation of its complexity, the broad range of its potential impacts on human health, and the difficulty of devising effective

[9]Under a cooperative agreement with EPA, a telephone survey was conducted in 1994 and 1996 that found that that 29 percent and 27 percent, respectively, of children age 6 and under were exposed to environmental tobacco smoke in their homes.

and affordable solutions. There are a number of major research needs implicit in these knowledge gaps and uncertainties that must be addressed to reduce the many remaining and significant health risks in the indoor environment. These risks include cancer, the indoor transmission of such diseases as colds, influenza, and tuberculosis; such building-related illnesses as Legionnaire's disease and hypersensitivity pneumonitis;[10] the range of nonspecific health symptoms associated with sick building syndrome and multiple chemical sensitivities; allergies; and the growing problem of asthma.

Experts GAO consulted were in general agreement that further reductions in exposures to and adverse health effects from indoor pollutants will require continued efforts to develop a sound scientific and quantitative understanding of the complex relationships among building factors, indoor pollutant exposures, and health effects. Exposure assessment, particularly to improve the understanding of the relative contributions of indoor and outdoor exposure to total human exposure to particular pollutants or pollutant classes, will be needed to resolve some of the uncertainty that currently clouds risk assessment for indoor pollutants. Additional research on health effects will also be needed to reduce uncertainty in risk assessment and to highlight those risks that merit priority attention for mitigation. There was consensus among these experts that continued progress in dealing with the indoor pollution problem requires research that promotes a clear understanding of cause and effect relationships—not just documentation of phenomena, as has often been the case up to now. There was also agreement that achieving this understanding will require multidisciplinary research teams that bring together experts in such areas as building systems, indoor pollutants and sources, exposure assessment, epidemiology, health effects assessment, and pollution control technologies.

Recommendations

GAO is not making any recommendations in this report.

Agency Comments

We provided the departments of Energy and Housing and Urban Development, the Environmental Protection Agency, the National Institutes of Health, the Occupational Safety and Health Administration, the Consumer Product Safety Commission, the National Institute for Occupational Safety and Health, and the National Institute of Standards and Technology with a draft of this report for review and comment. The

[10] A chronic respiratory distress syndrome characterized by a delayed immune response to a substance that sensitizes the immune system.

departments of Energy and Housing and Urban Development, the Occupational Safety and Health Administration, and the National Institute of Standards and Technology agreed with the contents of the report and had no comments. The Consumer Product Safety Commission, the Environmental Protection Agency, the National Institute for Occupational Safety and Health, and the National Institutes of Health also agreed with the report and provided technical and editorial comments that have been incorporated in the report, as appropriate.

Contents

Chapter 4 Despite Progress in Understanding and Managing the Risks Posed by Indoor Pollution, Many Uncertainties and Knowledge Gaps Remain

Appendixes

Table

Figures

Abbreviations

ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BASE	Building Assessment Survey and Evaluation
CDC	Centers for Disease Control and Prevention
CIAQ	Committee on Indoor Air Quality
CPSC	Consumer Product Safety Commission
DDT	dichloro-diphenyl-dichloro-ethane
DHHS	Department of Health and Human Services
DOE	Department of Energy
EPA	Environmental Protection Agency
HUD	Department of Housing and Urban Development
MCS	multiple chemical sensitivities
NCI	National Cancer Institute
NHLBI	National Heart, Lung, and Blood Institute
NIAID	National Institute of Allergy and Infectious Diseases
NIEHS	National Institute of Environmental Health Sciences
NIH	National Institutes of Health
NIOSH	National Institute for Occupational Safety and Health
NIST	National Institute of Standards and Technology
OSHA	Occupational Safety and Health Administration
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
TIME	Temporal Indoor Monitoring and Evaluation
VOC	volatile organic compound

Chapter 1

Introduction

Research related to the pollutants found in the indoor environment and the health hazards they present is currently carried out by a number of federal agencies. The specific research activities conducted or sponsored by these agencies and the focus of their research are largely determined by their organizational missions and mandates. A major impetus for federal involvement in research on indoor pollution was the energy crisis of the early 1970s and the concern about the impact of some energy conservation measures on the quality of indoor air. This concern led the Congress in 1986 to enact legislation assigning a formal indoor air research role to the Environmental Protection Agency (EPA) and mandating the creation of a mechanism to facilitate coordination among federal agencies of research and other activities related to indoor air quality.

The Federal Role in Researching Indoor Environmental Problems and Their Solutions

The involvement of federal agencies in research on the causes and the effects of human exposures to indoor pollutants and the options to manage the health risks posed by them has evolved over the years as awareness and understanding of the indoor pollution problem has grown.[1] The research of such federal agencies as EPA, the Department of Energy (DOE), the Consumer Product Safety Commission (CPSC), and the National Institute for Occupational Safety and Health (NIOSH) trace their beginnings to the energy crisis of the 1970s and its aftermath, specifically nationwide measures to make buildings more energy efficient. As steps were taken to conserve energy use in residential, office, and other types of buildings, through such means as insulating, sealing to prevent the infiltration of outside air, and lowering ventilation rates, their occupants began to experience increased health symptoms suggestive of increased exposures to irritating and perhaps harmful substances in the indoor air. Research conducted by CPSC and others revealed that many of the substances that were suspected of causing these problems and which were found in higher concentrations in tighter, more energy-efficient buildings were emitted by some of the very materials used to improve energy efficiency, as well as by building materials, interior furnishings, and products routinely used in homes, offices, schools, and other public buildings.

During the late 1970s and early 1980s, increasing public concern about indoor air pollution and growing scientific understanding of the problem resulted in passage of the Radon Gas and Indoor Air Quality Research Act

[1] The long-standing focus of research in this area has been on indoor air pollutants and related indoor air quality issues. However, as the scientific understanding of indoor contaminant exposures and exposure-related risks has improved, there has been a growing tendency to view the indoor environment more comprehensively. It is this more expansive understanding of the indoor environment that is the focus of this report.

of 1986,[2] which, for the first time, required EPA to establish a formal program of research with respect to radon and indoor air quality. This legislation also required EPA to disseminate the results of its research, establish an advisory committee comprised of federal agencies to help carry out its research and information dissemination program, and report to the Congress on indoor air-related activities. In 1989, EPA issued a report to the Congress on indoor air quality and radon,[3] detailing the research that it and others had conducted up to that time. This report also discussed EPA's general understanding of the indoor pollution problem and outlined a broad agenda of research that agency officials believed would be needed to increase understanding of the problem and the ability to devise effective solutions to it.

Although a number of bills have been introduced in the Congress since 1986 to extend the federal role in researching and managing the problem of indoor air pollution, to-date none has been enacted. While there have been specific appropriations measures and legislative directives related to the research activities of individual agencies, the federal involvement in this issue has remained essentially unchanged since passage of the 1986 legislation.

Agency officials and other experts who offered opinions on the adequacy of federal funding of indoor pollution-related research were in agreement that this funding has been quite modest in relation to the seriousness of the problem and its effects on public health and productivity. Within EPA, in particular, research related to the problem of indoor pollution has not fared well in the competition for limited resources. Explanations for this, provided by agency officials and cited in our prior work,[4] include the following: (1) the federal role with respect to indoor pollution remains essentially nonregulatory (i.e., one of disseminating, to the public, information resulting from research rather than using research findings as a basis to promulgate regulations); (2) the federal role does not involve significant amounts of grant moneys (apart from grant programs available for a few hazardous indoor pollutants, such as radon and lead); and (3) there are no specific forcing mechanisms (such as legislatively mandated time frames or goals) for most indoor pollution-related research like those that exist for research carried out under other legislative authorities, such as the Clean Air Act or the Safe Drinking Water Act. In

[2]Title IV of the Superfund Amendments and Reauthorization Act, P.L. No. 99-499, 100 Stat. 1613, 1758 (1986) (codified at 42 U.S.C. Sec. 7401 note (1995)).

[3]EPA, Report to Congress on Indoor Air Quality (Aug. 1989) 3 Vols.

[4]Indoor Air Pollution: Federal Efforts Are Not Effectively Addressing a Growing Problem (GAO/RCED-92-8, Oct. 15, 1991).

1991, we reported that federal indoor pollution-related research, including EPA's research program, had been constrained by the lack of funding. We noted that contributing to this situation were (1) the lack of a clear definition of research responsibilities among federal agencies, including an absence of specific research mandates for most federal agencies involved in research related to indoor pollution and (2) a substantial increase in EPA's overall program responsibilities over the years, while its budget remained essentially level. These factors have not changed in the intervening years and continue to serve as a constraint on federal research activities in this area.

In 1991, we also reported that the interagency Committee on Indoor Air Quality (CIAQ), established to coordinate the indoor air-related programs and activities of EPA and other federal agencies, had shown only limited effectiveness in performing this role. We attributed this to the limited participation by agencies other than EPA and to the lack of a clear charter for the organization, one that would define the roles and responsibilities of agencies and how they should work together to address indoor air issues. Agency officials familiar with CIAQ's recent operation told us that while it has functioned fairly effectively as a mechanism for agencies to inform one another of their respective indoor pollution-related activities and programs, including ongoing and recently completed research, it has not functioned well as a mechanism for developing a coordinated national research agenda or setting priorities for federally supported research related to the indoor environment.

Funding of Indoor Pollution Research Has Not Matched the Widely Recognized Risk Posed by Indoor Pollution and the Costs It Imposes on Individuals and Society

Many federal and state agencies, as well as other authoritative bodies, have recognized the significant risk to human health posed by the problem of contaminants in the indoor environment and have consistently ranked it among the top environmental health threats. In 1987, a comparative assessment of environmental risks conducted at the direction of EPA's Administrator by senior agency scientists, engineers, and managers concluded that indoor radon and other indoor air pollution ranked among the top 5 of 31 enumerated environmental problems in the risks they posed to human health.[5] EPA's Science Advisory Board, which was established in the Office of the EPA Administrator to provide independent, expert advice on scientific matters related to EPA's responsibilities, reviewed and endorsed this comparative risk ranking and called upon the agency to give a higher priority to funding such high-risk environmental

[5] EPA, Unfinished Business: A Comparative Assessment of Environmental Problems (Feb. 1987).

problems.[6] On numerous occasions since then, the Board has reiterated its view that indoor pollution represents a comparatively high risk to human health and has called on the agency to devote greater funding to researching and improving the scientific understanding of the problem.

In an August 1989 report to the Congress, EPA stated that ". . .indoor air pollution represents a major portion of the public's exposure to air pollution and may pose serious acute and chronic health risks. This evidence warrants an expanded effort to characterize and mitigate this exposure."

In December 1989, EPA published the results of studies of environmental priority setting in three regions of the country where indoor air pollution was recognized as a serious problem. The agency concluded in this report that the

". . .risk associated with most environmental problems does not differ much across the [geographic] areas studied. For example, indoor air pollution consistently causes greater health risks than hazardous waste sites whether one is concerned with New England, the Middle Atlantic Region, or the Pacific Northwest. Such consistent findings should play an important role in setting national environmental priorities."

In 1997, the Presidential and Congressional Commission on Risk Assessment and Risk Management considered the relative risks posed by various environmental problems and concluded that indoor pollution can pose a substantial public health risk.[7] The Commission's report contained a number of recommendations addressing the risks posed by pollutants in the indoor environment, including a recommendation that the Congress and the administration develop legislation mandating a coordinated strategy by EPA, CPSC, the Occupational Safety and Health Administration (OSHA), and other federal agencies to address this issue. The Commission noted that "while outdoor air pollution is extensively regulated, problems in offices, public buildings, and homes remain relatively unrecognized and unaddressed." The Commission also observed that a more effective and coordinated approach to dealing with this issue was unlikely to emerge without a mandate from the Congress and cooperation from stakeholders.

[6] EPA Science Advisory Board, Reducing Risk: Setting Priorities and Strategies for Environmental Protection (Sept. 1990).

[7] The Presidential and Congressional Commission on Risk Assessment and Risk Management, Risk Assessment and Risk Management in Regulatory Decision-Making, 2 Vols. (Jan. 29, 1997).

There is also a disparity between federal funding for indoor pollution-related research and the costs that indoor pollution imposes on individuals and society, according to estimates of these costs by EPA and other federal and private sector researchers. The costs associated with indoor pollution include the costs of medical treatment for those adversely affected by exposure to contaminants in the indoor environment as well as reduced productivity caused by workers' absences due to illness and by their impaired performance on the job as a result of exposure-related symptoms, such as headaches, eye and respiratory tract irritation, allergies, asthma, chronic fatigue, and a reduced ability to concentrate. Researchers at DOE's Lawrence Berkeley National Laboratory have estimated these costs, for the United States alone, in the tens of billions of dollars.[8] These same scientists have put the savings that might be realized as a result of improved indoor environments, achieved through a better understanding of the problem of indoor pollution and the development of more effective control and risk mitigation strategies, at a similarly high level. For example, nationwide savings and productivity gains from reduced respiratory disease have been estimated at between $6 billion and $19 billion annually. From reduced allergies and asthma, a subset of respiratory diseases, such savings and gains have been estimated at between $1 billion and $4 billion annually. From reductions in the health symptoms that are associated with sick building syndrome, such savings and productivity gains have been estimated at between $10 and $20 billion annually. Finally, from direct improvements in workers' performance that are unrelated to health (because indoor environmental factors can affect comfort and productivity without producing discernible health effects) estimates of productivity gains have been put at between $12 billion and $125 billion annually. According to the DOE scientists, a comparison of the potential economic benefits of improving indoor environments with the costs of achieving such improvements suggests that benefits exceed costs by a very large factor.

[8]William J. Fisk and Arthur H. Rosenfeld, Estimates of Improved Productivity and Health From Better Indoor Environments, Indoor Environment Program, Lawrence Berkeley National Laboratory, Office of Energy Efficiency and Renewable Energy, DOE (May 1997). Also published in Indoor Air, Vol. 7 (Sept. 1997) pp. 158-172.

From a Focus on Indoor Air to a Comprehensive View of the Indoor Environment

This report goes beyond the traditional focus on indoor air quality and embraces the broad definition of the indoor environment adopted in recent years by such agencies as EPA and NIOSH and by others, including EPA's Science Advisory Board and its Integrated Human Exposure Committee. This more encompassing and inclusive definition considers total human exposure (i.e., all pollutant sources, media pathways, and exposure routes) and takes account of the relative contributions of both indoor and outdoor sources to total exposure and risk. The definition is based on a recognition that factors influencing human health indoors go beyond inhalation exposures to pollutants found in indoor air, important as that particular medium and exposure route may be.

In embracing this more inclusive concept of indoor pollution, EPA has defined the indoor environment and its potential effects on human health by two guiding principles. First, exposures must occur within or be exacerbated by the building; the health impacts of concern need to be directly related to pollutant exposures that occur in the building or other enclosed space, such as an aircraft cabin. The exposures may result from inhaling pollutant-containing indoor air or may result from other exposure routes, such as skin contact or ingestion, or a combination of them. Impacts on human health and methods for reducing exposures and risks will vary by building type, use, and activities. Second, risk reduction must be achieved through better building design and construction, through development of less polluting products for indoor use, or through mitigation of existing exposures within the building or in its immediate vicinity. The second principle is intended to exclude some risks that, although they may occur indoors, originate outside the building and are best mitigated by actions at a distance from the site of exposure. For example, risks would be excluded if the source of the pollutants were industrial discharge, such as drinking water contaminated by lead tailings from a mine or air pollutants entering the environment from industrial smokestacks.[9] Risks would be included if the pollutants were added indoors, for example, drinking water contaminants from lead solder in indoor plumbing or air pollutants emitted from combustion or other sources within a building. Pesticide residues on food resulting from the spraying of crops would be excluded, while pesticides that are used directly indoors or that are used near the home and are tracked indoors would be included.

[9] While many people believe that exposures to ambient air pollutants take place only outdoors, such pollutants do not stop at a building's exterior shell. In fact, exposures to outdoor air pollutants largely take place indoors, with some modification by the building's interaction with the specific pollutants.

