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A National R&D Strategy for Toxic Substances and Hazardous and Solid Waste

Developed by

Toxic Substances and Hazardous and Solid Waste Subcommittee
Committee on Environment and Natural Resources
National Science and Technology Council

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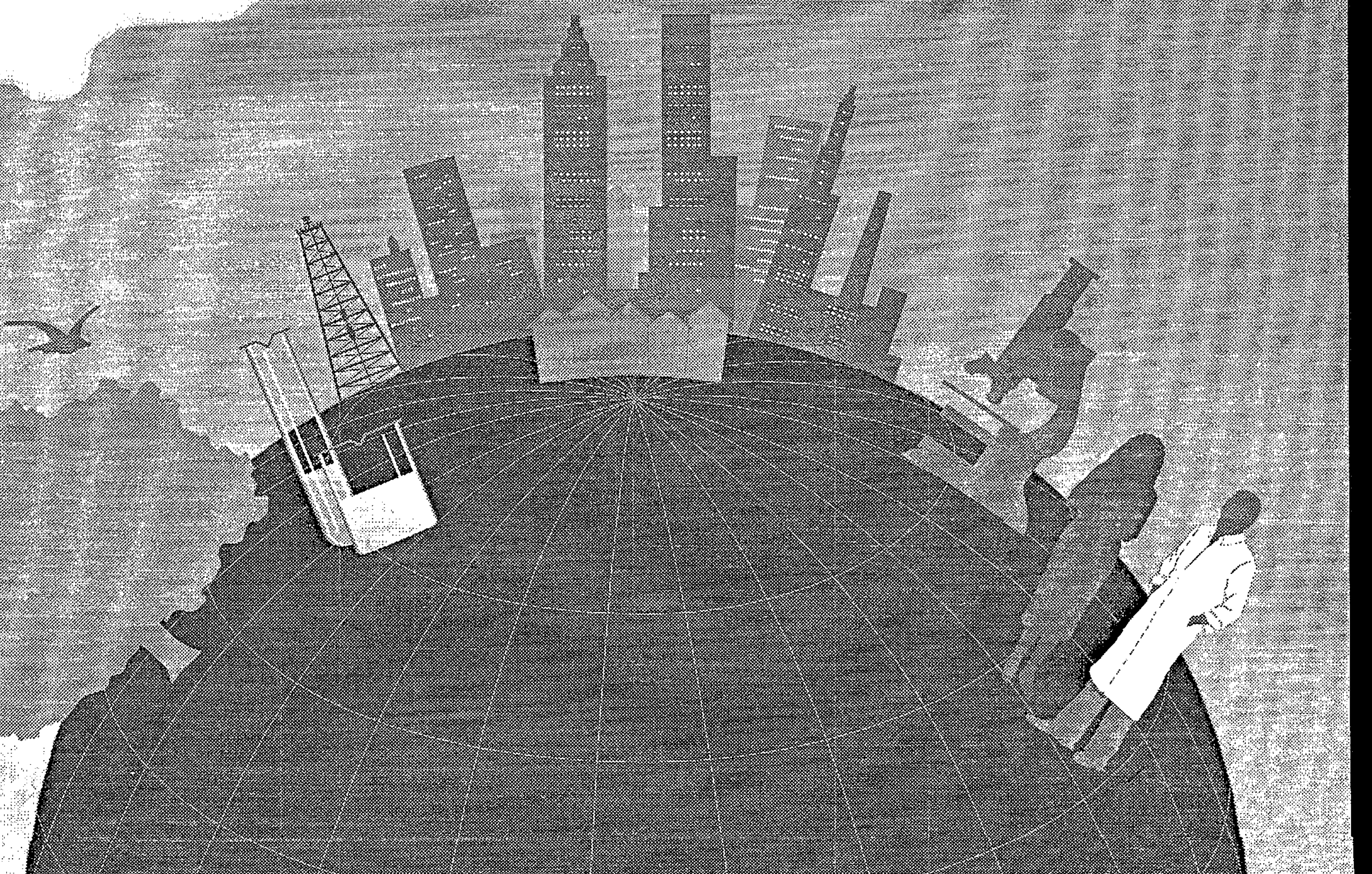

About the National Science and Technology Council

President Clinton established the National Science and Technology Council (NSTC) by Executive Order on November 23, 1993. The cabinet-level council is the principal means for the President to coordinate science, space, and technology policies across the federal government. NSTC acts as a "virtual" agency for science and technology to coordinate the diverse parts of the federal research and development enterprise. The NSTC is chaired by the President. Membership consists of the Vice President, Assistant to the President for Science and Technology, Cabinet Secretaries and Agency Heads with significant science and technology responsibilities, and other senior White House officials.

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To obtain additional information regarding the NSTC, contact the NSTC Executive Secretariat at 202-456-6100.

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The Office of Science and Technology Policy (OSTP) was established by the National Science and Technology Policy, Organization, and Priorities Act of 1976. OSTP's responsibilities include advising the President in policy formulation and budget development on all questions in which science and technology are important elements; articulating the President's science and technology policies and programs; and fostering strong partnerships among federal, state, and local governments, and the scientific communities in industry and academia.

To obtain additional information regarding the OSTP, contact the OSTP Administrative Office at 202-395-7347.

The Committee on Environment and Natural Resources (CENR), one of the nine committees, is charged with coordinating federally funded environmental and natural resources research and development (R&D).

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(http://www.whitehouse.gov/WH/EOP/OSTP/html/OSTP-Home.html)

The purpose of this report is to highlight ongoing federal research efforts in this science and technology (S&T) field and to identify new and promising areas where there might be gaps in federal support. The report is intended for internal planning purposes within the federal agencies and as a mechanism to convey to the S&T community the types of research and research priorities being sponsored and considered by the federal agencies. The Administration is committed to a broad range of high priority investments (including science and technology) as well as to deficit reduction and to a smaller, more efficient federal government. Theses commitments have created a very challenging budget environment--requiring difficult decisions and a well thought-out strategy to ensure the best return for the nation's taxpayer. As part of this strategy, this document does not represent the final determinant in an overall Administration budget decision making process. The research programs presented in this report will have to compete for resources against many other high priority federal programs. If these programs compete successfully, they will be reflected in future Administration budgets.

Acknowledgments

The CENR Subcommittee on Toxic Substances and Hazardous and Solid Waste wishes to express sincere appreciation to the Subcommittee Executive Secretariat, Points of Contact, and Members for their participation in the development and review of this document. Similarly, Subcommittee Chairs and their staffs were extremely helpful in assuring that the document achieved the highest level of quality possible, within the constraints of time and resources, in presenting this strategy document for the use of agencies, research institutions, scientists, and citizens interested in a Federal research agenda for toxic substances and hazardous and solid waste research. The Subcommittee also wishes to thank participants in the CENR Environmental Forum, and in subsequent external reviews of the strategy document, for their input representing the broad community of stakeholders in toxic substances and hazardous and solid waste research. The contributions of the Subcommittee R&D Strategy Drafting Work Group chaired by Stephen Lingle and the writing team leaders, Christopher Schonwalder, Jean Snider, Mike Slimak, and John Hunt, were essential to the preparation, review, and compilation of information included in this document.

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The Committee on Environment and Natural Resources (CENR) consists of seven issue subcommittees and three cross-cutting subcommittees—Risk Assessment, Social & Economic Sciences, and Environmental Technology. While this strategy for the Subcommittee on Toxic Substances and Hazardous and Solid Waste is presented within a risk assessment and risk management framework, it identifies *research needs for evaluating and managing risks associated particularly with toxic substances and wastes*. In contrast, the strategy of the Subcommittee on Risk Assessment addresses methodological research needs for evaluating a range of environmental hazards, including not only toxic materials but also the problems addressed by other CENR subcommittees (e.g., global change, natural hazards, air quality, water resources, and the loss of biodiversity).

A National R&D Strategy for Toxic Substances and Hazardous and Solid Waste

Strategy Framework

This strategy addresses federal research and development (R&D) related to managing toxic substances and hazardous and solid waste in the environment. Toxic materials[1] are of concern because they can cause harm to human health and ecological systems. The potential for this harm is typically expressed in terms of risk, so management of toxic materials involves assessing and managing risks. Consequently, the three sections of this strategy address: (1) Risk Assessment, (2) Managing Risks from Toxic Substances and Wastes, and (3) Social and Economic Aspects of Risk Management.

