Acid Rain Research
A Special Report

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Cover: Natural rainwater is already slightly acidic. How much additional acidity can be tolerated by nature is at the center of public concern over acid rain.

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ACID RAIN RESEARCH
A Special Report

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Acid Rain: The R&D Challenge

As the national strategy for dealing with acid rain evolves in the months ahead, one aspect is becoming clear: research and development will play a major role. Identifying the extent of natural resources at risk and the most rational mix of corrective actions demands careful consideration of the costs and potential benefits of all possible alternatives. If we are to achieve the common goal of preserving the environment as well as the quality of life in America, we owe it to ourselves to make the most informed choices that present knowledge permits. And we owe to future generations a continual effort to expand the knowledge base, refining our course of action as our understanding improves.

For EPRI and the electric utility industry, this dual responsibility means accelerating the already substantial environmental research on acidic deposition, as well as stepping up efforts to develop new technologies that offer cleaner coal combustion. EPRI and its utility members can take pride in sponsoring the largest privately funded research program on acid rain in the world. The $175 million the Institute plans to spend over the next five years on science and technology directly related to acid rain is in addition to a $300 million effort focused on advanced technologies that will generate electricity from coal cleanly and efficiently.

This latter effort includes a 100–200-MW demonstration of fluidized-bed combustion scheduled for startup in 1989 and a 100-MW demonstration of a coal gasification–combined-cycle (GCC) power system scheduled to start operation at Southern California Edison Co. next year. The GCC plant, using high-sulfur midwestern coals, will meet California's stringent emissions standards for SO_2 and NO_X. With utility and government collaboration in follow-on efforts to these pioneer plants, the technologies could be commercially available in the mid-to-late 1990s.

Based on the encouraging results of R&D EPRI has sponsored to date on these systems, we believe that a national emphasis on advanced clean coal technologies can have a more significant long-term environmental payoff than the costly retrofitting of middle-aged boilers. Some ecologically sensitive lakes in North America may require near-term remedial management from the effects of acidic deposition. The encouraging results achieved by Sweden in liming aquatic systems and restoring fish life deserve serious consideration by U.S. policymakers. It represents the only certain way of restoring acidified lakes and protecting sensitive lakes from inevitable acidification—with or without controls on coal-fueled power plants.

The next five years are critical to R&D efforts to solve the acid rain problems. EPRI's proposed national research program, which expands and accelerates the federal acid rain research plan prepared by the Interagency Task Force, could provide answers by 1988 to key questions on which the success of possible solutions depends. These include an accurate characterization of natural resources at risk, the economic consequences of different control options, and the most cost-effective courses of action to protect sensitive resources.

The articles that follow in this special issue of the *EPRI Journal* explore the present state of knowledge on acid rain and the various research programs we are pursuing to improve our understanding of the many elements of the problem. They demonstrate the breadth of the utility industry's commitment to applying R&D resources in the search for harmony between the twin imperatives of using our abundant coal resources efficiently and protecting the environment.

RE Balzhiser

Richard E. Balzhiser, Senior Vice President
Research and Development Group

Authors and Articles

Twenty-two men and women from six research programs in two EPRI divisions contributed to this special edition of the *EPRI Journal*. Together, those research professionals introduced the *Journal* staff to a virtual encyclopedia of information and insight about acid rain that has found its way into U.S. technical libraries during the past dozen years or more.

Eleven members of the Energy Analysis and Environment Division, headed by EPRI Vice President René Malès, aided in shaping and authenticating the opening presentation and the articles dealing with acid rain sources, transport, and environmental effects.

Malès has been director of the Energy Analysis and Environment Division since he came to EPRI from Commonwealth Edison Co. in 1976. During 20 years with the utility, he was director of economic research, assistant to the vice president of division operations, and after 1973, manager of general service. Malès was educated in mathematics and business.

Ralph Perhac, director of the Environmental Assessment Department since 1980, is also a member of the U.S. Acid Precipitation Task Force. Perhac is a geochemist with more than 15 years' experience in minerals exploration and research and was on the faculty of the University of Tennessee. Mary Ann Allan, a senior research assistant on Perhac's staff, came to EPRI in 1980 after three years with the U.S. Geological Survey.

Robert Brocksen, manager of the Ecological Studies Program from 1979 until August of this year, was formerly with the Environmental Sciences Division at Oak Ridge National Laboratory and, still earlier, was a research faculty member at the University of California at Davis. He is now a zoology professor and director of the Water Research Center at the University of Wyoming.

Four contributors from the Ecological Studies Program are Project Managers Robert Goldstein, John Huckabee, Robert Kawaratani, and Jack Mattice. Goldstein, specializing in atmospheric deposition, came to EPRI in 1975 after nearly six years as a systems ecologist in the Environmental Sciences Division at Oak Ridge. Huckabee, his counterpart for studies of toxic substances, has been with EPRI since 1979. A biologist with degrees also in zoology and physiology, he was formerly at Oak Ridge as a member of the research staff for eight years.

Robert Kawaratani joined the EPRI staff in 1975 as a biologist. Later completing his doctorate in environmental science, he now manages research dealing with toxic substances and their effects. Jack Mattice, a biologist and zoologist, came to EPRI in 1981 to manage research projects on aquatic resources. He was formerly with the Environmental Sciences Division at Oak Ridge for nine years.

Glenn Hilst is manager of the Environmental Physics and Chemistry Program. With EPRI since 1977, he is a meteorologist and for more than 20 years has specialized in the modeling and mapping of atmospheric systems.

Three project managers of the Environmental Physics and Chemistry Program are Peter Mueller, Ishwar Murarka, and Robert Patterson. Mueller is a chemist and environmental scientist, his work largely in atmospheric studies and instruments for measurement and analysis. Before coming to EPRI in 1980, he was with Environmental Research and Technology, Inc.

Murarka came to EPRI in 1979 following five years at Argonne National Laboratory, where he developed statistical designs and models for use in studies of aquatic systems. With degrees in geography, business, and soil science and statistics, he specializes in land and water quality studies. Patterson, with degrees in physics and environmental health, came to EPRI in 1981 after four years with SRI International and four years with GCA Corp., managing environmental planning and health research.

Nine research managers of the Coal Combustion Systems Division and EPRI Vice President Kurt Yeager provided guidance for the article on emission control technologies. Coordinating roles were played by George Preston, director of the Environmental Control Systems Department, and Michael Miller, the department's technical manager for environmental assessment.

Yeager has directed the Coal Combustion Systems Division since 1979, and previously he was the director of EPRI's Fossil Fuel Power Plants Department. He came to the Institute in 1974 from EPA's Office of Research, where he was director of energy R&D planning. From 1968 to 1972 he was with The MITRE Corp. as associate department head, guiding research in environmental controls and energy supply forecasting. Yeager holds two degrees in chemistry.

Preston, a chemical engineer, was named to his present post in 1981. He came to EPRI in 1978 after eight years with Occidental Research Corp. Miller joined EPRI in 1980. An environmental analyst and planner since 1973, he was formerly with Pacific Gas and Electric Co. and, still earlier, URS Corp. Miller's academic background is in chemistry, environmental studies, and public health.

Robert Carr is manager of the Air Quality Control Program, and Michael McElroy is project manager for NO_x reduction measures. Carr, a mechanical engineer, has been with EPRI since 1974 and was previously with KVB, Inc., as a utility consultant on boiler emissions.

McElroy came to EPRI in 1976. Also a mechanical engineer, he too came from KVB, where he had been a field engineer for four years.

Stuart Dalton has managed the Desulfurization Processes Program since 1979. A chemical engineer, he worked a total of eight years for Babcock & Wilcox Co. and Pacific Gas and Electric Co. before coming to EPRI in 1976.

Thomas Morasky and Richard Rhudy are project managers in the Desulfurization Processes Program, both of them concerned with development of scrubber systems using nonregenerable media. Educated in chemical engineering, Morasky joined EPRI in 1976, having been a research engineer with The Detroit Edison Co. for 10 years, involved in the development, installation, and startup of emission control systems. Rhudy, also a chemical engineer, has been at EPRI since 1977. He was formerly with Bechtel Corp. for 8 years, primarily as a staff engineer on air quality control design and pilot plant projects.

Callixtus Aulisio and Robert Row are research managers in programs of the Fossil Fuel Power Plant Department. Aulisio is a project manager in the Fluidized-Bed Combustion and Alternate Fuels Program. He came to EPRI in 1978 after four years with Pope, Evans & Robbins, Inc., as a supervisory chemical engineer for the design, startup, and test program of a pilot-scale fluidized-bed combustion unit.

Row joined EPRI's Coal Quality Program in 1982. Trained in chemical engineering and business, he was formerly with Utah International, Inc., for four years as an administrative analyst for mineral resource projects. His earlier experience included mining and metallurgical process design assignments with Bechtel Corp.


Malès


Allan


Goldstein


Patterson


Murarka


Hilst


Huckabee


Perhac


Kawaratani


Mattice


Mueller


Carr


Dalton


Brocksen


Yeager


Row


Morasky


Rhudy


Preston


Miller


McElroy


Aulisio

CLARIFYING THE SCIENTIFIC UNKNOWNS

Research is shedding light on the critical scientific issues of acid rain and opening up new control alternatives.

The term *acid rain* first issued from the pen of British chemist Robert Angus Smith in 1872. But it was not until the 1972 United Nations Conference on the Human Environment, exactly 100 years later, that the acid rain concept crossed the threshold of public awareness.

Today acid rain has become an issue of international import. It is a source of tension between Great Britain and Scandinavia in Europe, between the United States and Canada, and even between different regions of the United States. The charge is that emissions from burning fossil fuels, sometimes carried over long distances before returning to Earth, are contributing to harmful acidity in the waters, forests, and fields of near and not-so-near neighbors.

Such transboundary air quality problems have no precedent. Further, the issue contains many elements that cannot be proved or disproved, given our current state of knowledge. Nevertheless, there has been increasing pressure to curb emissions immediately on the theory that irreversible damage could occur during the time it will take to establish solid proof.

Now that momentum exists for establishing new controls, the challenge will be to keep our knowledge evolving apace. Without such knowledge, there will be no way to evaluate the many alternative strategies proposed, now and in the future.

Here we look first at acid rain as a physical/chemical phenomenon. Then we scan some of the major scientific questions surrounding it, the options for controlling or mitigating its effects, and the research now planned or under way to shed light on its scientific unknowns. Finally, we note the complexities of trying to resolve a scientific problem that has inherent economic and political dimensions.

What is acid rain?

Acid rain refers loosely to a mixture of wet and dry acidic deposition from the atmosphere. The wet part may be rain, snow, hail, sleet, fog, dew, or frost. The dry part, estimated to be about half of the total in the northeastern United States, consists of gases and solid particles that settle to Earth. Dry deposition can go into solution and begin behaving like acid rainfall as soon as it contacts surface moisture.

A solution's acidity is measured on the pH scale by its concentration of hydrogen ions. Because the pH value is a negative logarithm of this concentration, pH falls as acidity rises, and each full unit of change on the pH scale represents a tenfold increase or decrease in acidity. The range goes up to 14: a pH value of 1 is highly acidic (like battery acid), a value of 7 is neutral, and a value of 13 is highly alkaline (like lye).

If there were no contaminants except carbon dioxide in the air, rain and snow would be somewhat acid because they are tinged with carbonic acid that is formed continuously in the atmosphere when carbon dioxide reacts with airborne moisture. That influence alone can lower precipitation pH to a mildly acidic 5.6. Other naturally occurring contaminants also have an effect. Dust, for example, can bring the pH up to 7.0 or 8.0. And nitrogen oxide from lightning, chlorine from sea salt, and sulfur oxide from geysers, decaying vegetation, or the ocean can bring it down again to the 4.5–5.0 range. Measurements of rainfall pH in such remote areas as the Indian Ocean, the mid-Pacific Ocean, and the Amazon jungle have been recorded at these low pH levels.

Man-made emissions of sulfur and nitrogen oxides from burning fossil fuels can add significantly to this atmospheric loading of acid precursors—substances that precede and are the source of the acids that form. The heavily industrialized northeastern quadrant of the United States, embracing the Midwest through New England, produces man-made sulfur and nitrogen emissions that far outweigh those from natural sources. The region's 4.0–4.5 precipitation pH reflects this human contribution and makes it the geographic center of the nation's acid rain controversy.

Man-made emissions of sulfur and nitrogen oxides are now believed to be roughly equal in that region, although the relative role of nitrogen emissions is expected to grow. The sulfur emissions issue mostly from burning coal and oil in industrial plants, with electric utilities accounting for some two-thirds of the total. Utility combustion also accounts for about one-third of the nitrogen emissions, and almost half flow from the exhaust pipes of automobiles, trucks, and buses.

Sulfuric and nitric acids in the air can come from the atmospheric conversion of these precursor sulfur and nitrogen oxide emissions (SO_x and NO_x). Even though the quantitative side of the conversion reactions remains unclear, the sequence is partially understood: the oxide emissions can react with atmospheric oxidants, such as ozone (O_3), to form sulfates (SO_4) and nitrates (NO_3), which can then combine with water vapor (H_2O) to form sulfuric acid (H_2SO_4) and nitric acid (HNO_3).

The routes of long-range transport remain in doubt, but we know that SO_x emissions converted to airborne sulfates can travel hundreds of miles under the right mix of weather conditions. The consensus that such long-range transport can occur does not, however, rule out a major role for local emissions sources in acidic deposition. Local sources are thought to account for the bulk of the sulfur dioxide gas and sulfate-bearing particles that are dry-deposited on exposed surfaces.

U.S. sulfur emissions, except for the southeastern region, have actually declined in recent years, due largely to the retirement of older coal-burning power plants. But it is hard to tell what effect, if any, this emissions decline has had on rainfall acidity. One of the few sites in North America that has monitored rainfall pH for more than a decade, a site in New England, shows no substantial change in acidity but a slight decline in sulfate deposition. Nine sites in and around the state of New York, on the other hand, show mixed trends for both pH and sulfate—some slightly up, some slightly down.

Assessing the problem

The main concern about acid rain is cumulative ecosystem damage, especially to lakes and forests. In the United States the focus is on midwestern power plant emissions and their effect on the waters and woodlands farther east in New York and New England. The big questions are whether power plant emissions are in fact damaging these natural systems; how the potential effects can be controlled or mitigated; and who will bear the very substantial direct and indirect costs of implementing such procedures.

Pinning down exactly what power plant emissions do after they leave the stack is the first step in coming to grips with acid rain's scientific unknowns. The challenge is to describe the connection between emissions and deposition and, in particular, the geographic link. To clarify what is called the source-receptor relationship, we need a clearer picture of the connection between individual source areas (where emissions go up) and individual receptor areas (where they come down). We have to know how much and where acidic deposition will fall to Earth, given a known emissions profile.

Linearity is a relationship of direct proportion between two quantities. If one varies by a certain percentage, the other will vary by that same percentage. Nonlinearity is the norm for many atmospheric processes. In Europe the relationship of industrial emissions to rainfall acidity appears to be decidedly nonlinear.