The indoor environments of concern, or microenvironments as they are often called, comprise buildings of diverse types, including homes, office buildings, schools, day-care facilities, nursing homes, hospitals, restaurants, hotels, and public buildings. They also include such self-contained interior spaces as aircraft, train, and automobile interiors, where people also spend considerable amounts of time and could be exposed to a variety of potentially harmful contaminants originating from interior sources. Specifically excluded from consideration in this report are industrial work environments, which often present unique hazards to human health and, because of that, are governed by regulatory requirements and standards which, for the most part, do not exist for other indoor environments.

Related GAO Products

In a 1988 report dealing with the management of EPA and its mission of protecting the environment and human health,[10] we reported that EPA must have the best possible information on the nature of environmental problems and the effectiveness of measures taken to deal with them. We also noted that the agency needs to use such information in allocating its limited resources where they will do the most good—to those problems that pose the greatest risk and are most amenable to remedy. We recommended, among other actions, that EPA identify the critical research needs for implementing the agency's recently adopted initiative of managing for measurable environmental results and that it assess the status of methods and activities for determining human exposures to pollutants to provide a basis for deciding what additional research would be needed.

In a 1991 report concerned with the challenge of meeting public expectations with limited resources,[11] we noted that despite EPA's progress in addressing environmental needs, numerous environmental problems, including the problem of indoor air pollution, remained. We concluded that federal budget priorities should reflect the scientific understanding of relative risks to the environment and public health, as well as the feasibility and the cost-effectiveness of various approaches to reduce them, rather than relying on often inaccurate public perceptions of risks. We recommended that EPA work with the Congress to identify opportunities to shift resources from problems posing less severe risks to

[10] Environmental Protection Agency: Protecting Human Health and the Environment Through Improved Management (GAO/RCED-88-101, Aug. 16, 1988).

[11] Environmental Protection: Meeting Public Expectations With Limited Resources (GAO/RCED-91-97, June 18, 1991). See also, Environmental Protection Issues (GAO/OGC-93-16HR, Dec. 1992).

problems whose risks are greater and initiate actions to educate the public about relative environmental risks.

Objectives, Scope, and Methodology

This report responds to a request from the Ranking Minority Member, House Committee on Government Reform, for GAO to assess the progress made by EPA and other federal agencies in enhancing the understanding of the public health risks posed by pollutants present in the indoor environment and in developing solutions for controlling or mitigating them. Specifically, we were asked to (1) characterize the current scientific understanding of the health risks of pollutants commonly encountered in indoor environments and the sources of exposures to them; (2) provide information on the federal funding of indoor pollution-related research in recent years and on the advances in understanding of the nature of the problem and the ability to control it that have resulted from this spending; and (3) identify significant gaps in knowledge and understanding of the problem, the solutions for dealing with it, and the implications of these gaps for future research.

To address these objectives, we undertook an extensive review of the published scientific literature on indoor environmental pollution as well as such key related topics as exposure assessment and risk assessment. We also reviewed EPA's public and internal documents dealing with these subjects, including reports to the Congress, guidance documents intended to disseminate knowledge obtained through research activities, and a variety of internal reports and memoranda dealing with strategic planning, staff assessment of research needs, and proposed plans to address these needs. To identify federal agencies for inclusion in our review, we drew on the knowledge gained from prior work in this area and reviewed EPA's documents and proceedings of the interagency CIAQ, the interagency advisory and coordinating body relied upon to meet the requirements of the 1986 Superfund amendments. We also attended quarterly meetings of the Committee.

In our review, we included those agencies with the greatest stake in research related to indoor pollution, either as participants in or sponsors of such research or as major users of its results. These agencies are the Environmental Protection Agency (EPA), the Department of Energy (DOE), the Department of Housing and Urban Development (HUD), the Consumer Product Safety Commission (CPSC), the National Institute for Occupational Safety and Health (NIOSH), the National Institute of Standards and Technology (NIST), the National Institute of Environmental Health Sciences

(NIEHS), the National Institute of Allergy and Infectious Diseases (NIAID), the National Heart, Lung, and Blood Institute (NHLBI), the National Cancer Institute (NCI), and the Occupational Safety and Health Administration (OSHA).

To obtain the detailed information needed to address each of our objectives, we interviewed key agency officials, requested and reviewed pertinent agency documents, and submitted extensive written questions for formal responses from agency officials. In many instances, these questions were supplemented with follow-up questions and interviews to obtain additional details or clarifications on selected aspects of the agencies' activities. We requested information on expenditures for indoor pollution-related research from the agencies we reviewed for fiscal years 1987 through 1998 as well as anticipated spending for fiscal year 1999. Generally, the agencies were able to provide the requested expenditure data, however, in a few cases, agencies told us that they could provide only estimates of spending for the earliest years (see app. I for details of spending by individual agencies and explanations and qualifications on reported expenditure data). To account for inflation and to facilitate interyear comparisons, we have expressed all expenditure amounts in this report in 1999 constant dollars.[12]

To provide the broadest possible perspective on our objectives, in particular, the crucial questions of (1) the advances resulting from research conducted to-date and (2) the remaining knowledge gaps and research needed to fill them, we also sought the views of recognized authorities working outside the specific federal agencies included in the scope of our review. These experts were identified for us by officials of the agencies we reviewed as individuals that the agencies themselves frequently call upon for expert advice and were often the authors of the peer-reviewed scientific journal articles that we consulted. They included prominent researchers in academia, environmental medicine, state government, and national laboratories affiliated with DOE.[13] In addition, the pertinent views of some of these agency-identified experts, as well as those of other authorities in this field, were obtained from a detailed review of the extensive hearing record compiled by OSHA in connection with its proposed rule-making on indoor air quality.

[12]We used the Department of Commerce's chain-type price index for gross domestic product to convert figures on expenditures to their 1999 constant dollar values.

[13]We sought the views of a large number of experts who were recommended to us or who were identified by us through our review of the peer-reviewed scientific literature. A much smaller number of experts actually responded to our requests, however. Those individuals whose contributions were particularly helpful in the preparation of this report are listed in app. III.

We conducted our review from August 1998 through August 1999 in accordance with generally accepted government auditing standards.

Agency Comments

We provided the departments of Energy and Housing and Urban Development, the Environmental Protection Agency, the National Institutes of Health, the Occupational Safety and Health Administration, the Consumer Product Safety Commission, the National Institute for Occupational Safety and Health, and the National Institute of Standards and Technology with a draft of this report for review and comment. The Departments of Energy and Housing and Urban Development, the Occupational Safety and Health Administration, and the National Institute of Standards and Technology agreed with the contents of the report and had no comments. The Consumer Product Safety Commission, the Environmental Protection Agency, the National Institute for Occupational Safety and Health, and the National Institutes of Health also agreed with the report and provided technical and editorial comments which have been incorporated in the report, as appropriate.

The Emergence of Indoor Pollution as a Public Health Concern and a Focus of Research

Research supported by federal agencies and others in the 1980s and 1990s expanded the scientific understanding of the problem of indoor pollution and demonstrated that, for a broad range of hazardous chemical and biological pollutants, indoor exposures can greatly exceed exposures received outdoors. This research also showed that, in addition to inhalation risks, many building materials; furnishings; and products routinely used in homes, offices, schools, and other buildings; as well as many commonplace activities carried out in these buildings could pose health risks through such other routes of exposure as skin contact and ingestion.

While indoor environmental pollution is a matter of concern for all who spend a large portion of their time indoors, it poses special risks for particularly susceptible groups, such as the very young, the infirm elderly, and those with chronic health problems, such as cardiovascular and respiratory diseases. Infants and small children are at special risk from indoor pollutants because of their still developing (hence more vulnerable) body systems, because of their behaviors which bring them into closer contact with pollutants, and because they eat more food, drink more water, and breathe more air in proportion to their body weight than do adults.

The Growing Understanding of Health Risks Posed by Pollutants in the Indoor Environment

In 1970, when the Clean Air Act was massively overhauled to address the problem of air pollution caused by increasing urbanization, industrial development, and automobile use, there was relatively little awareness of the health hazards posed by pollutants present in indoor air and elsewhere in the indoor environment. Indeed, the indoor setting was widely viewed as a refuge from the environmental hazards encountered outdoors. As a consequence, the Clean Air Act was designed to apply only to ambient air, that is the air external to such structures as homes, schools, offices, and other public and private buildings.

Following the energy crisis of the mid-1970s, concern about the potential health risks of pollutants found indoors began to grow. Nationwide measures to improve the energy efficiency of buildings (such as added insulation, reductions in ventilation rates, and general tightening to reduce infiltration of outside air and energy loss) soon led to an increase in complaints by occupants of commercial and residential buildings about the quality of indoor air and an increase in reports of health and comfort problems. Commonly reported health symptoms included mucous membrane irritation, in particular, irritation of the eyes, nose, and throat;

nasal stuffiness and drainage; chest symptoms, such as coughing, wheezing, and chest tightness; headaches; chronic fatigue; and difficulty in concentrating. During this period, CPSC identified formaldehyde as the source of acute irritant reactions in individuals whose homes were insulated with a common type of foam insulation or constructed of large amounts of particleboard or plywood that contained formaldehyde. Concern over naturally occurring radon also began to increase, particularly when very high levels of radon were found in homes constructed in the Reading Prong geological formation in Pennsylvania, New Jersey, and New York. This led to radon becoming a major indoor air pollution program within EPA.

Complaints among office workers increased exponentially between the mid-1970s and the mid-1980s. During this period, NIOSH received a growing number of inquiries and requests for health investigations of indoor workplaces, such as office buildings and schools, which had previously been considered free of the contaminants found in industrial workplaces. NIOSH identified inadequate ventilation and moisture incursions as common problems in these workplaces and published recommendations for moisture control, pollutant source control, and scrutiny of building ventilation systems.

By the early 1980s, research had begun to demonstrate that the levels of many pollutants in indoor air were often higher than the levels in outside air (indoor concentrations typically were 2 to 5 times those found outdoors and sometimes much more). This understanding, coupled with knowledge of the high percentage of time most people spend indoors, gave rise to concern that indoor air pollution could constitute a greater risk to the general population than had been previously thought. Subsequent research sponsored by federal agencies and others has shown conclusively that indoor air can often contain far higher levels of hazardous pollutants than outside air and can thus pose a more serious threat to health. At the same time, research has increasingly pointed to the need to consider not only the hazards posed by inhaling contaminants in indoor air but other hazardous pollutants present in the indoor environment that could contribute to exposure through skin contact and ingestion. Such hazardous pollutants would include complex chemical mixtures contained in household dust, biological contaminants (including allergens, infectious disease agents, molds, and biotoxins), pollutant laden films and residues on indoor surfaces, chemical by-products of disinfection contained in tap water, and a variety of potentially harmful chemicals contained in a wide array of products routinely used in homes, schools, offices, and other indoor environments. Despite this increased knowledge, however, NIOSH has reported that satisfactory environmental explanations have yet to be found for the health complaints reported by the occupants of many buildings.

The Contributors to Health Risks in the Indoor Environment

During normal daily activities, people come into contact with environmental pollutants in the air they breathe, in the water they drink and wash in, in the food they eat, and in the materials and surfaces they touch. To present a health threat, however, a pollutant must make direct contact with a person by some route or combination of routes, such as inhalation, ingestion, or absorption through the skin. Exposure is quantified by taking into account (1) the routes of exposure to the pollutants; (2) the magnitude or concentration of the pollutant (e.g., parts per million or micrograms per cubic meter); (3) the duration of the exposure; and (4) the frequency of exposure.

Several factors contribute to making indoor environmental pollution the significant risk to human health that EPA and others have deemed it to be. These include (1) the large number and the variety of chemical and biological contaminants commonly encountered indoors, often in concentrations exceeding those typically found outdoors; (2) the proximity of a building's occupants to the indoor sources of pollutants, which facilitates actual contact with the pollutants through inhalation, ingestion, or absorption through the skin; and (3) the very high percentage of time most people spend in their homes, offices, schools, day care centers, and other indoor environments. Generally accepted estimates of this time, used by EPA and others, range from 80 to 90 percent. For certain population groups, including the very young, the infirm elderly, and the chronically ill (groups which are also among the most susceptible to the harmful effects of pollutant exposures), the percentage of time spent indoors is even greater. The large percentage of time spent indoors means that, even at relatively low concentrations, the contribution to total exposure by indoor pollutants from both indoor and outdoor sources can be much greater than the contribution from pollutants encountered outdoors.

Among the scientific developments that have made it possible to more accurately evaluate exposures to hazardous chemical pollutants indoors are monitoring devices and analytical techniques that have made it much easier to assess the total exposure of the general population to toxic substances in daily life. Monitoring devices—small and light enough for people to wear as they perform their daily activities—have allowed scientists to conduct studies that show which pollutants exist nearby, for example in the wearer's breathing zone, and in what concentrations. In addition, techniques have been developed to collect accurate samples of pollutants in the dust and the fine particles embedded in carpets and upholstery and deposited on floors and other indoor surfaces. Analytical techniques have also been developed that permit the determination of blood levels of pollutants and pollutant by-products from analysis of breath samples. Other innovative analytical techniques permit identification of pollutant exposures through analysis of biological markers (biomarkers) present in blood, urine, and tissue samples.[1] For example, the National Cancer Institute (NCI) has supported research on the molecular epidemiology of human cancer in which lung tumor tissues from nonsmokers are examined for genetic evidence linking exposure to environmental tobacco smoke to mutations in a particular tumor suppressor gene.[2] This research builds on the growing evidence that shows that environmental carcinogens, such as environmental tobacco smoke and radon, can leave "fingerprints" or molecular signatures of genetic damage in the tumor suppressor gene within human tumors.

As a result of "total human exposure" studies initiated by EPA in 1980 and subsequently expanded, the exposures to volatile organic compounds (VOC), carbon monoxide, pesticides, and dangerous particles of more than 3,000 people have been examined. Individually, these studies were designed to be representative of North Americans living in urban and suburban areas. Chemical analyses of samples taken in the studies identified the specific chemicals to which study participants were routinely exposed, including some 30 or so VOCs, many of which are known to cause cancer in people or animals.[3]

Among the surprising and often disquieting results of these studies was the finding that most people are likely to have the greatest contact with potentially toxic pollutants inside the places that they usually consider to be unpolluted—their homes, offices, and automobiles. Exposures stemming from sources normally targeted by the nation's environmental laws, such as Superfund sites and factory emissions, were found to be much smaller in comparison. This was true even in localities with an

[1]Measurements in breath, blood, urine, or tissue samples of environmental pollutants or of their biological consequences after contaminants have crossed one of the body's boundaries and entered human tissues.

[2]This gene is known as the p35 tumor suppressor gene.

[3]NIEHS' National Toxicology Program has conducted the bulk of federally funded testing of substances for carcinogenesis and other toxic effects.

abundance of chemical manufacturing plants. The primary sources of these indoor chemical pollutants appeared to be ordinary consumer products, such as air fresheners, moth repellants, insecticides, paints, solvents, adhesives, cleaning compounds, personal care products, and building materials and furnishings, as well as fumes generated by such everyday activities as bathing, laundering, cooking, and heating. Use of tobacco products was also confirmed to be a significant contributor to indoor pollution.

In 1985, EPA researchers consolidated information about how several hundred people in five states were exposed to benzene, a highly toxic chemical present in gasoline and known to cause leukemia in workers continually exposed to high concentrations. EPA's analysis revealed that the average concentration of benzene these people inhaled was nearly three times higher than typical outdoor levels. The researchers estimated that about 45 percent of the total exposure of the U.S. population to benzene comes from smoking (or breathing environmental tobacco smoke); 36 percent from inhaling gasoline fumes or from using various common products, such as glues; and 16 percent from other home sources, such as paints and gasoline stored in basements or attached garages.[4] Only about 3 percent of the average person's exposure to benzene was attributable to industrial pollution. Hence, eliminating all industrial releases of benzene would reduce health risks very little. On the other hand, even a modest decrease in cigarette smoking and exposure to environmental tobacco smoke would significantly reduce the likelihood of benzene-caused disease. For example, studies carried out at the time these findings were published showed that children of smokers died of leukemia at two to four times the rate of children of nonsmokers.[5]

Many other VOCs that are very toxic at high concentrations are similar to benzene in that they contribute to greater exposure-related risk indoors than outdoors. Two of these are tetrachloroethylene (also known as perchloroethylene or "perc") and chloroform, both of which cause cancer in animals exposed to high concentrations. Perc is used to dry-clean clothing. For most people, the greatest exposure to perc occurs when wearing recently dry-cleaned clothes or as a result of storing such clothing

[4]CPSC eliminated the use of benzene in paint strippers in 1977 by persuading industry to voluntarily reformulate these products.

