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Science Advisory Board

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FUTURE RISK:

RESEARCH STRATEGIES FOR THE 1990s

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The Report of The Research Strategies Committee
Science Advisory Board
United States Environmental Protection Agency

to

Lee M. Thomas
Administrator
United States Environmental Protection Agency

September 1988

Science Advisory Board
U.S. Environmental Protection Agency
Washington, DC 20460
September 1, 1988

Mr. Lee Thomas
Administrator
US Environmental Protection Agency
Washington, D.C 20460

Dear Mr. Thomas:

In the spring to 1987, you asked the Science Advisory Board to provide you with advice on ways to improve strategic research planning at EPA. Today we are transmitting to you the results of our investigation. This Report of the Research Strategies Committee has drawn upon the expertise of nearly fifty nationally-recognized scientists, engineers, and administrators in government, industry, academia, and environmental organizations.

We believe that this country's overall approach for protecting human health and the environment must evolve in response to changing circumstances, and that EPA's strategy for R&D must evolve to reflect that new approach. In essence, we are recommending that the Agency emphasize the prevention of pollution as its primary goal. This expansion of EPA's traditional role is necessary if we are to harness the energy and resources of Federal, state, and local governments, the private sector, and individual families in a national effort to reduce the health and environmental risks facing us in the 1990s and beyond.

This report, together with its five detailed appendices, provides clear guidance for shaping the strong environmental research program needed to reduce future risk. The recommendations described here, if implemented, would facilitate the successful conduct of that research.

We appreciate the opportunity to have conducted this study, and we look forward to a formal response from the Agency on the advice provided here.

Finally, we want to express our appreciation for the assistance we received from Tom Super of your immediate office and from the staff of the Science Advisory Board. All were instrumental in helping us prepare this report. We are very grateful for their efforts.

Sincerely,

Alvin L. Alm
Chair, Research Strategies Committee

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CHAPTER
ONE

Executive Summary

The Fundamental Importance of Research and Development

The ongoing national debate over the direction of U.S. environmental policy rarely focuses on the basic technical understanding that allows environmental problems to be identified and solved in the first place. Without a substantial investment in research and development, we would not understand the processes and practices that cause pollution, the means by which it is transported, the mechanisms of human exposure, the kinds of risks that pollution poses, or potential ways to reduce those risks. Without our knowledge base, we would be like those people in the Middle Ages who could not correlate lack of sanitation with mortality.

Fundamentally, most environmental contaminants are the inadvertent byproducts of a scientifically sophisticated and technologically advanced society; they can only be controlled through the application of the same scientific and technological skills. Our success at protecting public health and environmental quality in the modern world will be measured by the extent to which we understand and manage those human activities that can affect the environment both for better and for worse. We must have the technical capacity to anticipate environmental problems, whether those problems are birth defects caused by chemical exposures or changes in the global climate. We must be able to estimate the kinds and degrees of environmental risk, whether such risk is posed to segments of populations or to large ecosystems. And we must have the ability to define the most practical and efficient solutions to our environmental problems, whether those solutions are high-temperature combustion technologies for the incineration of wastes or the increased use of carpools and mass transit to reduce air pollution.

The longer we remain ignorant of environmental problems and their possible solutions, the greater the risk of adverse consequences to human health and environmental quality. Without our past and continuing research, we would not understand how seriously our children's intelligence and behavior can be damaged by lead contamination. We would not know that stratospheric ozone depletion is threatening the protective layer that shields the earth from the sun's ultraviolet rays. We would not understand the nature of the health risk posed by the naturally-occurring radon that sometimes seeps into people's homes. Even more important, without scientific research we would not have undertaken the different kinds of control actions that already have begun to reduce risk in these—and many other—areas.

Moreover, past environmental R&D efforts have proven to be very good investments. For example, the new technologies that EPA has developed to treat wastewater and dispose of hazardous wastes have led to substantial reductions in the cost of controlling pollution. If we are to

continue enjoying the enormous health, environmental, and economic benefits of environmental research, then our research investments must be guided by a comprehensive strategy that defines the most efficient and cost-effective approaches to reducing environmental risk in the future.

In order to reduce environmental pollution and its associated risks to public health and welfare, we use many tools—national environmental standards, control technology requirements, and enforcement procedures. But none of those tools can be used effectively until research has characterized the environmental problem at hand and helped define and develop the possible controls. Thus research is the most fundamental of the tools that promote environmental quality. Without the strong scientific and technical knowledge that results from research and development programs, standard-setting would not be possible, control technologies would not exist, and there would be nothing to enforce.

The Research Strategies Committee

Recognizing the overriding importance of research and development, EPA Administrator Lee Thomas asked the Science Advisory Board (SAB) to establish a special committee to advise him on ways to improve strategic research planning at EPA. The Administrator was concerned about an apparent imbalance between the Agency's short-term, program-related research and its longer-term, basic research. He sensed that EPA's immediate regulatory needs were driving its research and development efforts, while longer-term research equally important to achieving EPA's overall risk reduction goals was being neglected. Consequently, he asked the SAB for an independent, objective assessment of EPA's long-term research needs, and advice on how to incorporate those needs into EPA's research planning process.

The Research Strategies Committee of the SAB was created in response to the Administrator's request. Headed by Al Alm, former Deputy Administrator of EPA, and composed of nationally-recognized scientists, engineers, and managers with broad experience in environmental research, the Committee reviewed EPA's R&D program in the context of the nation's continuing need to understand environmental pollution and the risks it poses to human health and ecological systems.

As part of its review, the members of the Committee prepared detailed documents in five specific research areas:

- Sources, Transport, and Fate;
- Exposure Assessment;
- Ecological Effects;
- Human Health Effects; and
- Risk Reduction.

Among other things, those documents suggest directions to EPA for planning and implementing the environmental research needed by this country in the 1990s and beyond. Furthermore, they describe specific types of research that EPA should undertake in order to protect public health and environmental quality over the long term.

This summary report to the EPA Administrator is derived mainly from the more detailed findings and recommendations contained in the five Committee documents, which are listed as appendices on the inside back cover of this report. The five individual documents containing the complete findings of the Research Strategies Committee can be ordered from EPA's Science Advisory Board.

Conclusions

The Environmental Protection Agency is usually understood to be a regulatory agency. EPA indeed has the responsibility to regulate a wide range of sources—large and small, mobile and stationary—that emit pollutants into the environment. In the past, the Agency typically has fulfilled its regulatory responsibilities by mandating certain kinds of controls to capture pollutants before they escape into and contaminate the environment.

However, the Research Strategies Committee believes that EPA is more than a regulatory agency. EPA is also a research agency responsible, along with other Federal agencies such as the National Institute of Environmental Health Sciences, for defining the nature of—and possible solutions to—the nation's environmental problems. EPA is a technology transfer agency responsible for sharing with industry and state and local governments all the information, training, and technology needed throughout the country to protect the environment. EPA is an education agency responsible for teaching people how their individual actions can sometimes degrade—or protect—the environment. All these functions depend on a strong R&D program to identify and characterize environmental problems and develop effective solutions.