In the eastern United States, however, with its quite different topography and climate, the situation may be different. A recent report issued by the National Academy of Sciences (NAS) found "no evidence for strong nonlinearity" in the relationship between sulfur emissions and deposition. In other words, its findings imply that a 50% reduction in sulfur oxide emissions in states east of the Mississippi can yield close to a 50% reduction in deposition of wet and dry sulfate in this same broad region.

Some link clearly exists between what goes up and what comes down when viewed from the perspective of large regions and extended periods of time. But even if this link is nearly linear in character, as the NAS report suggests, we still do not have the information we need to protect those specific areas where acid rain is suspected of causing environmental change. Can a 50% reduction in emissions from midwestern power plants guarantee a reduction in rainfall acidity in the Adirondack Mountains of upper New York state? Can it guarantee reduced deposition in the New England states farther east? No one can say.

Clarifying the geographic source-receptor relationship is one of the most important challenges in acid rain research because optimal control strategies require this knowledge. Emissions controls are very expensive, so we must know where they will do the most good in order to apply them in a selective, cost-effective manner. Without better information on the source-receptor link, we cannot guarantee that reducing emissions will pay off by reducing deposition in the specific areas targeted. We cannot even tell whether control of local or distant sources will be most cost-effective in protecting those areas considered to be ecologically sensitive.

A parallel puzzle is the relationship of deposited acidity to ecosystem change. The potential for ecosystem change in response to acidic deposition has been demonstrated in the laboratory. And in the real world, geographic correlations between acid rainfall and acid lakes furnish circumstantial evidence that such changes are actually occurring. But we cannot assume that a correlation is a causal connection, nor can we attach numbers to these changes. We need comprehensive, long-term field data to quantify the magnitude and the rate of change—both major factors in understanding the extent of the problem.

Lake acidification is a highly charged environmental concern among residents of the northeastern United States and the adjacent provinces of Canada. Sportfishing and related activities are not only a part of local lifestyles, they are also part of the economic underpinning in such areas as the Adirondacks, where tourism and recreation are basic industries. What we know for sure is that some lakes in the Adirondacks are now too acid to support sport fish. What we do not know is how they got that way or whether the apparent trend toward increasing acidity in certain lakes is a strong or a weak one.

Core samples of lake sediments, which reveal a lake's accumulated chemical history, show that some of these lakes have been acidic for hundreds to thousands of years, long before exposure to man-made emissions. And comparative studies of Adirondack lakes show that they can differ markedly in pH even when the acidity of their rainfall is the same. Such findings do not rule out a contribution from acid rain, but they do make it clear that acid rain cannot be the only factor contributing to lake acidity.

Overall, the lake watershed is a complex geologic-biologic-chemical laboratory that can both produce and consume acids. Bedrock, soil depth and composition, live vegetation, organic debris, and the habits of local wildlife all play roles in the fluctuating pH balance. These are some of the factors that make one lake better equipped than another to cope with man-made acidic input. In some cases, acid rain falling within the watershed will follow a terrestrial pathway through deep mineral soils, particularly soils rich in calcium, which can neutralize the moisture before it reaches the lake.

Forests also draw anxiety about acid rain effects, especially following recent reports of forest damage in Vermont and in Germany. The main fear is soil impact. Acid-induced mobilization of aluminum ions in forest soil has been linked with reported damage because it is known that such ions can be toxic to the root systems of certain trees. On the other hand, some scientists find drought, pathogens, or heavy metal deposition more likely to be the source of the problem. In no case has actual forest damage been proved to result from acid rain.

The effects of acid rain on crops, materials, and human health are also being explored, but the connections here are more tenuous and the concern less urgent. What remains the biggest worry about acid rain is ecosystem impact. And the important thing to remember here is the context, the theater of operations. The Earth itself and all its subsystems are in constant flux between acidifying and alkalinizing influences. The amount of man-made acidity that a particular site can tolerate without damage—the safe threshold—depends heavily on the dynamic balance of other factors that are already operating at that site.

Meanwhile, because the potential for ecosystem change in sensitive areas is recognized to exist, vigorous efforts are under way to improve control of the precursor emissions that lead to acidic deposition.

Control / mitigation options

Many options are now available or are being developed to control the emission of acid precursors from power plants to the atmosphere. No single choice is best for all situations. Plant design, fuel type, and location all help determine what is most appropriate. In addition, there are many nontechnologic considerations in what may appear to be a simple technologic choice because the billions of dollars at stake in such decisions can have profound impact on the economic health of various industries and regions of the country.

One approach, already used, is to retire older coal-burning power plants. Such units have been replaced by new coal-burning systems with far more efficient emissions controls or by hydro or nuclear units that burn no fossil fuels. A variation on this theme is the practice of environmental dispatch, which restricts the use of older coal-fired plants when the weather makes pollutant buildup and conversion likely.

Flue gas desulfurization systems, commonly known as scrubbers, are the most efficient means of removing sulfur from stack gases of coal-burning power plants. They are also the most expensive, particularly if the attempt is made to retrofit older plants. Other retrofit options that are already available and require less capital investment include switching from high-sulfur to low-sulfur coal and physically cleaning coal before it is burned. On the frontier of emissions control, injecting limestone into the furnace where coal burning occurs to capture most of the emissions by chemical reaction may be commercially feasible for some plants in a few years.

But the most fundamental advance will be to generate power from coal in ways that minimize or eliminate airborne emissions and the consequent need for controls. New power generation technologies now being developed, such as fluidized-bed combustion and gasification–combined cycles, promise to produce electricity from coal in a manner that is not only intrinsically cleaner but also intrinsically more efficient than conventional coal-burning power generation systems. Investing in these new technologies, in addition to work on advanced retrofit emissions control, is important for the future of coal combustion, allowing the nation to move forward to the next generation of coal plants rather than tying us to continued use of older, less-efficient units that have been modified for environmental compliance.

Supplementing control measures are mitigation measures aimed at helping to reverse whatever environmental changes might occur. For example, lake acidity can be neutralized by adding lime or limestone to the water. This measure may allow fish to repopulate and sportfishing to be restored. Because every lake is different, individual treatment programs must be developed that are responsive to the needs of each lake. But the costs are still quite low compared with retrofit emissions control costs.

What all mitigation measures have in common is that they focus directly on the problem, be it acid lakes or corroding monuments or contaminated drinking water, rather than on the emissions that so far we can only suspect or assume to be a source of that problem.

Reversibility, like the magnitude and rate of ecosystem change, is another critical issue in acid rain research. What we really must find out is whether measurable and irreversible change is occurring, say, every year. Such a situation would clearly justify greater urgency than one in which change is minimal, occurs on a timeframe of decades, and is reversible at any point.

Besides NAS, the Environmental Protection Agency, the Office of Science and Technology Policy, and the Government Accounting Office (GAO) have all addressed the acid rain problem during the past year and have all stressed the need for better information. What is being done to provide this information?

International research

The United States federal acid rain research budget will total about $27 million in 1984. Canada is spending over $10 million a year. The United Kingdom is spending about $1–$1.5 million annually, and Scandinavia has a similar budget, but the yearly expenditure is less than $5 million for all Europe. Most of the worldwide research effort on acidic deposition is concentrated in the western hemisphere, with the governments of the United States and Canada and the electric utilities, through EPRI, taking the lead.

EPRI's environmental work, the world's largest privately funded research program on acid rain, centers in the Environmental Assessment Department of the Energy Analysis and Environment Division, where studies are under way on both atmospheric processes and ecosystem change. In addition, a special Economic and Environmental Integration Group within the same division is looking at a number of areas where economics and the physical sciences intersect. And the Coal Combustion Systems Division is exploring a spectrum of possibilities for emissions control.

In the realm of atmospheric processes, a major research target is the elusive source-receptor relationship. The NAS panel has already credited EPRI's Sulfate Regional Experiment (SURE) with providing the best data now available on air quality in the northeastern United States, and upcoming efforts focus on narrowing down the uncertainties that remain. For example, a massive tracer experiment is being developed to complement ongoing chemical and physical studies. This experiment will track the emissions transported from midwestern power plants to their final destinations—whether in the Adirondacks, in New England, or closer to their source.

In probing ecological effects, EPRI and government research agendas are complementary. Federal studies are surveying the actual status of individual receptor systems, particularly those that are deemed most susceptible. EPRI is exploring the general processes by which ecosystem preservation, change, and restoration may operate. At what point, for example, can we expect lake acidity to begin affecting fish? And how long will a liming treatment be effective?

EPRI's funding to answer such questions has taken a recent jump. The 1983 budget was about $10 million, up from an average of about $3 million in the preceding five years. In 1984 that figure will rise to $13 million and again to about $15 million in 1985. For the period 1984–1988, in the Energy Analysis and Environment Division alone, a total of $75 million is slated for the study of the scientific phenomena associated with acidic deposition.

Five-Year Plan: A Proposal to Accelerate the Research Effort

Regardless of what a utility, an industry, or a public body does today in dealing directly with combustion emissions or acid deposition, answers will still be needed for important questions about what is called acid rain. Accordingly, EPRI last summer proposed a national research plan that could well answer three key questions in the next five years: What resources are at risk? Where will countermeasures provide the most protection? What control actions will be most cost-effective?

Estimated to cost $890 million, the accelerated effort would incorporate $170 million of R&D planned by EPRI between now and 1988 and $165 million estimated to be in federal government plans. Thus, a gap of $555 million would have to be funded from some combination of the private and public sectors.

About $110 million of proposed environmental assessment research focuses on ecological effects stemming from the acidification of lakes, rivers, and forests. The objective is to confirm or contradict the judgment that these resources are most at risk, either nationally or in narrowly defined areas.

Atmospheric processes that transport and transform acidic ions are the link between emissions and deposition. Learning where best to apply countermeasures means analyzing and mapping those processes—research that must be markedly expanded from $105 million to $255 million for the 1984–1988 period.

Technology development is the biggest increment of the proposed program, increasing from $145 million now planned by government and industry to a five-year total of $480 million. Included are funds to demonstrate several new and retrofittable control technologies at full scale on coal-fired power plants. Another $45 million is proposed to experiment with and demonstrate techniques for mitigating the effects of acidic deposition.

EPRI foresees high probability for success with nearly all these R&D program elements if they are adequately funded in the prescribed five-year period.

Ecological Effects Fisheries and forests are seen as most likely to suffer from changed acidity, but the mechanisms are not clearly known. The research need is $110 million ($25 million more than now planned).

☐ Validate lake acidification model for predictive use elsewhere

☐ Characterize lakes and vegetation in watersheds of sensitive regions and use the model to predict changes

☐ Measure relative contributions of sulfate and nitrate acidity to the spring runoff where this factor is prominent in aquatic chemistry

☐ Identify affected aquatic and forest species sensitive to acidified waters, the levels of acidity involved, and mechanisms of damage; also identify acid-resistant species

Atmospheric Processes The routes of pollutant transport and the mechanisms of chemical transformation must be explored. The research need is $255 million ($150 million more than now planned).

☐ Make wide use of chemical tracers to track the movement of air masses and the deposition of acids or precursors

☐ Continue the development of models to portray and quantify source-receptor relationships

☐ Augment deposition monitoring networks in eastern states to match the density of emission source distribution

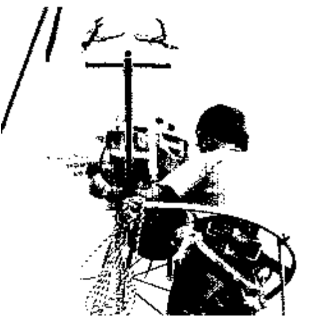
Cost-Effective Controls Utility emission reduction technologies, urban area strategies, and watershed chemical treatments have yet to be refined and tested. The research need is $525 million ($380 million more than now planned).

☐ Demonstrate limestone injection multistage burner (LIMB) technology, low-NO_x burners, scrubbers, dry sorbents for flue gas treatment, and fluidized-bed combustion in power plants

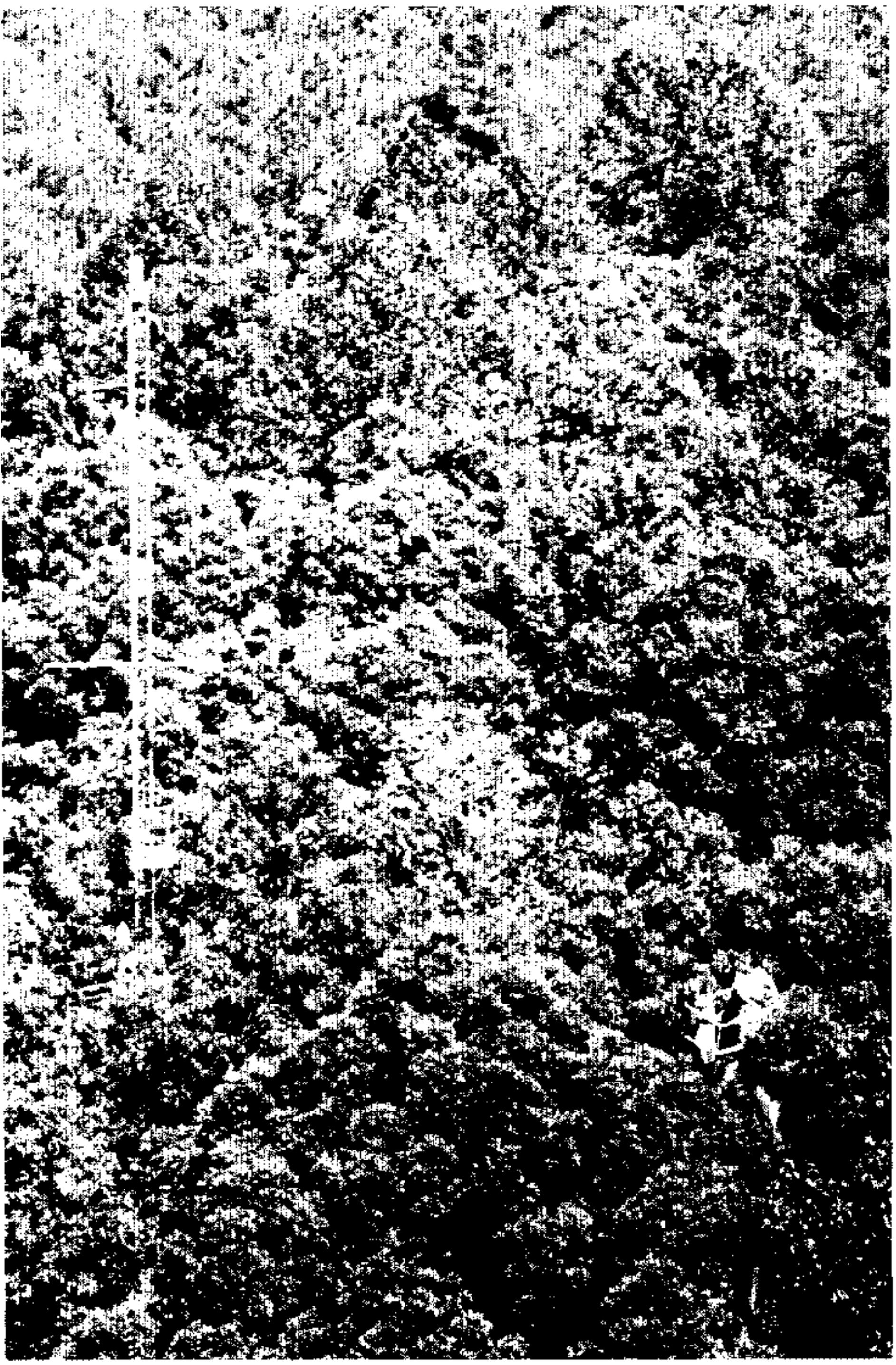
☐ Develop means for more-thorough physical cleaning of coal and recovery of the fine fraction

☐ Assess options for reduced industrial and automotive combustion emissions and reduced use of oil for space heating in the northeastern states

☐ Develop and demonstrate liming and other means for restoration and management of lakes and watersheds



Isolating and documenting the subtle links between airborne emissions, acidic deposition, and ecological effects requires careful and consistent gathering of data over many years, perhaps decades. Field researchers sample precipitation as it descends from the atmosphere through the forest canopy to the forest floor and into streams and lakes. Lake acidity is monitored, and fish and other aquatic life are gathered for laboratory testing.