[5]L. A. Wallace, "Human Exposure to Environmental Pollutants: A Decade of Experience," Clinical and Experimental Allergy, Vol. 25 (1995) pp. 4-9.

in their homes.[6] The major sources of exposure to chloroform (a by-product of the use of chlorine to disinfect drinking water) are drinking tap water, showering, boiling water, and washing clothes and dishes. The only way to minimize exposures to chloroform from these sources is to drink contaminant-free bottled water (or tap water filtered through a high-quality charcoal filter) and to improve ventilation in the bathroom, kitchen, and laundry to remove and dilute chloroform-laden vapors.

Carbon monoxide, one of a number of hazardous by-products of incomplete combustion, seriously interferes with the ability of the blood to carry oxygen. In addition to being capable of causing death at high concentrations (it is the nation's leading cause of death by poisoning),[7] it can be harmful to people with heart ailments at levels that are not unusual indoors. While it has long been known that carbon monoxide exposures can increase precipitously when people are in or near operating motor vehicles, other research has shown that indoor sources, such as poorly adjusted or improperly used indoor combustion appliances, such as gas stoves, space heaters, and water heaters, can also cause harmful, even fatal, levels of this hazardous air pollutant. Moreover, even when properly adjusted and used as intended, under certain conditions, these appliances can be significant sources of carbon monoxide as well as other hazardous air pollutants.[8]

Several developments in U.S. housing have contributed to reducing the performance reliability of gas furnaces and water heaters vented to the outdoors, thus making them potential sources of carbon monoxide: (1) energy efficiency of the devices has increased, thus reducing the temperature of the combustion exhaust gases; (2) houses have become tighter, increasing the depressurization caused by the use of exhaust fans in kitchens, bathrooms, and elsewhere in houses; and (3) more and larger exhaust fans are now included in a typical house. All three factors can lead to flow reversal (backdrafting) in the vents of gas-burning appliances during operation and make them significant sources of carbon monoxide. Headaches, lethargy, nausea, and dizziness have been noted in individuals exposed to moderately elevated doses of carbon monoxide. Flu-like

[6] In recent years, the dry cleaning industry has voluntarily made changes to the cleaning process to reduce exposures to perc.

[7] Deaths attributable to carbon monoxide have declined in recent years. Possible explanations for this include greater public awareness of the hazard resulting from public information campaigns and the development and use of safety devices, including carbon monoxide detectors, for home use.

[8] Blocked or defective flues, cracked heat exchangers, and improperly-sized appliances, among other conditions, can result in dangerously high levels of carbon monoxide even when the appliances are used as intended.

symptoms have been noted in individuals in whose homes gas stoves and unvented gas space heaters are used for heating during cold periods. On the whole, the U.S. population now receives greater exposure to carbon monoxide indoors than outside, in part, as a result of reductions in ambient levels achieved through regulatorily mandated reductions in automobile emissions of this toxic pollutant.

Another environmental hazard that poses a significant threat indoors is the presence of fine particles suspended in the air. These are particles of 2.5 microns or less in diameter that can be inhaled and can penetrate deep into the lungs, where they can cause damage to tissues. Studies conducted by NIEHS and others have associated elevated concentrations of fine particles in ambient air with premature death, although the mechanism by which these particles contribute to disease and death is not yet clearly understood. In one exposure study carried out in California, subjects carried devices capable of capturing these particles as they went about their daily activities.[9] The study found that exposures during the day were about 60 percent greater than would be expected on the basis of particulate levels in samples of indoor and outside air taken at the same time. The higher than expected exposures were attributable, in part, to the fact that as people move about they tend to stir up "personal clouds" of particle-laden dust from their surroundings. The researchers demonstrated that most of these fine particles resulted from combustion occurring indoors, such as smoking, cooking, and using fireplaces and wood-burning stoves.

Most pesticides, including those commonly used in and around the home and in schools, offices, and other indoor settings, are well-documented toxins that pose potential health hazards. In studies conducted in the late 1980s in Florida and Massachusetts, researchers studying indoor air contaminants found that indoor air contained at least five (but frequently ten or more) times higher concentrations of pesticides than the outside air they sampled. Surprisingly, the indoor concentrations included pesticides approved only for outdoor use. Apparently, chemicals applied to the foundations of these houses to attack termites had found their way indoors, either through seepage through the soil and the buildings' exterior shells as a gas or by being tracked in on people's shoes. Subsequent research has shown that pesticides and herbicides applied to lawns and other outside areas can easily be tracked into houses. Moreover, these

[9]EPA and the California Air Resources Board sponsored this study in Riverside, California, in 1990. This study was the first probability-based survey of personal exposures to inhalable particles. The study's 178 participants, representing 139,000 nonsmoking Riverside residents, carried personal monitors for a day to measure their exposures to particles, elements, and nicotine.

substances persist in the indoor environment far longer than they would outdoors and thus prolong the period of exposure.

Pesticides and herbicides that breakdown or otherwise dissipate within days outdoors, through the action of sunlight, bacteria, and weather, can persist for years in indoor carpeting where they are protected from such degradation. This has been shown by indoor measurements of the pesticide DDT (dichloro-diphenyl-dichloro-ethane), which was banned in the United States in 1972 because of its toxicity and environmental effects. Researchers examining indoor contaminants in Midwestern houses in 1992 and 1993 found that 90 of the 362 houses they examined had traces of DDT in their carpets.

This research also demonstrated, as have other studies, that carpeting is an effective reservoir for contaminants other than pesticides. For example, the researchers found that concentrations of seven toxic organic chemicals that are produced by incomplete combustion, called polycyclic aromatic hydrocarbons (PAH), were present in older carpets at levels above those that would trigger a formal risk assessment for soil on residential properties near a hazardous waste site.[10] These chemicals have been proven to cause cancer in animals and are suspected of being capable of causing cancer in humans.

Indoor exposures to microbiologic organisms (e.g., fungi, bacteria, and viruses) or their products are related to a variety of health problems, including Legionnaire's disease and asthma, and probably also to allergies, nonspecific symptoms, and communicable respiratory infections. Less is known about the measurement of these exposures, however, than is known about the measurement of indoor toxic chemical exposures.

Although the foregoing examples are merely suggestive of the types of pollutant hazards commonly found in the indoor environment, they illustrate why EPA, its Science Advisory Board, the Presidential and Congressional Commission on Risk Assessment and Risk Management, and others have assigned indoor environmental pollution a relatively high environmental risk ranking. While people tend to view their homes, offices, and most other indoor environments (with the exception of

[10]Advantages of carpets include the fact that they can serve as effective noise dampers and covers for wood and other floors in poor condition. They also provide better traction than bare floors, which can be slippery when wet. Additionally, while carpets take more time to keep clean, if they are kept very clean, they may remove more pollution from the indoor air than they add. However, carpets tend to collect deep dust as they age, even if they receive regular cleaning. Moreover, wetted carpets serve as an effective cultivation medium for molds, bacteria, and dust mites.

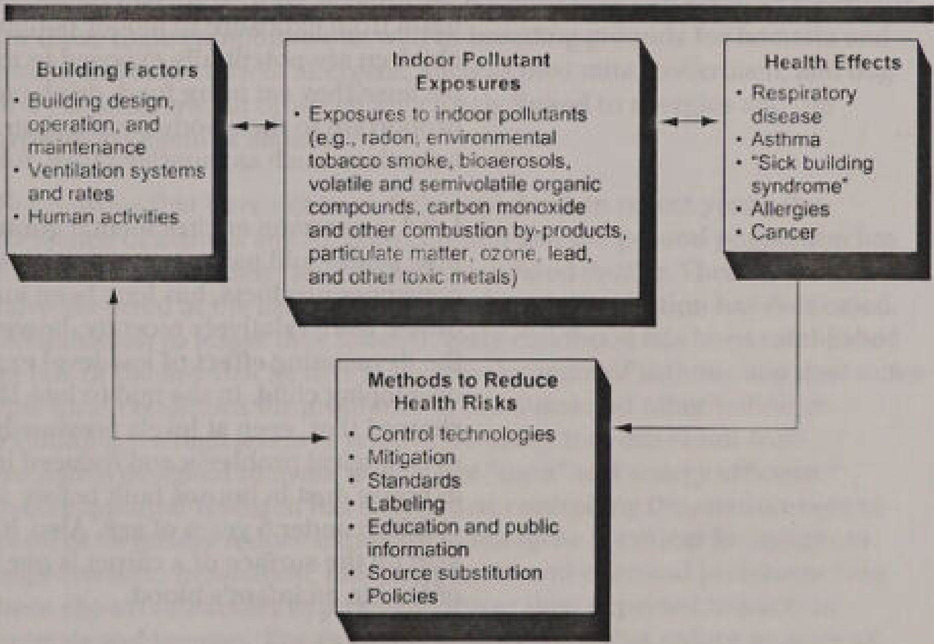
industrial workplaces) as refuges from pollutants found in ambient air and elsewhere in the outdoor environment, this view may often be unwarranted. A wide variety of activities that people routinely perform in their homes, schools, offices, and other indoor environments can make their own particular, and often substantial, contributions to overall pollutant exposures and to the health risks that they represent. A few of the ordinary activities that can contribute to exposures include cooking; doing crafts and hobbies; interior painting and other building renovation activities; cleaning and polishing metal, wood, and other indoor surfaces; furniture refinishing, especially using solvents for stripping paints and varnishes; using carbonless copy paper; using computers, printers, and other electronic office equipment; using air fresheners and bathroom deodorizers; and operating humidifiers.

The healthfulness of the indoor environment is also often adversely affected by a failure to follow practices important in maintaining a healthy indoor environment. These include (1) good housekeeping practices to maintain cleanliness and discourage proliferation of cockroaches and their allergy producing products; (2) controlling indoor humidity and taking other measures to discourage growth of dust mites and reduce exposures to dust mite allergens[11]; (3) proper operation and maintenance of heating, air-conditioning, and ventilation systems; (4) avoiding use of gas stoves and unvented combustion appliances to warm indoor spaces in cold weather; (5) care in the use and storage of paints, pesticides, cleaning agents and other toxic chemical substances; and (6) preventive maintenance aimed at protecting the integrity of the building's external shell of roof, windows and exterior walls and preventing the infiltration and intrusion of moisture that could encourage the growth of molds. Maintenance, preventive and routine, is especially important in commercial and institutional buildings, with their high occupant densities and large and complex ventilation systems. Investigations by NIOSH of problem buildings show that inadequate ventilation and dirt or moisture in ventilation systems are associated with increases in occupant symptoms.

[11]Dust mites thrive in environments with high humidity. They and the allergens they produce also collect in carpets, upholstery, bedding, and other soft surfaces where they are more difficult to control than on smooth, hard surfaces, such as tile or hardwood floors. Effective reduction of exposures of sensitive individuals to dust mite allergens may also require such additional measures as frequent washing of bed linens in water of at least 130 degrees (hotter than that provided by typical domestic hot water systems) and encasing mattresses and pillows in covers impermeable to dust mites.

Figure 2.1 depicts the complex, multifactor nature of the problem of indoor pollution and illustrates the relationships among these factors.[12]

Figure 2.1: Relationship Among Building and Human Factors, Human Exposures, and Health Effects



Source: GAO's presentation of information from the Ernest Orlando Lawrence Berkeley National Laboratory, DOE.

Indoor Pollutants Constitute a Particular Threat to Infants and Children

The pesticide residues and vocs found in the indoor environment are estimated to cause as many as 3,000 cases of cancer a year in the United States. This makes these indoor pollutants a significant health threat, similar, if not equal in magnitude to, radon and secondhand tobacco smoke.[13] Moreover, research has shown that toddlers and young children who crawl and play on the floor and regularly place their hands in their mouths are at even greater risk than the rest of the population from these

[12]For simplicity in presentation, indoor allergens, such as dust mite, cockroach, and pet allergens, are included here as indoor pollutants. In fact, these substances are often considered separately, since they are naturally occurring, nontoxic substances (proteins) that constitute a health concern only for those individuals (albeit a substantial segment of the population) who have become allergic to them because their immune systems make an allergic immune response. Sensitization to allergens appears to be genetically influenced.

[13]L. A. Wallace, "Human Exposure to Environmental Pollutants: A Decade of Experience" Clinical and Experimental Allergy, Vol. 25 (1995) pp. 4-9; L. A. Wallace, "Comparison of Risks From Outdoor and Indoor Exposure to Toxic Chemicals" Environmental Health Perspectives, Vol. 95 (1991) pp. 7-13.

substances and from the toxic mixtures of household dust found on floors and other surfaces and embedded in carpets in their homes, schools, and day-care centers. Their still developing neurological, immunologic, digestive, and other bodily systems make them particularly susceptible to harm from exposure to indoor pollutants. In addition, toddlers and young children are potentially exposed to much higher levels of indoor pollutants because they eat more food, drink more fluids, and breathe more air in proportion to their body weight than do adults and engage in risky behaviors, such as mouthing toys, furnishings, and other nonfood objects.

Lead, a common environmental contaminant found in household dust, pipe solder, old paint, some ceramics and glassware, and certain other consumer products, has long been known to cause health problems at high doses. Until relatively recently, however, there was little appreciation for the devastating effect of low-level exposures early in life on the fetus and developing child. In the mid-to late-1980s, research supported by NIEHS showed that, even at levels previously thought safe, children can suffer neurological problems and reduced intelligence from lead exposure. Lead in house dust in houses built before 1950 is a major source of exposure of children under 5 years of age. Also, it has been found that the quantity of lead on the surface of a carpet is one of the best predictors of the amount of lead in an infant's blood.

Similarly, children's lungs are more susceptible to the harmful effects of environmental tobacco smoke than those of adults. In infants and young children up to 3 years of age, exposure to secondhand smoke causes an approximate doubling in the incidence of pneumonia, bronchitis, and bronchiolitis. There is also strong evidence of increased middle ear infections, reduced lung function, and reduced lung growth as a result of such exposure.[14] In addition, it has been estimated that infants, possessing a tiny fraction of an adult's body weight, may ingest five times more pesticide and other pollutant containing dust per day on average than adults. Improved sampling and measurement techniques have made it possible to estimate the exposure of infants to a variety of indoor pollutants with much greater confidence. For example, scientists are now able to estimate that in 1 day the average urban infant will ingest 110 nanograms of benzo(a)pyrene, a very toxic PAH. This amount is equivalent to what the child would get from smoking three cigarettes in a day. While it is not currently possible to assess the potential health risk of such

[14]EPA, CPSC, American Lung Association, and American Medical Association, Indoor Air Pollution: An Introduction for Health Professionals (1994) pp. 3-5.

exposures,[15] research has clearly established that, for young children, house dust is a major source of exposure to a variety of toxic substances, including heavy metals, polychlorinated biphenyls (PCB) and other persistent organic pollutants.[16] Again, carpets and similar soft, porous materials may be matters of concern, because they can serve as reservoirs for these toxic compounds, as well as breeding grounds for bacteria and molds and collectors of allergens, such as dust mite, cockroach, and dog and cat allergens, all of which are closely linked to allergies and the growing problem of asthma.[17]

For reasons that have not been fully explained, in recent years, the incidence of asthma among both children and the general population has increased dramatically, as have asthma-related deaths. These increases have occurred at the same time that ambient air pollution has decreased. Sensitization to house dust mites in early childhood has been established as one of the key risk factors in the development of asthma, and dust mites find ideal conditions for proliferation in houses and other buildings exhibiting the high levels of relative humidity that can result from measures designed to make them more "tight" and energy efficient.[18] NIAID supported research has shown that controlling the environment to prevent or greatly reduce exposure to allergens is critical for symptom improvement. In addition, biocontaminant and chemical pollutants have been shown to interact to produce greater than expected impacts in animals and humans. For example, studies show that indoor sources of combustion pollutants, such as gas stoves, wood stoves, and fireplaces, have a statistically significant association with the exacerbation of asthma. Recent studies have also shown that respiratory virus infections are strongly associated with asthma attacks in children and that building factors, such as ventilation, are associated with the risk of respiratory infections. According to NIOSH officials, it is because of findings such as these that children and asthma are now generally included in the topic of

[15]Although it has been estimated that the ingestion of foods accounts for most of the exposures to PAHs, exposures through skin contact and inhalation appear to have more significant effects on human health. The concern over inhalation exposure to airborne PAHs centers on the potential of these compounds to cause lung cancer.