Based on this fundamental belief that EPA is a multi-faceted agency with diverse responsibilities, the Research Strategies Committee concludes that EPA needs to reshape its strategy for addressing environmental problems in the next decade and beyond. In addition to the current emphasis on Federally-mandated controls that are put in place to clean up pollutants *after* they have been generated, the Agency must develop a strategy that emphasizes the reduction of pollution *before* it is generated. A strategic shift in emphasis from control and clean-up to anticipation and prevention is absolutely essential to our future physical, environmental, and economic health.

Over the first 18 years of its existence, EPA has tended to emphasize the use of pollution control equipment to reduce health and environmental risks. That approach, commonly called "end-of-pipe" control, was appropriate considering the kinds of environmental problems that faced the nation in the 1970s, and the kinds of environmental laws that were enacted during the 1970s. The approach was predicated on a number of factors, including the notion that "the polluter pays". That is, the person/organixation responsible for the problem should bear the brunt of correcting the problem. For example, for the nationwide control of automobiles, powerplants, refineries, and municipal wastewater, Federally-mandated end-of-pipe controls were sensible, targeted, relatively efficient, and reasonably cost-effective, and such controls will continue to play an important role in our future environmental protection efforts.

As we move into the 1990s, however, our strategy for reducing environmental and health risks must evolve in response to changing circumstances. For one thing, we are discovering environmental contamination in our homes—e.g., radon—and in the stratosphere—e.g., chlorofluorocarbons—that are not emitted by "pipes" in the traditional sense. Some kinds of environmental contamination, such as run-off from farms and construction sites, are decentralized and therefore not amenable to Federal command-and-control solutions. And because so many new or residual environmental problems, such as indoor air pollution and ground-level ozone, are linked to thousands—if not millions—of small sources of pollution, traditional approaches to pollution control are not likely to be as effective in the future as they have been in the past.

Furthermore, we have learned that traditional end-of-pipe controls have tended to move pollution from one environmental medium to another, not eliminate it. For example, air and water pollutants captured at the end of the pipe usually are disposed of on land. However, land disposal of hazardous pollutants now is being curtailed, and land disposal of non-toxic wastes is increasingly constrained by a scarcity of disposal sites. The shrinkage of our land disposal capacity will limit the shifting of pollutants between media, thus forcing us to find alternatives to end-of-pipe controls.

There is a further reason why we will have to augment our traditional approaches to pollution control with innovative alternatives. Despite the success of our past efforts, some pollutant loadings are still too high, and they are overwhelming the capacity of the environment to assimilate them. For example, since their introduction in the early 1970s, factory-installed controls on automobile exhausts have proven to be an effective way of reducing the air pollutants—like carbon monoxide (CO) and volatile organic compounds (VOCs)—emitted by individual cars. However, total loadings of CO and

VOCs still pose environmental problems in many parts of the country, because the total number of cars, and the total number of miles they are driven, have increased substantially since 1970.

Finally, we have to develop a new environmental protection strategy to address future environmental problems that may not be as reversible as past forms of air and water pollution. We may not be able to add ozone, or subtract carbon dioxide, from the upper atmosphere, no matter how much risk is posed by stratospheric ozone depletion or global warming trends. We will find it extremely difficult to replace estuarine ecosystems, and impossible to replace species of plants and animals, if they are lost. Clearly, the magnitude of these risks requires that we develop and maintain a national environmental strategy that emphasizes prevention, because, in some cases, we will not be able to act after the fact.

Besides working to improve the end-of-pipe controls we have relied on in the past, this country has to develop new, less toxic substitutes for the waste products that end up in the environment. We have to redesign our manufacturing processes so they generate less waste. We have to improve the efficiency of our energy use so that total combustion emissions are reduced. We have to educate all our citizens about the actions they can take during their daily lives to reduce pollution. As we modernize our industry in response to the competitive pressures of a global marketplace, we must recognize that less waste and increased efficiency are often two sides of the same coin; our ability to reduce waste and pollution will be one measure of our ability to compete in the international economy of the 1990s and beyond. In short, EPA's R&D program has to be planned and implemented to support the wide range of activities, examples of which are shown in Figure 1, that must be undertaken throughout our society if we hope to protect our health and environment from future risk.

This inevitable shift in EPA's long-term environmental protection strategy will have enormous implications for EPA's R&D program. Just as EPA has emphasized command-and-control approaches because of statutory requirements, its R&D program has emphasized short-term, program-related research that supports regulatory development. That kind of R&D emphasis is understandable given the fact that EPA's statutorily-mandated regulatory responsibilities have grown dramatically over the past decade, while its R&D budget has shrunk.

However, if EPA's environmental protection strategy is to be refocused on the reduction of pollution at its source in anticipation of environmental problems, then EPA's R&D program has to be expanded and reoriented to include much more basic, long-term research not necessarily tied to the immediate regulatory needs of EPA's program offices. Moreover, EPA must expand and improve the pool of scientific and engineering talent necessary to identify and solve environmental problems.

FIGURE 1

Example Risk Reduction Strategies

	Individuals	Communities and Community Groups	Industry	Federal and State Governments
PREVENT POLLUTANT GENERATION	Conserve Energy	Reduce pesticide use	Substitute raw materials and redesign processes	Ban certain materials
RECYCLE AND REUSE	Return wastes to recycling centers	Promote and operate recycling centers	Reclaim solvents	Purchase recycled products
TREAT AND CONTROL	Inspect and remove asbestos	Treat water supplies	Treat hazardous waste	Mandate air and wastewater treatment standards
REDUCE RESIDUAL EXPOSURE	Avoid fishing and swimming in polluted waters	Operate clean sanitary landfills	Operate clean chemical landfills	Establish high-level radiation disposal facilities

The Ten Recommendations

In support of its belief in the essential value of a strong, coordinated EPA R&D program that has as its long-term goal the prevention or reduction of environmental risk, the Research Strategies Committee makes the following recommendations:

1. EPA should shift the focus of its environmental protection strategy from end-of-pipe controls to preventing the generation of pollution. EPA should use a hierarchy of policy tools that support national efforts to 1) minimize the amount of wastes generated; 2) recycle or reuse the wastes that are generated; 3) control the wastes that cannot be recycled or reused; and 4) minimize human and environmental exposures to any remaining wastes.

2. To support this new strategy, EPA should plan, implement, and sustain a long-term research program. In conjunction with EPA's program offices and the external scientific community, EPA's Office of Research and Development should develop basic core research programs in areas where it has unique responsibilities and capabilities.

3. EPA needs to establish better mechanisms to ensure that a coherent, balanced R&D strategy is planned and implemented. EPA needs to establish an internal Research Strategy Council to oversee its R&D program; a standing committee of the Science Advisory Board should provide an independent review of EPA's core research program; and the Assistant Administrator for Research and Development should be changed from a political to a career position.

4. EPA must improve its capability to anticipate environmental problems. EPA should explicitly develop and use monitoring systems that help the Agency anticipate future environmental conditions, and it should create a staff office that would be responsible for anticipating environmental problems and then recommending actions to address them.

5. EPA should provide Federal leadership for a national program of ecological research by establishing and funding an Environmental Research Institute. The Institute would conduct a core ecological research program, monitor and report on trends in ecological quality, and provide a catalyst for ecological research efforts funded by other Federal agencies, state governments, universities, and the private sector.