Risk assessment is essential for both policy and technical decisions regarding risk management. It is used to determine priorities for risk management (addressing the worst risks first) and to guide the actual process of managing the risks (such as determining appropriate clean-up levels for contaminated sites). Risk assessment is scientifically complex because it involves integrated steps of hazard assessment (hazard identification and dose-response assessment), exposure assessment, and risk characterization. The first part of this strategy addresses the research needed to provide the information and data required to perform scientifically credible and sound risk assessments.

Risk management involves efforts to prevent or control the impact of toxic materials on human health and ecological systems, including managing hazardous and solid wastes. The R&D priorities in this strategy on risk management revolve around research, development, and demonstration of technologies and approaches for the monitoring, prevention, control, and remediation of toxic materials. These are the primary tools of risk management, but their use must be guided by a process that starts with risk assessment, involves decisions about appropriate levels of risk and costs of alternative ways to reduce risks, and incorporates other technical, legal, and social factors. Compliance with laws and regulations and minimizing civil liability are legal elements of risk management.

Social and economic factors play a key role in both risk assessment and risk management. This strategy highlights some of the research needs in these areas essential to improve our ability to make more effective risk management decisions. Knowledge, fears, desires, and needs of local residents, concerns of regional and national interest groups, and those of affected tribal, national, state, and local governments all should be considered in the decisionmaking process. Cost effectiveness, sustainable development, economic incentives, environmental justice, and public participation are some of the important social and economic considerations that are addressed in the strategy.

Vision and Goals

The vision for this strategy is to understand, prevent, and reduce human and ecological exposure to toxic materials and their adverse human health, ecological, and social and economic consequences.

"Toxic materials" or "toxic substances" refers to the range of environmental toxicants including toxic releases to all media, new and existing chemicals, pesticides, biotechnology products, ionizing and nonionizing radiation, oil and chemical spills, and solid, hazardous, radioactive, and mixed wastes.

Actions will be guided by principles such as sustainable development, community involvement, environmental justice, wise ecosystem management, and the risk of alternatives.

The strategic goals relative to assessing and managing risks associated with toxic substances and hazardous waste are:

- Protection—Protect human health and the environment from adverse effects associated with exposure to toxic materials.
- Assessments—Ensure appropriate priorities and levels of protection through the use of scientifically sound and demographically sensitive assessments of risk and cost/benefit.
- Innovative Environmental Technologies—Develop and apply safer, faster, better, and more cost-effective technologies for reducing and monitoring exposures of humans and the environment to toxic materials.
- Pollution Prevention—Promote pollution prevention as a primary guiding principle for ensuring that less toxic materials enter the environment. Encourage a prevention-based ethic in all sectors of society.
- Sustainable Development—Demonstrate that a clean environment and economic growth can be mutually supporting. Achieve both environmental protection and economic growth through government and private sector collaboration.
- Two-Way Communication and Community Involvement—Ensure that all stakeholders have access to reliable information about sources and levels of pollution in their communities and promote stakeholder involvement in all aspects of the environmental decisionmaking process.
- Environmental Justice—Assure that the benefits of environmental protection can be shared equitably by everyone in the society and that no specific group is at greater risk from toxic materials based on their racial, ethnic, or socioeconomic status.
- Emergency Response/Unintentional Releases—Prevent and respond to oil and other hazardous substances spills and chemical incidents so as to minimize environmental injury and protect public safety and ecological integrity.
- Occupational Safety and Health—Reduce worker and household exposure and health and safety risks presented by waste, radioactive materials, and other toxic materials encountered in the workplace or carried home on workers' clothing and equipment.
- Federal Facilities—Cost-effectively clean up or contain toxic contamination at federal sites which pose a risk to human health and the environment. Assure that federal facilities are in compliance with all environmental and occupational laws and regulations.

Policy-Relevant Questions

The research priorities presented in this strategy directly support the development of policies for assessing and managing risks from toxic materials. Risk assessment as a whole is central to policy formation. But science cannot always provide clear, complete, and unambiguous answers for policy formation. Some of the more difficult policy issues that are impacted by the research priorities in this strategy are listed below:

- How to use risk assessment for public policy decisions? How to use comparative risk analyses in making risk management decisions?

- How to express and explain uncertainty in risk assessment?

- How to disseminate and coherently explain risk/benefit information to improve risk communication and public involvement in environmental decisionmaking?

- How to weigh health risks and risks to ecological systems for different endpoints in making risk management decisions?

- How to use cumulative risk in the risk assessment and management paradigms?

- How to incorporate environmental justice concerns in risk assessment and management?

- How to use federal government resources to promote development and application of innovative environmental technologies?

- How to establish protocols and procedures for technology testing and verification?

- How to use life-cycle assessment as a decision-making tool for managing toxic materials?

- How to select appropriate technologies and approaches to achieve the most cost-effective prevention, control, and remediation of toxic materials?

Scientific and Technological Goals

The four scientific and technological goals are:

- To advance the science of risk assessment to support toxic substances and hazardous and solid waste management, including:

    - Understanding the effects of exposures to toxic materials on human health and ecological systems, including the toxicological mechanisms that produce those effects and the variation in susceptibility and response among people and ecological systems.

    - Developing processes for predicting and measuring exposure to humans and ecological systems, and uncovering the processes leading to those exposures.

    - Estimating risk and characterizing and communicating those estimates.

- To demonstrate and evaluate more cost-effective, innovative technologies for pollution prevention, control of toxic wastes and emissions, site characterization, remediation, and restoration to support sustainability.

- To advance the science of monitoring and predicting environmental concentrations and effects, as well as the fate and transport of toxic materials.

- To generate and collect data and develop evaluative methodologies for the social and economic consequences of pollution and clean-up efforts.

Risk Assessment of Toxic Substances and Wastes

Conceptual Framework

The assessment of risks to human health from toxic materials follows a widely accepted paradigm produced by the National Academy of Sciences (NAS) in 1983 and reiterated by the NAS in 1994 in *Science and Judgement in Risk Assessment*; the assessment of risks to ecological systems from toxic materials is follows the guidelines published in 1992 in EPA's *Framework for Ecological Risk Assessment* (EPA/630/R-92-001). The risk assessment paradigm is a framework for organizing analyses of pertinent data in a way that emphasizes the interdisciplinary nature of the work. The four elements of the framework are: (1) hazard identification; (2) dose response assessment (note that elements 1 and 2 are referred to as "hazard assessment" in this strategy); (3) exposure assessment; and (4) risk characterization. This section of the strategy is organized around this paradigm.

Hazard Assessment. Understanding the hazards of toxic materials to either human health or ecological systems involves the same fundamental scientific principles of chemistry and cellular biology. Assessment of human health is focused on one species of concern with many endpoints with differing impacts on individuals such as cancer, neurological effects, and reproductive effects. Ecological hazard assessment is directed towards many species with endpoints with differing impacts on populations and communities of populations. Much of hazard assessment depends on epidemiologic research and studies to understand fundamental similarities and extrapolate among species and situations. Research on variation of fundamental processes within the human species and among nonhuman species within a family or taxa must be conducted to support good assessments in the future. The accuracy and precision of risk assessments are dependent upon an understanding of mechanisms of toxic effects. Simple observations of toxic endpoints in "bioassays" provide little information critical to both appropriate interspecies (model to human) extrapolation and dose-response evaluations. True assessment of risk must be based upon biological understanding of processes, not on mere statistical extrapolations. The goal is to place risk assessment on a firm scientific base from which outcome prediction—a prime characteristic of a mature science—can be accomplished.

Exposure Assessment. The exposure assessment element of the risk assessment paradigm asks the questions: "What are the routes and pathways of exposure? How many people are exposed? What is the extent, duration, and magnitude of exposure?" Exposure assessments generally are based on direct monitoring of environmental concentrations of toxic materials, fate and transport models to predict exposure levels, or assays of toxic materials in humans, wildlife, or ecological systems. There are differences in the exposures and effects from exposures among individuals and groups of individuals that must be identified and understood to develop appropriate protection strategies. It is also important to understand the environmental justice implications of: (1) the distribution of exposure levels in the population; (2) highly exposed segments of the population; and (3) more susceptible subpopulations.