[16]Robert G. Lewis, Christopher R. Fortune, Robert D. Willis, David E. Camann, and Jeffrey T. Antley, "Distribution of Pesticides and Polycyclic Aromatic Hydrocarbons in House Dust as a Function of Particle Size," Environmental Health Perspectives, Vol. 107 (Sept. 1999) pp. 721-726.

[17]There are simple, low-cost ways to reduce exposures. For example, the tracking-in of pesticides, PAHs, lead, and other contaminants can be greatly reduced by the use of commercial grade doormats and, especially, by removing shoes upon entering a house.

[18]DOE-supported researchers are exploring the effectiveness of various dehumidification strategies in reducing allergen exposures. Although this research has reported important findings, it has not yet delivered definitive solutions.

indoor environmental quality, whereas before about 1990 this connection was not generally made.

Federal Agencies' Funding of Indoor Pollution Research and Advances Resulting From This Research

From fiscal year 1987 through fiscal year 1999, federal agencies reported that their actual and planned expenditures for indoor pollution research totaled almost $1.1 billion in 1999 constant dollars. During this period, about two-thirds of the spending went for research conducted or sponsored by four institutes of the National Institutes of Health (NIH), primarily to provide a better understanding of the health effects associated with indoor pollution, including allergies, asthma, and infectious diseases.

The scientific understanding of indoor environments has advanced significantly over the past two decades. This progress results from an international research effort in which research funded by the U.S. government and a few state governments has played an important part. There has been notable progress in characterizing the problem of indoor environmental pollution, in developing measurement and modeling tools to study the interrelated factors that contribute to the problem, and in identifying and developing strategies to mitigate it. The scientific knowledge resulting from this research has been widely disseminated in a variety of documents aimed at a range of audiences, including the general public, building designers, building managers, public health professionals, school administrators, product manufacturers, and service providers. The benefits of this research include reduced exposures to and adverse health effects from some indoor pollutants (and concomitant savings in health care costs) and the emergence of a variety of new businesses and jobs to provide services related to ventilation, indoor environmental quality, and energy-efficient buildings.

Overview of Federal Funding for Indoor Pollution Research

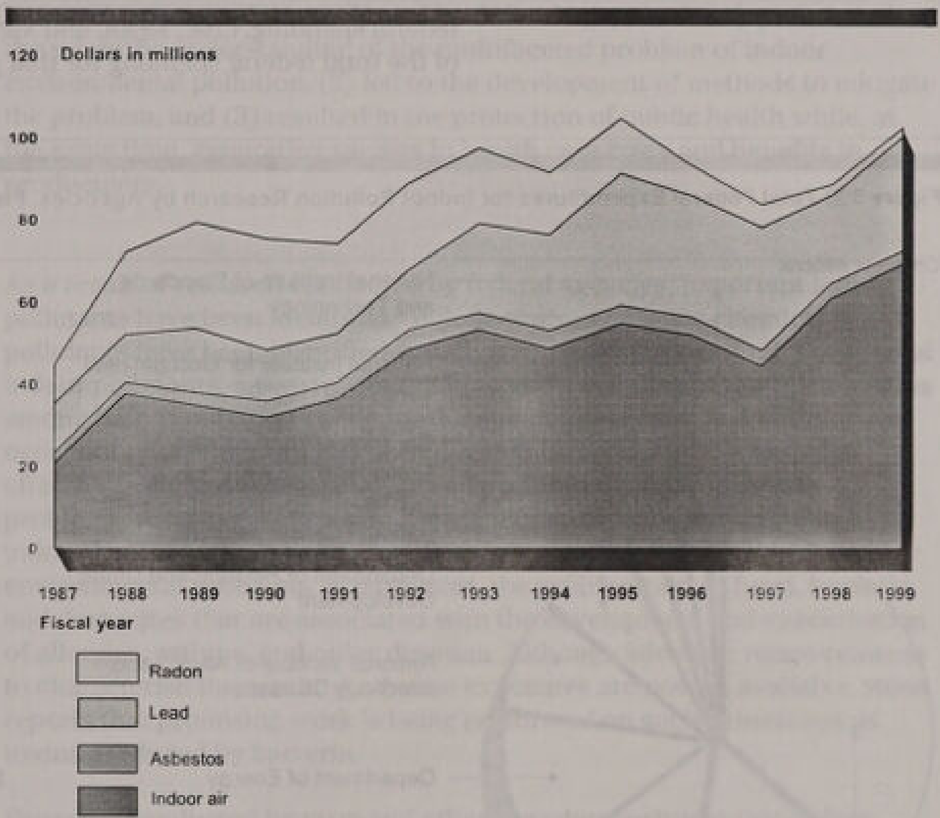
Federally funded research on indoor pollution includes both basic and applied research. Basic research is designed to answer fundamental questions about the sources and the characteristics of indoor pollutants, the environmental pathways and exposure routes by which people come into contact with them, the mechanisms by which they operate to adversely affect human health, and, where health effects in buildings are not well understood, the nature, the magnitude, and the causes of these health effects. Applied research is more problem-specific in nature. It includes research to identify and evaluate techniques for eliminating or controlling specific pollutant sources and exposures.[1]

[1]Although basic and applied research are commonly distinguished, it may be more accurate and useful to view research as a continuum leading from basic understanding of a given problem to the development of a solution to the problem. The head of the Indoor Environment Department of the Lawrence Berkeley National Laboratory told us that some research needed to bridge between basic and applied research falls into an intermediate, gray area (which researchers sardonically refer to as "the valley of death") and never gets funded. The result is that solutions do not get into the marketplace.

The federally funded research we reviewed included both intramural research (performed internally by an agency's own professional staff) and extramural research (performed outside an agency on a contractual, grant, or other basis by researchers affiliated with national laboratories, universities, or other organizations). Also included was research involving partnerships and cooperative agreements between agencies and with private-sector organizations. Each agency was asked to survey past activities and identify the research and funding amounts that it considered as contributing to the scientific understanding and improvement of indoor environments.[2] Annual spending for indoor pollution research peaked in fiscal year 1995 at about $103 million and then declined to an average of about $87 million per year over the 3 succeeding fiscal years. However, planned spending for fiscal year 1999 represents, essentially, a return to the fiscal year 1995 level (see fig. 3.1). Just over half of the agencies' actual and planned expenditures went for research related to indoor air, while about one quarter went for research related to the hazard posed by lead in the indoor environment. While spending for research related to radon has declined in recent years, spending for research related to indoor air and lead has generally increased.

[2]We received spending data on indoor pollution-related research from 10 of the 11 federal agencies included in our review. OSHA advised us that, although it uses findings resulting from the research of others, it performs no scientific research of its own on indoor pollution.

Figure 3.1: Total Federal Expenditures for Indoor Pollution Research by Category of Research, Fiscal Years 1987 Through 1999



Notes: Amounts are expressed in constant 1999 dollars.

Amounts for fiscal year 1999 represent planned expenditures.

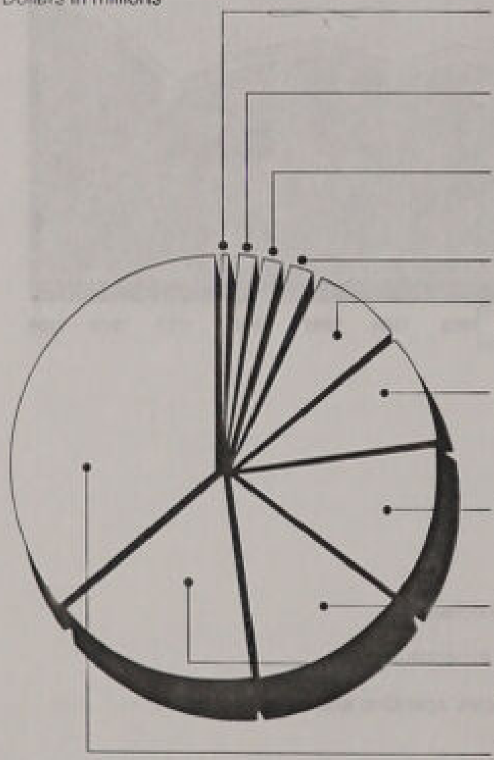
See appendix I for details of the individual agencies' spending and explanations and qualifications of reported expenditure data.

Source: GAO's analysis of data from the CPSC, DOE, EPA, HUD, NCI, NHLBI, NIAID, NIOSH, NIEHS, and NIST.

NIEHS accounted for about 37 percent of the nearly $1.1 billion in federal spending for indoor pollution research from fiscal year 1987 through fiscal year 1999 (see fig. 3.2). Taken together, four institutes within NIH accounted for about 64 percent of the total federal spending for that period. EPA, DOE, and HUD were the next largest spenders on research related to indoor pollution. These three agencies' actual and planned expenditures for the period ranged from 7 percent to 13 percent of total federal spending. CPSC, NIOSH, and NIST each accounted for 2 percent or less of the total federal spending for that period.

Figure 3.2: Total Federal Expenditures for Indoor Pollution Research by Agencies, Fiscal Years 1987 Through 1999

Dollars in millions



National Institute of Standards and Technology	$5.9
National Institute for Occupational Safety and Health	$14.6
Consumer Product Safety Commision	$16.8
National Cancer Institute	$19.5
Department of Housing and Urban Development	$75.7
National Institute of Allergy and Infectious Diseases	$93.7
Department of Energy	$136.5
Environmental Protection Agency	$140.4
National Heart, Lung, and Blood Institute	$175.2
National Institute of Environmental Health Sciences	$399.7
Total	**$1,077.9**

Notes: Amounts are expressed in constant 1999 dollars.

Amounts for fiscal year 1999 represent planned expenditures.

Spending amounts do not add to total because of rounding.

See appendix I for details on the individual agencies' spending and explanations and qualifications of reported expenditure data.

Source: GAO's analysis of data from the agencies cited.

Advances Resulting From Indoor Pollution Research

Research sponsored or conducted by federal agencies has (1) advanced the scientific understanding of the multifaceted problem of indoor environmental pollution, (2) led to the development of methods to mitigate the problem, and (3) resulted in the protection of public health while, at the same time, generating savings in health care costs and benefits in productivity.

Characterization of the Problem of Indoor Pollution

As a result of research conducted by federal agencies, important indoor pollutants have been identified.[3] Indoor sources of many chemical pollutants have been identified and, to some extent, quantified. For several indoor pollutants, a general quantitative understanding of the relationships among indoor pollutant concentrations, indoor sources, and building and occupant characteristics has been developed, providing the basis for effective pollutant control measures. In addition, indoor moisture problems, resulting from leaks, water incursions, and condensation of indoor humidity, have been identified as important contributors to indoor environmental problems, in particular, the proliferation of fungi, bacteria, and dust mites that are associated with the development and exacerbation of allergies, asthma, and other diseases. Although adequate measurements to characterize the resulting adverse exposures are not yet available, NIOSH reports that promising work is being performed on such substances as toxins produced by bacteria.

Research conducted by NIAID and others has demonstrated that indoor allergens, such as those from house dust mites, cockroaches, and pets, are particularly important in the development and exacerbation of allergies in genetically susceptible individuals. Individuals become sensitized or "allergic" to the allergens when their immune systems produce allergic antibodies. When allergens interact with these antibodies in the lungs, an inflammatory reaction and asthma may result. Research has shown that individuals who have produced antibodies to these indoor allergens have a substantially increased risk of developing asthma. In many parts of the United States and elsewhere in the world, the predominant allergen is from house dust mites. Research has also shown that, in susceptible children, high levels of exposure to this allergen in early childhood substantially increase the likelihood of both sensitization and asthma.

In the United States, illness due to asthma is disproportionately high among inner-city residents. Research has shown that one risk factor that is

[3] However, research by DOE, NIOSH, and others on nonspecific symptoms in buildings has shown that other important pollutants have not yet been identified. These pollutants have been found to be associated with inadequate ventilation and poor ventilation system design and maintenance.

unique to many inner cities is exposure to cockroach allergen. Among children with asthma who live in inner cities, the combination of allergy to cockroach allergen and exposure to high levels of it is associated with increases in both hospitalizations for asthma and unscheduled asthma-related medical visits. Exposure to high levels of cockroach allergen in early childhood not only increases the risk for more severe asthma, but also increases the likelihood of the development of asthma before age 6. Current research by NIH institutes and others is directed at reducing both exposures to and the effects of indoor allergens, thereby reducing the burden of asthma.

Results of federally funded research on the VOC formaldehyde illustrate the progress that has been made in chemical pollutant and source characterization. Research on indoor formaldehyde sources and emission processes, conducted by several federal agencies and others, has demonstrated that formaldehyde emissions from urea formaldehyde foam insulation, pressed wood building materials, paints, and many other common indoor sources have been responsible for many of the complaints about poor indoor air quality, including such health symptoms as eye, nose, and throat irritation and respiratory distress, that followed efforts to make buildings more energy efficient in the 1970s. The findings of their research have stimulated industry to develop products and building materials with much lower emissions of formaldehyde. As a result, high indoor concentrations of formaldehyde are less common today than in the past.

Federally funded research on radon, sponsored by DOE, EPA, and HUD, among others, has led to the identification of the major source of radon in homes. Prior to this research, it had been generally believed that building materials were the principal source of indoor radon. This research, however, demonstrated that emissions from building materials were not large enough to account for the radon levels found in many U.S. homes and that the major source of radon in most homes was the radon contained in soil gasses. These gasses can enter the building as a result of interactions of its shell with wind and temperature differentials between its interior and exterior. As a result of federally sponsored research, a dynamic model was developed that could quantitatively account for the variations in indoor radon concentrations attributable to these forces. Without such a sound, quantitative scientific understanding of the source and entry mechanism for radon into buildings, it would not have been possible to design effective mitigation technologies to reduce radon in homes and its associated health risks.

Development of Measurement, Modeling, and Other Investigative Tools

As a result of federally funded research, methods to measure indoor pollutant concentrations, pollutant emission rates, ventilation rates, and indoor air distribution patterns have improved greatly over the last two decades. Mathematical models for air leakage and air flow in buildings, both of which affect indoor environmental quality, have been developed and validated to aid research and building design. Protocols and procedures have been developed and standardized to investigate suspected environmental quality problems in a variety of building types.

As a result of research supported by several federal agencies, measurement methods involving the use of small and large environmental chambers and test houses have been developed to advance understanding of the emission characteristics of different indoor pollutant sources over time and under different indoor environmental conditions, including temperature and humidity. EPA researchers have developed measurement methods to test a variety of building and furnishing materials and consumer products. This research has resulted in guidance that has been adopted by the American Society of Testing and Materials (an industry standard-setting organization) and is now used by the private sector in the United States and internationally to characterize organic emissions from indoor materials and consumer products. Manufacturers of office furniture, carpets, adhesives, and other materials use the test methods to evaluate their products and provide emissions information to architects and consumers.[4] In addition, EPA has designed and constructed a state-of-the-art room-sized indoor air research facility that permits characterization of emissions from products and processes that cannot readily be studied using small chambers. The facility allows researchers to study, under controlled environmental conditions, such indoor activities as the use of paints, solvents, cleaners, and other consumer products that can adversely affect indoor environmental quality. EPA, CPSC, and other agencies have also devoted considerable research to developing models that are used to simulate indoor pollutant concentrations and exposures under varying use scenarios.