6. EPA should expand its efforts to understand how and to what extent humans are exposed to pollutants in the real world. To help improve current understanding of human exposure, EPA should place much greater emphasis on the use of personal monitors and biomarkers, and it should validate many of its human exposure models.

7. EPA should initiate a strong program of epidemiological research. Such studies should be designed to support regulatory efforts and to develop information on potential new environmental and health problems.

8. EPA should expand its efforts to assist all those parts of society that must act to prevent/reduce environmental risk. Since state, local, individual, and private sector actions will become increasingly important for reducing the amount of waste and pollution generated, EPA needs to improve the education, training, technology transfer, and research programs that support such actions.

9. EPA needs to increase the numbers and sharpen the skills of the scientists and engineers who conduct environmental research. EPA should increase grant programs and initiate training programs to increase the national supply of technical personnel, and it should use existing mechanisms, such as the Intergovernmental Personnel Act, to bring about a closer collaboration between EPA scientists and engineers and the external scientific and engineering community.

10. EPA's R&D budget should be doubled over the next five years. If the nation is willing to spend $70 billion per year cleaning up and protecting the environment, then it is reasonable—indeed, barely sufficient—to spend one percent of that amount on EPA research that helps determine how the national environmental protection budget can be allocated most effectively.

CHAPTER
TWO

Background

When the Environmental Protection Agency was established in 1970, one of its major missions was to integrate the different environmental protection responsibilities then existing in different Federal agencies. Before 1970, those responsibilities had been organized primarily by the different environmental media—air, water, and land—that they were meant to protect. Yet, as President Richard Nixon noted in his message to Congress establishing EPA: "Despite its complexities, for pollution control purposes the environment must be perceived as a single, interrelated whole." EPA's organization plan recognized the intermedia causes and effects of air, water, and land pollution, and proposed a "far more effective approach to pollution control" which would:

- Identify pollutants.
- Trace them through the entire ecological chain, observing and recording changes in form as they occur.
- Determine the total exposure of man and his environment.
- Examine interactions among forms of pollution.
- Identify where in the ecological chain interdiction would be most appropriate.

Thus EPA was launched with the explicit assumption that it would be concerned not simply with the effects of particular pollutants in the different environmental media, but with the larger, overarching issues related to human health and environmental quality. The Agency was intended to take a long-term view of the overall condition of the environment and its capacity to support a healthy life for all species, including humans.

EPA's R&D responsibilities were defined in the same broad terms. According to the 1970 Reorganization Message:

> *"The EPA would have the capacity to do research on important pollutants irrespective of the media in which they appear, and on the impact of these pollutants on the total environment. Both by itself and together with other agencies, the EPA would monitor the condition of the environment—biological as well as physical. With these data, the EPA would be able to establish quantitative 'environmental baselines'—critical if we are to measure adequately the success or failure of our pollution abatement efforts."*

In the years that followed, the new Agency was given a host of specific responsibilities beyond its more general mandate. In response to widespread public concerns, Congress passed a series of major environmental laws requiring EPA to protect air quality, water quality, and drinking water, control pesticides and toxic substances, ensure the safe disposal of solid and hazardous wastes, and clean up abandoned hazardous waste sites.

In each of these areas of specific responsibility, EPA faced substantial scientific uncertainty. The risks posed by the different pollutants in different media were not well understood. In many cases the technologies needed to control them were unknown or not yet fully developed. Thus, despite its original charter to take a long-term view of human health and environmental quality, EPA has had to devote a larger and larger share of its R&D budget to the support of near-term regulatory development required by environmental law.

EPA's emphasis on R&D that supports its specific legislated responsibilities has had two negative effects on its long-term research efforts. First, it has sharply limited the resources available for long-term research. Second, the long-term research that has been planned by EPA often has been subject to funding cuts in favor of projects with more immediate public and political interest. In short, funding for long-term research at EPA is not only very limited, but it is also tenuous from year to year, conditions that tend to undermine the research itself, the morale of the scientists and engineers who conduct it, and the respect and cooperation of the scientific community outside EPA.

This situation, which is understandable in terms of immediate public concerns and limited R&D budgets, is very short-sighted in terms of national policy. For a number of reasons, an R&D program shaped almost exclusively by the near-term needs of EPA's program offices will not necessarily provide the scientific and engineering information needed to protect human health and environmental quality over the long term.

First of all, EPA's regulatory activities are not necessarily focused on the environmental problems that pose the greatest risks to public health and welfare. Rather, they are focused on the environmental problems defined in EPA's enabling legislation, which in turn reflects public concern about the effects of different contaminants in different environmental media. Yet neither the depth of public concern nor the stringency of environmental law is necessarily an accurate measure of the relative seriousness of the environmental risks facing us today. The public ultimately will understand those risks, just as they are beginning to understand the implications of global warming, but not until unnecessary health and environmental costs have been imposed, or irreversible damages have occurred.

Second, the environmental laws that EPA currently administers in most cases require EPA to impose

end-of-pipe controls on classes of pollutant sources across the nation as a whole. Those end-of-pipe controls—usually on large pollution sources like powerplants, or on large classes of pollution sources like automobiles—have worked reasonably well, and they have resulted in measurable improvements in environmental quality. However, the steady increase in some pollutant loadings—like solid waste—and the intractability of some pollution problems—like ground-level ozone—despite end-of-pipe controls necessitate that more and more small, decentralized sources be controlled. Controlling such sources will require the use of a number of different risk reduction approaches like materials substitution, redesigned products and production processes, recycling, and lifestyle changes. Yet the kinds of research that would support such approaches are not likely to be initiated by EPA program offices with extensive and immediate Federal command-and-control responsibilities.

Third, implementing pollution control alternatives like materials substitution, recycling, and lifestyle changes will require that state and local governments, private industry, and individual families all take steps to reduce the generation of wastes and contaminants. This decentralization of risk reduction responsibilities is positive and necessary in light of our growing recognition that significant environmental risks are linked to the typical activities of our everyday lives.

Although the Federal government's role in such circumstances may change, EPA still has the responsibility to conduct research that will help other parts of our society act to reduce environmental risks. EPA must fulfill that responsibility, because no one else will. The private sector is unlikely to undertake research on risk reduction techniques that will not have wide commercial application. No one company, or industry, is likely to have a unique, sizeable stake in many future environmental issues, thus making basic environmental research hard to justify to management or investors. Municipal governments—one important user of risk reduction research—traditionally have not invested in such research, because they can barely afford the cost of the traditional technologies needed to manage solid waste, treat wastewater, or protect drinking water.

In short, no individual local government or private business is likely to fund research needed by many local governments and private businesses to help reduce their waste streams. Yet, as more and more elements of our society become directly involved in the business of risk reduction, such research clearly is needed.

Fourth, the specific regulatory requirements of EPA's program offices often result not in the eradication of a pollutant, but in the transfer of that pollutant from one medium to another. Even though EPA was established explicitly to address the cross-media effects of pollutants, their sources, and their control technologies, the Agency's media-oriented program structure, developed to implement media-oriented legislation, has found it difficult to integrate cross-media concerns. The same media-oriented programs are unlikely to have an immediate interest in research that addresses cross-media issues.