The Coal Combustion Systems Division has another $100 million budgeted to study emissions control over the next five years. Much of it will apply to the acid rain problem. For example, how can we bring down the cost of scrubbers and lessen their adverse impact on power plant performance? Other research efforts continue to explore alternative retrofit options and to develop entirely new generating systems that can sidestep the need for postcombustion emissions control.

Weighing alternatives

We know far more about acid rain now than we did when it first surfaced as an environmental concern a decade ago, but much remains to be done. Most of our reliable data are too recent to show conclusive trends. So there are still large gaps in our understanding of the relationship between the three vital pieces in the scientific puzzle: emissions, deposition, and ecosystem effects.

The degree of uncertainty, and the timeframe for resolving it, differ at different points on the research continuum. Preliminary clues may emerge rapidly through laboratory experiments, but the researcher's and the society's need for answers about acid rain can do nothing to speed up long-term data collection in the field. Clouds will form, winds will blow, rain will fall, and the seasons will turn at their own pace. It will take another 5 years, 10 years, or even more of widespread field observations to establish conclusive trends in deposition patterns and environmental effects.

What can we do in the meantime? How can we forestall the possibility of environmental damage, assuming that 5 or 10 years could make a difference? Emissions control cost projections run very high, even for selective controls that target specific sources rather than try to blanket entire regions of the eastern United States. Because such huge sums are at stake and because the groups that must bear these costs may not be the same as the ones receiving the bene-

ADEPT: A Decision Analysis Framework for Policy Makers

Policy making related to acid rain is particularly difficult because of the scientific uncertainties and sharply differing value judgments involved. These factors make conventional cost-benefit modeling virtually impossible. As an alternative, EPRI has sponsored development of a model based on a fairly new technique called decision analysis, which can explicitly incorporate uncertainties and differing value judgments.

The result is a computer code called ADEPT (acid deposition decision tree). This model provides an analysis framework that can be used by policy makers to ask a variety of important "what if?" questions. At the same time, the model allows experts with widely differing opinions to see how important their disagreements are likely to be in influencing the final results.

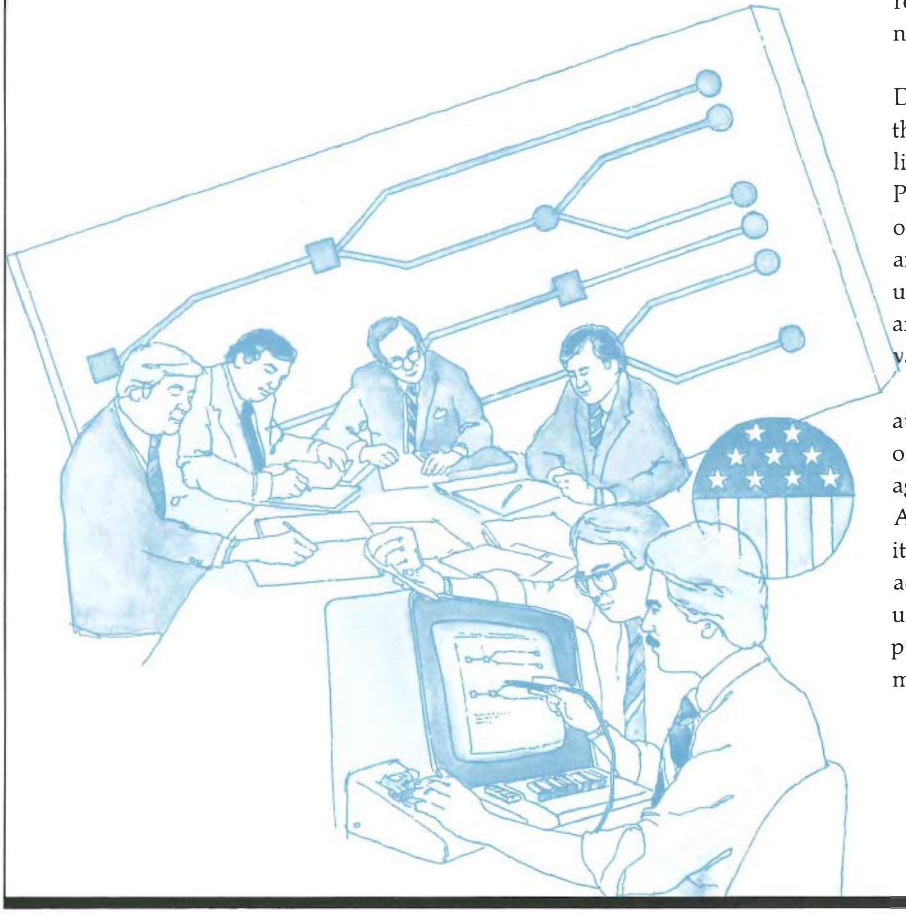
In decision analysis, alternative courses of action are laid out in a tree diagram with branch points representing either key decisions or critical uncertainties. Each path through the tree then represents a possible scenario. Probabilities are assigned to various outcomes at the points of uncertainty, and a monetary cost is given for each outcome. The model can then be used to calculate the expected costs and benefits resulting from each choice of a given decision.

For example, the Air Quality Task Force of the Minnesota-Wisconsin Power Suppliers Group used the model to examine the potential costs and benefits to Minnesota of a regional control program covering the 31 states of the acid rain mitigation study (ARMS) region and eastern Canada. The analysis showed that the added benefits from stricter control in Minnesota would be very small compared with the increase in control cost.

In addition to providing a way of calculating expected costs associated with alternative scenarios, the ADEPT model shows how sensitive various results are to changes in particular assumptions and what the value of new information is likely to be. Specifically, the model can be used to calculate the likely costs and benefits of waiting for more research and to estimate the relative value of various research alternatives.

The ADEPT model, developed by Decision Focus, Inc., is available through EPRI's TEAM–UP computer library, as well as through the Electric Power Software Center. The purpose of the EPRI project was to provide an analytic framework that could be used by utilities, regulatory bodies, and other interested parties to evaluate various acid deposition scenarios.

The model is already being applied at state and federal levels in the study of acid deposition. Several federal agencies are currently testing the ADEPT computer code and plan to use it to evaluate policy alternatives. In addition to the Minnesota application, utilities in several states are making preliminary studies based on the model. □



fits, apparently simple control decisions are not simple at all.

Given a choice of control strategies to meet tighter standards, many utilities might switch to cleaner, low-sulfur coal rather than install expensive scrubbers. Such a course would moderate the rate increases that are likely to hit midwestern utility customers no matter what form of emissions control is chosen, since all of them are costly. But this switch would mean other shifts as well. Coal-switching would move jobs from the Midwest and the East, center of the high-sulfur coal industry, to Wyoming and other western states.

This is just one example of the chain of consequences that could follow from an apparently straightforward decision. The other options for emissions control are similarly complicated when we look at the interests of all the groups and regions that may be involved. Retrofitting scrubbers, for instance, would allow the continued use of high-sulfur coal and minimize geographic shifts in coal production and jobs, but the total bill to be somehow divided—probably among groups within the northeastern quadrant—would be higher by billions of dollars per year.

The policy-oriented GAO federal report sums up the situation this way: The choice among alternative courses of action, it says, "involves an allocation of the burden of risk, among industry, consumer, labor, environmental, and other interests, and the different regions of North America. It is, therefore, more than a scientific and economic decision; it involves political judgments on how our society's resources—and burdens—should be spread among these constituencies."

To break down such complex decisions into more-manageable segments, some policymakers are turning to a method known as decision analysis. The ADEPT (acid deposition decision tree model) method developed for EPRI is one example of the decision analysis approach. It can help separate scientific issues from political issues where such a separation is necessary to clarify the nature of the problem.

EPRI's charter is to provide scientific information. Scientific information alone cannot determine policy decisions. But it is essential input to well-informed decision making and it is essential in evaluating those policies that the body politic creates. ■

Further reading

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Inventory of Acid Deposition: Research Projects Funded by the Private Sector. Final report for RP1910-3, prepared by General Research Corp., February 1983. EPRI EA-2889.

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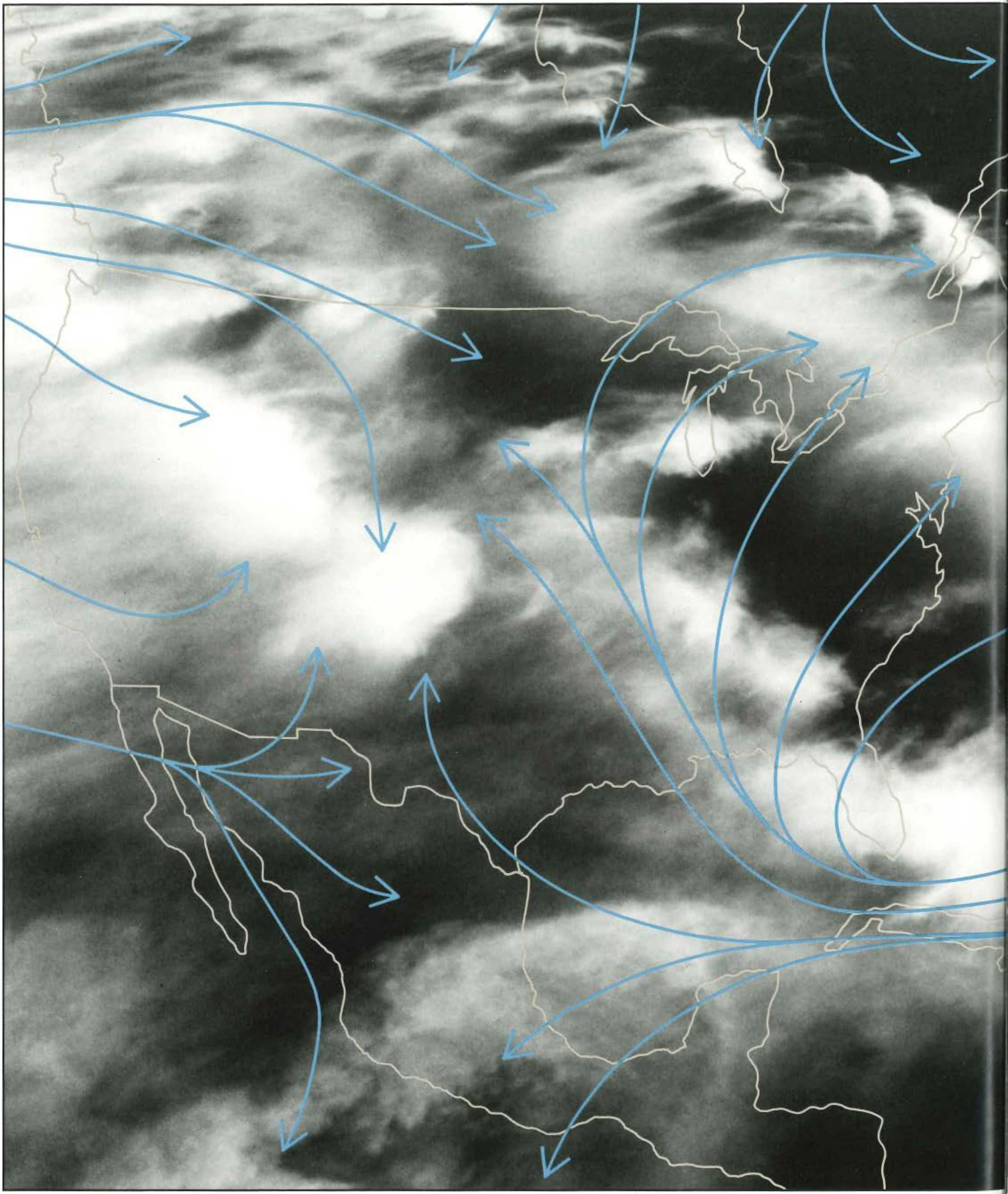
This article was written by Mary Wayne, science writer. Technical background information was provided by Ralph Perhac and René Malès, Energy Analysis and Environment Division; Kurt Yeager, Coal Combustion Systems Division.



Acid Rain: Sources and Transport

TRACING THE PATHWAYS OF ATMOSPHERIC CONVERSION

Weather, the largest, most-complex interactive system on Earth, decides where acidic deposition will finally be a problem. New tracer experiments should speed understanding of how atmospheric processes affect emissions transport and chemical conversion.

Characterizing the phenomenon of acidic deposition by the popular statement "What goes up must come down," although valid in a broad sense, is not very useful if one wants to know *how, where,* and *in what form* what goes up comes down. The sources of fossil fuel emissions, their chemical transformation in the environment, their routes of transport, and their return to Earth's surface involve the totality of physical and chemical processes that occur in the atmosphere, as well as many that occur on the ground.

The atmospheric processes involved in acidic deposition are complex and defy simple characterization. But tracking the evolution of the chemical pollutants provides a quick overview of the transformation cycle. Oxides of sulfur (SO_2) and of nitrogen (NO_x) are among the principal chemical products of fossil fuel combustion. Over half of the emissions of these gases fall to Earth relatively near their source without changing form. With the aid of sunlight and chemical oxidants also present in the atmosphere, some of the remaining sulfur and nitrogen is transformed into new compounds—sulfates (SO_4) and nitrates (NO_3). These new substances, together with the oxide forms, can be chemical precursors of the acid compounds H_2SO_4 and HNO_3 formed in the atmosphere. These acids are the ones of final concern in the acid rain question.

A key uncertainty in acidic deposition is whether the relationship between SO_2 and NO_x and the acidity of wet or dry deposition—the source-to-receptor relationship—is linear. That is, if society reduces the level of its pollutant emissions, can it expect an improvement of similar degree in the deposition of acidic materials and in the resultant environmental effects?

The best that science can tell us at this point is maybe, maybe not. We know that the governing equations describing atmospheric processes are not linear. But can linear equations approximate some of these processes well enough to be used in making rational decisions on how to control acidic deposition? On this, the scientific jury is still out.

Based on 17 years' observations at one site in eastern North America, the National Academy of Sciences could conclude only that the source-receptor relationship is not strongly nonlinear. Before science can venture a more confident guess, it must have a much better understanding of the many physical, chemical, and biogeochemical variables involved overhead and in the ground.

A major element of EPRI's research related to acidic deposition spans the gamut from emissions through atmospheric transport and chemical transformation to deposition and terrestrial transport. Objectives include the identification and measurement of key pollutant emissions; a quantitative understanding of the transformation; better techniques for measuring the quality of air and precipitation; and methods for predicting the behavior and fate of pollutants. More than 30 individual research projects completed, under way, or planned address these objectives.