NIST has developed techniques for measuring building ventilation performance, which have included the use of tracer gas and automated systems to measure building ventilation rates. NIST has also developed and demonstrated techniques to assess air distribution effectiveness in mechanically ventilated buildings as well as building airflow and indoor air quality models that permit assessment of the indoor air quality impacts of

[4]Notwithstanding progress in this area, EPA officials expressed the opinion that product testing for emissions is still in its infancy and that while emissions data are available for some products from some manufacturers, much more remains to be done.

a number of contaminant sources. DOE has developed innovative ventilation measurement strategies intended for broader use in research on the relationship between ventilation and health.

NIOSH, which has conducted hundreds of investigations of suspected indoor environmental quality problems in office buildings, schools, and other institutional settings, has developed, with EPA, standardized protocols for conducting such investigations and eliciting information from a building's occupants regarding their health symptoms and perceptions of indoor environmental quality. These protocols are now widely used in diagnosing suspected problems in buildings and responding to the occupants' complaints. Since 1992, NIOSH has also undertaken an epidemiologic research program on the health effects of indoor environmental quality in nonindustrial indoor workplaces.[5] Products have included (1) a comprehensive review and synthesis of the worldwide epidemiologic literature on this topic to summarize what is known and to identify the best future research strategies; (2) a study showing that, in buildings with indoor environmental quality complaints, low ventilation rates and poor design and maintenance of their ventilation systems are associated with increased building-related breathing symptoms; and (3) a recent study documenting a strong association between elevated temperatures—within the conventional comfort range—and increased reporting by a building's occupants of health symptoms and discomfort.

Development of Mitigation Methods

For many indoor pollutants, source reduction or elimination has been shown to be the most effective and cost- and energy-efficient method to mitigate or prevent problems. Effective control measures have been developed for some, but not all, indoor pollutant sources. Research has also demonstrated the effectiveness of several energy-efficient ventilation and air distribution technologies in controlling pollutant exposures, and high performance technologies, such as particle and gaseous filtration and dehumidification, have been identified. The importance of avoiding low rates of ventilation has also been clearly demonstrated through research and communicated widely. Research has also shown that mechanical ventilation systems can themselves be a source of indoor pollutants (e.g.,

[5]This epidemiologic research is intended to identify relationships between office workers' symptoms and a range of indoor environmental characteristics. Inadequate ventilation, inadequate air distribution, dirt in duct work, and moisture in mechanical systems are the primary problems found to be associated not only with eye, nose, and throat irritation but also with asthma-like symptoms. While often no specific pollutant or pollutants could be identified, research points to the kinds of pollutants that could have caused such problems. NIOSH reported that sampling strategies and analytical techniques are being developed to identify the pollutant components that are the cause of symptoms in over 30 percent of U.S. office workers.

dust and molds) as well as a means to disseminate pollutants throughout a building.

Federally funded research on the health effects of secondhand tobacco smoke has helped stimulate local and state smoking ordinances, employer policy changes regarding smoking in the workplace, and changes in individuals' behavior. By conducting comprehensive risk assessments of environmental tobacco smoke and publicizing these risks, federal agencies have contributed to the reduction of this source of pollution in a variety of indoor environments. As a result, involuntary exposure of nonsmokers to tobacco smoke, at least outside of private homes, has decreased dramatically over the past decade.

Research supported by NIEHS and others on the health effects of low-level exposures of children to lead has resulted in the Centers for Disease Control and Prevention (CDC) lowering the acceptable blood lead level for children. NIEHS has also supported research investigating promising treatment and intervention strategies for low-level lead exposures, including a clinical trial to determine the efficacy of treatment with drugs designed to bond with lead in human bodies and, thus, prevent or reduce neurobehavioral problems in children. Another NIEHS-supported study has provided preliminary evidence that dietary calcium might reduce the release of previously absorbed lead from the bones of pregnant and lactating women, thereby significantly reducing the transmission of lead to the fetus and developing child. If additional work verifies this finding, it offers a significant and inexpensive technique to reduce lead exposure in infants.

EPA, HUD, and other agencies have sponsored research to develop and demonstrate cost-effective radon mitigation and prevention technologies for use in homes, schools, and other buildings. These techniques, which have been widely applied, include (1) soil depressurization (installing suction pipes beneath a building's foundation to passively vent radon or using such pipes in conjunction with a fan to actively pull the radon-containing soil gas away from a building before it can enter); (2) sealing cracks and other openings in a building's foundation to help prevent radon from entering; and (3) increasing a building's pressurization (using a separate fan or a building's ventilation system to create positive pressure to prevent the entry of radon).

Dissemination of Research Findings

A number of federal agencies have played an important part in broadly disseminating the findings and the practical applications of research on indoor environmental pollution—including its sources, its health effects, and the most effective methods for controlling it. This has been done thorough a variety of means, including agency web sites, information clearinghouses, and published materials of a general and specialized nature. Drawing on the results of their own research and that of others, such as DOE and NIST, and on the vast amount of information on indoor environmental problems gleaned from investigations of "problem buildings," EPA and NIOSH collaboratively published an indoor air quality guide for use by commercial building owners and facility managers.[6] In cooperation with nonfederal partners, including the American Lung Association and the National Education Association, EPA later published a similar guidance document for use in schools by school administrators, facility managers, and others.[7] EPA and CPSC, in cooperation with the American Medical Association and the American Lung Association, published a guide to indoor environmental health problems and risks for use by health professionals to provide them with information to aid in understanding the indoor environmental dimension of many commonly encountered health conditions.[8] CPSC has disseminated knowledge gained from research on the indoor environmental impacts of consumer products in a variety of public advisories and other publications, which deal with subjects as diverse as asbestos, biological pollutants, combustion appliances, formaldehyde, lead, and paint strippers.

On a more technical level, EPA has collaborated with the American Institute of Architects to develop a comprehensive, environmentally focused resource document, the Environmental Resource Guide,[9] which provides technical information to architects and other design professionals on a range of issues to help them evaluate the environmental impacts of their design decisions and specifications. Indoor pollutant sources that can affect indoor environmental quality are a major component of the guide. The guide disseminates EPA's research results on source characterization and indoor air modeling and provides guidance that architects, designers, builders, and manufacturers can use in selecting and manufacturing building materials, furnishings, and products.

Federally supported researchers, in particular those associated with DOE and NIST, have been active resources in industry standard-setting

[6] EPA and DHHS (NIOSH), Building Air Quality: A Guide for Building Owners and Facility Managers (Dec. 1991).

[7] EPA, Indoor Air Quality: Tools for Schools (May 1995).

[8] EPA, CPSC, American Lung Association, and American Medical Association, Indoor Air Pollution: An Introduction for Health Professionals (1994).

[9] EPA, Environmental Resource Guide (undated).

organizations, such as the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and the American Society of Testing and Materials. These organizations have made significant contributions to establishing or revising standards that can have an important influence on indoor environmental quality and public health—such as ASHRAE's proposed standard, currently under development, relating to ventilation requirements for residential buildings.[10] Much information resulting from federally sponsored research is also communicated to industry and professional organizations via conference presentations, newsletters, and trade and scientific journals.

The Health and Economic Benefits of Federally Funded Research on Indoor Environments

There is consensus among the agency officials and experts we contacted that federally funded research on indoor environments has resulted in improvements in public health with concomitant savings in health care spending and reduced absences from work and school due to indoor environment-induced illnesses. As a result of the wide dissemination of research findings, building professionals have begun to modify building designs, material selections, and building operation and maintenance practices in ways that improve the indoor environment and protect the health of a building's occupants.[11] As a result of broader public understanding of indoor pollution issues, many individuals are now more aware of potential health hazards in the indoor environment and are making behavioral and consumer choices based on perceptions of their impact on exposures and risks. With improved understanding of the indoor environmental factors that can affect health, health care professionals are better able to diagnose and treat indoor pollution-related illnesses and recommend changes in individuals' behaviors and surroundings that promote good health. An increasing number of manufacturers are making decisions regarding their products that are based on an understanding of potential indoor pollution problems. Some are even turning public concern for indoor environmental quality into a marketing advantage, emphasizing the indoor environment friendly nature of their products.

Federally supported research has also helped to stimulate a multifaceted and steadily growing indoor environmental quality industry that employs a substantial number of people and offers a broad range of products and

[10]This standard, currently under development and consideration by ASHRAE, is referred to as ASHRAE Standard 62.2, "Ventilation and Acceptable Indoor Air Quality in Low-rise Residential Buildings."

[11]Nevertheless, EPA officials and others told us that much remains to be done in this area.

services. Participants in this burgeoning industry include (1) manufacturers and installers of residential ventilation systems; (2) manufacturers of new products for ventilation systems in commercial buildings; (3) manufacturers of air-cleaning equipment, high-efficiency air filters, and pollutant detection and control devices; (4) consultants who investigate, diagnose, and remediate indoor environmental problems in commercial and institutional buildings; (5) radon, asbestos, and lead mitigation contractors; and (6) consultants who guide the building design and construction processes in a manner that promotes good indoor environmental quality.

Despite Progress in Understanding and Managing the Risks Posed by Indoor Pollution, Many Uncertainties and Knowledge Gaps Remain

Over the past decade and a half, significant strides have been made in identifying and understanding the risks posed by chemical and other contaminants commonly found in homes, offices, schools, and other indoor environments. Fifteen years ago, the scientific understanding of indoor environmental pollution—including the sources of indoor contamination, people's exposures to various pollutants and allergens, the potential health effects, and building dynamics—was relatively limited. Notwithstanding the considerable progress in understanding and addressing these issues, however, the consensus of the experts we consulted and the scientific literature we reviewed is that much remains to be learned regarding virtually every aspect of the problem of indoor environmental pollution. The progress that has been made has increased the awareness of the problem's complexity, the broad range of its potential effects on humans, and the variability of individual susceptibility to its effects. Improved scientific understanding of the problem has also, we were told, underscored the importance of devising comprehensive, multidisciplinary approaches to investigating and controlling pollution in a diversity of indoor environments.

Although pioneering studies of total human exposure to environmental pollutants have provided evidence of the significant contribution of indoor sources to overall pollutant exposure, our review of the scientific literature and of information provided by agency officials and outside experts showed that many gaps and uncertainties remain in the assessment of exposures to known indoor pollutants. These gaps relate to such factors as the specific sources of exposures; the magnitude of exposures; the relative importance of various routes of exposure (inhalation, ingestion, and skin contact); the nature, the duration, and the frequency of human activities that contribute to exposures; and the geographic distribution of exposures to specific indoor pollutants for the U.S. population as a whole. Such gaps in understanding currently limit the ability to perform comprehensive risk assessments for most pollutants found indoors.[1] Similarly, while progress has been made in identifying many indoor pollutants, research continues to bring to light additional pollutants, such as chemical-laden fine particles, chemical compounds that are capable of mimicking human hormones and interfering with the

[1]For indoor allergens, which cause disease only in individuals who become sensitized or "allergic" to the allergens, risk assessment is more complex. Allergic inflammatory reactions and asthma result from the interaction of allergens with allergic antibodies in the lung and other organs. The levels of both allergens and antibodies determine the magnitude of the response. Genetic factors, as well as levels of allergen exposure early in life, affect the degree of sensitization.

human endocrine system, toxins from indoor fungi and bacteria,[2] and infectious disease agents whose presence and potential for harm in indoor environments have not been fully explored or appreciated.

Likewise, while research has shed light on the carcinogenic potential of some toxic contaminants encountered indoors (e.g., radon and environmental tobacco smoke), much less is known about the multiple noncancerous health effects of indoor exposures to low-level concentrations of indoor contaminants, for example neurological, immunologic, developmental and other effects.[3] Similarly, very little is known about how to convert descriptions of nonspecific symptoms into objective, quantitative data; the relationship between symptoms and disease in the context of the indoor environment; and the impact of comfort on the productivity of office workers. There are also significant gaps in the understanding of the health effects of biocontaminants and the mixtures of chemical pollutants to which people are exposed in indoor environments, including the extent to which the actions of the pollutants may be additive or synergistic, or even antagonistic. For the nonspecific symptoms reported since the 1970s in some commercial and institutional buildings (sick building syndrome symptoms), neither the nature of the disease (e.g., immunologic, toxic, or irritant) nor the specific exposures responsible are yet well understood. This is true also of the variable cluster of symptoms that have been most commonly referred to as multiple chemical sensitivities (MCS) or environmental illness.[4] Such gaps in the scientific understanding of health effects, like those relating to exposure assessment, also limit the ability to perform comprehensive risk assessments of most indoor environmental pollutants.

According to our review of the scientific literature and our contacts with agency officials and outside experts, other areas needing additional research include

[2]For example, ongoing research conducted by CDC suggests that one of several causes of infant pulmonary hemorrhage may be toxins from a specific type of mold in an infant's environment.

[3]Most chemicals in commercial use have not been tested for their potential to cause adverse health effects; less than one-third of regulated, high-production chemicals, including many found indoors, have undergone even a preliminary screening level of testing for adverse health effects.

[4]MCS is a controversial issue. Some medical groups, such as the World Health Organization and the American Academy of Allergy, Asthma, and Immunology, prefer the name "idiopathic environmental intolerances" for these symptoms because, in their opinion, the term MCS makes an unsupported judgment on causation (i.e., environmental chemicals), does not refer to a clinically defined disease, and is not based on accepted theories of underlying mechanisms nor validated clinical criteria for diagnosis.

- the relationships among the factors that affect the indoor environmental quality of residential, small office, and school buildings and the occupants' perceptions of the quality of their indoor environments to allow the development of strategies to improve these environments and protect the health of the occupants;
- the tools to better measure and control ventilation to help those who design and operate buildings ensure that their efforts result in healthier indoor air;[5] and
- the motivations of key decisionmakers who influence indoor environmental quality to develop strategies and techniques to influence them to make choices that are conducive to good indoor environmental quality.

These areas of research were identified by agency officials; by prominent academic and other researchers we contacted; and through examination of agency reports and published, peer-reviewed scientific literature. They do not constitute a comprehensive catalog of indoor pollution-related research needs or a prioritized list of them. Instead, they are intended to illustrate the scope and the variety of research that is needed to address the uncertainties and fill the gaps in the current understanding of the problem of indoor environmental pollution and provide the tools to effectively manage the risks it poses. In addition to being broad and resource intensive, most of the research requires sophisticated, multidisciplinary approaches. We were told that this could best be ensured through a coordinated, cooperative effort involving multiple federal agencies, state and local governments, universities, and, where feasible and appropriate, industry, professional associations, standard-setting groups and other private sector organizations. EPA officials told us that an additional compelling reason for such a comprehensive and concerted research effort is the fact that very strong and persuasive data are needed to motivate voluntary risk management actions in a largely unregulated area, such as indoor environments, in contrast to other environmental areas that are subject to extensive federal, state, and local government regulation.