Cross-media environmental problems are especially troubling in light of recent concerns over the risks posed by land disposal of solid and hazardous wastes. In the 1970s air and water pollutants concentrated and collected by end-of-pipe controls were routinely disposed of on land. Now, however, the disposal of wastes on land is strictly regulated. Our growing need to eliminate pollution, not simply move it from place to place, is causing us to look beyond end-of-pipe pollution controls. Yet program-related research is not likely to provide the kind of information needed to develop and implement those new controls.

Finally, an R&D program driven by existing policy considerations will be inherently weak to the extent that it fails to anticipate the future. As the history of human disease clearly demonstrates, curing a disease already afflicting large numbers of people is much more difficult and expensive than preventing the outbreak of disease in the first place. Similarly, reducing the presence of a pollutant in the environment *in anticipation of* an environmental problem, rather than *in reaction to* an environmental problem, is a more sensible national policy. EPA's program offices must react to the environmental problems that caused their enabling legislation to be passed; consequently, they have insufficient incentive to support long-term research that investigates the fundamental relationships of ecosystem structure and function that can give early warning of possible environmental problems in the future. Yet that kind of research, seen in the perspective of long-term quality of life and long-term costs, may be the most important of all.

In summary, although EPA's near-term research provides essential support to the program offices in their efforts to carry out their immediate statutory responsibilities, that research does not support the kind of integrated approach to risk reduction that will be needed to protect human health and the environment over the long term. The long-term research that is critical to the shaping of future national environmental policy is not being adequately planned or funded at EPA today.

CHAPTER THREE

The Ten Recommendations

1 EPA should shift the focus of its environmental protection strategy from end-of-pipe controls to preventing the generation of pollution.

Many of the most serious environmental problems facing this country will not be solved through the use of end-of-pipe controls alone. In some cases, like ground-level ozone, end-of-pipe controls have already been applied, but more needs to be done. In some cases, like indoor air pollution, end-of-pipe controls simply are not appropriate or practically feasible. And in some cases, like hazardous waste disposal, end-of-pipe controls are becoming more and more expensive. If we hope to protect the environment and human health from environmental problems like stratospheric ozone depletion, hazardous wastes, and surface water and estuarine pollution, we have to begin controlling pollution long before it reaches the end of the pipe. We have to prevent pollution at its source.

As the Federal agency primarily responsible for protecting human health and environmental quality, EPA should refocus its strategy for controlling pollution. As it has already begun to do in some areas, EPA should encourage the use of a broader array of policy tools, including those that foster changes in individual, community, industry, and institutional behavior. EPA should make a greater effort to apply different policy tools in the following order:

- Whenever possible, environmental protection efforts first should be aimed at minimizing the amount of wastes or pollutants generated. Thus waste reduction at its source—for example, through product design changes, industrial process changes, or material substitution—should be a primary objective.
- For those wastes or pollutants that are generated, every effort then should be made to recycle or reuse them in an environmentally sound manner. For example, community recycling programs should be an important feature of the nation's solid waste disposal efforts, and industry should be encouraged to reuse as much of its hazardous process wastes as possible.
- For those wastes or pollutants that cannot be recycled or reused, treatment, destruction, and disposal technologies should be applied. These risk prevention/reduction tools, like municipal wastewater treatment facilities and automobile emissions controls, are usually the basic regulatory component of EPA's existing programs.
- After all reasonable waste reduction options have been applied, human and environmental exposures to any remaining wastes should be minimized. Containment and isolation of radioactive wastes is one example of this approach. Figure 2 illustrates this hierarchy of policy options for reducing risk.

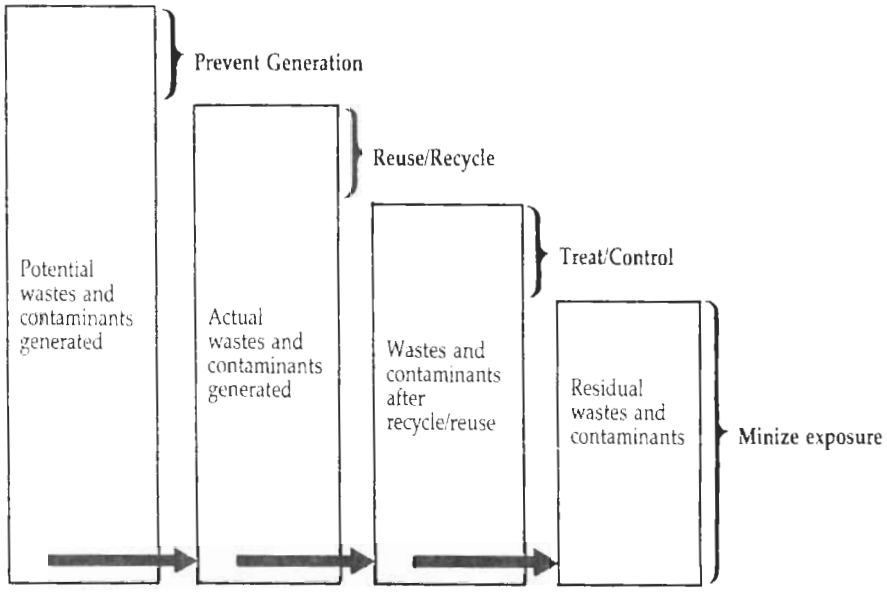
There are a number of advantages associated with shifting our pollution control emphasis from the end of the pipe to the source of the pollution. For one thing, it is often cheaper to redesign industrial processes, or separate and recycle solid waste, than it is to pay for the disposal of wastes in well-controlled landfills or incinerators. They are certainly more cost-effective than the remedial programs that are sometimes necessary to remove wastes or contaminants from the environment.

Reducing pollution at its source also avoids the cross-media problems that may result when end-of-the-pipe control of pollution in one medium simply transfers the pollution to another medium. Finally, by reducing the use of materials known to be harmful to human health or the environment, we can reduce the worker and consumer exposures that sometimes occur even if the end of the pipe is well controlled.

Just as EPA's regulatory role will change as it incorporates this broader approach to environmental protection, its R&D role will change as well. EPA must conduct research that supports materials substitution, industrial process changes, and recycling technologies, because it is unlikely that any individual community or small business will have the incentive or resources to do it. Even though such R&D may not directly support EPA's regulatory activities, it will support this country's broader environmental goals. It also will be an invaluable aid to all the businesses and communities and families across the country that must change their everyday lives if we are to solve some of our most pressing environmental problems.

FIGURE 2

Hierarchy for Risk Reduction Research



2 To support this new strategy, EPA should plan, implement, and sustain a long-term research program.

As is evident in the language used to establish EPA in 1970, the Agency's responsibilities go beyond the regulatory actions mandated by environmental statutes. EPA is also responsible for supporting in a broader way the basic health and environmental objectives from which its regulatory programs are derived. Therefore, EPA's R&D efforts have to be targeted not only on short-term, program-related issues, but also on longer-term issues related to risk prevention/reduction in general.

EPA should begin immediately to identify those core areas of research where it has unique responsibilities and capabilities, and where long-term efforts are needed to identify, assess, and mitigate serious risks. Those core research areas should be selected according to their ability to:

- Address environmental problems that can be expected to persist for a decade or more;
- Generate scientific results that are likely to support a number of existing and/or anticipated Federal, state, or local control programs, whether regulatory or non-regulatory; and
- Provide scientific information, engineering innovations, or new technology unlikely to be generated by the private sector, other parts of the Federal government, or state governments.