Risk Characterization. Risk characterization is the communications transition point between assessment and management. It *integrates* results of the other parts of the assessment, *evaluates* strengths and weaknesses of the data and conclusions, and *communicates* these results and their implications in terms useful to the risk manager and others. The integration of the individual characterizations of hazard, dose-response, and exposure describes who or what is at risk and why. The characterization must also provide an evaluation of the overall quality of the assessment and the degree of confidence the authors have in estimates of risk and the conclusions drawn. Important uncertainties and interpretation of data must be explained to the risk manager. A risk characterization should be alert to the potential for racial or cultural bias resulting in failures to gather data on minority or socioeconomically disadvantaged populations, or failure to correctly identify and count members of such populations in large samples.

Effectively communicating the results of the assessment to the risk manager, stakeholders, and the community is essential to their reaching a decision about what risk management actions need be taken, if any. The results of the assessment must be explained in terms useful for these purposes. Executive Order 12898, addressing environmental justice, requires both the identification of communities disproportionately affected by environmental pollution, and the participation of community residents in designing studies to assess and redress inequities. Consequently, the risk communication should be tailored to inform and aid in the education of community residents when appropriate.

Current State of Understanding

Hazard Assessment

Human Health. Until recently, efforts in the hazard identification of toxic materials have focused on cancer as the main endpoint of concern with other endpoints (e.g., neurological, reproductive, and developmental effects) receiving less attention. Efforts to establish dose-response relationships for carcinogens have largely been of a curve-fitting nature that make linear low dose estimates of response at lower exposures. For non-carcinogens, the approach has generally been to identify a "No Observed Adverse Effect Level" (NOAEL) or a "Lowest Observed Adverse Effect Level" (LOAEL). Uncertainty factors are then used to estimate a dose below which an unacceptable level of effects would not be expected to occur in humans. Moreover, the relative risk for different racial, ethnic, and economically disadvantaged populations have been neglected until recently. The cumulative effects of these factors require description and quantification. Much of the information on toxic materials has come from animal testing on individual chemicals. Little is known about the hazards of chemical mixtures and exposures with other stressors. Differences between animals and humans with respect to absorption, distribution, metabolism and excretion (toxicokinetics), and susceptibility to the action of the agent have made extrapolation of effects seen in animals to the human situation problematic both qualitatively and quantitatively. It has also been difficult to extrapolate the results of lifetime animal studies or long-term occupational studies to environmental exposures lasting much shorter periods of time (e.g., childhood exposures for children living near Superfund sites).

Ecological. During the past 30 years, research on the ecological hazards of toxic materials has primarily focused on the development of empirical toxicological data with greater emphasis placed on aquatic rather than terrestrial systems. These data reflect the first generation of approaches that effectively contributed to the assessment of adverse impacts resulting from overt toxic effects (e.g., lethality and growth effects) caused by exposure to environmental chemicals. With some exceptions, extrapolations of toxic effects across species and endpoints were based on the empirical evaluation of existing data. For example, water quality criteria for the protection of aquatic life are based on the assumption that the variety of tested species are representative of the vast array of untested aquatic species. Comparable data for the protection of plant and wildlife species are very limited especially with regard to endangered species. It is clear that empirically-derived hazard data cannot be developed for each combination of chemical and species.

Human Health *and* Ecological. In the past few years there has been an increasing emphasis on the development of new approaches using a mechanistic basis of extrapolating across species and chemicals. For example, understanding relationships between mechanisms of toxic responses and chemical structure have made possible the prediction of potency for untested chemicals that are based on modes of action. Although these newer models have proven effective for predicting the acute toxicity of many xenobiotics, there remain significant uncertainties in predicting metabolic activation and chemical reactivity, which are the processes that underlie the chronic toxicity of the most potent environmental chemicals. There has also been increasing concern that the first generation of approaches are not adequate for assessing the chronic effects of persistent bioaccumulative chemicals such as dioxins, furans, and those compounds suspected of acting as endocrine disruptors. In the context of extrapolating across species, the recent development of physiologically-based toxicokinetic (PB-TK) models for animal to human extrapolation and for aquatic organisms reflects an important step towards a predictive capability. Initial linkage of PB-TK models with mechanistic research provides a rational approach to identify critical toxicokinetic and toxicodynamic processes that underlie the differences in responses of species to chemicals. There is currently a paucity of data for developing these models.

Exposure Assessment

Procedures have been reasonably well developed to monitor environmental media and provide point estimates of mean exposure levels. While basic data on human behavior are used in modeling, genetic and cultural differences are not accounted for. Simple fate models are generally capable of predicting environmental concentrations, although with varying degrees of capabilities. There is, however, great uncertainty in many of these predictions. While existing fate and transport models can be tailored to be used for small, site-specific problems, use at a higher scale, like watersheds, is limited by the complexity of the natural processes that must be linked together for large system models. The primary uncertainty of extrapolating laboratory hazard data to ecosystems in the field is the uncertainty about the actual chemical dose received by individuals.

Modern computing has removed many intractable hurdles in the science of modeling chemical behavior in the environment. While models are available to simulate transport of chemicals in the atmosphere, soil, surface water, and groundwater, most models are limited in their ability to accurately simulate the impact chaotic weather events have on exposure, as well as the risk reduction which accompanies chemical and biochemical transformations. Models of resuspension of contaminated sediments, which control long-term risks of persistent chemicals, are in their infancy. Models of bioavailability are still in the conceptual stage even though the physical and chemical interactions that influence bioavailability are known. Soil/air interactions are largely unknown. Degradation models are seldom reliable, especially for industrial chemicals.

Reducing the uncertainty of exposure assessment will be accomplished by improving methods for measuring toxic forms of chemicals and developing more realistic information on the processes that control chemical transport and fate. Such information lags far behind the engineering of the computer frameworks for the models. Studies of fundamental ecosystem processes need to be designed in the context of the risk paradigm and with a new prospective from the modeling frameworks already developed. For example, current progress in exposure assessment has shown that most transport occurs during storm events. While sediment chemistry is becoming understood, sediment physics with respect to the energy of resuspension is a critical knowledge gap. Metal speciation has been modeled from a chemistry perspective, but not in the context of bioavailability or toxicity. Persistence and natural assimilation capacity of ecosystems for toxic materials are essential to making strategic choices in risk reduction and pollution prevention. In addition, biomarkers and other more diagnostic methods of measuring exposure are needed.

Risk Characterization

Risk characterization has long been overlooked as an area of research, the most common reasoning being that if the other two parts of a risk assessment were done correctly, the risk characterization would follow in a relatively straightforward manner. Experience has shown this to be presumptuous. Much of the criticism of risk assessments can be traced to inadequate risk characterization. Although we currently do integration of hazard, dose-response, and exposure for carcinogen assessments where simplifying assumptions have been made (dose linearity, simple exposure scenarios, etc.), it is much more difficult to see how these pieces fit together in ecological assessment or in noncancer health assessments. Complications such as mixtures, cumulative risk, short-term versus long-term exposures, and the effects of biological variability have been dealt with in crude ways (or not at all) in assessments. Moreover, the effects of racial or ethnic differences and of economic disadvantages have been neglected until recently. The research necessary to properly integrate the parts of a risk assessment in all but the most simple cases has not been performed. Basic research and methods development is required for a better understanding of risk assessment and risk management.

There has been some recent research into risk-related uncertainty analysis, but it has not yet developed to the point of being second nature to the assessors themselves. Quantitative statistical treatments of uncertainty are well founded and established, but the application and adaptation of these techniques to risk assessment still needs some research. Presentation of the qualitative aspects of risk assessment uncertainty has not been well studied or developed. Before risk characterization can routinely present the confidence of the assessment to the risk manager, research must be done and methods established for both the qualitative and quantitative aspects of uncertainty. Additional work is needed on how to better communicate risks. As statistical analysis plays an important role in risk characterization, communication strategies must be developed to facilitate its explanation. Research is needed to develop clear and concise messages about the results of the risk characterization. The risk communication strategy also should involve stakeholders, including community members.

Research Priorities[2]

Hazard Assessment

Although ongoing research is making important advances, significant uncertainties in predicting hazards of toxic materials remain. Significant uncertainties are found in bioavailability from dermal exposures, dose-response relationships, and variation in susceptibility within and across species. Uncertainties also permeate chronic noncarcinogenic processes, especially reproductive and developmental endpoints. The uncertainty of dealing with chemicals with complex modes of action deserves attention. In addition, it is essential that data and models be developed that will allow the prediction of health endpoints in humans and endpoints that can be used in ecosystem studies to predict the sustainability of sensitive populations of aquatic life and wildlife. For example, endocrine disruptors are generally thought to have receptor-based mechanisms that affect reproductive success and, therefore, could have an effect on population dynamics. Thus, in addition to life-cycle studies, research on these chemicals must be conducted at the organ, cellular, and subcellular levels to identify toxic mechanisms and receptors. This information is necessary to quantitatively predict responses for untested chemicals and establish the critical physiological and biochemical properties that underlie differences between species.