Exposure Assessment

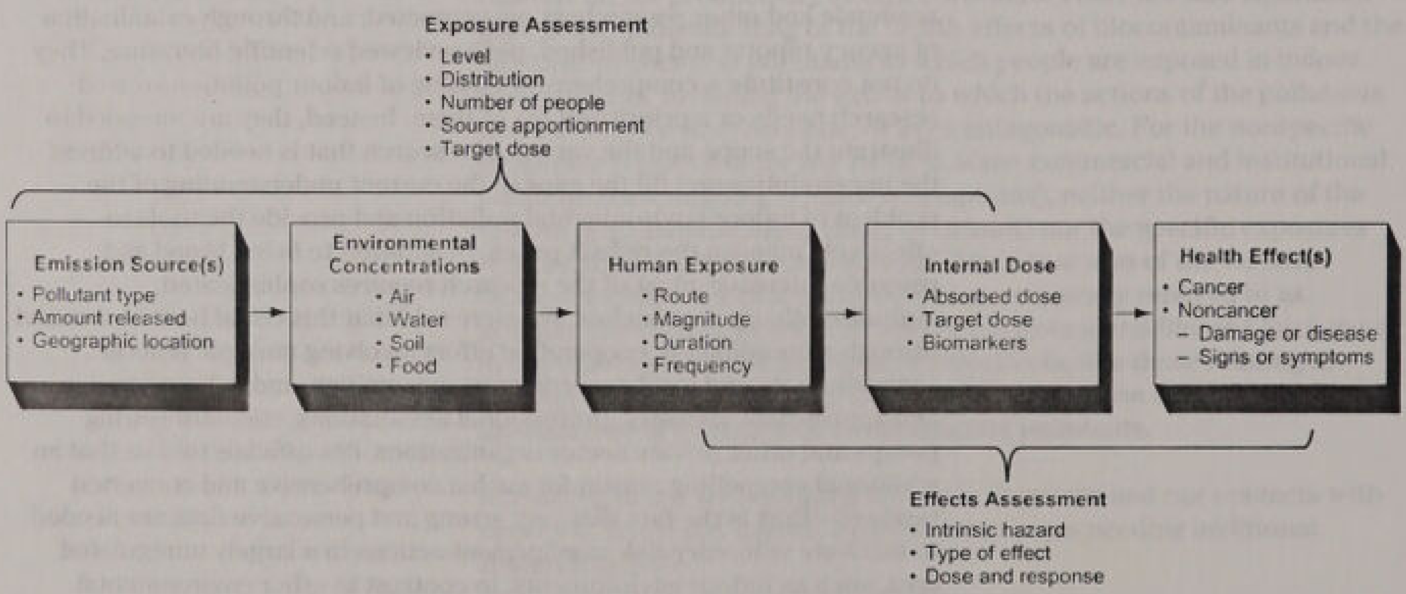
Estimating the health risks associated with a pollutant is based on two activities, exposure assessment and effects assessment. In exposure assessment, the sources, the media concentrations, the exposure, and the received dose are evaluated. A principal goal is to estimate exposure levels

[5]EPA officials told us that research is also needed to develop cost estimates for various risk management options to improve indoor air as well as cost/benefit analyses for their implementation.

and the number of people exposed (e.g., the population exposed to particular air pollutants at concentrations that exceed national ambient air quality standards or occupational safety standards).

The series of events depicted in figure 4.1 serves as the conceptual basis for understanding and evaluating the impacts of environmental pollution on human health. It shows exposure as a key element in the chain of events that begins with the release of a pollutant into the environment and that can lead, ultimately, to environmentally induced disease or injury.

Figure 4.1 Relationship of Exposure Assessment and Effects Assessment to the Environmental Health Paradigm



Source: Ken Sexton, Sherry G. Selevan, Diane K. Wagener, Jeffrey A. Lybarger, "Estimating Human Exposure to Environmental Pollutants: Availability and Utility of Existing Databases," Archives of Environmental Health , Vol. 47, No.6 (Nov.-Dec. 1992) pp. 398-406.

Despite the obvious importance of exposure data in evaluating environmental hazards, our review of scientific literature, agency documents, and information provided by outside experts showed that such data have not been collected in a systematic or comprehensive manner. Only limited information is available for environmental exposures of populations and selected subpopopulations, such as children, the chronically ill, and other particularly susceptible groups. Consequently, understanding historical trends, estimating current levels, predicting future directions, and making comparisons among geographic locations are difficult. Gaps in information concerning exposures to pollutants in indoor environments are a part of the larger problem of gaps in the data on exposure. These gaps impede evaluating the relative contributions of indoor and outdoor sources to total human exposure to specific pollutants. They also impede evaluating the public health risks posed by various indoor pollutants as well as the need for actions to mitigate them.

Much of the current scientific understanding of the potential health risks posed by pollutants in indoor environments stems from pioneering field studies conducted a decade or more ago. While these early studies provided important insights on the health hazards in the indoor environment, they did not constitute a definitive assessment of the indoor environment's contribution to total human exposure to the large number of pollutants of potential concern. They pointed to the need for a much larger, more strategic and integrated research effort designed to improve the understanding of human exposure to pollutants. Such a comprehensive effort would need to consider and assess such key factors as (1) the sources of pollutant exposures; (2) the magnitude of exposures; (3) the routes of exposure; and (4) the nature, the duration, and the frequency of human activities that contribute to exposures. It would identify more precisely the relative contributions of indoor and outdoor pollutant sources to total exposure and highlight variations in exposures among geographic regions and particularly susceptible subgroups, such as infants and young children.

Such a comprehensive and integrated body of research was actually defined and planned as a result of work in the mid-1980s by the Total Human Exposure Research Council (composed mostly of EPA scientists), but it was never carried out. The Council's report laid out an agenda of short-term and long-term research to address key uncertainties and knowledge gaps concerning the risks posed by human exposure to hazardous environmental pollutants, including identifying where and how exposures occur.[6] Among the numerous research needs identified in the report were

[6]EPA, Total Human Exposure Research Council, Research Needs in Human Exposure: A 5-Year Comprehensive Assessment (1990-1994) Sept. 1988.

- improved methods and instrumentation to measure individuals' exposures to specific pollutants and pollutant classes;
- additional field studies to supplement and confirm information obtained from earlier studies;
- the development of total human exposure models based, in part, on the recorded activity patterns of real populations and subgroups; and
- improved biological markers and other techniques to account for exposure by all routes and integrate the consequences of intermittent and continuous exposures.

According to current and former EPA officials who participated in or were familiar with the Council's report and the body of research that it laid out, the reasons for the failure to implement that research included the large, long-term commitment of resources that would have been required as well as shifts in research emphases at EPA. EPA has recently taken steps to improve the scientific understanding of human exposures to environmental pollutants through cooperative efforts with other agencies and through initiatives of its own, such as the National Human Exposure Assessment Survey and the Cumulative Exposure Project. These initiatives are still in the early stages of implementation, however, and have yet to produce significant results. NIOSH officials told us that any comprehensive program on exposure assessment in indoor environments must recognize that some indoor exposures with important health effects, whether chemical or biological, have either not yet been identified or are not currently measured in a way that correlates with the human health effects of interest.

Research on Specific Indoor Pollutants and Their Health Effects

Our review of the scientific literature, agency documents, and information obtained from a range of experts indicated that many gaps remain in the scientific understanding of indoor pollutants and their effects on human health. Improving the healthfulness of indoor environments requires a better understanding of the heath risks and the effects resulting from indoor pollutants. In many cases, we found, a lack of the kind of scientifically rigorous and quantitative information on causal relationships between health symptoms, exposure, and dose response relationships that is needed to establish health standards for the general population and susceptible subpopulations and inform policies and guidance for remedial actions. To facilitate the development of cost-effective and energy-efficient methods for improving indoor environmental quality and aid research on health effects, a better scientific understanding of the nature and the behavior of selected indoor pollutants is essential. The dependence of indoor pollutant concentrations and exposures on characteristics of building design, operation, maintenance, and furnishings also must be better understood to permit mitigation of the effects of indoor pollutant exposures..

Knowledge gaps, while numerous, appear to be greatest for indoor particles, in particular, biological aerosols (bioaerosols)—liquid or solid particles containing biological materials, such as viruses; bacteria; molds; pollens; and pet, cockroach, and dust mite allergens. Although the specific causal exposures have not been identified in many cases, such airborne particles have, in general, been implicated as a cause of allergic diseases, asthma, infectious diseases, and some of the nonspecific symptoms characteristic of sick building syndrome. Increases in disease and mortality are also associated with elevated concentrations of particles in ambient air, but the exposures to these particles appear to occur predominantly indoors and vary with a building's characteristics. Our analysis of published and other data indicated that substantial additional research would be required to

- better identify indoor sources of particles,
- quantify rates of particle emission from sources as well as rates of particle removal through such processes as deposition on indoor surfaces,
- better understand how a building's characteristics (e.g., the type of ventilation and ventilation rates) affect indoor concentrations of particles from outdoor air, and
- develop the capability to model and predict indoor particle exposures.

Our review also identified gaps in the scientific understanding of the degree to which indoor sources and concentrations of bioaerosols are influenced by such factors as indoor humidity levels; heating, ventilation, and air-conditioning system design features and maintenance; water incursions and leaks; moisture condensation; interior cleaning practices; and types of indoor surfaces. NIOSH officials told us that these influences would be most critical for the bioaerosols that are ultimately implicated as causing indoor health effects.

The specific exposure mechanisms for particles, especially bioaerosols, also need to be understood in much greater detail. For bioaerosols associated with infectious or allergic disease, information on size distributions is currently very limited. Data on particle size are important because size greatly influences the natural indoor particle removal processes, the effectiveness of control options (e.g., ventilation and air filtration) and the location of particle deposition in the human respiratory system. For infectious bioaerosols (those containing viruses, molds, or bacteria), there are also gaps in the scientific understanding of how the period of viability is affected by indoor temperatures and humidity levels. As with many indoor pollutants, it is not currently feasible to establish quantitative standards for exposures to bioaerosols, because of the inadequacies of current measurement methods for most bioaerosols and the lack of information on the relationship between exposure and response. After epidemiologic research identifies exposure assessment strategies for specific bioaerosols and their associated health effects, progress towards developing health standards will be possible.

According to the scientific literature and experts we consulted, VOCs and semivolatile organic compounds are two additional classes of indoor pollutants for which additional research will be required to resolve scientific uncertainties related to health risks. To fill gaps in current understanding, research needs to focus on the particular compounds and mixtures of such compounds that have been shown or are suspected to be the most irritant and toxic (including neurologic effects). Research objectives would include identifying sources, quantifying emission rates, and providing a better understanding of how building factors modify exposures through such mechanisms as absorption and adsorption. Other objectives would include the evaluation of the relative significance of various routes of exposure. While most effects may result from the inhalation of gases, these compounds might also have effects by binding to particles, such as floor dust. Thus, exposures could also occur through skin contact and ingestion, especially in infants and small children engaging in hand-to-mouth behavior.

Recent findings that indoor chemical reactions can take place between VOCs and ozone (present in ambient air, largely as an indirect result of automobile, utility, and other industrial emissions) raise additional questions concerning the significance of these reactions to the overall problem of indoor environmental pollution. Indeed, the chemistry of the indoor environment, including chemical reactions of indoor pollutants with indoor materials (perhaps generating new pollutants), interactions of chemical pollutants from indoor and outdoor sources,[7] and interactions of chemical and biological pollutants was shown by our review to be a broad area requiring research to resolve uncertainties and fill gaps in the scientific understanding of this issue.

[7]In addition to ozone, sulfur dioxide and nitrogen dioxide are examples of ambient air pollutants that infiltrate indoor environments and present potential health risks to occupants.

Until the mid-1980s, the primary emphasis of indoor environmental research was on pollutants linked to serious health effects experienced by a relatively small proportion of the population, for example, cancer resulting from exposures to carcinogens. However, there is now considerable evidence that the indoor environment substantially affects a number of less severe health problems frequently experienced by a much larger proportion of the population. These problems include (1) communicable diseases, including such respiratory illnesses as common colds and influenza, which are experienced frequently throughout life by virtually everyone;[8] (2) allergies, which affect the health of approximately 20 percent of the U.S. population; (3) asthma, a debilitating condition, which is experienced by an estimated 6 to 12 percent of the U.S. population; and (4) a set of nonspecific irritation and central nervous system health symptoms (generally referred to as symptoms of sick building syndrome), which are often experienced in the workplace by an estimated 20 to 30 percent of U. S. office workers[9] and are a major source of complaints in schools as well.[10]

At present, there are limited federal research efforts on nonspecific symptoms. There is also limited research aimed at determining the influence of indoor environments on communicable respiratory illnesses. With regard to the association of asthma with indoor environmental conditions and allergies unaccompanied by asthma, there has been a significant amount of research in recent years, but much more is required to fill gaps in the scientific understanding of these problems. NIAID officials told us that current research includes attempts to reduce the levels of indoor allergens, including those from house dust mites, cats and dogs, cockroaches, and molds, and to determine whether reduction of these allergens mitigates the severity of allergy and asthma. The officials noted that available methods to control exposure to certain allergens, such as cockroach, appear to be of limited effectiveness. An alternative method to control responses to allergens is to block the production of antibodies to allergens, but currently available approaches, chiefly "immunotherapy," have limited effectiveness. We were told that additional research is needed to develop new approaches to block the production of antibodies to

[8]As well as some more serious respiratory diseases, including tuberculosis and Legionnaire's disease.

[9]Researchers at DOE's Lawrence Berkeley National Laboratory have estimated the percentage of office workers who experience these symptoms at 20 percent. NIOSH has estimated the percentage at 30 percent.

[10]Joan M. Daisey and William J. Angell, A Survey and Critical Review of the Literature on Indoor Air Quality, Ventilation, and Health Symptoms in Schools (Lawrence Berkeley National Laboratory, Mar. 1998).

allergens and determine the effectiveness of this in preventing and treating asthma and allergic diseases. African-American and Hispanic children in inner cities bear a disproportionate burden of asthma-related illness, and their responses to cockroach and other allergens account for a substantial part of their high rate of illness. Thus, in the opinion of NIAID officials, a major focus of research efforts to block the production of antibodies to allergens should be on inner city children.

Building Studies

EPA, in coordination with a number of other federal agencies, has sponsored major studies of commercial and governmental office buildings in recent years.[11] These studies included developing questionnaires and exposure assessment methods and were intended to provide baseline data on building characteristics, occupants' perceptions of indoor environmental quality, occupants' health symptoms, and other factors relating to large office buildings representative of such buildings nationwide. Future analyses of these data may identify relationships between occupants' responses and building factors or specific indoor exposures that will help in formulating policies for healthier indoor environments. Similar data are currently lacking, however, for the nation's residential buildings; for small office buildings, which house a significant fraction of the nation's office workers; and for schools. A better scientific understanding of the factors contributing to pollutant exposures and associated health risks in these indoor environments as well as the measures that might be taken to mitigate these hazards would be facilitated by a coordinated series of studies of representative samples of residential, small office, and school buildings. Such studies, by providing quantitative data on key building characteristics and aspects of building operation and maintenance believed to influence occupants' exposures to pollutants, would permit the epidemiologic analyses necessary to define environment and response relationships. Factors of interest would include

- the type of building and its age;
- the materials of construction;
- the type of ventilation;
- the ventilation rate (the rate of indoor air exchange with outside air);

[11]These studies are, respectively, the Building Assessment Survey and Evaluation (BASE) study and the Temporal Indoor Monitoring and Evaluation (TIME) study. The BASE study is a multiyear study designed to define the status of indoor air quality and occupants' perceptions in a cross section of at least 100 commercial office buildings nationwide. The TIME study is a study over a period of time encompassing seasonal changes of the status of federal government office buildings with respect to indoor air quality and occupants' perceptions of their indoor environment.

- the presence of soft surfaces, such as carpets, draperies, upholstery, or fibrous insulation within ventilation systems that can act as reservoirs for indoor pollutants;
- the control of moisture and the evidence of excessive moisture within the buildings and their ventilation systems;
- the indoor storage and use of potentially polluting products;
- the presence of indoor combustion sources;
- the methods and frequency of maintenance and cleaning of buildings and their ventilation systems; and
- the indoor activities of occupants (e.g., cooking, crafts, hobbies, printing, or photocopying).

According to the experts and the scientific literature we consulted, ensuring that appropriate methodologies are used in research to clarify the influence of building characteristics on health effects requires research teams that are multidisciplinary in nature, with individuals trained in such disciplines as epidemiology, medicine, chemistry, building systems, exposure assessment, and microbiology. Among the objectives of such research would be to learn how building design features, furnishings, and operations and maintenance practices influence both exposures to pollutants, allergens, and infectious disease agents and health. Collecting such data, using appropriate epidemiologic and statistical strategies, and developing databases to analyze this information would permit the development and the validation of predictive models of exposures to environmental pollutants by the occupants of residential, small office, and school buildings. These models would, in turn, allow the identification of specific building factors or exposures related to health effects of interest. It would then be possible to develop cost-benefit analyses for steps designed to mitigate exposures associated with adverse health effects, including analysis of economic benefits to building owners who are willing to undertake the necessary remediations. This information would also permit the development of educational tools for occupants and owners as well as optimal approaches for manufacturers, architects, builders, and building managers to design, construct, and operate buildings and ventilation systems for effective pollutant exposure control.

Ventilation Measurement and Control

Despite considerable research related to ventilation, many of aspects of building ventilation require further research. According to the published literature we reviewed and experts we consulted, there is a particular need for research to provide satisfactory answers to the question of how the exchange of indoor and outdoor air relates quantitatively to health effects, specifically the relationship of a building's ventilation rates with the health of its occupants. Such information has great importance and usefulness for organizations that specify minimum building ventilation rates in standards and codes.