The Research Strategies Committee has prepared five separate documents—listed as appendices to this report—that examine the current state of environmental research and recommend a number of important core research areas related to: 1) the sources, transport, and fate of pollutants; 2) the assessment of human and environmental exposures; 3) ecological effects; 4) human health effects; and 5) risk reduction in general. A list of candidate core research areas discussed in the five appendices to this report is shown in Figure 3. EPA should use those suggestions as the starting point in its formal efforts to define a specific list of core research areas.

FIGURE 3

Candidate Core Research Areas

Sources, Transport, and Fate
- Characterizing sources and discharges
- Transport, conversion, and interaction in the environment
- Models for predicting form and concentration of pollutants
- Methods for anticipating future environmental problems

Exposure Assessment
- Total exposure assessment methodology
- Personal monitoring
- Models for predicting exposure
- Biological markers of exposure

Ecological Effects
- Assessing risks to ecological systems
- Defining the status of ecological systems
- Detecting trends and changes in ecological systems
- Predicting changes in ecological systems

Health Effects
- Neurotoxicity
- Reproductive toxicity
- Respiratory system effects
- Carcinogenicity
- Biological markers of disease
- Methods of extrapolating animal effects to humans
- Epidemiology

Risk Reduction
- Preventing pollutant generation
- Combustion and thermal destruction
- Separation technologies
- Biological approaches for detoxification and degradation
- Chemical treatment of concentrated wastes and residues
- Ultimate containment methods and approaches
- Exposure avoidance
- Risk communication
- Incentives for risk reduction
- Education and technology transfer
- Environmental management and control systems

3 EPA needs to establish better mechanisms to ensure that a coherent, balanced R&D strategy is planned and implemented.

EPA's formal process of defining core research areas should begin with the Agency's senior scientists and engineers in consultation with its program offices. It is important that the program offices be included in the process, so that the Agency's long-term R&D efforts are related to the basic scientific uncertainties that impede EPA's short-term regulatory efforts. Program office involvement in defining core research areas also will help link the two different—but complementary—aspects of EPA's overall R&D program.

EPA also should find ways to involve the external scientific community and other affected groups—such as state governments and universities—in defining core research areas and the R&D programs undertaken in those areas. For example, the Science Advisory Board could convene periodic workshops involving EPA's scientists and engineers, EPA's program offices, and external interests in order to build consensus and external support for EPA's core research programs.

EPA's commitment to an R&D strategy that balances short-term and long-term research needs must be institutionalized. Unless an appreciation of the relative value of long-term research is built into EPA's planning and management structure, such research will continue to be underemphasized.

EPA should take steps to ensure that long-term research needs and risk reduction opportunities are considered as part of a coherent, balanced R&D strategy. First, EPA should establish a new Research Strategy Council made up of the Administrator, Deputy Administrator, the Assistant and Deputy Assistant Administrators for Research and Development, and the Deputy Assistant Administrators of the program offices. Using their broad Agency experience, the members of the Council would oversee the process of defining core research areas, and they would review and approve the core research programs planned each year. The Council would focus especially on long-term, cross-media environmental problems that are not the specific responsibility of any EPA program office, and they would ensure that R&D funds are available to study such problems. In short, the Research Strategy Council would work to ensure that EPA's R&D plans respond to environmental concerns beyond those addressed by EPA's statutorily-mandated regulatory programs.

In order to assist the Council incorporate a long-term perspective into EPA's research planning process, the Science Advisory Board should establish a standing Research Strategies Committee that would review EPA's core research programs and advise the Research Strategy Council on its content and quality. That kind of external, independent review would bring a broader perspective and wider range of scientific expertise to EPA's R&D planning process.

Finally, in order to improve the likelihood that long-term research plans in fact are implemented over the long term, EPA's Assistant Administrator for Research and Development (ORD) should be changed from a political to a career position. Throughout EPA's history, no ORD Assistant Administrator has held the position for more than three years; since 1980, no individual has remained in that position more than two years. Consequently, no leader of EPA's R&D program has stayed at the Agency long enough to implement a sustained, long-term research strategy. If the Assistant Administrator for ORD could expect to stay in office for an extended period, then it is more likely that a long-term research strategy would be carried forward to completion.

4 EPA must improve its capability to anticipate environmental problems.

Because environmental legislation tends to be driven by public concerns about existing environmental problems, EPA's statutorily-mandated regulatory programs tend to be focused on existing environmental problems. EPA's R&D program, in turn, is almost entirely devoted to the definition, assessment, and control of existing problems.

Yet, as history has shown again and again, cleaning up chemicals in the environment after biological damage already has occurred is difficult, expensive, or impossible from a practical standpoint. Worker illness led to the discovery of Kepone in the James river; dead and dying cattle led to the discovery of polybrominated biphenyls in feed; malformed oysters led to the discovery of tributyltin in harbors. In each case, the problem was not discovered until substantial health and/or economic costs had been incurred, and each case entailed a long and expensive clean-up program.

Clearly, great benefit can be derived from the identification of trends in environmental quality before they begin to cause serious ecological or human health problems. With more lead time, material substitutes can be developed, manufacturing processes redesigned, or traditional end-of-pipe controls put in place at substantially lower cost. Early identification and response to a potential problem can sharply reduce adverse effects on human health and environmental quality. Public discussions of different possible courses of action are likely to be more reasonable and less emotionally charged, if the public does not feel a sense of emergency or catastrophe.

There are a number of steps EPA should take to enhance its ability to anticipate environmental problems before public fears are aroused, and before costly, after-the-fact clean-up actions are required. For example, EPA should broaden its data-gathering efforts. Monitoring programs are valuable for their ability to paint a picture of present conditions; if continued, they can help describe what has happened to the quality of an ecosystem over time. But they also are invaluable tools for helping anticipate the future; they can be used to predict the environmental consequences of continued patterns of pollutant loadings.

EPA needs to begin monitoring a far broader range of environmental characteristics and contaminants than it has in the past. Although we understand a lot about the handful of chemicals that already are known to cause environmental problems, we know relatively little about the thousands of chemicals used in modern society, and that possibly could cause adverse efects on human health and ecosystems over the long term. Thus EPA should expand its use of monitoring activities that can foretell health and ecological risks. Past analysis of the muscles and adipose tissue have provided invaluable information on a wide range of contaminants actually accumulating in living creatures. Those kinds of studies should be increased in the future.

EPA should take two specific steps to improve its anticipatory capacities. First, EPA should undertake research on techniques that can be used to help anticipate environmental problems, and it should make a more concerted effort to be aware of and interact with the research efforts of other Federal agencies concerned with the identification and anticipation of environmental problems. Such research would involve a retrospective examination of how problems have been identified in the past, and it should utilize emerging techniques for forecasting future environmental conditions.