For human health, much more information is needed to understand the effects of short-term exposure that the risk assessor must often address. Most of the population is not exposed to toxic materials from any one source for their entire lifetime because of changes in address or changes in habits/lifestyles or introduction/reduction of pollution sources throughout life. Certain populations definable by cultural patterns, socioeconomic status, or race may, on the other hand, have lifetime or nearly lifetime exposures because they stay in one locale. Studies of effects of chronic exposure give information that is more relevant to stable than to mobile parts of the population. Most of the health effects studies from which we draw our information on toxic materials are studies of effects of chronic exposure.

The ability to extrapolate from tested species to untested ones must be improved. This improvement in extrapolation requires information on the physiological and biochemical similarities

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[2] Throughout this document, no indication of relative priority is intended in the way research needs and priorities are presented.

and differences between species in the context of the underlying toxicokinetic and dynamic processes. This knowledge coupled with the development of PB-TK and biologically-based dose-response models will assist in predicting dose-to-target organs and the resultant effects when empirical data are not available. Federally funded research over the past several decades has demonstrated that the best approach for information needs is to refine advanced animal extrapolation models which permit a minimum toxicological data set to predict effects for many other species. Developing species-to-species extrapolation methods for fish, wildlife, and birds is not only more cost-effective than expanding animal testing programs, this strategic approach is the only one to protect endangered species which cannot be tested.

For ecological assessment, the effects of chemicals on survival, growth, reproduction, and development of organisms can be an important component in protecting sustainable populations of aquatic life and wildlife. The development of tools that predict population dynamics in the face of natural forcing functions (e.g., temperature, rainfall, light intensity), chemical stressors, physical modifications, and biological interactions is needed to integrate the vast array of information that is becoming available.

There is very little information available on the variation in susceptibility to chemicals within the human species or among other species and taxa. Improved understanding of the variation in response to toxic materials would reduce the uncertainty of risk estimation and allow for a better evaluation of the "conservativeness" of existing approaches. Knowledge of mechanisms of action of toxic materials at the subcellular level would shed much light on these differences in response.

The assessment of chemical impacts in natural systems typically involves complex mixtures. Although advances have been made in developing a mechanistically-sound basis to interpret and predict acute toxicity, there are very limited data and techniques available for addressing the chronic effects of mixtures. Mixtures of persistent bioaccumulative chemicals are of particular concern. A strategic choice is to focus on the effects of reactive chemicals and persistent bioaccumulative chemicals thought to have receptor-based mechanisms of action. These have the potential for great hazard as well as great uncertainty in current predictive power. Some sections of the country may experience unusually high concentrations of toxic materials due to factors such as proximity to hazardous waste and Superfund sites, industrial pollutants, and landfills. As a consequence the communities in these areas may bear greater risk of health effects from cumulative exposures to multiple chemical stressors. Risk assessments should be conducted in these disproportionately affected communities.

The strategic research needed includes the following:

- Improved understanding of the biological basis for toxicity and development of biologically-based methods for extrapolating effects between species.
- Improved knowledge of the range and distribution of individual and interspecies variability in susceptibility to toxic materials.
- Effects of short-term exposures to toxic materials at different chronological ages of life.
- Expansion of database on the noncancer effects of toxic materials.
- Development of database of relevant physiological and biochemical characteristics of organisms for extrapolation of effects.
- Development of predictive models of population dynamics for selected ecological or societal species of interest.

- Effects of dermal exposures on cancer and noncancer endpoints.

- Improved understanding of the effects of complex mixtures.

Exposure Assessment

The same basic scientific principles generally apply in assessing human and ecological exposure to environmental contaminants. Both types of assessments must consider the activity patterns of the organism of concern and the different ways that contact can occur with contaminants. Both types of assessments are also aimed at evaluating various indicators of impact. Most human assessments focus on endpoints, such as body burdens or health effects. Ecological assessments can also look at health effects in animals or alternative indicators of ecological impact, such as species diversity or population trends. The following discussion analyzes the knowledge gaps in the exposure area and proposes areas of research to address them in the future. The overall goal of this research is to generate the basic information that risk managers need to identify and analyze opportunities for reducing exposure to environmental contaminants and associated risks. A dual track strategy is proposed to develop the needed exposure related information:

- One approach is to focus on sources of environmental contaminants and work prospectively along the pathways of transport and dispersal.

- The second approach is to start with human body burdens (or other direct measures of exposure) or analogous ecological endpoints and work retrospectively through the process of bioaccumulation and uptake.

At some point these two lines of inquiry should meet to give us a much more complete understanding of the process and properties of exposure. The key elements of these two tracks are presented in Table 1 below.

Table 1. Dual Track Strategy for Exposure Assessment Research

PROSPECTIVE APPROACH	RETROSPECTIVE APPROACH
Gather data on release rates of contaminants from sources.	Gather data on levels of contaminants in humans/wildlife and data on indicators of ecological hazard such as species diversity, population trends, etc.
Gather data on levels of contaminants in media potentially impacted by sources.	Gather data on the levels of contaminants in media contacting humans or animals.
Develop fate models to predict media levels based on source releases.	Gather data on rates which receptors contact environmental media and develop models to predict uptake in organisms from food, air, etc.
Use media data to validate and improve fate models.	Use media data to validate and improve uptake models.
Extend models to cover bioaccumulation through the food chain and attempt source-to-receptor validation.	Link uptake models to food chain models and attempt source-to-receptor validation. Evaluate geographic trends in data on body burdens and sources to see if links can be made.

Table 1. Dual Track Strategy for Exposure Assessment Research (Continued)

PROSPECTIVE APPROACH	RETROSPECTIVE APPROACH
Design exposure sampling methodologies for integrating small concentrated subpopulations and small diffuse subpopulations in health data collection research.	Focus health effects research resources on communities disproportionately affected by environmental pollution.

The "prospective track" would include the following efforts:

- More data are needed on contaminant release rates from sources and contaminant levels in the environment media impacted by sources. These data can be used to identify geographic and temporal trends. Geographic trends can be useful for identifying sources and mechanisms of impact. Temporal trends can be used to help evaluate effectiveness of regulatory programs.
- Understanding abiotic processes that control the transport, persistence, and bioavailability of chemicals in soils, natural waters, and sediments.
- Understanding bioaccumulation and metabolic processes that control biodegradability of chemicals in microbial populations in soils, natural waters, and sediments.
- Validation work is needed to test the effectiveness of existing fate and transport models and guide further development of exposure assessment models for different media.
- Understanding the health outcome of exposures to complex mixtures by poor and disadvantaged populations.

The "retrospective track" would include the following efforts:

- More diagnostic methods and biomarkers for defining the route of exposure and exposure history. This would include surveys of contaminant levels in tissues and other direct measures of exposure.
- More data are needed on human activity patterns to help develop distributions of exposure factors, such as food ingestion rates, time spent in various settings, etc.
- Better procedures are needed for assessing dermal exposure, especially to contaminants in soil. Experimental protocols need to be developed and validated to determine dermal absorption properties of chemicals in various matrices and for various races.
- Better procedures are needed to assess complex exposure scenarios involving multiple sources/chemicals and multiple pathways of exposure and populations of varying class, race, and ethnicity. This would include developing procedures using biomarkers and other direct measurement techniques for assessing exposure. Direct measurement techniques include use of various types of monitors, such as personal air samplers, to measure individual exposure as it occurs. These approaches are well suited to assessing complex exposures involving intricate behavior patterns and spatially variable contaminant levels.

- Investigative methods to collect exposure data from minorities, socioeconomically disadvantaged populations, or other disproportionately affected groups (e.g. such as subsistence fishermen, children, women, and elderly). Investigations should also be sensitive to the need for community involvement at all stages of research.

Risk Characterization

In order to make risk characterization the effective tool that it needs to be, immediate attention needs to be paid to the research necessary to develop the science:

- Methodological research is needed on how hazard, dose-response, and exposure can be integrated in more complex cases (ecological assessments, mixtures, cumulative exposures, etc.).