Emissions

The first step in shedding light on the relationship between pollutant emissions and their fate is to learn how much of each of the important chemicals is emitted and from where. But there are few inventories of either recent or long-term emissions that are detailed or accurate enough to be considered of much use in continental-scale atmospheric research. That is, in part, because of the scope and precision of emissions monitoring required and the inherent uncertainties in estimating area emissions on the basis of a few point measurements.

According to the National Academy of Sciences' 1983 report on acidic deposition, the most reliable data on key pollutant emissions affecting rural areas comes from EPRI's Sulfate Regional Experiment (SURE) conducted in 1977 and 1978. SURE covered the 31 eastern states of the United States and parts of southeastern Canada. Extensive checks and supplemental field monitoring have narrowed the uncertainty in measurement to 10–15% of the observed or estimated value.

EPRI's SURE inventory provides the daily rates and seasonal totals of all SO_2 and NO_x emissions, as well as particulates and hydrocarbon species. SURE also logged emissions of a key acid-precursor chemical, the anion sulfate, which, to a lesser degree, is produced by fossil fuel combustion.

Despite the limitations of existing emissions inventories, some conclusions regarding man-made pollutant emissions, based in large part on SURE data, can be made.

The available long-term emissions data indicate that from 1965 to 1978, sulfur emissions in the United States, except in the Southeast, declined an average of 8%; the reductions in key specific regions have been more pronounced: 20% for SO_2 in the Northeast and 40% in the Midwest. In the Southeast, however, SO_2 emissions have increased about 20%. Whatever ecological effects of precipitation acidity are now observed must be viewed within the context that overall sulfur emissions have unquestionably declined in rate in recent years.

Based on annual averages from the SURE inventory, sulfur emissions from all sources in the study area total 85,000 t/d. Total nitrogen emissions average 32,000 t/d. And 52,000 t/d of various chemically reactive hydrocarbons are released to the atmosphere.

In general, industrial sources, including utilities, account for most of the SO_2 and particulates and about half of the NO_x. The utility contribution to total sulfur emissions in the eastern United States varies from about 55% in the winter to about 65% in the summer. Utilities and highway vehicles contribute most of the NO_x, and industrial and transportation sources contribute most of the hydrocarbons.

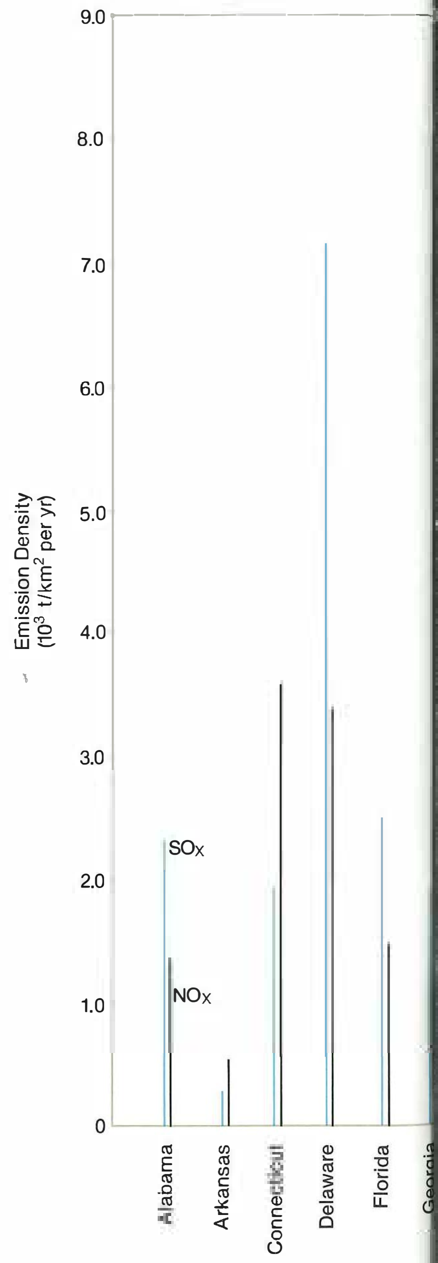
Sulfur and nitrogen are also present in the atmosphere from natural sources, such as decaying organic matter. These sources were formerly believed to play a significant role in acidic deposition. But an EPRI-sponsored assessment of biogenic sulfur emissions in the SURE region indicates an estimated total of about 150 t/d, which might approach 1–2.5% of the man-made sulfur contribution.

Much, however, remains to be learned about North American pollutant emissions. The distribution of emissions over time and area must be known with greater accuracy in order to improve the performance of models, or numerical constructs, with which the source-receptor relationships are studied.

To overcome some of the limitations in existing emissions inventories, EPRI is sponsoring an inventory of 1982 emissions, which is expected to be available at the end of 1984. The project will locate major point sources exactly; minor point sources will be grouped in an 80-km^2 (31-mi^2) grid map. The inventory data will be produced in a format that will accommodate updates; more extensive checks on the accuracy of the data will be made.

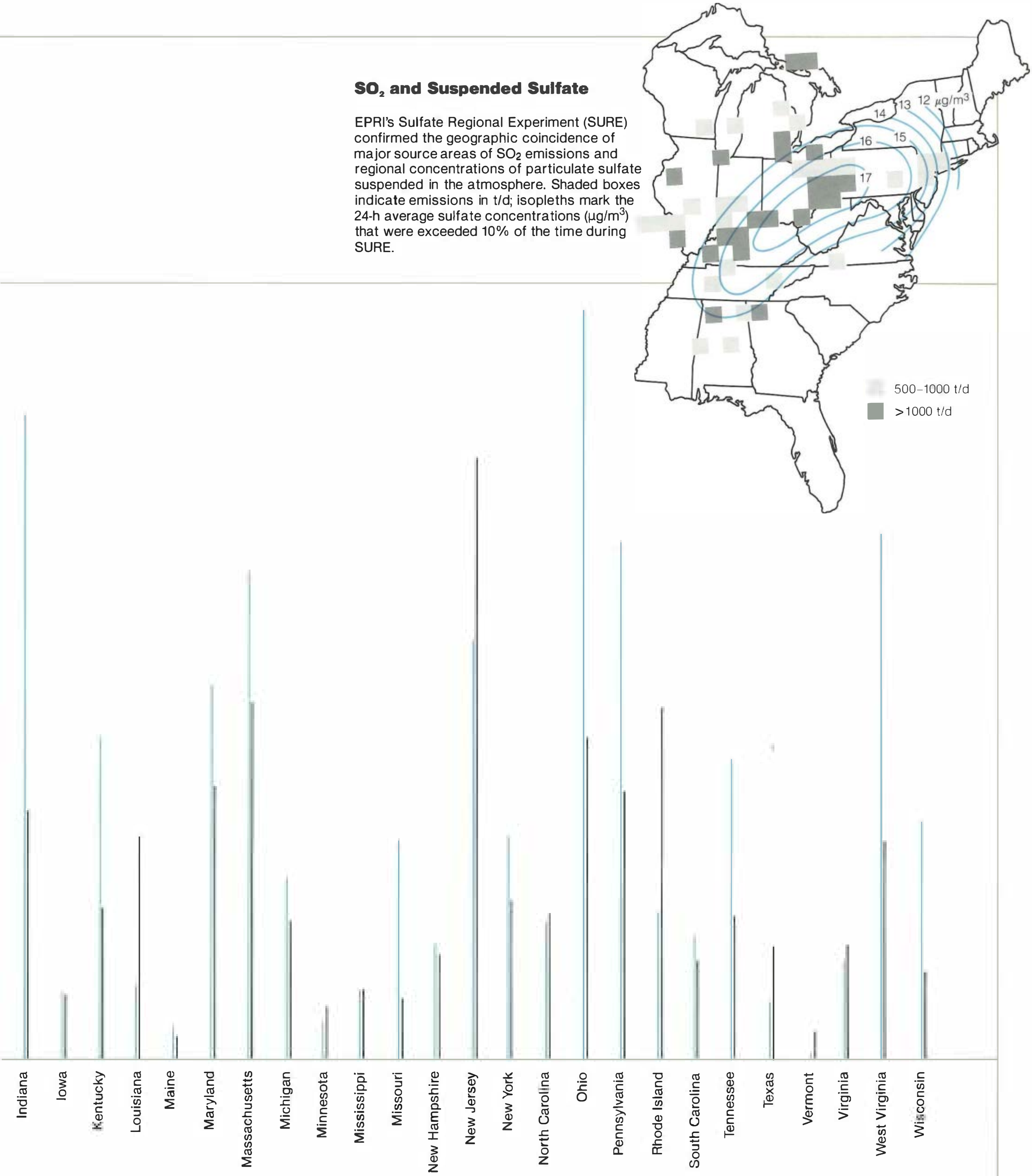
Emission Densities

Because states vary widely in size, emission densities (expressed in tons emitted per km^2 per year) are more useful to researchers than estimates of total emissions for each state. Represented here are the densities of estimated 1980 emissions of all sulfur and nitrogen oxides from all sources in 32 eastern states. Source: Adapted from EPA, 1983.



SO₂ and Suspended Sulfate

EPRI's Sulfate Regional Experiment (SURE) confirmed the geographic coincidence of major source areas of SO_2 emissions and regional concentrations of particulate sulfate suspended in the atmosphere. Shaded boxes indicate emissions in t/d; isopleths mark the 24-h average sulfate concentrations (µg/m^3) that were exceeded 10% of the time during SURE.



Atmospheric transport

More than half of the SO_2 emitted from fossil fuel combustion returns to Earth as either dry gas or particles before it can be chemically transformed. Typically, this occurs within 200–300 km (130–190 mi) of a source. Winds carry the remaining SO_2, along with sulfates and nitrates, over longer distances, sometimes as far as 1000 km (620 mi).

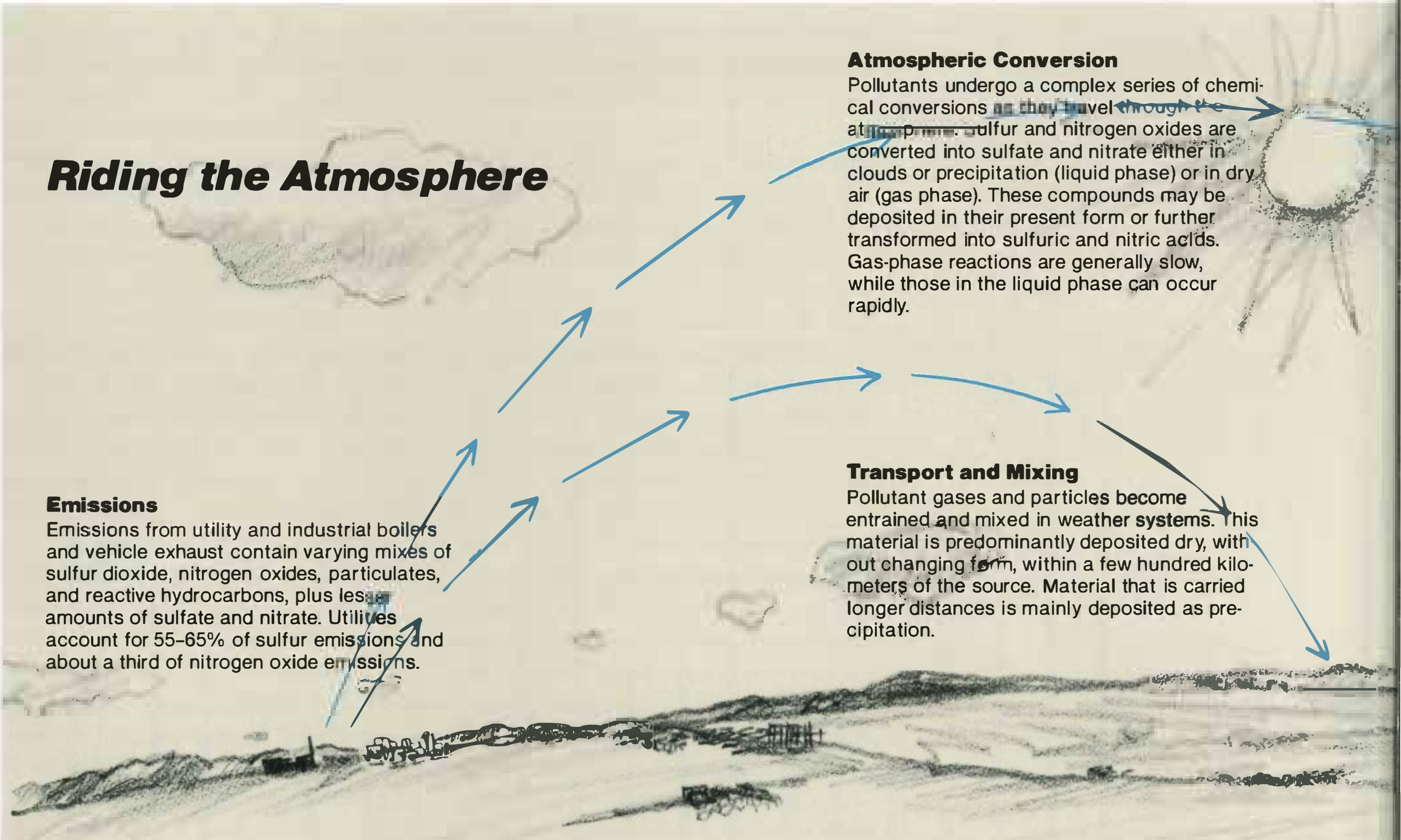
As is the case with all stages in the continuum from emissions to biologic effects, the boundaries used to distinguish one category from another are often more conceptual than real. A case in point is the role of a source parameter—for example, stack height—in the succeeding arena of activity and research interest: the transport of pollutants in the atmosphere.

In the 1960s and early 1970s, many industrial and commercial emission sources, including fossil-fuel-fired power plants, replaced short (typically 60 m, or about 200 ft) stacks with taller ones (averaging 200 m, or 650 ft) as a way to reduce ground level pollutant concentrations in the surrounding areas. This solution to limitations on local concentrations was eminently successful, but it also set the stage for occasional longer-range transport.

Local meteorology and terrain around a source exert such a dominating influence on stack emissions from any height, however, that it is difficult to pinpoint the effect of stack height on pollutant transport against the background of weather and other local features, such as hills and valleys. Measurements of plume rise made during EPRI's plume model validation studies are adding to a detailed understanding of the role of effective stack height, a key feature in plume mixing and transport.

Transport processes represent the greatest realm of uncertainty in acidic deposition because they include the largest, most complex interactive system on Earth—regional weather. Weather drives the two processes that are most important in determining whether pollutant

Riding the Atmosphere



Atmospheric Conversion
Pollutants undergo a complex series of chemical conversions as they travel through the atmosphere. Sulfur and nitrogen oxides are converted into sulfate and nitrate either in clouds or precipitation (liquid phase) or in dry air (gas phase). These compounds may be deposited in their present form or further transformed into sulfuric and nitric acids. Gas-phase reactions are generally slow, while those in the liquid phase can occur rapidly.