Second, a staff office should be created within EPA for the purpose of evaluating environmental trends and assessing other predictors of potential environmental problems before they become acute. The primary mission of this office would be to identify potential and emerging ecological and human health problems. The office would analyze potential problems, drawing upon technical expertise within and outside the Agency. The office would also prepare an annual report to the EPA Administrator that describes potentially significant trends in health and environmental data and outlines possible Agency responses. The conclusions and recommendations of that report then would be considered in EPA's strategic planning for research and development.

5 EPA should provide Federal leadership for a national program of ecological research by establishing and funding an Environmental Research Institute.

Ecological systems such as forests, rangelands, and fresh and saltwater wetlands are enormously valuable from both an environmental and economic perspective. Yet we understand relatively little about how those complex, interrelated systems are being affected over time by pollutant loadings. Most past ecological research has investigated the effects of particular pollutants on particular species—for example, the development of single species ecotoxicological test methods to support regulations under the Toxic Substances Control Act. The larger questions related to total pollutant loadings, multimedia effects, and cumulative, long-term effects on interwoven biological communities remain unanswered.

A number of Federal organizations besides EPA—for example, the Department of Interior, the Department of Agriculture, the National Oceanic and Atmospheric Administration, the National Institute of Environmental Health Sciences, and the National Science Foundation—carry out research on ecological systems, the ways in which they are affected by environmental pollution, and the potential human health consequences of those ecological alterations, as do private organizations, universities, and state governments. With the exception of the investigation of human health effects, however, there has been little national focus or leadership for those efforts. Furthermore, ecological research in this country is neither coordinated nor comprehensive enough to provide an ongoing assessment of the health of various ecosystems.

Because EPA has the primary Federal responsibility for protecting ecosystems, EPA should provide the Federal leadership for an enlarged, coordinated program of national ecological research. To provide the visibility, stability, and intellectual focus for that research, EPA should establish and fund a new Environmental Research Institute. The Institute should be operated by a contractor, much like the Department of Energy's national laboratories, and it should have several specific functions:

- It should conduct a core ecological research program.
- It should define the ecological endpoints that need to be monitored to provide an overall picture of ecological health, determine which of those endpoints are not being currently monitored, and support monitoring activities to fill data gaps.
- All relevant ecological data, whether generated inside or outside the Institute, should be collected by an Office of Data Systems within the Institute. Those data should be used to define trends in ecological quality, and those trends should be described in an annual report to the nation on the overall quality of the environment.
- It should provide a national focal point for ecological research useful not only to EPA, but to other interested parties as well. Thus it should be prepared to conduct research funded by, or in cooperation with, other Federal agencies, state governments, universities, and the private sector.
- It should participate with the two EPA Centers of Excellence—at Cornell University and the University of Rhode Island—that are dedicated to ecological research.

Because of the excellent resources already functioning in the Public Health Service, especially the National Institutes of Health, the Environmental Research Institute would not engage in health effects research. Nor would it supersede ongoing ecological research efforts. Rather, it is meant to supplement and build on current ecological research in a systematic, coordinated, and collaborative way. The overall goal of the Institute should be to define a comprehensive ecological research program and then implement those parts of it that are not already being carried out either inside or outside the Federal government. In fact, because the Institute would provide centralized leadership for the nation's ecological research efforts, other Federal agencies, state governments, or the private sector may be interested in funding specific kinds of ecological research of particular interest to them. Although EPA should provide the initial administrative impetus and funding, and be prepared to continue its support over the long term, the Environmental Research Institute should act and be perceived as a national institution of national benefit.

6 EPA should expand its efforts to understand how and to what extent humans are exposed to pollutants in the real world.

Generally accepted toxicological test methods have been developed for determining the adverse health effects of different substances. In assessing risk, however, it is also necessary to know the concentrations and durations to which people are exposed during their daily lives. In fact, there is usually greater uncertainty about the level, duration, and pattern of human exposure than there is about the health effects of a given level of exposure. Although considerable progress has been made in developing effective methods of measuring human exposure, much more needs to be done.

Exposure assessment in the past has consisted simply of determining the concentration of a chemical in the immediate vicinity of an individual and then making various assumptions about the levels inhaled or ingested. In reality, however, the important toxicological question is: How much of the chemical actually impinges on the internal target organ? Physical and biological processes can affect the concentration of the pollutant that is absorbed and retained by a particular organ. Alternatively, some processes actually can convert a chemical into a more toxic substance in the body.

Recent progress has been made in verifying and quantifying exposure by examining biological tissue for the presence of the chemical of concern or the presence of biochemicals of concern—i.e., investigating tell-tale "biomarkers." EPA should act aggressively to improve techniques for assessing individual exposures, validate exposure models, and improve the use of biomarkers as indicators of exposure.

The Science Advisory Board enthusiastically supports the Total Exposure Assessment Methodology (TEAM) approach to determining human exposure. This method involves the use of personal monitors that measure an individual's total exposure to different substances during the course of daily activities. The TEAM approach first demonstrated the importance—in some cases, the overriding importance—of indoor air pollution.

This direct way of measuring exposure needs to be utilized more extensively. It not only can measure the exposure of selected individuals (e.g., those expected to be most highly exposed), but it also can be used to define the distribution of exposures throughout a large population. Improved techniques are needed to extend the use of this important tool to a wider range of chemicals.

Currently, EPA often measures the concentration of a chemical at some emitting source (e.g., a smokestack), and then uses mathematical modelling to estimate the concentration to which different individuals are exposed. Using these computer-driven models, the Agency has been able to estimate exposure levels that would occur under a wide variety of assumed conditions, thus generating data that would have been very difficult, if not impossible, to measure directly.

However, the Agency needs to undertake a critical review of the many different available models in order to determine their site-specific applicability and estimate their accuracy and precision. Although model validation is complex and expensive, EPA has an obligation to lead efforts in this area. EPA should develop a priority ranking of models to be evaluated, and establish a schedule for validating the most important ones.

The use of biomarkers is an interdisciplinary effort that links physical, environmental, and biomedical scientists in an effort to anticipate and reduce human risk. EPA should expand its efforts in this area. In particular, the Agency needs to explore the increased use of biomarkers as quantitative biochemical indicators of environmental exposure and biological effects. EPA also should make every effort to draw on the expertise and research results found in other Federal agencies—such as the National Institute of Environmental Health Sciences, the National Cancer Institute, and the National Center for Toxicological Research—that already have well-established programs in this rapidly emerging research area.

Finally, EPA's Centers of Excellence program has proven to be an effective way of involving the academic community in targeted environmental research, thus generating new scientific knowledge useful to EPA and the nation as a whole. That program should be expanded through the support of a new university-based Center of Excellence dedicated to exposure assessment.

7 EPA should initiate a strong program of epidemiological research.

From a regulatory perspective, good epidemiological data are invaluable. Because those data are generated through the study of large numbers of real people living in the real world, the conclusions drawn from them are widely accepted and acted upon. For instance, current efforts to limit smoking in public places are being driven by a widespread belief that passive smoking is harmful to health, a conclusion based to a large extent on epidemiological data.

EPA also has based some of its most important health regulations on epidemiological data. National standards that limit the concentration of air pollutants, for example, are set at levels to protect against the health effects seen in epidemiological studies. The Harvard-based Six Cities Study, sponsored by the National Institute of Environmental Health Sciences, was extremely valuable to EPA during its recent reviews of its particulate and sulfur dioxide air quality standards.