- Methods for both the qualitative and quantitative aspects of uncertainty analysis must be specifically applied to risk assessment, and the resulting methodology made a routine part of risk characterization.

- Methods are needed to assess cumulative risk in site-specific populations and to apply that risk to decisionmaking processes.

- Research is necessary to know how to include cultural and behavioral aspects in research design. For example:

  - How do lifestyles of different cultures affect models of risk analysis?

  - What are the implications for research findings owing to the measures used to quantify study results?

  - What types of exposure analyses and dose-response mechanisms would be of interest to different communities?

- A specific effort is needed to improve the way risk assessment is communicated to the public and the risk manager, including development of statistical and communications tools.

There is a need to invest more in university-based research and research training, as well as outreach, to assure the kind of graduates skilled in interdisciplinary risk assessment that brings together the relevant specialists for hazard assessment, exposure assessment, and risk characterization.

Managing Risks from Toxic Substances and Wastes

Conceptual Framework

To reduce risks from toxic materials to humans and ecological systems we must reduce exposure, susceptibility, or the level of toxicity. For many years the primary emphasis was placed on reducing exposure by "end-of-pipe" control, by storing or "disposing" of wastes through burying in landfills, placement in abandoned salt mines, injection into deep wells below the potable water table, or like methods. Leaving toxic contamination in place and restricting access or limiting possible future land uses is another approach that has been used in the past. Many of these methods are not viewed as effective in the long-term and are often seen as simply shifting exposure to future generations.

Much of the emphasis of the last several years has shifted to methods to prevent production of toxic materials and treatment methods that reduce mobility of toxic contaminants (and consequently exposure) or that permanently reduce levels of toxicity. In waste management and remediation, this has been a requirement of laws such as the Comprehensive Environmental Response, Compensation, and Liability Act (Superfund) and the Resource Conservation and Recovery Act (RCRA). The primary focus of future R&D, as described in this strategy, is to provide technology and methods to minimize the further production of toxic materials and to treat and remediate already existing toxic materials through innovative technologies that provide greater permanent risk reduction at lower cost. Policies and approaches for managing toxic materials in the environment require linking of technology options with risk assessments to ensure appropriate levels of risk reduction. A hierarchy of technology approaches should be considered that starts with prevention and includes control, remediation, and monitoring. The strategy focuses on managing the risks of toxic materials from various waste types, including hazardous, solid, agricultural, and mineral wastes. The strategy deals with these waste types uniformly, regardless of the "source," and the hierarchy of technology approaches is applicable to all waste types.

Pollution Prevention. Pollution prevention is the preferred approach for managing risks from toxic materials. Generally, it achieves the greatest levels of reduction for both exposure and toxicity. Prevention can include use of less toxic inputs, use of less energy or raw materials, or use of more efficient, cleaner processes or better product design, or use of methods to prevent accidental spills and releases. Increased prevention will ultimately reduce needs for managing wastes and cleaning up contaminated sites.

Control. End-of-pipe or end-of-stack control technologies have become the mainstay of pollution control over the last 20 to 30 years as federal laws and regulations have specified acceptable emission levels based on use of "best available control technology." This regulatory "lock-in" of existing technology has had a chilling effect on development and use of more innovative technologies that could achieve an equal or greater reduction in risk for less cost. In addition, many conventional control technologies have not permanently reduced toxicity, but have often shifted toxic materials from one media to another. Over time, pollution prevention will reduce the need for end-of-pipe controls, so that research in this area should decline in the long-term in favor of prevention R&D. This must be phased, however, because existing and new regulatory requirements still rely heavily on these control technologies. New innovative technologies and practices are needed over the next several years to lower compliance costs and improve risk reduction associated with pollution control. (In addition, more flexible regulatory approaches must be put in place to encourage use of these innovative methods.)

Remediation. The mismanagement of toxic materials in the past has left a legacy of contaminated soils, sediments, and groundwater. Consequently, while this strategy emphasizes a shift in emphasis in the long term to prevention R&D, increased emphasis must be placed for the next several years on demonstrating and evaluating innovative technologies related to controlling and removing the risks from these past problems. The current and projected costs to remediate the vast number of contaminated sites in the U.S. are enormous. These costs, as well as the risk these sites pose to human health and the environment, can be reduced through deployment of innovative technologies that will provide more cost-effective identification, prioritization, monitoring, and clean up.

Monitoring. Characterization and monitoring of toxic materials in hazardous and toxic waste in all media is essential for both assessing and managing risk. Without cost-effective characterization and monitoring technologies it is not possible to either initiate the most appropriate remediation activity or determine whether real decreases in risk are being achieved by either control or pollution prevention approaches. Effective monitoring used as a benchmark for residual risk reduction is essential across all categories in the waste management strategy. In addition, more effective monitoring is key to moving from technology-based to performance-based controls. Continuous monitors, remote sensors, and various markers can verify actual performance and provide incentives for more efficient controls. Some communities and sections of the country may experience unusually high concentrations of toxic materials due to factors such as proximity to hazardous waste sites and industrial emissions to the environment. As a consequence these communities may be at greater risk of health effects from cumulative exposures to multiple chemical stressors. These disproportionately affected communities should be identified and considered for priority risk management to reduce the risk of exposures. Development of innovative monitoring technologies will provide the edge needed in identifying disproportionately affected areas and in realizing more cost-effective clean up, compliance, and pollution prevention.

Global population growth and economic development present major new challenges to our ability to manage solid, hazardous, and toxic wastes and maintain and improve the quality of the environment and protection of human health. Current projections are that by the year 2050, world population will roughly double, and world economic output will increase five-fold. This will lead to production and consumption patterns that can greatly increase both the quantities of wastes and the levels of toxic materials released to the environment. This expected growth also poses economic and social challenges. The costs of conventional pollution control divert financial resources from more economically productive uses. Consequently, it is essential that we:

- Base management of wastes and toxic materials on high quality risk assessments, and set priorities based on risk.

- Greatly improve the effectiveness and efficiencies of this management through emphasis on the development and use of innovative, cost-effective technologies to prevent, control, remediate, and monitor toxic materials in the environment.

The strategy for risk management R&D focuses upon the scientific and technological developments to directly address and achieve the goal of "sustainable development" and to indirectly provide support to the goal of "environmental justice." Sustainable development has been defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." The term is also commonly understood to refer to simultaneous achievement of a clean environment and economic growth. Environmental justice means that the risks associated with toxic materials and wastes should be managed equitably across all sectors of society.

Current State of Understanding

Pollution Prevention

Pollution prevention research is still relatively young in relation to other environmental technology areas. Research to date has generally focused on 3 areas: (1) tools and methods for analyzing prevention alternatives; (2) cleaner technologies and processes (including identification of less toxic inputs); and (3) information dissemination.

Tools range from practical guides for conducting assessments to sophisticated computer models for process design and toxic materials substitution. Life cycle assessment is perhaps the most fundamental tool. Further research is needed to complete development and refine all of these tools.

Designing cleaner technologies and processes is at the heart of research needs in pollution prevention. Examples of this research include development of new (cleaner) synthesis pathways for chemicals (such as photochemical or biochemical conversion), identification of less toxic substitutes for organic solvents, developing less polluting production technologies (such as non-chlorine bleaching of wood pulp, and painting and coating technique with reduced emissions of volatile organic compounds), and developing and demonstrating environmentally safe maintenance procedures (such as cleaning and degreasing). To date several individual technologies or unit operations have been developed, but comprehensive, manufacturing base-focused R&D is only beginning.

Information dissemination is a critical adjunct to R&D to bring about commercial application. Therefore, it must be included in the national research agenda. Much has been done, but more innovative and effective approaches are needed especially in communities with high illiteracy rates or where English is a secondary language. These approaches range from establishing better integrated networks of technical assistance providers to more effective dissemination of information to the public to promote pollution prevention.

Pollution Control

Although a wide range of control technologies exist, many are not cost-effective, and may not reduce risks adequately. For example, current drinking water treatment depends heavily on chlorination and filtration to remove contaminants. Chlorination produces disinfection by-products that are themselves toxic. Furthermore, drinking water distribution systems can release toxic metals if proper pH controls are not maintained. Conventional treatment technologies for air emission and wastewater often shift and concentrate pollutants from one media to another with little toxicity reduction. Development of the technology for containment and removal of spilled oils has been supported by the government and private industry for a number of years. Recently, as a result of the Comprehensive Environmental Response, Compensation, and Liability Act (Superfund) and the Oil Pollution Act of 1990, it has become increasingly important to develop suitable control methods for hazardous and toxic material spills. A need for innovation across all media to improve control for toxic materials is a certainty. Suggested research priorities reflect areas believed to offer the greatest potential for further risk reduction.