Transport and Mixing
Pollutant gases and particles become entrained and mixed in weather systems. This material is predominantly deposited dry, without changing form, within a few hundred kilometers of the source. Material that is carried longer distances is mainly deposited as precipitation.

Emissions
Emissions from utility and industrial boilers and vehicle exhaust contain varying mixes of sulfur dioxide, nitrogen oxides, particulates, and reactive hydrocarbons, plus lesser amounts of sulfate and nitrate. Utilities account for 55–65% of sulfur emissions and about a third of nitrogen oxide emissions.

The link between sources of pollutant emissions and the fate of acidic compounds produced in the atmosphere involves many stages. Much of the atmospheric research in acidic deposition focuses on the mechanisms of long-range transport and the pathways of chemical conversion.

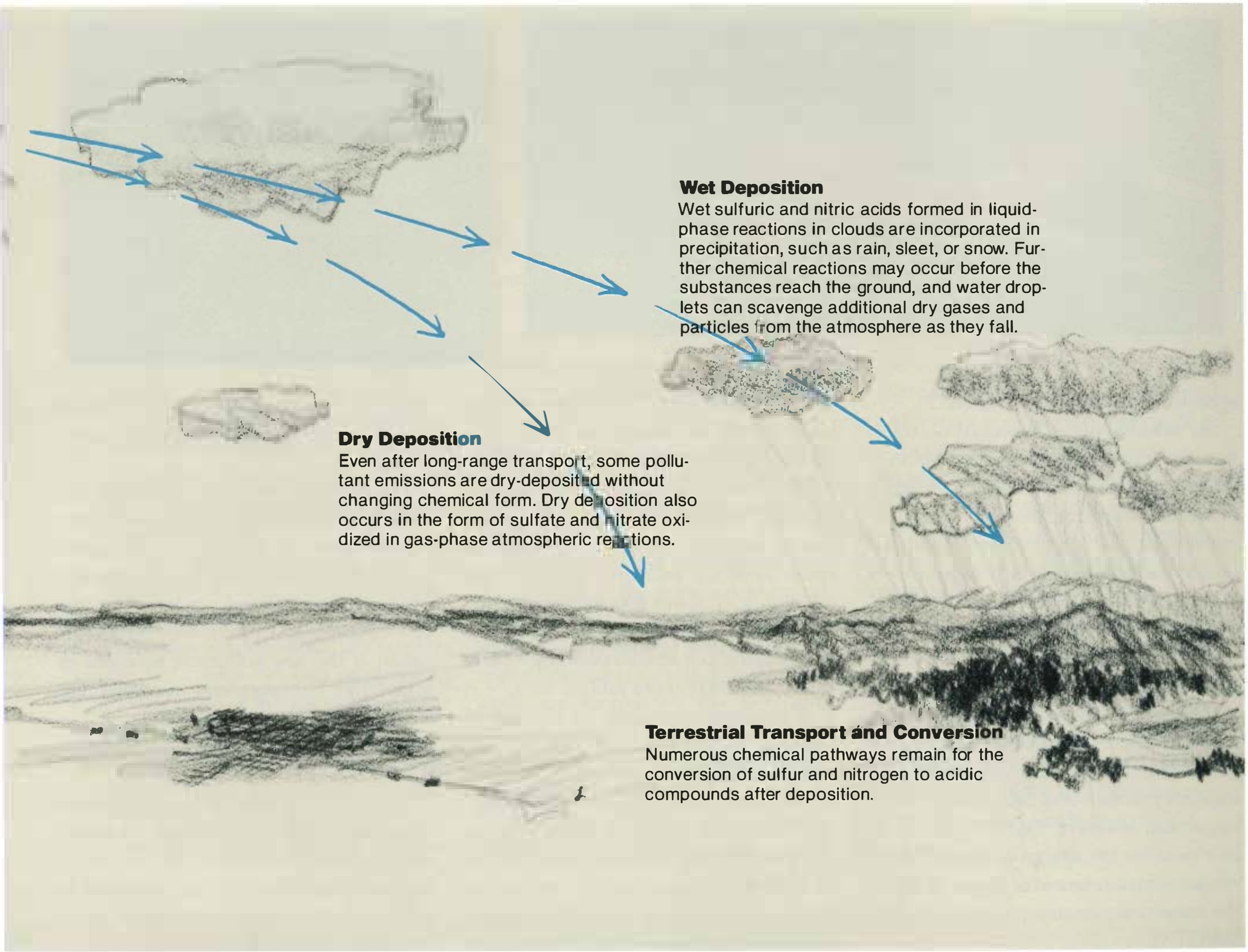
emissions are deposited as dry particles and gas near a source or are carried into the lower atmosphere to form acidic compounds. These are advection, the movement of a volume of air and pollutants with the wind, and diffusion, the intermixing of this volume with surrounding air and other reactive pollutants.

The extent to which advection, diffusion, and chemical transformation occur is a function of the pollution's atmospheric residence time, or the time between emission and deposition. Residence time is, in turn, governed by meteorology, terrain, and transport processes. Even though there is no debate that long-range transport of some pollutants occurs, a meaningful assessment of the relative scales of transport—from local to regional to continental to global—cannot yet be made.

Models of wind trajectories, pollutant residence times, and large-scale meteorologic processes would be greatly improved if better methods were available for measuring long-range transport. Chemical tracers hold great promise of filling in significant portions of the transport puzzle.

Chemically unique or radioactive tracer materials can be detected and measured in very dilute concentrations long distances from their point of release upwind. With enough tracer releases and subsequent measurement, a detailed pattern of air flow begins to emerge. Perfluorocarbon compounds are considered ideal for this purpose because of their nonreactive nature and their detectability in concentrations as low as one part per quadrillion (10^{15}), making it possible to track pollutant transport over distances exceeding 1000 km (620 mi).

EPRI is currently working in this pioneering area of atmospheric research through its participation in the cross-Appalachian tracer experiment (CAPTEX), cosponsored with the National Oceanographic and Atmospheric Administration (NOAA), the Department of Energy (DOE), the Environmental Protection Agency (EPA), and the Canadian Atmo-

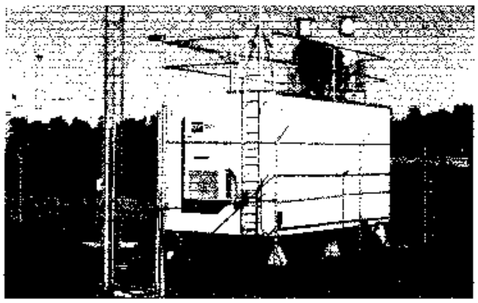


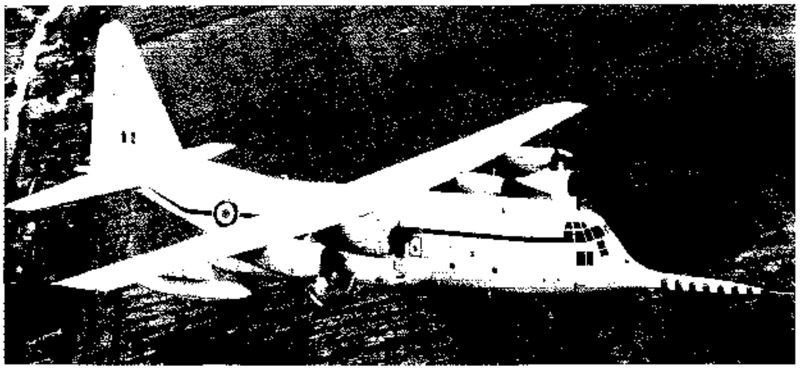
Wet Deposition
Wet sulfuric and nitric acids formed in liquid-phase reactions in clouds are incorporated in precipitation, such as rain, sleet, or snow. Further chemical reactions may occur before the substances reach the ground, and water droplets can scavenge additional dry gases and particles from the atmosphere as they fall.

Dry Deposition
Even after long-range transport, some pollutant emissions are dry-deposited without changing chemical form. Dry deposition also occurs in the form of sulfate and nitrate oxidized in gas-phase atmospheric reactions.

Terrestrial Transport and Conversion
Numerous chemical pathways remain for the conversion of sulfur and nitrogen to acidic compounds after deposition.

Chemical tracers that can be tracked long distances and detected in dilute concentrations provide a way of studying the trajectories of pollutants in long-range transport. Specially equipped aircraft and ground monitoring stations are used in tandem to collect data downwind of the tracer release points. When analyzed, air samples gathered in both types of data collection can yield clues about the mechanisms of pollutant transport, as well as the chemical reactions that take place.





spheric Environment Service (AES).

Six releases of perfluorocarbon tracer were made this fall in Ohio and Ontario. A wide arc of measurement sites—including 80 surface samplers, 20 upper air sounding stations, and 4 aircraft—recorded data on the tracer material as it moved from the sources to the mid-Atlantic, New England, and southeastern Canada.

CAPTEX is a major step toward a better understanding of pollutant transport in the lower atmosphere. The observation data will help define the number of upper air measurements necessary to improve trajectory models and calculations. More important, however, CAPTEX will serve as a pilot for the design of a much more extensive measurement of upper air flow—the massive aerometric tracer experiment (MATEX).

A coauthor with EPA of the preliminary conceptual design of MATEX is Glenn Hilst, manager of EPRI's Environmental Physics and Chemistry Program. MATEX, proposed to begin after 1984, would involve numerous releases of tracer material, according to Hilst, and a network of about 600 monitoring stations, 100 aerometric sampling stations, and as many as 8 aircraft covering an area of 160 million km^2 (62 million mi^2).

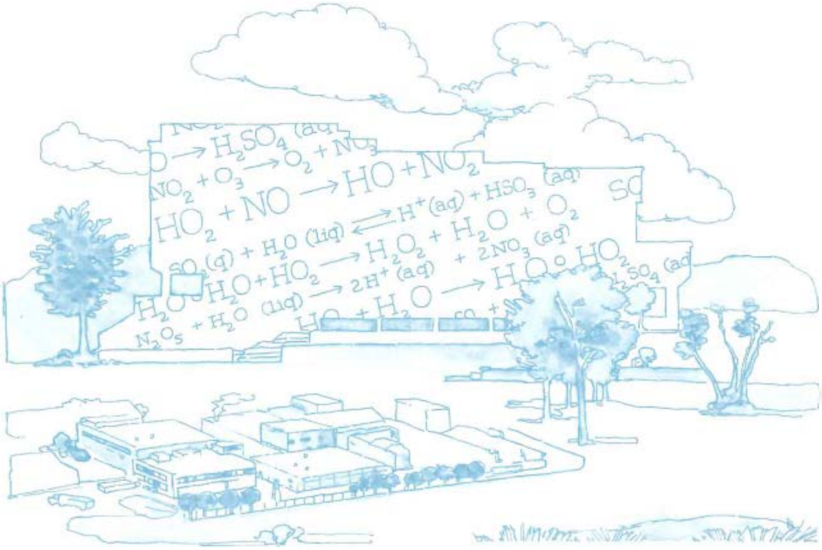
A preliminary estimate of the cost of MATEX, including a full year of field work, is about $110 million. "The price tag for MATEX may appear to be steep," says Hilst, "but viewed in terms of emission control costs on the order of billions of dollars per year that are envisioned for electric utility power plants alone, even a modest fine-tuning of control strategies on the basis of MATEX results would make the project highly cost-effective."

MATEX will be designed so that the data from the measurements will have several uses: in evaluation of present methods for estimating source-receptor relationships, in development of an improved empirical relationship, in identification of the key pollutants involved in long-range transport, and in assessment of alternative control strategies.

Atmospheric conversion

When pollutants encounter precipitation in clouds as they move through the atmosphere, typically within 3–5 days in eastern North America, chemical oxidation is enhanced and sulfuric and nitric acids can be formed. But the chemical reactions

Linearity: A Closer Look at the Source-Receptor Relationship



The relationship between emissions of acid-producing pollutants and acidic deposition has been the subject of recent study and debate. This is the so-called source-receptor relationship, a term that is often confusingly applied to large geographic areas as well as to specific source-receptor pairs.

The crux of uncertainty and disagreement is the extent to which this source-receptor relationship is linear, or proportional. If it is approximately linear, a given percent of change in the level of emissions will produce a similar percent of change in the acidity of wet and dry deposition. If instead the relationship is nonlinear, a change in emission levels will not yield a proportional response in deposition acidity.

Based on limited empirical data as well as on theoretical considerations, the National Academy of Sciences has concluded that "there is no evidence for a strong nonlinearity in the relationships between long-term average emissions and deposition." The double negative suggests that linearity was concluded, but an accurate interpretation of this statement requires a closer look at the bases on which it was made, as well as its implications for acid rain control strategies.

Some important caveats were attached to the academy's conclusion. It applies only to long-term average emissions and deposition in all eastern North America—an area representing 31 states east of the Mississippi River, as well as the eastern provinces of Canada. And in postulating a proportional reduction in precipitation sulfate levels from SO_2 emissions reductions, it assumes that all other factors—including meteorology, the geographic distribution of SO_2 emissions, as well as emissions of NO_x and key oxidants—remain unchanged.

It is important to note that the academy's conclusion addressed the source-receptor relationship over eastern North America, not the relationship between specific sources, or areas, and specific receptors. Because of the limitations of existing models of atmospheric transport, the academy concluded that the consequences of changing the geographic distribution of emissions, such as reducing emissions in one area more than in other areas, cannot be predicted.

A key uncertainty regarding linearity is whether the principal chemical transformations that occur in the chain from SO_x and NO_x to sulfates and nitrates and thence to sulfuric and nitric acids are limited by the SO_2 and NO_x available in the atmosphere for oxidation or by the oxidants themselves. If the processes are oxidant-limited, then control strategies aimed only at reducing sulfur emissions may prove ineffective, for as long as there are insufficient oxidants, formation of sulfates and their acidic compounds would remain the same until SO_2 concentrations are reduced below some critical value.

The academy concluded, based on analysis of the molar ratios of sulfate to nitrate in precipitation and SO_2 to NO_x in emissions, that these ratios for emitted and deposited material are similar in eastern North America. This is a necessary but not sufficient condition for linearity in acid formation.

Because the conversion of NO_2 to HNO_3 and its incorporation into cloud water are believed to be fairly efficient and rapid processes, the academy interpreted the available evidence as suggesting a similarly efficient oxidation of SO_2. "It is therefore improbable," the panel concluded, "that the oxidation of SO_2 is sufficiently hindered by a lack of oxidant to cause a disproportionately small reduction in sulfate concentrations in precipitation as a result of a given reduction in SO_2 emissions." □

depend on a host of meteorologic variables, including the intensity of solar radiation, the number and type of clouds, relative humidity, and the presence of other pollutants in the air.

The last chemical link in the transformation of SO_x and NO_x to acids—hydrogen—is available in the atmosphere from hydrocarbons, a pollutant form that results mainly from automobile exhaust. Add sunlight and water and the ingredients for forming acidic compounds are all present. Depending on the concentration of hydrogen ions, the basis for calculations of pH value, the subsequent precipitation—rain, snow, or fog—is more or less acidic.

The basic chemical mechanisms by which SO_x and NO_x react with oxidants to form acids and acid-producing compounds are fairly well known. A precise characterization of the reactions and associated cloud processes, however, has only recently begun to evolve.