However, to support its regulatory activities, EPA makes much greater use of occupational studies and laboratory studies of animals. Although such studies can provide useful information, the relevance of those results is sometimes questioned. For example, because concentrations of chemicals found in occupational settings are usually much higher than those found in the general environment, adverse health effects found in workers may or may not necessarily translate into health risks for the general population—which also includes children and the elderly—exposed to lower concentrations. Laboratory studies of test animals are sometimes questioned because of differences between the metabolic and regulatory processes of test animals and humans, in addition to the generally large difference in dose levels. Furthermore, the population of test animals used in laboratories are far more homogenous than human populations.

Although occupational and animal studies will continue to play an important role in environmental research, EPA needs to increase its use of non-occupational epidemiological studies, which optimally allow the assessment of potential adverse human health effects at exposure levels of concern to the general public. In spite of their limitations, such studies—in combination with well-conducted experimental research—can form the basis for a "weight-of-evidence" that may generate consensus within the scientific community regarding a given environmental health risk.

EPA could improve the cost-effectiveness of its epidemiological research, and broaden the usefulness of the results, by combining its efforts with those of other government agencies. For instance, EPA could add to existing data bases (for example, the National Health and Nutrition Examination Survey), and cooperate with existing studies of the workplace (for example, the Dioxin Registry Study), particularly when such studies are able to relate dose to adverse effect. Within EPA, epidemiological research should be coupled directly with an improved capability to monitor and assess exposures—for example, through the wider use of personal monitors and biomarkers.

Furthermore, EPA should expand its cooperative epidemiological research with other countries where existing pollution levels are several times higher than in the United States. In addition to obtaining valuable scientific data for the United States, such an effort could foster environmental protection efforts globally, and enhance U.S. relationships with other nations.

8 EPA should expand its efforts to assist all those parts of society that must act to prevent/reduce environmental risk.

If our future efforts to protect human health and environmental quality are to be successful, more and more elements of our society must take steps to prevent/reduce risk. State and local governments, large and small businesses, and individual families must act to reduce the wastes and contaminants that are generated every day as we go about our normal lives. State and local governments have to rethink their zoning laws if we hope to protect our fragile estuarine areas; manufacturers have to redesign their production processes if we hope to control hazardous wastes; families have to separate their garbage if community recycling programs are to succeed. The prevention/reduction of environmental risk in the future is going to require not only Federal regulations and end-of-pipe controls, but also changes in lifestyle and behavior throughout our society.

EPA needs to do a better job conducting research that will be useful to all the different elements of our society involved in preventing/reducing risk. Then it must find better ways of transferring the results of that research to the end-users, especially the end-users who are likely to achieve the greatest risk reduction. To control chemical wastes, for example, technology transfer efforts should be targeted initially to industries that use chemicals but have little expertise in the chemistry of waste management. Small- and medium-sized hazardous waste generators could benefit substantially from EPA's technology transfer efforts, because they often are not aware of source reduction and recycling options. State and local governments are an especially important target for the transfer of technical information and training tools, because they are responsible in large part for the implementation and enforcement of existing Federal environmental legislation, and they are likely to play a major role in our national response to future environmental problems.

In short, EPA must make a greater effort to generate information about the full range of risk prevention/reduction techniques and then transfer that information to all the different people who will need to use it in the future. EPA also must ensure that those end-users, especially state governments, are involved in the planning of EPA activities that are intended to serve them.

In addition, EPA should support the development and implementation of education programs that teach targeted groups about different kinds of environmental risks and the steps that they can take to prevent/reduce them. Such support should include educational materials, handbooks, audiovisuals, seminars, and training courses. EPA's current information and training related to asbestos removal is a good example of the content and value of that kind of support, and it should be replicated in areas such as lead paint removal and integrated pest management.

EPA also should work cooperatively with private industry and universities to incorporate environmental studies and training into academic curricula. Students studying business, chemistry, public policy, economics, medicine, and mechanical, electrical, and petroleum engineering should all be exposed to the concept of environmental risk and the techniques of environmental risk reduction. As with so many other problems, widespread public education is one of the best ways to reduce environmental risk, and EPA must play a major role in environmental education.

Finally, EPA should carry out research—including non-traditional research—that will be useful to the universe of end-users. EPA should dedicate R&D funds not only to collect environmental data and develop control techniques useful to a broad spectrum of people, but also to study more effective ways of communicating information. For example, EPA should try to find better ways of defining risk itself, and better ways of educating the public about the nature of risk and the steps they can take to prevent/reduce it. Moreover, many effective actions that reduce environmental risk do not employ traditional control technologies, e.g., restricted activities in wetlands, integrated pest management practices, and right-to-know activities. EPA must have a strong research program to support those kinds of actions at the state and local levels.

9 EPA needs to increase the numbers and sharpen the skills of the scientists and engineers who conduct environmental research.

The single most important element of our national environmental R&D effort are the environmental scientists and engineers themselves. Whether those scientists and engineers work inside or outside EPA, their numbers, education, skills, and professional experiences must be enhanced if we are to attain our national risk prevention/reduction goals. Thus EPA must do more to increase the amount and improve the quality of the scientific and engineering talent dedicated to environmental research.

To that end, EPA must strengthen the links between EPA and the external scientific community. Those linkages are valuable for a number of reasons. Environmental research is not an activity unique to EPA; it is being conducted in public and private sector laboratories and universities across the country and internationally. EPA's research should take place in that larger context, so that it supports and builds on the environmental research carried out elsewhere.

Furthermore, each of the elements of our national environmental research effort will be improved by the cross-fertilization of scientific ideas inside and outside the Agency. The more the scientific community at large understands about EPA's scientific goals and projects, and the more that EPA's scientists know about research outside the Agency, the greater the benefit to our national effort as a whole.

EPA could improve this intellectual cross-fertilization by encouraging an increased exchange of scientists and engineers between EPA and the external scientific community, both nationally and internationally. Existing mechanisms like the Intergovernmental Personnel Act and the Visiting Scientists and Engineers Program could be used to bring outside talent into the Agency for relatively short, rotational terms. The proposed Environmental Research Institute also could be a source of technical personnel willing to work in EPA laboratories. Similarly, EPA scientists and engineers should be encouraged to broaden their experience through sabbaticals at universities or outside laboratories, and there should be opportunity for EPA personnel to work at the Environmental Research Institute. EPA scientists and engineers also should be encouraged and allowed time to contribute more extensively to peer-reviewed periodicals.

EPA also must devote more resources to the development of new scientists and engineers who will expand the pool of technical professionals available to study environmental problems. Without the steady infusion of young talent into university, state, Federal, and private sector laboratories, the country could face a personnel shortage that would cripple our future environmental protection efforts.

Thus EPA should expand its support for its investigator-initiated external grants program. Up to ten percent of an expanded EPA R&D budget should be spent on grants to the nation's colleges and universities. Not only do those grants lead to high-quality research, but they also provide training opportunities for young scientists and engineers working on their undergraduate and post-graduate degrees. Those students in time will become the backbone of our national environmental research effort, because they will be capable of providing the broad scientific and engineering expertise needed in the future at the Federal, state, and local levels. Furthermore, EPA should initiate a program that provides training grants to colleges and universities interested in helping to develop young scientists and engineers.