Remediation and Restoration

Risks to humans from toxic materials in contaminated sites derive from contaminated groundwater and airborne particulates and from direct or indirect exposure to contaminated soils. For many sites, radioactivity and explosion or fire are also major risks. Most of these sites also release toxic materials to various ecosystems through direct contact, leaching, or runoff. Groundwater contamination at these sites has been the most difficult technical issue and represents a large part of clean-up costs. Groundwater contamination is perceived by the public as a major health issue and may present high risks at specific sites. It is also of concern because it degrades a natural resource and reduces its future uses. A recent NAS study found that groundwater clean up is expensive (estimates of up to $1 trillion over the next 30 years) and that existing technologies are generally not capable of effectively addressing the problem. (Dense non-aqueous phase liquids, for example, are not readily removed by existing treatment methods.) The study recommended a major national R&D effort to develop more cost-effective groundwater clean-up technologies.

Another problem associated with many sites where a cost-effective technical solution is not within reach is mixed radioactive and chemical wastes. Many contaminated federal sites cannot be effectively remediated until technologies are developed and demonstrated to address this problem. A federal R&D focus is particularly important because of the uniqueness of managing mixed radioactive and chemical wastes for federal sites.

One of the principal ways to reduce both costs and risks during remediation is to treat contaminated soils in place (*in situ*) without excavation. Methods for *in-situ* treatment are a major focus of current R&D efforts and should remain a priority into the future. In recent years, advances have been made in technologies such as bioremediation and soil vapor extraction, but further development of these and other technologies is needed. The demonstration and evaluation of these innovative technologies is an essential step in the development process. Implementation of technologies to the field, with regulatory acceptance, can only be accomplished through this manner. The thrust of federal R&D, then, is to transition technology from the laboratory to the field, where cost savings can be realized.

Monitoring

Great advances have been made in the last decade in the science and technology associated with characterization and monitoring. New approaches for chemical, biological, and physical sensing have been developed. These new technologies must be exploited for environmental purposes and developed into practical cost-effective tools for managing toxic and hazardous waste if we are to achieve our goals. These technologies include the design, development, and operation of characterization and monitoring instrumentation with associated quality assurance aspects. Monitoring systems encompass microsensors, chemical sensors, biosensors, ground-based mobile platforms for sensors, sampling services, automated systems for tracking pollutant levels, and advanced technologies for data collection and analysis, including biological and complex ecological assemblages.

A significant cost in site remediation is site characterization and monitoring. Post-remediation monitoring is also needed to demonstrate to regulating authorities that cleaned sites are in compliance with policies such as RCRA. Innovative methods that are non-intrusive, provide real time results, and improve long-term detection capability at low cost need further development or field testing. A critical site characterization issue with enormous future costs and risks is the detection and identification of unexploded ordnance. The end of the Cold War has brought about a significant reduction in the military threat facing the United States. But an unfortunate legacy of years of military training and testing is the large number of unexploded ordnance on federal facilities. In addition, conflicts throughout the Third World have left an enormous number of mines scattered throughout the countryside, which continue to cause great harm and prevent productive use of the land. The critical step to addressing these related problems is the cost-effective detection and identification of these objects.

Development of in-process monitors are needed as part of new manufacturing and other industrial processes designed under tenets of industrial ecology. For control, continuous, low cost monitoring of waste streams is required for market-based and multi-media regulatory approaches. Legislation such as the Clean Water Act (CWA) and the Clean Air Act (CAA) are drivers behind the need to monitor hazardous chemicals in process effluents or emissions. Unique military disposal operations, resulting in hazardous emissions; release of volatile organic compounds from certain treatment processes; and hazardous air emissions and wastewater from plating and finishing processes are just a few of the areas requiring advanced or innovative monitoring technologies. Global monitoring technologies and national monitoring programs are of interest as a means of conserving, protecting, and enhancing natural resources. Monitoring systems may be strategically established to provide information of broad international interest, such as climate change effects on a global or regional scale. Improved monitoring techniques can be used to track the concentration and impact of toxic substance releases to the environment.

Research and Development Priorities

Although addressing the R&D priorities set forth below will require significant resources, these resource investments will yield substantial decreases to the much larger costs currently associated with site remediation and with environmental degradation caused by wastes and toxic materials. Over time, the environmental program will move from one based on remediation and control to one based on prevention, control, and monitoring.

For the public to reap the benefit of research and development in all four areas discussed below, technologies must transition from the lab into the field and be implemented and put into commercial operation. The key to this transition is the proper demonstration and evaluation of new technologies. A priority in all four areas is thus to develop protocols for testing innovative technologies to develop scientifically credible data on cost and performance, and to use these protocols to verify performance.

Pollution Prevention

In order to develop proactive solutions to reduce the use and/or release of toxic materials, R&D priorities are to:

- Develop and evaluate pollution prevention options that can be incorporated into federal regulations and in enforcement and compliance agreements.
- Develop and validate tools, such as life cycle analysis (LCA), and computerized process design models to incorporate pollution prevention into products and processes.
- Form partnerships with industry, academia, and all levels of government to develop a new generation of cleaner technologies and processes, focusing on specific industry sectors.
- Develop and evaluate new technologies to reduce pollution from agricultural chemicals and animals waste management with a special focus on protecting sensitive ecosystems.
- Disseminate information on pollution prevention approaches, techniques, and technologies.
- Provide technical assistance to help small businesses evaluate prevention approaches to comply with regulations and reduce costs.

Pollution Control

R&D priorities for treatment of air, solids, and wastewater, as well as spill containment and removal are to:

- Develop, demonstrate, and commercialize innovative, low cost, and low maintenance technologies for use by small communities in treating their wastewater and drinking water.
- Develop, demonstrate, and evaluate improved methods to reduce risk from disinfection by-products, lead, copper, bacteria, and viruses in drinking water.
- Develop, demonstrate and test approaches to address non-point source releases of toxic materials, including storm water runoff, combined sewer overflow, and agricultural runoff.
- Develop practical and scientifically valid tools and new approaches to manage watersheds, including the impacts of sewage sludge, storm water discharges, nonpoint source pollution, toxic chemicals, contaminated sediments, and habitat modifications.
- Develop and demonstrate emerging control technologies for toxic air pollutants from combustion and incineration processes.
- Develop cost-effective controls for treatment of toxic wastes formed during chemical synthesis, manufacturing processes, and mineral extraction. Priority should be on high toxicity, hard-to-treat wastes.

- Develop and evaluate response technologies to mitigate the impacts of inadvertent spills or discharges and facilitate the expediency of clean-up efforts.

- Develop better methods to remediate environments impacted by oil spills or chemical releases.

- Develop and evaluate technologies to mitigate underground leaks from pipes and tanks, including improved leak detection, and more cost-effective clean up. The effectiveness of natural attenuation in managing petroleum plumes is also an R&D priority.

Remediation and Restoration

Effective clean up of hazardous waste sites, such that existing and future environmental quality objectives are met, can be realized through the following R&D priorities:

- Conduct field evaluations of technologies to obtain data on performance, cost of performance, environmental effects, and range of applicability for the remediation of radioactive wastes, mixed wastes, contaminated soils, and groundwater contaminated plumes.

- Develop a national federal test sites program to identify test sites at federal facilities and to support demonstrations and evaluations at these sites.

- Develop, demonstrate, and evaluate *in-situ* technologies, such as bioremediation, for remediation of contaminated soils, landfills, and subsurface plumes without excavation, transportation, or incineration.

- Develop, demonstrate, and evaluate innovative technologies for the characterization, identification, and remediation of energetic materials (including unexploded ordinances, chemical munitions, etc.).

- Develop technologies to characterize, model, monitor and remediate contaminant plumes in groundwater, particularly dense non-aqueous phase liquids (DNAPLs) such as certain chlorinated solvents.

- Develop new information management and quality assurance tools and procedures to improve the speed with which data are collected, tracked, interpreted, and reviewed at sites.

- Coordinate development of robotics, waste separation, and characterization technologies that are applicable to high-level waste, mixed wastes, landfills and contaminated soils, and groundwater contaminant plumes.

- Develop, evaluate, and demonstrate innovative technologies to remediate and restore environments impacted by oil spills or chemical releases.