The two main pathways of chemical conversion of SO_2 and NO_x to sulfates and nitrates and to sulfuric and nitric acid correspond to the two principal states of matter in the atmosphere—gas and liquid. These involve reactions in dry air (gas phase) and in liquid water drops, such as found in clouds and fogs, suspended in the air (liquid phase).

In the gas phase, pollutants are oxidized to acids, which are scavenged by cloud water and precipitated as rain or snow. According to Peter Mueller, who manages many of EPRI's atmospheric chemistry projects, the basic chemistry of this path is well understood. The reaction mechanisms and oxidation rates of SO_2 and NO_x are known. The major oxidants are the hydroxyl radicals (OH), hydroperoxyl radicals (OH_2), and ozone (O_3).

On the basis of cloud chemistry measurements, EPRI-sponsored researchers have concluded that most of the nitrate in precipitation gets there by the gas-phase path; but only about 20–25% of SO_2 emissions appearing as sulfate in precipitation are attributable to gas-phase oxidation in clouds, fogs, rain, and snow.

Because SO_2 and NO_x concentrations are highest near major emission sources, the gas-phase chemical reaction path is considered the more important conversion route in the vicinity (10–200 km or 6–130 mi) of sources.

In the liquid phase, SO_x and NO_x are incorporated in atmospheric water droplets that may also contain hydrogen peroxide (H_2O_2), ozone, oxygen, and particles. Reaction rates, at least of SO_2 with hydrogen peroxide and ozone, are well known. Carbon, iron oxide, and manganese oxide particles can accelerate the oxidation of SO_2 to sulfate.

The amount of sulfate formed in the liquid phase is dependent on atmospheric levels of SO_2 and hydrogen peroxide. In some areas, on some occasions the amount of hydrogen peroxide available to oxidize the SO_2 is very small, while at other times more than enough H_2O_2 is present to oxidize all the SO_2.

Based on current knowledge, according to Mueller, the liquid-phase reaction with hydrogen peroxide is believed to be the most important route in eastern North America for the conversion of SO_2 emissions to sulfate in precipitation. But partly because of few measurements of SO_2 and hydrogen peroxide in the gas and liquid phases, a definitive assessment of how sulfate found in precipitation at specific sites is related to SO_2 emissions from known locations cannot be made. This must await considerably improved understanding of atmospheric chemistry.

A major factor in atmospheric chemistry that should not be discounted is the extent to which acids formed in the atmosphere are neutralized by naturally occurring base (alkaline) materials, including gaseous ammonia and aerosol particles containing metal oxides or carbonates. The principal products are ammonium sulfates and nitrates and metal sulfates and nitrates containing calcium, magnesium, iron, and other materials.

This continuous neutralization process is influenced by geography and variations in the concentrations of other copollutants, however. More alkaline substances are present in the atmosphere of the Midwest than in the rural Northeast. So, given equal sulfate concentrations, precipitation would be less acidic in the Midwest than in the Northeast.

Deposition

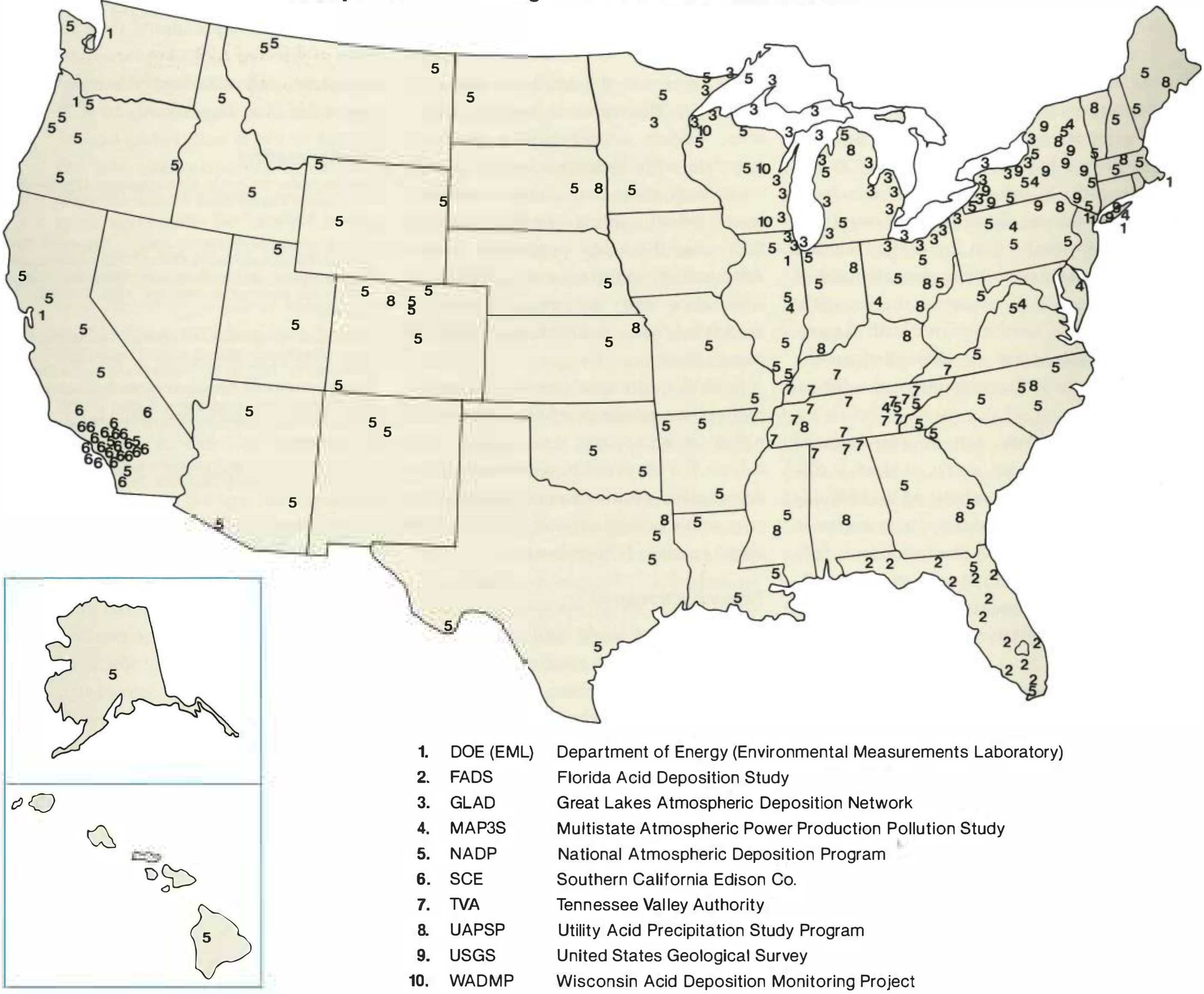
Pollutant deposition, whether near the source or far away, is controlled by a number of mechanisms but can be discussed in terms of the two main pathways, dry and wet. Compared with many of the other atmospheric variables, processes, and uncertainties, deposition may appear to be straightforward, but it is, in fact, marked by much uncertainty as well. The unknowns, especially with respect to dry deposition, relate to difficulties in obtaining accurate measurements of deposition rates.

Only a few sites in eastern North America have monitored and collected weekly precipitation chemistry data over more than four or five years and with consistent sampling methods. One such site is the Hubbard Brook Experimental Forest in New Hampshire. The 17-year deposition record from Hubbard Brook reportedly indicates that the molar ratios of sulfates to nitrates in precipitation are similar to the ratios of SO_x to NO_x that can be seen in eastern U.S. emissions.

For dry deposition, several factors illustrate the current uncertainties, the most important of which is that measurements of dry deposition have tended to be under experimental conditions that were not realistic. Adding to the uncertainty is the fact that several complex mechanisms convey dry particles or gas to the ground, and it is difficult to determine which of these dominate under different conditions. Near-surface mechanisms for particle deposition include gravitational settling, thermodynamic propagation by warmer air molecules, and molecular-level electro- and thermophoretic effects.

In addition, considerable uncertainty marks the role of different surfaces as dry deposition receptors. For example, cell-size openings (stomata) on leaf surfaces are known to influence gaseous deposi-

Precipitation Monitoring Networks in the United States



1.	DOE (EML)	Department of Energy (Environmental Measurements Laboratory)
2.	FADS	Florida Acid Deposition Study
3.	GLAD	Great Lakes Atmospheric Deposition Network
4.	MAP3S	Multistate Atmospheric Power Production Pollution Study
5.	NADP	National Atmospheric Deposition Program
6.	SCE	Southern California Edison Co.
7.	TVA	Tennessee Valley Authority
8.	UAPSP	Utility Acid Precipitation Study Program
9.	USGS	United States Geological Survey
10.	WADMP	Wisconsin Acid Deposition Monitoring Project

Most of the major precipitation monitoring networks that have operated in the United States in the last 15 years are still in use, although the location and number of sites in some networks have varied over time. Because the monitoring networks have employed different sampling techniques, sampling frequencies, and analytic methods, the data sets are not necessarily comparable. The inset photograph shows a typical field laboratory for analyzing precipitation samples gathered in the EPRI-managed utility acid precipitation study program.

tion rates, and reemission of sulfur compounds from plant surfaces has been detected.

Given these uncertainties, estimates of the time and area distributions of dry deposition are subject to wide variations. In general, the process of dry deposition is believed to be about as effective as wet deposition in removing pollutants from the atmosphere. Because about one-third of all SO_2 emitted in the eastern United States is known to be transported out of the region, it is assumed that roughly one-third of northeastern North American emissions are dry-deposited on the continent and the remainder are deposited wet.

Wet deposition can be any form of precipitation—rain, snow, or sleet. It differs from the dry variety in that liquid-phase chemical reactions occur in clouds and below clouds as precipitation is falling. Wet deposition may be more important than dry processes in areas of high average precipitation far from emission sources.

The processes by which precipitation elements are formed are well understood. The most important of these is nucleation, the kinetic process by which water molecules condense on the surface of aerosol particles. Others include diffusional attachment (in which pollutant molecules or particles diffuse through the air to the surface of water molecules) and scavenging (in which falling water droplets or ice crystals collide with aerosols).

Several major deposition chemistry programs are under way in the United States to obtain more detailed and accurate measurements of these and other factors. One of the most detailed daily monitoring networks is being managed by EPRI for a group of 35 electric utility organizations in the eastern United States. The Utility Acid Precipitation Study Program (UAPSP), established in 1981 and now totaling 20 monitoring stations, incorporated five stations set up initially for EPRI's SURE project.

Preliminary analyses of data from the monitoring stations, some of which have been operating since late 1978, tend to confirm observations made in other networks, including SURE. Hydrogen, sulfate, and nitrate ion concentrations tend to be highest in the Midwest and occasionally in Pennsylvania and Massachusetts. Sulfate concentrations generally correlate with hydrogen ion concentrations, indicating that sulfate and, to a lesser extent, nitrate are the materials that cause the acidic properties of rain. Ammonium, nitrate, and calcium are sometimes—but not as consistently—associated with reduced hydrogen ion concentrations.

Sulfate concentrations are generally higher than nitrate except in snow, where nitrate is up to four times higher than sulfate. For as yet unknown reasons, snow accumulates nitrates more efficiently than rain, while accumulations of sulfates are about equal in rain and snow.

Terrestrial transport

Deposition of acids and acid-forming substances marks the end of their journey through the atmosphere, but it does not mean the end of chemical transformations. Biogeochemical processes take over where atmospheric processes leave off to produce or consume acids and other chemicals that shift the pH equilibrium in soil or water. Sulfates and nitrates that have not been transformed into acids in the atmosphere may still undergo chemical reactions back on Earth.

EPRI-sponsored research has begun to clarify many of the variables that influence terrestrial transport and transformation. These include bedrock geology, deep soil layer mineralogy, and precipitation flow paths.

The relevance of understanding atmospheric chemical processes, as well as those that occur on the ground, becomes apparent when considering different control strategies. If the strategy is simply to control or limit all sulfur emissions from all sources, much of the uncertainty surrounding atmospheric processes becomes moot, while transformations on the ground take on more importance. If, however, it can be determined that either local or long-range transport dominates the movement of pollutants, the effectiveness of selected control options demands a clearer understanding of atmospheric processes than we presently have.

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This article was written by Taylor Moore. Technical background information was provided by Mary Ann Allan, Robert Goldstein, Glenn Hilst, John Huckabee, Peter Mueller, Robert Patterson, and Ralph Perhac, Energy Analysis and Environment Division

European Experience: National and International Concerns

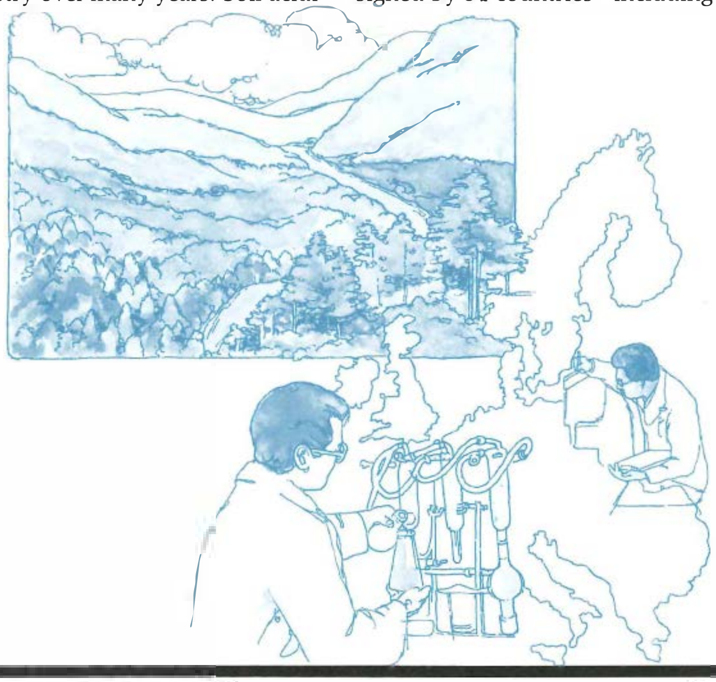
Acidic deposition became an environmental and political issue in Europe earlier than in North America. But controversy over ecological effects and control strategies continues despite agreement by many European nations to act on the problem. And although the current recession in Europe has to some extent reduced demand for electricity, in turn lowering the rate of emissions, it is also pinching national research budgets.

Recently conflicting assessments of damage to forests from acidic deposition have fueled much of the consternation in Europe. Attention was focused on Bavarian forests by the work of Göttingen University Professor Bernard Ulrich, who found significant damage to trees but inconclusive evidence that it was caused specifically by acidic deposition. Ulrich has hypothesized that continuing deposition of present concentrations of SO_2 and acid rain can cause indirect damage to forests by gradually changing the soil chemistry over many years. Soil acidification could cause forests to become more susceptible to naturally occurring stresses and diseases.

On the other hand, an eight-year ecosystem perturbation study in Norway found no significant effects on forest vegetation growth there. The project results note, however, the difficulty in estimating time scales for chemical reactions in soils and forest plants. And it suggests that the leaching of base cations from the soil might be accelerated by acidic inputs, resulting in long-term effects that are difficult to discern.