Those who design and operate buildings require better tools to help ensure that their efforts result in healthful indoor air for building occupants. Such tools include practical guides based on the use of sophisticated air flow models (ideally integrated with pollutant exposure models), improved sensors for important classes of indoor pollutants that can be linked to ventilation control systems, and a wide array of standard practices and guidelines that cover everything from building diagnostics through building operation and maintenance practices. We were told that there is a particular need to develop, evaluate, and demonstrate improved methods for measuring and controlling ventilation rates in commercial and institutional buildings. While source control (pollution prevention) is always the preferred method of avoiding unhealthy exposures, in practical terms, it is ventilation with outside air that is the primary means used in office buildings, schools, and other large buildings to maintain acceptable levels of indoor air pollutants. However, ventilation rates in buildings ventilated with mechanical systems are typically difficult to measure and sometimes poorly controlled. According to the limited data available, average ventilation rates appear to vary widely among buildings of the same type (e.g., office buildings); and, within large buildings, rates can differ greatly between rooms, floors, and zones. As a result, some buildings may have ventilation rates below the minimum levels specified in building codes and industry standards, while others have ventilation far above the specified rates. Reducing indoor air quality problems without wasting energy and increasing costs depends on improving ways to control ventilation in the nation's buildings.

Residential buildings present a different set of problems requiring research. The vast majority of homes have no mechanical ventilation systems to bring outside air into them to dilute concentrations of indoor pollutants. The ventilation rates in homes typically depend on the number and the size of accidental air leaks in their shells, the occupants' actions with respect to opening windows and doors, the use of exhaust fans, and the weather conditions. With the current emphasis on energy conservation, building tightness, and climate control to provide year-round comfort to occupants, the need for research to develop affordable, robust, and energy-efficient ventilation systems for residential use was cited by a number of authorities. Ideally, such systems would be automated and would incorporate sophisticated filtration, monitoring, and sensing capabilities (for indoor air pollutant and humidity control) to help ensure healthful indoor air on a continual basis.

Strategies and Techniques for Influencing Key Decisionmakers

Decisions that can have profound effects on indoor environmental quality and, consequently, on the health, the comfort, and the productivity of a building's occupants, are made by a multitude of nongovernmental decisionmakers. These include architects, builders, engineers, maintenance contractors, building owners and operators, as well as the occupants themselves. We were told by experts who have performed or reviewed studies in this area that these individual decisionmakers frequently do not appreciate the impacts of their decisions on indoor environmental quality and, when this is the case, may need to be provided with appropriate information and guidance.[12] However, even when the decisionmakers do have some understanding of the potentially adverse impacts of their choices and actions, they may nevertheless make decisions that do not appropriately balance the societal costs and benefits of ensuring a high level of indoor environmental quality. Additional research is needed, we were told, to clarify the reasons why decisionmakers are often not motivated to protect the quality of indoor environments and to identify strategies to motivate them to make concern about indoor environmental quality a more integral part of their decision-making. Such research would include the identification of techniques and incentives for influencing motivation.

Some of the reasons why decisionmakers are often not motivated to value and promote good indoor environmental quality are already known, if insufficiently studied. In the case of many large office buildings, the owners are not the employers of the workforce that occupies the buildings. Thus, the owners do not directly benefit from improvements in the workers' health, comfort, and productivity. The owners are primarily motivated to maximize profits by minimizing costs for building design, construction, and operation. Likewise, architects and design engineers of speculative investment buildings, owners of apartment buildings, contractors who make repairs and renovations, and maintenance and pest control contractors often receive little or no benefit from making

[12] For example, parents of infants and small children need information on currently available ways to protect their children from chemical and other contaminants in house dust, dust mite and other allergens, molds, and other indoor pollutants. This information and that which will be developed in future research will be of little value until it is used to reduce exposure. Thus, research is also needed on methods that are effective in bringing about behavioral changes that contribute to reducing exposures.

decisions that improve or protect the indoor environment. Even within a company that owns and operates its own buildings, the department responsible for their operation does not typically benefit from improvements in the health, the comfort, and the productivity of the workforce. The prevailing incentives tend to influence all of these decisionmakers to focus primarily on minimizing short-term or initial costs.

We were told that additional research is required to improve the understanding of the range and the mechanism of influence of various decisionmakers on indoor environmental quality and of the institutional barriers that often motivate them to neglect it. A related need, cited by federal agency officials and others, is to evaluate policy options and other techniques to overcome the low priority often given to indoor environmental quality, for example by shifting the costs of poor indoor environmental quality to the decisionmakers. Possible methods for accomplishing this, which were identified and will require further assessment, include (1) insurance policies that would reduce health and other insurance costs when practices conducive to good indoor environmental quality and health are implemented, (2) model leases that would require lessors to operate and maintain their buildings in a manner consistent with good indoor environmental quality, and (3) various regulatory approaches. To better inform and motivate decisionmakers, we were told, research is also needed to develop improved quantitative information on the economic costs and benefits of implementing technologies and practices that improve indoor environments. The reason for this is that, in many instances, the financial benefits associated with improved health and productivity will be very large relative to the costs. As these benefits become more generally known and understood, an increased demand for good indoor environmental quality should result.

Conclusions

Agency officials and other experts we consulted were in general agreement that additional reductions in exposures to and adverse health effects from indoor pollutants will require continued efforts to develop a sound scientific and quantitative understanding of the complex relationships among building factors, indoor pollutant exposures, and health effects. Significant progress, we were told, will require research to understand cause and effect relationships—not just to document phenomena. Without a sound understanding of causality, it will not be possible to develop cost-effective solutions to indoor pollution problems.

These experts were also in general agreement that filling the major remaining gaps in the scientific knowledge and understanding of indoor environmental pollution and devising effective solutions to this problem will necessitate comprehensive, coordinated, multidisciplinary programs of research along the lines of those described in this report. Accomplishing these endeavors will require research teams that bring together expertise from a variety of disciplines, including building systems, ventilation, chemistry, epidemiology, exposure assessment, health effects assessment, and pollution control. We were also told that, because the private sector has little economic incentive to conduct such research, the major portion of this research will, of necessity, have to be supported by the federal and state agencies that have been the primary sponsors of this research to-date, including those agencies that were the subject of our review. The magnitude of this research effort suggests that accomplishing it in the most expeditious, effective, and efficient manner will require coordination, consultation, and cooperation among agencies—in developing a consensus research agenda, setting and prioritizing research objectives, and identifying ways to collaborate so that their respective skills, assets, and expertise are optimally utilized. An example of this, conducted within the occupational health community by NIOSH, is the National Occupational Research Agenda process. A multidisciplinary, multisector team is working to define and facilitate a priority research agenda that will improve the health of U. S. workers in indoor environments, such as offices and schools.[13]

While research has shed considerable light on the problem of indoor environmental pollution since it first became a prominent issue, the pace of progress in understanding and controlling the problem has not been as rapid as many experts believe it should be, particularly in view of the seriousness of the potential health effects and the sizeable potential benefits of effective solutions to the problem. As one experienced and widely respected academic researcher told us, in describing the need for a comprehensive body of research on U.S. residential buildings, "without such a coordinated and extensive effort, the nation will still be nibbling at the edges of [this] problem and its substantial public health impacts for at least several more decades."

[13]While agreeing that coordination, consultation, and cooperation among agencies is needed to develop a consensus research agenda and set broad priorities for indoor pollution-related research, CPSC cautioned that individual federal agencies must retain the ability to set their own research priorities in light of the activities and the identified needs that relate to their respective missions and areas of responsibility.

Expenditures of Ten Federal Agencies for Research on Indoor Pollution

Following is a table and a discussion about ten federal agencies' spending on indoor pollution-related research for fiscal years 1987 through 1998, as well as planned spending for fiscal year 1999.[1] We asked the agencies to take a broad view of indoor pollution-related research. For example, aside from such widely recognized indoor pollutants as carbon monoxide, radon, lead, asbestos, formaldehyde, and volatile organic compounds, we asked agencies to consider such other indoor pollutants as pesticides, ozone, and biological contaminants, including allergens and infectious bioaerosols. We also asked the agencies to take a broad view of their research activities. We asked them to report, in addition to expenditures for basic research, spending on activities broadly related to improving the scientific understanding of indoor environments, including building studies and investigations of indoor pollution-related complaints in problem buildings. Also requested was spending related to the development of pollution prevention and control strategies for indoor environments and economic studies to estimate the costs associated with indoor pollution and the potential benefits from improving indoor environmental quality . Each agency was given the discretion to identify the specific research activities and associated spending that it considered to be germane to our request. For purposes of presentation, we have grouped the reported research expenditures into four categories: indoor air, lead, radon, and asbestos.

[1]Our review covered the activities of eleven federal agencies. However, the Occupational Safety and Health Administration (OSHA) advised us that they do no scientific research on indoor pollution-related issues. Instead, they rely on the research of the National Institute for Occupational Safety and Health and other federal and state agencies in administering their regulatory functions. Accordingly, we received no information on expenditures for indoor pollution-related research from OSHA.

Appendix I
Expenditures of Ten Federal Agencies for Research on Indoor Pollution

Table I.1: Total Spending for Indoor Pollution-Related Research by Ten Federal Agencies, Fiscal Years 1987 Through 1999

Dollars in thousands

	Expenditures, by fiscal year					
Agency	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**
Consumer Product Safety Commission (CPSC)						
Indoor air	$1,681	$776	$1,922	$1,571	$1,267	$1,222
Lead	96	8	21	176	174	229
Asbestos	141	50	103	17		
Subtotal	$1,918	$834	$2,045	$1,764	$1,441	$1,451
Department of Energy (DOE)						
Indoor air	2,597	2,544	1,792	1,707	1,882	1,871
Radon	4,571	14,056	17,095	16,646	12,884	11,724
Subtotal	$7,168	$16,600	$18,887	$18,353	$14,766	$13,595
Department of Housing and Urban Development (HUD)						
Indoor air	28	195		86		115
Lead		841	6,754	3,271	987	356
Radon		54	90		236	460
Subtotal	$28	$1,089	$6,844	$3,358	$1,223	$931
Environmental Protection Agency (EPA)						
Indoor air[a]	3,340	3,971	4,413	3,909	4,265	9,255
Lead						931
Radon	4,064	3,533	4,606	4,592	3,986	3,814
Asbestos			237	999	627	1,143
Subtotal	$7,404	$7,504	$9,256	$9,499	$8,878	$15,143
National Cancer Institute (NCI)						
Indoor Air	1,208	268	819	1,129	1,096	562
Radon	199	390	288	1,758	1,175	1,169
Subtotal	$1,407	$657	$1,107	$2,888	$2,271	$1,731
National Heart, Lung, and Blood Institute (NHLBI)						
Indoor Air	[f]	17,959	17,290	14,957	15,801	15,641

Expenditures, by fiscal year							
1993	1994	1995	1996	1997	1998	1999[a]	Total
$1,561	$1,424	$571	$593	$643	$788	$1,011	$15,030
222	235	30	31	71	87	53	1,432
							311
$1,783	$1,659	$601	$624	$714	$875	$1,064	$16,773
2,193	2,097	1,734	1,437	1,028	1,015	1,200	23,096
10,526	9,836	9,285	3,770	2,980	b		113,374
$12,719	$11,933	$11,019	$5,206	$4,008	$1,015	$1,200	$136,469
56	161				102	8,800[c]	9,542
5,375	7,213	9,178	8,168	8,941	3,959	10,100[d]	65,145
	109	89					1,038
$5,431	$7,484	$9,267	$8,168	$8,941	$4,061	$18,900	$75,725
11,006	10,765	11,713	8,199	9,444	11,873	6,775	98,926
1,556	1,543	1,169	784	615	109	60	6,767
2,082	1,882	1,418	586	174	173		30,910
368	297	77	74				3,822
$15,011	$14,487	$14,377	$9,644	$10,233	$12,155	$6,835	$140,425
270	307	195	345	242	247	252	6,939
1,066	1,266	660	1,171	1,228	1,245	989	12,603
$1,336	$1,573	$855	$1,515	$1,470	$1,491	$1,241	$19,541
16,353	15,412	16,564	16,579	8,079	9,780	10,787	175,202

(continued)

Dollars in thousands

	Expenditures, by fiscal year					
Agency	1987	1988	1989	1990	1991	1992
National Institue of Allergy and Infectious Diseases (NIAID)						
Indoor air	5,672	4,620	4,938	3,673	7,358	7,654
National Institute of Environmental Health Sciences (NIEHS)						
Indoor air	5,309	6,074	2,524[g]	3,619[g]	2,887[g]	9,317
Lead	11,694	10,580	8,563	8,702	10,556	12,916
Radon	530	1,570	3,096	3,560	3,151	3,557
Asbestos	2,260	2,727	2,762	2,834	3,259	3,541
Subtotal	$19,794	$20,950	$16,946	$18,714	$19,852	$29,332
National Institute for Occupational Safety and Health (NIOSH)						
Indoor air	389	447	414	672	1,085	1,678
National Institute of Standards and Technology (NIST)						
Indoor air	391	261	257	247	331	291
Total spending by type of research						
Indoor air	20,614	37,113	34,370	31,570	35,972	47,606
Lead	11,789	11,428	15,338	12,149	11,716	14,432
Radon	9,364	19,603	25,175	26,556	21,432	20,725
Asbestos	2,402	2,776	3,102	3,850	3,886	4,685
Total	**$44,170**	**$70,920**	**$77,985**	**$74,125**	**$73,007**	**$87,448**

Expenditures, by fiscal year							
1993	1994	1995	1996	1997	1998	1999[a]	Total
8,582	8,114	7,880	6,286	7,129	10,815	10,973	93,695
8,972	7,985	13,623	16,430	15,517	23,415	26,035	141,707
14,165	13,923	21,097	20,129	19,699	16,697	17,022	185,742
4,310	1,663	1,635	1,768	1,149	1,188	1,211	28,390
3,592	4,021	4,339	4,087	3,680	3,657	3,078	43,838
$31,039	$27,592	$40,695	$42,414	$40,045	$44,957	$47,346	$399,677
3,063	1,259	1,030	766	1,101	1,191[b]	1,477[b]	14,572
336	328	515	578	642	818	864	5,859
52,391	47,852	53,827	51,212	43,825	60,044	68,173	584,568
21,317	22,915	31,474	29,112	29,326	20,853	27,235	259,086
17,985	14,756	13,086	7,294	5,532	2,606	2,200	186,314
3,960	4,318	4,416	4,161	3,680	3,657	3,078	47,971
$95,653	**$89,841**	**$102,803**	**$91,779**	**$82,363**	**$87,159**	**$100,686**	**$1,077,938**

Notes: All amounts are expressed in constant 1999 dollars.

Amounts for fiscal year 1999 represent planned expenditures.

Numbers may not add to subtotals and totals because of rounding.

Source: GAO's analysis of data from the agencies listed.

[a]The amounts for fiscal year 1999 represent planned expenditures.

[b]DOE's indoor radon research program was replaced in fiscal year 1998 by a new, but related, research program on the effects of low-dose radiation.

[c]HUD officials said that because their plans for spending fiscal year 1999 funds for the Healthy Homes Initiative have not yet been finalized, it is difficult to predict whether all of the planned expenditures will specifically relate to indoor air research or possibly one of the other categories of indoor pollution-related research. However, they believe that the majority of the planned expenditures will relate to indoor air research.

[d]Included in HUD's fiscal year 1999 planned expenditures for lead research is a carry-over of $3.2 million from its fiscal year 1998 appropriations. HUD had planned to spend about $7.2 million for lead research in fiscal year 1998 but was able to obligate only about $4 million of these funds prior to the close of the fiscal year.

[e]EPA has historically tracked research expenditures only for indoor air activities. Because indoor pollution-related research might be conducted under several EPA programs, EPA conducted a special survey to estimate expenditures for indoor pollution-related research. The activities included in the survey may include more than those historically tracked and included by EPA in its research budget line item for indoor air.

[f]NHLBI was not able to provide its expenditures for research related to indoor pollution for fiscal year 1987.