10 EPA's R&D budget should be doubled over the next five years.

Over the last ten years, EPA's budget for research and development has declined dramatically. EPA's FY 1980 budget provided $398 million (in constant 1982 dollars) for R&D. By FY 1983, that figure had declined by almost half, and since then it has risen to about $317 million. In other words, during the past decade EPA's R&D resources have shrunk by about 20 percent in real terms. (See Figure 4.)

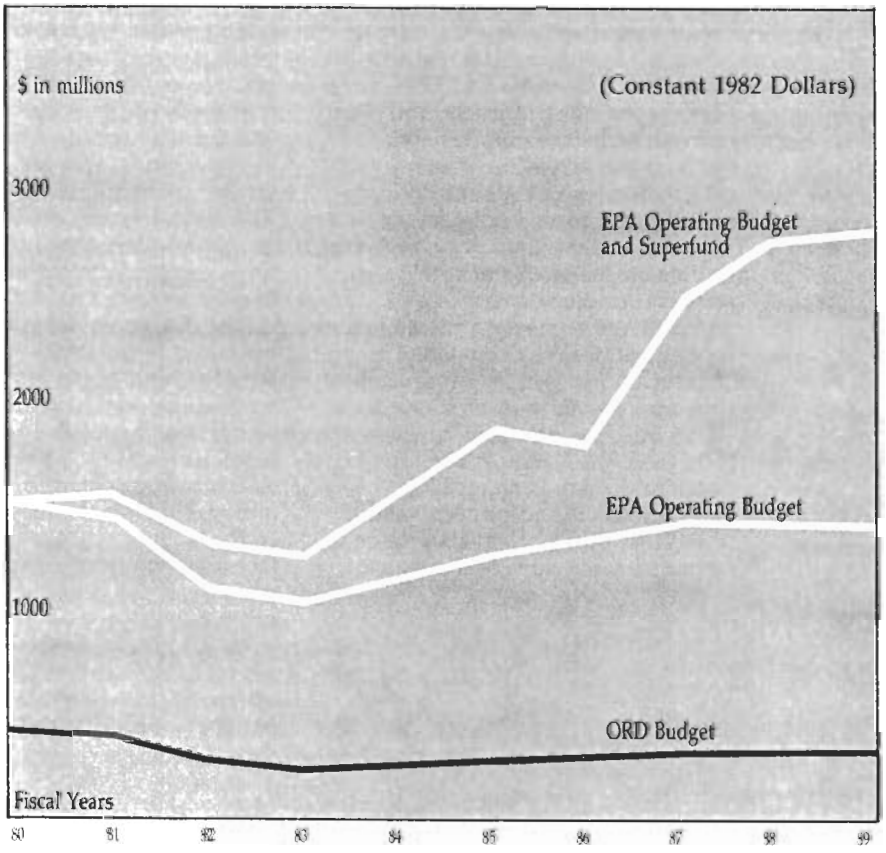
In that same period, EPA's need to better understand environmental risk has grown substantially. Congress has enacted major environmental laws—e.g., Superfund (1980), RCRA amendments (1984), Superfund amendments (1986), Safe Drinking Water Act amendments (1986), and Clean Water Act amendments (1987)—that give EPA broad new regulatory responsibilities in areas clouded with scientific uncertainty. Several new environmental concerns of national and/or international proportions—like acid rain, indoor air pollution, radon, stratospheric ozone depletion, and global warming—have emerged over the past decade. Thus the nation's need for better scientific information on the likely causes and effects of a wide range of environmental problems has been growing at the same time as EPA's ability to fund the research that will generate that information has been shrinking.

EPA's R&D efforts must be expanded rapidly, especially in its core research areas, because of the long-term health, environmental, and economic benefits they will bring to the nation as a whole. While the value of EPA's applied research often is apparent, the benefits of basic research may not manifest themselves as quickly or as directly. Yet basic research is equally valuable to our physical and economic health in the long run. Basic research is valuable because it clarifies the nature of chemical processes that may contribute to, and biological processes that may be affected by, the environmental contamination that often results from human activity. Basic research is valuable because it can help us see the long-term subtle changes in ecosystems that foretell serious risks in time for us to use risk reduction options other than expensive, after-the-fact, clean-up technologies. Finally, basic research is valuable—indeed, invaluable—because it provides the fundamental knowledge that is essential for innovative, economically-productive applied research within and outside EPA.

Therefore, the Research Strategies Committee strongly recommends that EPA's R&D budget be doubled over the next five years. An increase of $375 million may seem extravagant, especially in light of the current Federal budget deficit and strong

FIGURE 4

Funding History (1980-1989) Constant 1982 Dollars



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public pressure to balance the Federal budget. However, the nation invests approximately $70 billion per year in pollution control, and that figure is increasing. We should be willing to invest at least one percent of that amount to achieve the kind of health, environmental, and economic benefits that have resulted from past R&D efforts. Expending a small fraction of our national pollution control budget to fund an EPA R&D program that, among other things, would help determine the most effective ways to invest our national pollution control budget does not seem unreasonable.

An expanded national investment in EPA research is even more justifiable in terms of the economic value of the resources that research is meant to protect. It is difficult to put a price on human health or environmental quality. How much are we willing to pay—as either individuals or as a nation—to preclude a single incidence of cancer, or a single birth defect? How much are we willing to pay to save a single wetland, or preserve visibility in a scenic area? Such questions have been debated within EPA and the larger scientific community for many years. And while we have not found a final answer, the stakes continue to go up. For example, the health, environmental, and economic consequences associated with the connection between atmospheric pollution and global warming are staggering. Environmental research can clarify the situation by providing scientific data to guide any actions we may have to take to protect the habitability of the planet. Given the resources at risk, and the investment we willingly make to control risks that are well-defined, a doubling of EPA's R&D budget seems a most appropriate use of national resources.

This report has been derived mainly from five detailed documents prepared by the Research Strategies Committee of the Science Advisory Board. The five documents are:

APPENDIX A: *Strategies for Sources, Transport and Fate Research. (SAB-EC-88-040A).*
Describes the importance of understanding fundamental environmental processes, improving the accuracy with which they can be modeled, and identifying escalating/emerging environmental problems.

APPENDIX B: *Strategies for Exposure Assessment Research. (SAB-EC-88-040B).*
Describes a program which incorporates integrated exposures, indicators of exposure, measures of uncertainties, and cooperative activities across the country.

APPENDIX C: *Strategies for Ecological Effects Research. (SAB-EC-88-040C).*
Describes the need for approaches to assess risk to ecological systems, determine environmental status and trends, and predict future changes.

APPENDIX D: *Strategies for Health Effects Research . (SAB-EC-88-040D).*
Describes the growing role of environmental factors in the etiology of human illness and disease, the importance of long-term basic research in identifying and resolving health problems, and specific research areas and technologies that appear to offer particular promise for the future.

APPENDIX E: *Strategies for Risk Reduction Research. (SAB-EC-88-040E).*
Describes the overall risk reduction concept and specific research areas to support it, including administrative changes, education and technology transfer, and cooperative efforts with the private sector.

Copies of these documents can be obtained by writing

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