In West Germany, where environmental groups have gained considerable electoral strength, the government has embarked on a 50% SO_2 emissions reduction program. So far, it is the only major industrial European nation to firmly commit to cut atmospheric pollutant loading; other nations are considering their options.

Last March the Convention on Long-Range Transboundary Air Pollution, signed by 34 countries—including the United States and Canada—was ratified. Negotiated in 1979 by the United Nations Economic Commission for Europe (ECE), the agreement marks a first step toward a unified Western European approach to solving the problem of acidic deposition. No overall plan for joint research or for emissions reduction has yet been implemented, however.



Meanwhile, Sweden is proceeding with a major liming effort to reverse lake acidification believed to be caused by industrial emissions. Although the focus of ecological studies in central Europe is on forest damage, effects in Scandanavia have been seen mainly in aquatic systems.

In this connection, Britain has launched a major investigation of acidic deposition and its effects on Scandanavian fisheries. With funding from the Central Electricity Generating Board (CEGB) and the National Coal Board, the Royal Society will manage the $7.5 million research program with help from scientific academies in Norway and Sweden.

EPRI has been involved in some of the European research through its information exchange agreement with CEGB; it also cosponsored the North Sea study of long-range pollutant transport with CEGB's Central Electricity Research Laboratories. In addition, an EPRI-sponsored study of aluminum biogeochemistry in forest watersheds includes four European sites, one each in Norway, Sweden, West Germany, and England. Ulrich is a coinvestigator with EPRI on this project; the West German site is among those studied in his earlier work. □

Acid Rain: Environmental Effects

DISCERNING THE CHANGE IN WATERS AND WOODLANDS

Lakes and forests are at the center of controversy over the effects of acid rain. Research on the response of these ecosystems to acidic deposition focuses on the questions of how, how much, and how fast.

Acid rain falls on lakes and ponds, streams and rivers, forests, crops, buildings, and statues in parts of eastern North America and Europe—that much is certain. But once it lands, the environmental effects of acid rain are anything but certain. Some claim that rain is acidifying lakes and killing fish in the northeastern United States, Canada, Sweden, and Norway; withering forests in West Germany and New England; and crumbling historic buildings. Others assert that these charges have yet to be proved. Most researchers agree, however, that it is hard to quantify the connections between acid rain and environmental effects.

Starting with lakes

Lakes and other surface waters are as good a place as any to begin to explore the complex effects of acid rain on the environment. Some of the most puzzling questions concerning lakes are also some of the most basic questions: Is there an increasing trend toward acidification of lakes, and if so, what is causing it? How does acidification affect lakes? How extensive are the susceptible regions? How fast is change occurring, and is change reversible?

These questions are difficult to answer because of a shortage of scientifically credible, consistent, long-term data on trends in surface-water acidity, especially for the inaccessible, high-elevation lakes that are most likely to be affected by acid deposition. Not only are data limited, but there are differences in the way data were acquired. Surface-water acidity measurements made before 1960 used methods that tended to yield too-high pH readings because of chemicals added to the water in the testing process. Further, many of the reported acidity trends are based on comparisons made from only two points in time, several years apart. Often, data were collected at different times of the day or on different days of the year, ignoring normal daily, monthly, or seasonal variations in water acidity levels caused by, for example, algae activity.

Sometimes, different data can even lead to seemingly different conclusions on acidification trends. For example, one data base collected from 1929 to 1937 for a sample of 217 high-elevation lakes in the Adirondacks showed that 4% of the sample had pH levels below 5.0. By 1975, 51% of those lakes reportedly had a pH below 5.0. According to another recent data base collected on 2273 high-elevation Adirondack lakes—which represent 80% of the lakes above 1000 ft (305 m)—only 4.7% of the lakes sampled had a pH less than 5.0. In both recent data bases, roughly 105 lakes were at a pH of less than 5.0, but the statistics—51% vs. 4.7%—sound markedly different.

Despite the shortage of good data, the conflicting reports that the available data sometimes produce, and the questions regarding long-term data comparisons, many researchers now agree that some lakes in different parts of the world have shown trends toward increased acidity over the past 50 years or so. Reports from the Adirondacks, Norway, Sweden, and

Canada cite examples of such lakes. Similarly, some correlations between lake acidity and decreased fish population can be established.

Unfortunately, the true extent of lake acidification or of damage to fisheries is far from understood. In a recent report to Congress, the U.S. National Acid Precipitation Assessment Program notes, "Many of the reported cases that suggest acid deposition is the cause of some observed change in an aquatic ecosystem are based on circumstantial evidence and lack documentation of the mechanisms linking cause and effect. At present, the extent of actual aquatic damage is not well established."

Some examples of lake acidification may have been caused by man-made pollution. In Ontario, for example, recent acidification of the La Cloche lakes downwind from the Sudbury region has been well documented, and much of the damage has been attributed to atmospheric emissions of acids and metals from vast smelting operations near Sudbury and Wawa.

The causes behind acidification trends in northern New England, the Adirondacks, and other parts of Canada are still uncertain, and natural causes cannot be overlooked. In the Adirondacks, for example, many lake watersheds are underlain by noncalcareous bedrock and thin soils. Such watersheds may lack the ability to neutralize acidity, whether the acidity is produced by organic decay of dead material in the watershed or by rain itself. Logging, forest fires, storm blowdown, and other conditions can also instigate or aggravate acidification by permitting normal or acid rain to run freely into lakes without neutralization by rock and soil.

Seeking explanations

Convinced that at least some of the acidified lakes were the result of acidic deposition, researchers needed to establish a firm relationship between the deposition of atmospheric acids and the acidity of surface waters before they could determine how many lakes were susceptible to acidification, how fast changes were occurring, and whether the changes were reversible. One of the most popular acidification hypotheses among scientists compared lake acidification by atmospheric input to the titration of a beaker of alkaline solution. A lake was assumed to have some finite alkalinity that was consumed as acidic deposition was added.

Another popular hypothesis held that the bedrock underlying a lake was the deciding factor in lake acidification. If this rock contained adequate amounts of calcite and other minerals to neutralize acidity, the lake would be unscathed; if the bedrock was nonreactive, the lake was likely to become acidified. But this hypothesis, too, had flaws. Researchers noticed that lakes with the same bedrock did not become acidified at the same rate. Plainly, a better understanding of the acidification process was required.

EPRI entered research into the ecological aspects of acidification in 1977, with the initiation of the integrated lake watershed acidification study, or ILWAS. The study was designed to look at three neighboring lakes in New York State's Adirondack Mountains. Woods, Sagamore, and Panther lakes received the same amount of acidic deposition and shared the same nonreactive granitic bedrock. Yet their pH values were different: Woods Lake was highly acidic; Sagamore Lake was slightly acidic; Panther Lake was neutral. More than rain and bedrock was at work here, and EPRI reasoned that this was a good opportunity to investigate how acid rain and lakes interacted.

ILWAS was solidly based on intensive data collection. The lakes and their surrounding watersheds were divided into eight distinct data compartments: atmosphere, forest canopy, snowpack, soil, hydrologic catchments, bogs, streams, and lakes. Field studies painstakingly characterized the properties of each compartment. At selected locations measurements were made of the ambient air quality and of the quantity and quality of water that moved through each compartment. Data were collected monthly, weekly, or as otherwise required.

"Five years and some half a million data points later, we had found some very interesting things," notes Robert Brocksen, until recently manager of the Ecological Studies Program in EPRI's Energy Analysis and Environment Division and now director of the Wyoming Water Research Center of the University of Wyoming at Laramie. "We learned that bedrock geology alone was not adequate to define the sensitivity of lakes to acid rain and that you can't understand the relationship between atmospheric acid and acid in surface waters without considering the entire watershed."

Bedrock, soil, hydrology, vegetation—everything about a lake and its watershed had an effect on how that lake reacted to incoming acidity, according to Project Manager Robert Goldstein, who has directed ILWAS since its inception. Bedrock, as researchers earlier suspected, does indeed have an important—although not all-important—influence on acidification. ILWAS showed that soil is also a critical buffering agent and that most of the neutralization of incoming acidity, in fact, occurred in deep soils. The thicker the layers of neutralizing soil, the more neutralization could be accomplished. Loamy soils that held onto the water did a better job of buffering than impermeable soils, such as hard-packed clay, or soils that permitted too-rapid transfer of water, such as sand and silt.

Hydrology was also found to have important effects on incoming acidity. If the terrain surrounding a lake was extremely steep, incoming rain would tend to rush into the lake without an opportunity for adequate buffering in the soil layers. A more gentle terrain would tend to increase neutralization time. Snowpack, too, had an important influence on lake acidity. During the winter, precipitation acidity collected in the snowpack. In spring, when the snow melted, large volumes of this acidified water rushed over the soil or through only the topmost soil layers, greatly reducing buffering capacity and resulting in a springtime acidity surge.

Even watershed vegetation had an impact on lake acidity. Researchers found that the foliage of broadleaf deciduous trees tended to neutralize the acid in incoming rain, whereas the needles of conifers tended to increase the acidity of the rainwater that passed through them.

These and many more ILWAS findings were incorporated into a comprehensive model that permitted the researchers to simulate how the lakes would perform under different acidity inputs, factoring in not only the altered acidity but also the watershed's soil depth and type, bedrock, vegetation, and other characteristics. This year an expanded version of ILWAS, called the regional integrated lake watershed acidification study (RILWAS), was begun to assess the ILWAS framework, as well as the acidification vulnerability of an entire region.

The first RILWAS objective involves applying the ILWAS model in both northern Wisconsin and the southern Appalachians. At two lakes in Wisconsin and a large stream watershed in North Carolina—each of which has unique hydrologic, soil, and climatic features—researchers will try to refine the ILWAS model.

The second RILWAS objective, development of a regional assessment methodology, calls for applying a less-intensive ILWAS approach to 20 watersheds in the Adirondack Park area. The watersheds have been selected to represent a variety of mineralogies, bedrock types, hydrologies, and fisheries that exist in the region. Both parts of RILWAS are cofunded by local utilities, as well as by state and local government agencies.

Once completed, the ILWAS–RILWAS model will help explain the influences that different factors have on lake acidification. The completed model will be able to suggest how a given lake will behave under either increased or reduced acidic deposition input. It will also be able to indicate if a lake will be subject to acidification over a given period of time. It should also be able to indicate if the acidification of a given lake can be reversed.

Vanishing fish

While researchers are grasping for the connections between acid rain and acid lakes, they are also trying to define the connections between lake acidification and the disappearance of fish. A lack of fish and other biota has been observed in some lakes that had high levels of acidity, leading many researchers to conclude that acidic deposition—either man-made or natural—was responsible for the losses (there is no evidence to suggest that loss of fish is related to loss of their food). Because fish are the species most noticeably absent from acidified waters and because of their high public visibility as both food and sport, fish have been the focus of researchers' concerns.

High acidity levels in water can most definitely disrupt the bodily salt balance of a fish to the point where the fish is unable to function, and dies. Even if acidity levels are not high enough to kill mature fish, acidity may damage delicate fish eggs and fry, possibly during the sudden surges of acidity that can accompany spring snowmelt. Researchers also know that acidification of waters can mobilize toxic metals, such as aluminum, from soil and bedrock and that these metals can harm fish, possibly by disrupting gill structure, by causing oversecretion of mucous and subsequent suffocation, or through toxic accumulation in body tissues.

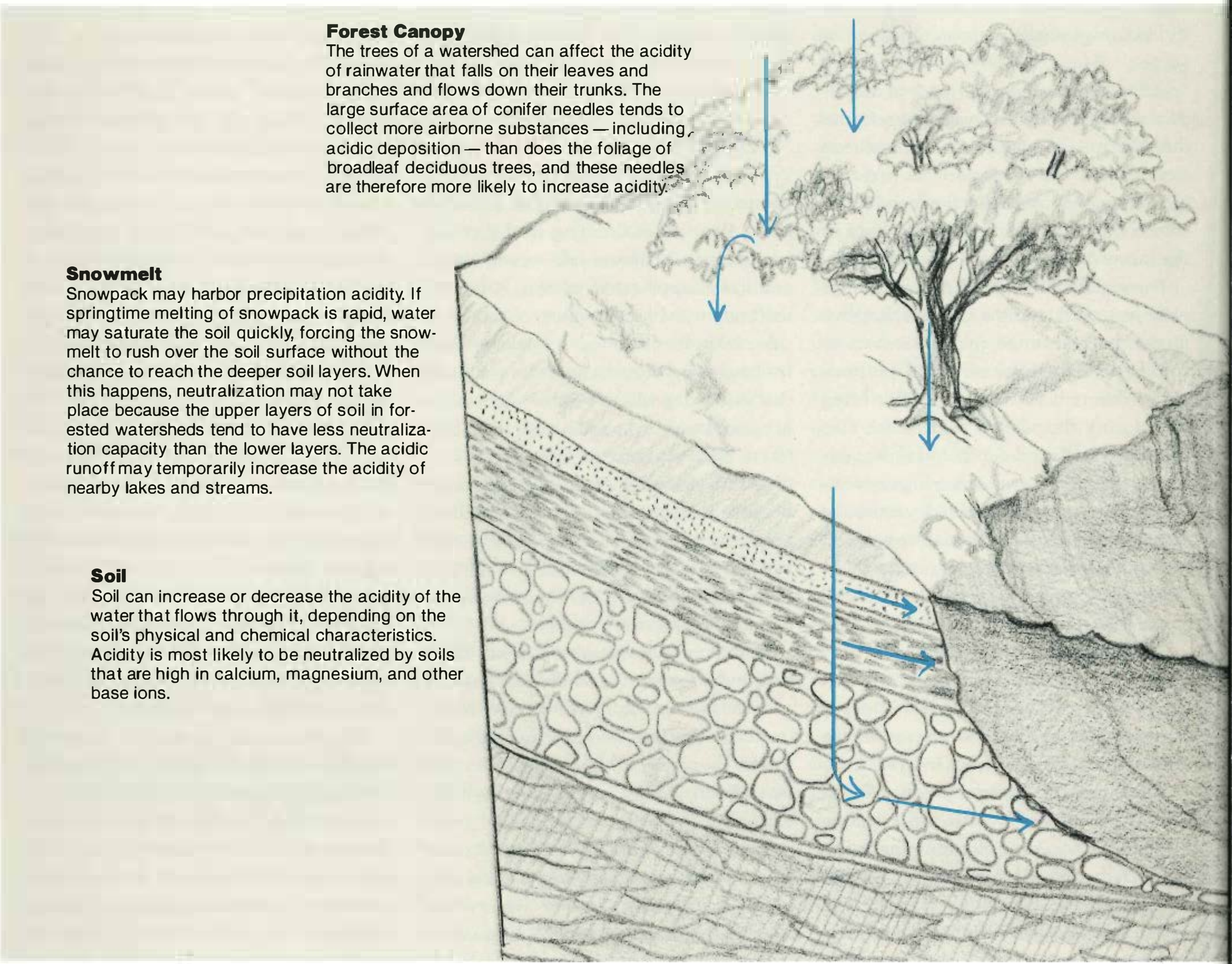
But despite the known effects of acidification on fish, circumstantial correlations between surface water acidity and the absence of fish do not establish a direct cause-and-effect relationship between the two. In only a few cases are data available showing that fish populations declined as water acidity gradually increased. Researchers have yet to establish a direct connection between acidification and fish losses, a task complicated by the fact that many other factors can cause fish loss and many fish losses of past years were reported without any attempt to document the possible causes.