[g]NIEHS was not able to provide its expenditures for intramural resources devoted to indoor air research for fiscal years 1989, 1990, and 1991. Also, NIEHS cautioned that information on expenditures for fiscal year 1987 through fiscal year 1991 for indoor air research had to be estimated and, consequently, is not as reliable as the expenditure information the agency provided for this category of research for fiscal year 1992 through fiscal year 1999. NIEHS officials believe that expenditures reported for other categories of indoor pollutants (i.e., radon, lead, and asbestos) should be reliable for all the years reported.

[h]The spending data for NIOSH does not include any reimbursements that it may have received from other agencies. NIOSH received about $372,000 in reimbursements from other agencies in fiscal year 1998 and anticipates reimbursements of $195,000 in fiscal year 1999.

[i]Only expenditures for indoor pollution-related research made from NIST's appropriations are shown; reimbursements from other federal agencies and contributions made by private sector research groups are not shown. All of NIST's spending has been for research related to indoor air. However, NIST has received funding from other agencies for lead and radon research.

Consumer Product Safety Commission

During fiscal years 1987 through 1999, the Consumer Product Safety Commission (CPSC) told us that its actual and planned expenditures for indoor pollution-related research has totaled about $16.8 million. From fiscal years 1987 through 1994, CPSC's budget for this research averaged about $1.6 million annually. However, by fiscal year 1995, its budget for indoor pollution-related research had dropped to about $600,000 and has been less than $900,000 through fiscal year 1998. In fiscal year 1999, CPSC's spending for this research is expected to reach $1 million for the first time since fiscal year 1994, primarily because of increased work relating to carbon monoxide poisoning. CPSC has had its overall budget trimmed some 60 percent since the mid-1970s, after adjustment for inflation. Also, staff levels have been reduced by over 40 percent. Despite these cutbacks, CPSC believes that it is able to maintain an effective indoor pollution research program. According to CPSC staff, the agency is allocating sufficient resources to address the hazards associated with consumer products used indoors (e.g., lead hazards; carbon monoxide poisoning; and chemicals and materials used in children's apparel, toys, and other articles).

Department of Energy

During fiscal years 1987 through 1999, the Department of Energy (DOE) told us that its actual and planned expenditures for indoor pollution-related research has totaled about $136.5 million. About 83 percent of the funds were devoted to indoor radon research. The remaining funds, about $23.1 million, went toward research on ventilation and energy.

DOE's expenditures for indoor pollution-related research reached their peak in fiscal year 1989 at about $18.9 million. However, by fiscal year 1997, the last year for a separate indoor radon research program within the Department, funding had declined to about $4 million.[2] Actual and planned expenditures for ventilation and energy-related research for fiscal years 1997 through 1999 have been about $1.1 million annually, about 42 percent of what they had been in fiscal years 1987 and 1988. Furthermore in fiscal year 1999, the budget line item for indoor pollution research was eliminated as part of DOE's efforts to consolidate and streamline its budget. According to a DOE official, it is difficult to estimate what impact the elimination of the line item will have on future research related to indoor environments. However, he believes there is a good possibility that research on indoor environments may get less funding in the future. For fiscal year 2000, he stated, DOE is requesting an estimated $1.3 million for indoor pollution-related research, slightly more than the $1.2 million it plans to spend in fiscal year 1999.

[2]DOE's indoor radon research program was replaced in fiscal year 1998 by a new, but related, research program on the effects of low-dose radiation. Although the goal of DOE's indoor radon research program was to understand the health effects resulting from exposure to indoor radon, the research program has covered a broad array of research topics ranging from geology to aerosol physics to the molecular biology of radiation-induced cancer.

Department of Housing and Urban Development

During fiscal years 1987 through 1999, the Department of Housing and Urban Development (HUD) told us that its actual and planned expenditures for research related to indoor pollution has totaled about $75.7 million. Over 85 percent of the funds were devoted to lead research; the remaining funds were spent for indoor air and radon research.

HUD saw a dramatic increase in its indoor pollution-related research program in fiscal year 1999 with the implementation of its Healthy Homes initiative. This initiative will use television commercials, newspaper ads, brochures, and a toll-free information line to help parents protect their children from the potentially deadly hidden dangers in their homes. The initiative will offer information concerning such hazards as lead paint, carbon monoxide, radon, and electrical and fire hazards. In fiscal year 1999, HUD will devote $8.8 million to indoor pollution-related research under this initiative. Of this amount, the Congress directed that at least $4 million be devoted to preventive measures to correct moisture and mold problems in inner-city housing where toxic mold exposure has been linked to acute pulmonary hemorrhage and infant death.

Aside from research on lead and the Healthy Homes initiative, HUD's remaining research has largely focused on indoor radon and on ventilation requirements and moisture control in manufactured housing.

A new program, the Partnership for Advancing Technology in Housing, has the potential for making a contribution to research on indoor environments. This program, which is a partnership between HUD and industry, is aimed at spurring the creation and the widespread use of advanced technologies to improve the quality, the durability, the energy efficiency, the environmental performance, and the affordability of the nation's housing. Although research is an important part of the program, a HUD official stated that most of the $10 million appropriated for the program for fiscal year 1999 has been allocated for uses other than indoor pollution-related research.

Environmental Protection Agency

During fiscal years 1987 through 1999, the Environmental Protection Agency (EPA) told us that its actual and planned expenditures for indoor pollution-related research have totaled about $140.4 million. Almost $99 million, or about 70 percent, of the funds were devoted to indoor air research and $30.9 million, or about 22 percent, to radon research. Lead and asbestos research have accounted for about $6.8 million and

$3.8 million, respectively, of the actual and planned expenditures since fiscal year 1987.

EPA's expenditures for indoor pollution-related research reached their peak during fiscal years 1992 through 1995, averaging about $14.8 million over this 4-year period. However, from fiscal years 1996 through 1998, spending for this research dropped to an annual average of about $10.7 million, representing an average decline of about $4 million annually during this 3-year period. In fiscal year 1999, EPA's spending for this research is expected to decline even further, to less than $7 million. Despite the prominent role in research and information dissemination assigned to EPA by the Superfund Amendments and Reauthorization Act of 1986, indoor pollution-related research will receive only about 1.3 percent of the $520 million that EPA's Office of Research and Development will spend for research in fiscal year 1999.

EPA's Science Advisory Board has expressed concern that EPA has not committed sufficient funds to indoor pollution-related research. In April 1998, the Board stated that EPA's fiscal year 1999 budget request for research was not likely to be sufficient to meet the indoor pollution-related research goals in the agency's strategic plan. The Board questioned the allocation of research funds between ambient and indoor air, particularly given their respective risk profiles. The Board stated that the scientific understanding of indoor pollutants is still in its infancy when compared to environmental science for the outdoor environment. The Board said that there is a need for some intermediate to long-term research to better understand the nature of indoor pollutants, their sources, and their dynamic behavior. The Board concluded that budget constraints appeared to be driving the budgeting process and not the actual scientific needs.

Despite the Board's concern, EPA eliminated the budget line item for indoor air research in its fiscal year 2000 budget to fund what it views as higher priority activities based on risk and statutory mandates. While acknowledging that there will be a decreased emphasis on indoor pollution-related research, EPA officials stated that such research will continue under other programs, such as children's health, particulate matter, and air toxics. In March 1999 testimony before the Subcommittee on Energy and Environment, House Committee on Science, the Board reiterated its concerns about the adequacy of EPA's fiscal year 2000 funding for indoor pollution-related research. The Board, however, said that it was hopeful that its concerns could be minimized by the steps that EPA has taken to incorporate certain aspects of indoor pollution-related research into other broader research projects.

National Cancer Institute

During fiscal years 1987 through 1999, the National Cancer Institute (NCI) told us that its actual and planned expenditures for research on health risks posed by indoor pollutants has totaled about $19.5 million. NCI supports research on the health effects of radon and environmental tobacco smoke with respect to the cause, the diagnosis, the prevention, and the treatment of cancer.

NCI has played a major role in clarifying the carcinogenic hazard posed by radon through its epidemiologic studies of underground miners and the general population. To assess the risks of domestic radon exposure, a series of population-based, case-controlled studies of lung cancer in populations, including nonsmoking women, are being conducted. One of these studies examines the radon exposure of residents living in underground dwellings in China. Another study is attempting to validate the use of miner-based models for radon risk assessment. Almost 65 percent of NCI's actual and planned expenditures for indoor pollution-related research has gone towards radon research.

The remainder of NCI's research related to indoor environmental health risks has primarily concerned the relationship between environmental tobacco smoke and lung cancer. One on-going study by NCI involves examining tumor tissues from the lungs of nonsmokers for genetic evidence linking the tumors to exposure to secondhand smoke. According to NCI, there are many important and unanswered research questions concerning the cancer risk posed by environmental tobacco smoke, and plans are being developed to expand research to provide answers to these questions.

Since fiscal year 1987, NCI has devoted about $1.5 million annually to research on health risks posed by pollutants in the indoor environment. While spending has fluctuated somewhat over the years, we were told that these fluctuations were more a function of the competitive grant process than changes in program emphasis by NCI.

National Heart, Lung, and Blood Institute

During fiscal years 1988 through 1999, the National Heart, Lung, and Blood Institute (NHLBI) told us that its actual and planned expenditures for research related to the health effects of indoor pollutants has totaled about $175.2 million. NHLBI supports a wide spectrum of research on the health effects of indoor air in support of its mission to advance scientific understanding of the cause, the diagnosis, and the treatment of heart, lung, and blood diseases. Some of its exposure assessment and health effects research is concentrated on ozone, environmental tobacco smoke, particulate matter, and other factors that might alter the inflammatory response and the susceptibility to lung disease.

NHLBI's indoor pollution-related research supports a wide range of asthma research, such as investigating how different indoor environmental exposures in early life interact with genetic factors and the developing lung to cause asthma. Medication to control asthma and its effects on lung growth and development are also being studied by NHLBI as are strategies for reducing children's exposure to indoor allergens and irritants, particularly in school settings. NHLBI officials estimate that, historically, about 75 percent of its total indoor pollution-related research expenditures has gone toward research on asthma and allergens.

From fiscal years 1988 through 1996, NHLBI's spending for indoor pollution-related research averaged about $16.3 million annually. However, in fiscal year 1997, spending for this research decreased to about $8.1 million and through fiscal year 1999 is expected to remain below $11 million. NHLBI officials told us that the recent decrease in yearly funding for indoor pollution-related research is attributable to a change in research emphasis from the broad category of chronic diseases of the airways to a greater focus on chronic asthma. According to NHLBI officials, research on environmental exposures received a greater emphasis under general research related to chronic diseases of the airways than under research focusing on chronic asthma.

According to NHLBI, its health effects research has wide applicability. For example, its current research on the cellular, molecular, and genetic mechanisms in asthma will enhance the understanding of inflammatory and immune processes in other lung diseases. NHLBI officials told us that regardless of the trigger, understanding the mechanistic basis of disease is essential to the development of preventive and therapeutic strategies.

National Institute of Allergy and Infectious Diseases

During fiscal years 1987 through 1999, the National Institute of Allergy and Infectious Diseases (NIAID) told us that its actual and planned expenditures for indoor pollution-related research have totaled about $93.7 million. During fiscal years 1987 through 1990, NIAID's annual expenditures averaged about $4.7 million. However, beginning in fiscal years 1991 through 1997, NIAID's expenditures for this research increased to an average of about $7.6 million annually. According to NIAID officials, the increase in research spending during fiscal years 1991 through 1997 was largely attributable to an increased emphasis on research relating to asthma among inner-city children. Specifically, from fiscal years 1991 through 1995, NIAID funded the National Cooperative Inner City Asthma study, which demonstrated a number of risk factors associated with increased asthma severity, especially exposure to cockroach allergens. A follow-on study, the Inner City Asthma Study (1996-2000), is now testing the impact that a comprehensive environmental intervention program involving the reduction of levels of indoor allergens, such as cockroach, house dust mite, and mold, would have on asthma morbidity. Historically, about 78 percent of NIAID's expenditures for indoor pollution-related research have gone toward research on asthma and allergens.

NIAID's actual and planned expenditures for indoor pollution-related research have continued to increase, reaching almost $11 million annually in both fiscal years 1998 and 1999. While some of these increases are attributable to new grants, NIAID officials told us that, in part, the increases are attributable to having a broader definition of what constitutes indoor air quality research. Based on new scientific understandings, certain grants are now considered indoor air quality research that had not previously fit that definition. While much of NIAID's research on health effects covers outdoor as well as indoor exposures to disease-causing agents, NIAID officials told us that it appears that indoor sources, such as cockroach and house dust mite allergens, are, in general, more important causes of asthma than outdoor allergens.

National Institute of Environmental Health Sciences

Among the agencies covered by our review, the National Institute of Environmental Health Sciences (NIEHS) has devoted the greatest amount of funding to indoor pollution-related research. During fiscal years 1987 through 1999, NIEHS told us that its actual and planned expenditures for this research have totaled about $400 million. NIEHS has, for the most part, experienced a steady growth in its funding for this research. For example, planned funding of $47.3 million for indoor pollution-related research for fiscal year 1999 is over 60 percent greater than the $29.3 million that was expended in fiscal year 1992.

NIEHS' actual and planned expenditures for indoor air research from fiscal years 1987 through 1999 have totaled about $141.7 million. A significant portion of its indoor air research—about 31 percent—has been related to asthma because its incidence, morbidity, and mortality have increased over the last decade, especially among children. Indoor air research, including research into asthma and allergens, has seen the largest increase in funding over the years that were examined. In fiscal year 1999, NIEHS expects to spend about $26 million on indoor air research compared to a funding level of about $9.3 million in fiscal year 1992.[3] Also, NIEHS has devoted significant resources to studying the health effects of lead—with actual and planned expenditures for lead-related research totaling about $185.7 million since fiscal year 1987. In fiscal year 1995, NIEHS launched a major clinical trial designed to determine if children's learning and behavior problems can be reversed or reduced after exposure to lead.

NIEHS' basic research on heath effects is aimed at gaining a better understanding of various diseases and illnesses that are triggered by both indoor and outdoor pollutants. Thus, NIEHS' research has broad applicability to both indoor and outdoor sources of pollutants.

National Institute for Occupational Safety and Health

During fiscal years 1987 through 1999, the National Institute for Occupational Safety and Health (NIOSH) told us that its actual and planned expenditures for indoor pollution-related research have totaled about $14.6 million. Almost 60 percent of these expenditures went towards evaluating health hazards relating to nonindustrial indoor work environments. NIOSH considers these workplace investigations of reported health symptoms, potential occupational exposures, and problems of building operation and maintenance to be an important part of its indoor pollution-related research.

NIOSH's annual expenditures for indoor pollution-related research reached a peak in fiscal year 1993 when about $3.1 million was expended. The significant increase in expenditures for that year was attributable to a fivefold increase in the number of requests from workers for health hazard evaluations, largely the result of a national news broadcast that highlighted the problems of indoor air quality and provided NIOSH's toll-free telephone number. From fiscal years 1994 through 1996, NIOSH's expenditures for research on indoor environments steadily declined. However, beginning with fiscal year 1997, indoor pollution-related research spending has been increasing. In fiscal year 1999, NIOSH plans to spend about $1.5 million for this research, as the Institute undertakes

[3]Approximately $11.7 million of this amount will go specifically for research on asthma and allergens.

priority projects identified through its National Occupational Research Agenda.

National Institute of Standards and Technology

The National Institute of Standards and Technology (NIST) has had a limited, but growing budget for indoor pollution-related research. Its overall spending has ranged from a low of about $247,000 in fiscal year 1990 to a high of about $864,000 in planned expenditures for fiscal year 1999. NIST told us that during fiscal years 1987 through 1999, its actual and planned expenditures for indoor pollution-related research have totaled about $5.9 million. However, because NIST does much of its research on a reimbursement basis on behalf of other federal agencies, such as DOE and HUD, the total funding for indoor pollution-related research under the control of NIST is much higher. During fiscal years 1987 through 1999, NIST was responsible for administering almost $14.4 million on indoor pollution-related research, of which about 59 percent was provided through reimbursements from other federal agencies.

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