- Develop techniques to measure the health of ecosystems and the effectiveness of restoration efforts.

Monitoring

R&D priorities in the area of monitoring hazardous chemicals in process streams, emissions, and whole ecosystems are to:

- Develop and demonstrate innovative field screening techniques which will allow for the rapid and cost effective assessment of contaminated sites.

- Develop innovative subsurface characterization and monitoring methods, with particular emphasis on DNAPLs in groundwater and unexploded ordinances.

- Develop tools for monitoring systems for the management of large areas affected by non-point source pollutants.

- Develop low cost continuous monitoring systems for in-line industrial process controls, air and water streams, and the long-term monitoring of contamination sites.

- Expand surveillance of adverse human effects associated with exposures from oil spills and chemical releases.

- Develop techniques for improved ecological diagnosis and monitoring, including research on the modulation of effects on habitat conditions, species life stage, and physiology.

Social and Economic Aspects

Management of risks from toxic materials and wastes raises significant economic and social issues. The economic issues have at least two dimensions. One is that the costs of environmental compliance affect the profitability of private companies (and thus economic growth) and can also consume large amounts of public funds. The second is that the innovative technological solutions that can reduce these costs are often not developed or commercialized due to economic constraints such as lack of capital. Although economic issues per se are not the primary focus of research under this strategy, they have important policy implications and drive the technical research priorities in certain directions. For example, economic considerations suggest that:

- Pollution prevention research should be given high priority because of its link to sustainable development and importance as a strategy for promoting environmental justice..

- Innovative technologies for control and remediation that can reduce risk at lower life-cycle cost are essential.

- Legislation, regulations, and other government policies must provide sufficient flexibility to allow innovation to occur and to allow and encourage the use of innovative technologies.

- Financial support for R&D and commercialization, selectively infused, coupled with removal of other barriers to commercialization such as lack of test sites and performance verification, must be provided.

- An effective federal program to catalyze and enhance environmental technology development can yield important gains in the position of U.S. companies in global markets.

Under these conditions, stringent environmental requirements can actually lead to enhanced competitiveness and economic strength.

Social issues also have at least two dimensions. One concerns involving the public and encouraging two-way flow of information in decisions about risk management. Meaningful involvement demands that the public have access to reliable and understandable information about sources and levels of toxic materials in their communities, their associated risks, and that they have the opportunity to participate in the decisionmaking process for managing these risks. The second critical social dimension is equity. Although existing information is incomplete, it is generally accepted that involuntary risks from toxic materials and their management are not shared equally by all socioeconomic sectors in our society. For example, while the federal government is aware that dietary risk from pesticides varies across different income, ethnic, and age groups, present survey results cannot provide disaggregated dietary intake estimates for these groups from different commodities. Similarly, there is insufficient information correlating exposure from waste management with different socioeconomic groups. Examples such as these strongly indicate that significant new studies and surveys are needed to effectively carry out a national policy of "environmental justice."

Research Priorities

The priorities for social science and economics research relative to toxic and hazardous substances are to:

- Identify and pilot economic incentives to encourage private sector development and commercialization of innovative risk management technologies.
- Develop analytic tools for integrating environmental and economic decisions.
- Develop new approaches and tools to provide the public with quality data in a form that allows them to evaluate the role of toxic materials in their community and to participate in the decisionmaking process.
- Develop techniques to identify and survey "high end" behavior which impacts exposure levels across different socioeconomic groups (e.g., dietary consumption patterns for high pesticide residue commodities).
- Establish a standard, tiered evaluative process for screening jurisdictions for disproportionately adverse health effects from environmental contaminants, including baseline health evaluations for comparing exposure levels in the general population with those in subpopulations (e.g., biologically susceptible, socioeconomic subgroups of interest).
- Advance research at minority colleges and universities with expertise in environmental justice issues.
- Evaluate the peer review process for racial and cultural insensitivity, and include community review for projects conducted in communities.
- Expand surveillance of adverse physical and psychological effects associated with living on or near solid and hazardous waste sites.
- Identify factors to encourage community participation, and develop public participation models for conducting exposure and health effects studies (also for waste management facility siting).
- Seek to reduce future disproportionate risk by providing models of prevention, remediation, sustainability, and community input to adversely impacted communities.
- Examine geographic/racial distribution and disparities of inspection and enforcement rates and evaluate factors in attitudes and criteria that could lead to disparities.
- Evaluate the impact of market-based pollution controls on all populations with emphasis on minority and socioeconomically disadvantaged populations.

- Evaluate state, tribal, and local government environmental justice initiatives and characterize conditions leading to their success or failure.

- Evaluate how cultural values and health conditions associated with race, class, and ethnicity, affect risk assessment processes and risk management decisions.

- Develop and evaluate economic models to be used for cost/benefit analyses, including contingent valuation and life cycle methods, and noncancer health and ecological effect valuation.

External Input

The following policy direction to federal agencies addresses external input and participation in developing and implementing the national environmental technology strategy. The guidance addresses industrial and stakeholder participation and is as follows:

- Leverage federal resources by increasing cost-shared partnerships with the private sector, states, and federal agencies for development and testing of innovative environmental technologies. Make access to federal facilities easier for federal, state, local agencies, and the private sector.

- Accelerate national use of innovative environmental technologies for clean up of federal and state sites. Work across federal agencies to address institutional and regulatory barriers that inhibit public-private partnerships. Provide technical assistance for implementation of innovative environmental technologies. Increase the number of improved technologies/systems (bench, pilot, or full-scale) demonstrated that address major environmental problem areas.

- Strengthen partnerships with stakeholders. Improve decisionmaking process so it is open and accessible, results in decisions that are technically and economically feasible, environmentally sound, health and safety conscious, addresses public values and concerns, and can be implemented. Increase stakeholder participation in decision- making process.

International Dimension

The following policy direction to federal agencies addresses the international dimension for innovative waste management technology and fully supports the Environmental Technologies Exports: Strategy for U.S. Leadership, (Trade and Promotion Coordinating Committee, November 1993). The guidance is:

> *"The U.S. must lead in world environmental stewardship and in advancing the goal of sustainable development. Environmental technologies are central to achieving these goals. U.S. governmental export promotion will foster partnerships with U.S.-based private sector firms to expand opportunities and will improve financing mechanisms for exporters. U.S. firms should take full advantage of exploding world environmental remediation markets and assist in developing sustainable economies of the future."*

Selected Milestones

This strategic plan is designed to help eliminate redundant research and promote complementary efforts, enhance efficiency and accountability in federal research, and improve cross-governmental cooperation and communication. It focuses on research needs related to improving the **assessment** and **management of risks** associated with these materials, as well as the **social and economic factors** that influence risk assessment and management. The plan is organized according to these three research areas—Risk Assessment of Waste and Toxic Substances, Toxic Substances and Waste Risk

Management, and Social and Economic Aspects of Waste and Toxic Substances. This strategic plan should provide a reasonably good map for prioritizing future R&D efforts and for improving our Nation's ability to minimize the health and environmental risks posed by toxic and hazardous substances. Examples of milestones for 1995 through 1999 follow.

Risk Assessment

- Endocrine-Disruptor Chemicals. Produce a national research strategy on endocrine-disruptor chemicals. Such chemicals (e.g., DDT and some PCBs) may cause hormone-related problems such as decreased fertility in humans and certain types of hormone-related cancers (e.g., breast cancer) and may be associated with ecological problems such as wildlife population loss. This research approach will provide a coordinated effort to improve understanding of the extent to which these chemicals cause significant public health or ecological effects and the need for policies to mitigate such impacts.

  Specific projects include: (1) organization of an international conference to identify research needs (April 1995) and publish proceedings (January 1996); (2) followup meeting(s) to further refine research needs and implement research to address selected high priority needs (FY 1996); and (3) creation of an Endocrine Disruptor Research Coordination Committee to promote adoption of the research needs by different components of national and international government, industry, and private research groups, and to maintain an active communication dialogue on research progress resulting from implementation of the ensuing research strategy (FY 1996).

- Genetic Susceptibility. Produce a comprehensive national strategy to develop prevention and treatment approaches for diseases with a genetic component. The discovery of genetic susceptibility to diseases, such as cancer, can lead to immediate public health actions such as screening populations likely to be susceptible for the disease early in life.

  Specific projects include: (1) expansion of research on the genetic susceptibility of breast, prostate, bladder, and lung cancer (FY 1996-1997); and (2) organization of an international conference to address priority needs and ethical issues involved in genetic susceptibility research (fall 1996).

- Dioxin Reassessment. Finalize the reassessment of the health and ecological effects from exposure to dioxin and related compounds. This reassessment has major implications because of the ubiquitous exposure and the potential of these compounds to cause harm at low levels of exposure. This assessment will have major impacts on regulations to control emissions on dioxins, as well as future pollution prevention efforts.

  Specific projects include: (1) exposure research on source identification and testing, deposition modeling/measurement, food surveys, and trend analyses (within 2 to 3 years); (2) investigation of the pharmacokinetics and pharmacodynamics of 2,3,7,8-TCDD and related compounds—dioxins, furans, and dioxin-like PCBs; emphasis will be given to biochemical and biological markers of toxicity primarily for noncancer endpoints including development and reproductive toxicity, endometriosis, and immunotoxicity (within 2 to 3 years); and (3) preparation of a report on data and methods for assessment of ecological risks of 2,3,7,8-TCDD and related chemicals to aquatic life and associated wildlife (FY 1996).

- Ecological Effects and Exposure. Improve tools for conducting ecological risk assessment. Increased emphasis will focus on making risk assessment a more effective tool for decisionmakers by developing and improving models for estimating and predicting exposure and environmental fate and effects; improving methods for monitoring and assessing exposure; better defining the responses of communities and ecosystems to toxic chemical stressors; and developing place-based ecological assessments.

Specific projects include: (1) study of the relationship of hydrology to South Florida ecosystems (summer 1996); (2) investigation of comparative risks of ecological threats to the Pacific Northwest (spring 1997); and (3) conduct of ecological assessments of the Mid-Atlantic Highlands (spring 1997).

- Hazardous Air Pollutants. Provide tools to measure hazardous air pollutants (HAPs) both in the environment and at the sources of emissions, as well as source receptor modeling to estimate contribution of specific sources to ambient levels. Health effects (primarily noncancer) and monitoring research will help characterize the potential risks from HAPs emitted from a wide variety of sources from dry cleaners to chemical plants. This research is needed to implement the Clean Air Act Amendments of 1990.

  Specific projects include: (1) development of source monitoring methods for HAPs identified in the Clean Air Act consistent with the legislative schedule for development of maximum achievable control technology standards; (2) demonstration of techniques to monitor a wide variety of HAPs and carry out source receptor modeling in an urban setting (Baltimore, MD) to support the Urban Air Toxics program; and (3) development of methods to better characterize noncancer endpoints and the effects of exposure to mixtures of chemicals in support of both the Urban Air Toxics program and residual risk analyses.

Risk Management

- Pollution Prevention. Develop, evaluate, and promote the use of pre-competitive technology that has the best potential for reducing pollution. This goal will be achieved by developing innovative methods and tools; evaluating technologies and processes; and conducting outreach and technical assistance.

  Examples of specific projects include: (1) development of an integrated energy, prevention, and manufacturing efficiency analytical tool (1996); (2) development and demonstration of simulation of clean processes (1996 - 1997); (3) research on alternative "green" chemistry synthesis for petrochemical feedstocks (1997); (4) evaluation of cleaner process alternatives for selected industries dominated by small businesses, such as printing and metal finishing (1996 - 1997); (5) provision of technical information to small businesses and manufacturers through cooperative federal/state outreach programs (1996 - 1998); and (6) provision of information on pollution prevention data, activities, and research through an online interactive electronic Internet-based information system (1996 - 1998).

- Pollution Prevention in the Minerals Industry. Develop new technology to allow the minerals industry to avoid the generation of toxic/harmful wastes. Focus on the development of tools and techniques that increase the competitiveness of the U.S. minerals industry while significantly reducing the negative environmental consequences of minerals production.

  Specific projects include: (1) demonstration of a pilot-scale in-situ copper mining process (June 1998); (2) demonstration of a commercially viable alternative to cyanide for the heap leaching of gold (September 1998); and (3) pilot demonstration of bioleaching techniques for mineral production (June 1999).

- Metals Extraction/Recovery Technology. Adapt, modify, and apply the techniques used by industry to extract metals from their host environments to the remediation of metals and related contaminants from soils, sediments, and waters. Demonstrate these improved techniques in the remediation of abandoned sites on federal lands. Work with the regulatory authorities, land managers, contractors, and citizen groups to assure the acceptability and cost-effectiveness of these improved technologies.

Specific projects include: (1) demonstration of techniques to control the contamination associated with acid drainage/metal mobilization at a field scale on Forest Service sites (October 1997); (2) demonstration of a pilot-scale unit for the clean up of contaminated military small arms firing ranges (October 1997); and (3) provision of design and technical assistance in the construction of a full-scale unit for the vitrification of radioactive contaminated wastes based on the pilot unit being operated at the Bureau of Mines' Albany Research Center.

- Bioremediation Technology. Improve and develop bioremediation technologies for contaminated water, soil, and air.

  Specific research will be directed toward: (1) identification of the microorganisms involved and the interactive and sequential roles played by cometabolizing bacteria, and by surfactants and solubilizing agents that may be produced to facilitate biodegradation (FY 1997 - FY 1998); (2) exploration of the feasibility of adding organisms possessing broad host-range, self-transmissible degradative plasmids to promote the most effective rates of waste chemical degradation or establish new and relevant degradative activities within microbial populations (FY 1998); and (3) field studies on selected aqueous RCRA wastes—first on solvent and munitions wastewaters and later on chlorinated aromatic hydrocarbons or pesticides—employing sulfate and methanogenic reducing processes in anaerobic filters and granular activated carbon (GAC)-assisted anaerobic expanded beds (FY 1999). Pilot biosystems have been successfully developed using conventional anaerobic and GAC-assisted anaerobic treatment of high and low strength industrial aqueous wastes and leachates from contaminated sites.

- Remediation Technology Demonstration. Demonstrate key innovative environmental remediation technologies at federal facilities. Innovative technologies and technology systems are needed to address major problem areas and enable cost-effective remediation. Specific demonstrations have been targeted for completion in order to foster timely acceptance—by stakeholders, regulators, and users—of the innovative remediation technology systems.

  Specific projects include: (1) demonstration of three or more pilot-scale radioactive mixed waste treatment technologies to substantiate the potential to treat 90% of the current DOE mixed waste inventory (November 1997); (2) demonstration of the ability to retrieve and treat liquid tank waste (June 1997); (3) demonstration of the capability to treat heavy metal and dense nonaqueous phase liquid (DNAPL)-contaminated soil and groundwater in situ (January 1997); (4) demonstration of the capability to contain potential source terms that may show migration (January 1997); (5) demonstration of the capability to decontaminate concrete surfaces and volumes (December 1997); and (6) demonstration of technologies at selected sites under actual conditions for remediation of unexploded ordinance, heavy metals, and petroleum derivatives; compliance with regulations for underground storage tanks; and reduction/prevention of pollution from coatings and fuel cells (FY 1995 - FY 1997).

- Technology Verification. Implement a national program to verify performance of innovative environmental technologies. Performance verification is needed to enable commercialization of technologies that can improve environmental performance and reduce costs.

  Specific projects include: (1) expansion of the Department of Defense's Environmental Security Technology Certification Program (FY 1996 - FY 1997); (2) establishment of a market-based verification process for environmental technologies by EPA—working with other federal agencies, states, and the private sector (a pilot program will be selected in 1995, operation will begin in

1996, and the program will be expanded in 1997); and (3) expansion of the number of federal sites available for federal technology demonstration projects (FY 1995 - FY 1996).

Social and Economic Factors

- Socioeconomic Projects Related to Pollution Prevention. Solicit proposals and award research grants for the conduct of socioeconomic initiatives related to pollution prevention to support projects directed toward furthering the objectives of the President's Environmental Technology Initiative. This research may include projects focused on policy reforms, opportunities for building innovative capacity, and diffusion of innovative prevention technologies. The purpose of this socioeconomic research is to apply existing knowledge in pioneering attempts to effect social or institutional change with respect to promoting development and implementation of innovative technology (FY 1995).

- Environmental Justice. Explore the dimensions of community-led research and better integrate this model into EPA's research strategy. Community-led research relies heavily upon the knowledge of residents who typically lack scientific training. Consequently, research designs can prove problematic to researchers concerned with scientific methods (FY 1995).

CENR Toxic Substances and Hazardous and Solid Waste Subcommittee

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