For example, a lake may have been naturally acidic all along. Such a lake may never have supported fish, or if it was stocked with fish in recent times, the fish would have eventually died out. Even if fish were indigenous to a lake, they may have been killed by other causes besides acidification, such as by pesticides. Where acidity seems to be the cause of fish losses, the condition may be the result of either natural or man-made causes.

To sort out the fish loss mystery, researchers need more and better data on fish populations and the effects of acidity on fish. This information would ordinarily be gathered through field monitoring, but 10 or more years could be required to get a good data base, and by that time, more fish populations could be affected. EPRI has opted for a faster research approach that combines modeling, laboratory tests, and field tests.

This new study, beginning now and expected to run five years, will start by developing a model of fish populations in nonacidic but environmentally sensitive watersheds, such as those with thin soil layers and noncalcareous bedrock. According to Project Manager Jack Mattice, laboratory tests will then be conducted to assess the effects of acidification, such as decreased pH and increased aluminum, on fish at various stages of development. The results will be factored into the model to predict the relative population levels of the fish in an acidified environment. Model predictions will then be verified by comparison with field observations. Meanwhile, another EPRI project will examine how mobilized aluminum affects fish and other biota by studying data collected at some 17 different sites.

The final fish population model may ultimately be used in conjunction with the ILWAS model. The ILWAS model will characterize the chemistry to be expected for different watersheds; then the fish population model can be used to pre-



Forest Canopy
The trees of a watershed can affect the acidity of rainwater that falls on their leaves and branches and flows down their trunks. The large surface area of conifer needles tends to collect more airborne substances — including acidic deposition — than does the foliage of broadleaf deciduous trees, and these needles are therefore more likely to increase acidity.

Snowmelt
Snowpack may harbor precipitation acidity. If springtime melting of snowpack is rapid, water may saturate the soil quickly, forcing the snowmelt to rush over the soil surface without the chance to reach the deeper soil layers. When this happens, neutralization may not take place because the upper layers of soil in forested watersheds tend to have less neutralization capacity than the lower layers. The acidic runoff may temporarily increase the acidity of nearby lakes and streams.

Soil
Soil can increase or decrease the acidity of the water that flows through it, depending on the soil's physical and chemical characteristics. Acidity is most likely to be neutralized by soils that are high in calcium, magnesium, and other base ions.

dict how the fish population in that watershed will respond. Through these two models, informed decisions can be made on how to protect fish in sensitive areas.

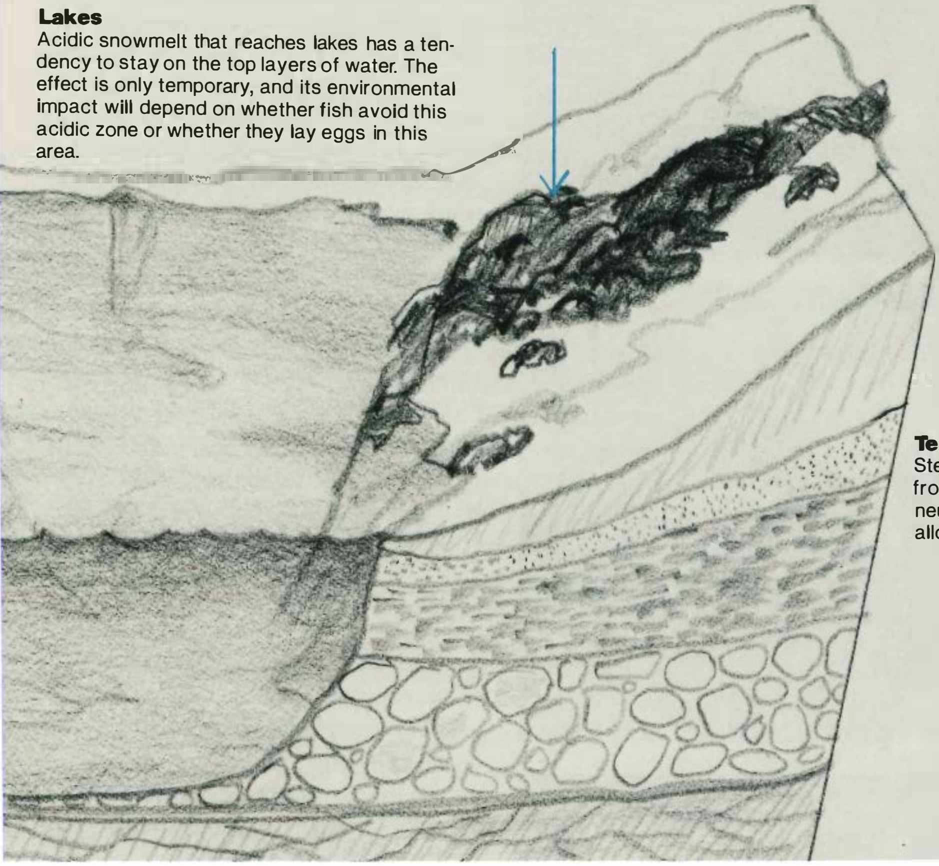
Where acidification has caused fish disappearance, there are several possibilities for restoring the fish. Liming acidified lakes is one technique. Large quantities of crushed limestone, slaked or hydrated lime, or unslaked lime or quicklime are added to the water or applied to the nearby ground or forest. The high alkalinity of the lime neutralizes the water, and the lake can be restocked as necessary. Sweden, which has no way of controlling the emissions of neighboring countries that are blamed for its acid rain problems, has been carrying out an intensive liming program for several years; lakes are also being limed in Norway, Canada, and the United States.

Although liming is being used to improve the pH of many lakes, a number of unanswered questions concerning this approach still remain, according to Project Manager Robert Kawaratani. Studies to date have not fully quantified how effective liming is in restoring lake habitat, how long it is effective, what the most economical and effective ways of applying the lime are, and what possible liming side effects might be. EPRI is now beginning a study to test-lime three acidified lakes in the Adirondacks—two without fish and one with fish—to try to come up with some of the answers.

Another way of dealing with acidified lakes may be to introduce fish that can survive in higher acidities. Such fish would be either individuals that have been deliberately and systematically acclimated to higher acidities or species

Flow Paths Through the Watershed

Rainwater is modified as it flows through a watershed — over tree leaves and branches, across bedrock outcrops, and through soil and snowpack. Until recently, researchers were uncertain of the effects of these complex interactions on rainwater acidity. New research is now identifying how flow paths influence rainwater and its potential for subsequent effects on the ecology.



Lakes
Acidic snowmelt that reaches lakes has a tendency to stay on the top layers of water. The effect is only temporary, and its environmental impact will depend on whether fish avoid this acidic zone or whether they lay eggs in this area.

Bedrock
Rainwater usually moves rapidly over the surfaces of exposed bedrock and hard-packed clay because of their general impermeability. This results in minimal neutralization. Rainwater may also travel too quickly through highly porous soils for significant neutralization to take place. In general, the thicker the soil, the greater the opportunity for neutralization.

Terrain
Steep gradients may conduct rainwater rapidly from one place to another, reducing possible neutralization time. More gentle terrain may allow longer reaction time.

that are naturally acclimated. Researchers still have questions about this strategy, too. Most acclimation experiments have investigated only the short-term response of adult fish to acid stresses, and no one knows if acclimation ensures long-term survival and successful reproduction. It may not be possible, for example, to acclimate newly fertilized eggs to acidified water. Further research will tell.

In the forests

Meanwhile, in the forests, another acid rain puzzle is confounding researchers. Trees, primarily conifers, have been damaged or are dying at unusually rapid rates in recent decades in certain areas of the northeastern United States and Europe. According to quantitative documentation, red spruce have declined atop summits in Vermont's Green Mountains, a decline that has also been observed in the upper elevations of New York and New Hampshire. Pine diebacks have been observed in New Jersey's Pine Barrens. And in West Germany, large areas of Norway spruce and fir have died or appear to be injured.

What troubles researchers is that all these areas receive large amounts of acid rain and other pollution. Certain researchers believe that there may be a connection between tree dieback and acidic deposition. Some think that acid rain leaches essential nutrients, such as calcium, from soil and tree leaves. Others hypothesize that the rain's acidity breaks down the protective waxy cuticle on the surfaces of leaves or needles, opening the way for infection or insect infestation. A more recent hypothesis holds that when acid rain mobilizes aluminum in the soil, the fine root hairs of trees absorb the phytotoxic metal, the metal disrupts the roots' delicate water equilibrium, the fine roots die, and so do the trees.

Despite all these hypotheses, there has never been any direct evidence that acid rain is the cause of declining tree growth in North America and Germany. What researchers have found, according to Project Manager John Huckabee, is a collection of conflicting research results suggesting that if acidic deposition is creating problems, it may be acting in combination with other factors (including droughts, which stress the tree population, or highly phytotoxic gaseous pollutants, such as ozone and sulfur dioxide). For example, researchers speculate that the spruce affected in New England may have been weakened by a long drought in the late 1950s and early 1960s; a similar drought may have debilitated the pine stands in New Jersey's Pine Barrens. And in West Germany, sulfur dioxide levels are reported to be relatively high because of heavy industrialization.

Two EPRI studies being conducted by the University of Washington at Seattle and Oak Ridge National Laboratory are examining the hypothesis that acid rain leaches calcium and other nutrients from forest soils. The Washington study is a control study, monitoring conifer and red alder growth in the relatively unpolluted northwest forests to assess normal soil nutrient levels. The Oak Ridge study is monitoring deciduous hardwoods in an eastern forest where there are acid rain and other pollutants. By comparing the two sets of data, researchers will get a better picture of what effect pollutants have on soil nutrients.

EPRI's above-mentioned study of aluminum mobilization in lakes and streams will also examine the effects of aluminum mobilization on forests. Data on precipitation, aluminum chemistry, soil chemistry, and tree growth will be collected at about 17 different sites, most in North America but some in Europe, in an effort to see if trees are really being harmed by aluminum mobilized by acid rain.

The hunt for acid rain's environmental effects demands data from everywhere, whether that requires measuring soil effects with lysimeters, collecting snowpack for study, or seining fish for observation.

Soil Chemistry: Alteration Through Ion Exchange and Buffering

When rain—acid or otherwise—reaches the ground, it either runs off directly into lakes and streams or filters through soil. Soil has the ability to decrease or increase the acidity of this incoming rainwater, depending on the soil's physical and chemical composition.

A soil's physical composition determines its ability to interact chemically with water. Made up almost entirely of inorganic materials, soils come in varied mixtures of three particle sizes. Sand, the coarsest of soil particles, is generally least chemically reactive because of its chemical composition and its large 50–2000-μm diameter. Besides being individually less reactive, these large particles tend to fit together with large spaces in between, so water can flow more quickly through predominately sandy soils. Because of these physical and chemical characteristics, sandy soils permit water to pass through without much chemical alteration.

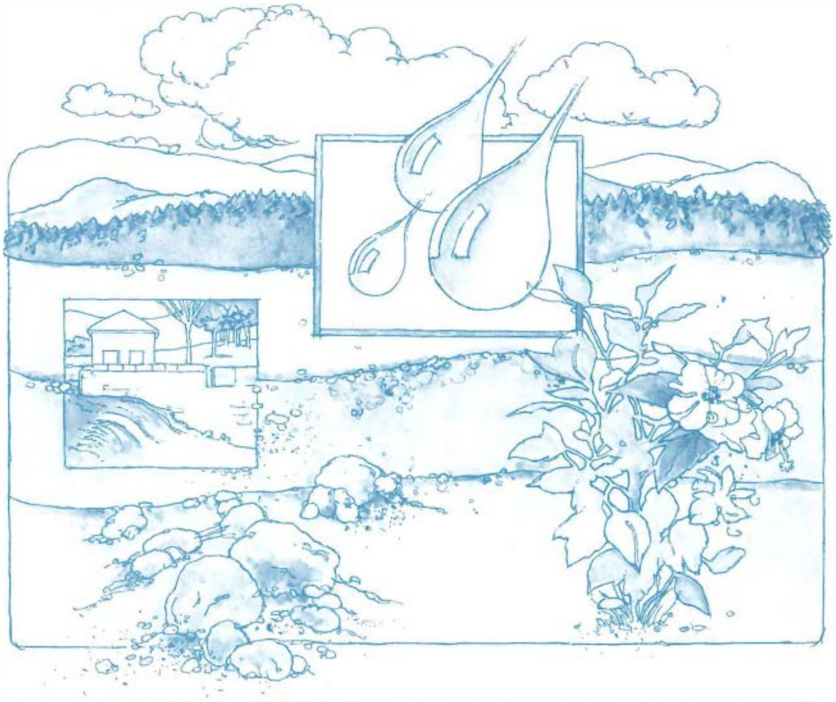
Silt, the next coarsest of soil particles at 2–50 μm in diameter, is typically more chemically reactive than sand, and its permeability is typically less. Clay, the finest of all soil particles, is less than 2 μm in diameter and is generally the most chemically reactive of all. Further, soils rich in clay have very low permeability and therefore the water passing through them travels more slowly, which can allow more reaction time. As a result, clay-rich soils have the greatest capacity to chemically alter the water that moves through them.

When rain falls on forests, it will first react with foliage, bark, or other materials and undergo chemical changes. Such contacts may decrease or increase the acidity of the water. When rainwater finally contacts soil, the pH of the incoming water can be further altered by the soil in two basic ways: ion exchange and buffering reactions.

Ion exchange occurs when the ions attached to the soil particles are exchanged for ions dissolved in water. Consider the case of water coming into the soil in an acidic state (i.e., containing hydrogen ions). When this water comes into contact with clay particles saturated with calcium and magnesium ions, a selective ion exchange may occur in which some of the hydrogen ions are exchanged for some of the calcium and magnesium ions. Thus, the acidity of the incoming water is reduced and the soil acidified. The degree of neutralization and acidification depends entirely on the number of base ions available on soil particles and the hydrogen ions available in the incoming water.

Soils can also act as buffering agents for changing the acidity of rainwater. These agents, such as calcite and dolomite, have the capacity to remove the hydrogen ions from rainwater by forming various chemical substances with them, such as carbonic acid, bicarbonate, or carbon dioxide. The degree of buffering depends on the buffering agents available for reaction.

Although soils can reduce the acidity of incoming rainwater, certain soils may actually increase water acidity. This generally occurs in forest soils, which contain top layers with a high proportion of organic material, such as leaf litter. (Most soils include only about 1% organic material; forest soils may contain up to 50%.) The decaying organic material produces acids, and these acids may in turn acidify the water that runs through the soil. □



Acidity overwhelmed

Although the extent to which acid rain affects lakes and forests still baffles researchers, at least one acid rain question seems well on the way to resolution. That question is the effect of acid rain on agricultural crops and soils. Although early studies suggested that acidic deposition might cause crop damage, later studies on field-grown crops have resulted in the consensus that crops face no danger from acid rain. According to the 1982 Annual Report of the National Acid Precipitation Assessment Program, "The most consistent conclusion to be drawn from agricultural research at all scales and with all species has been 'no effect' at current average ambient pH levels of 4.0 to 4.2."

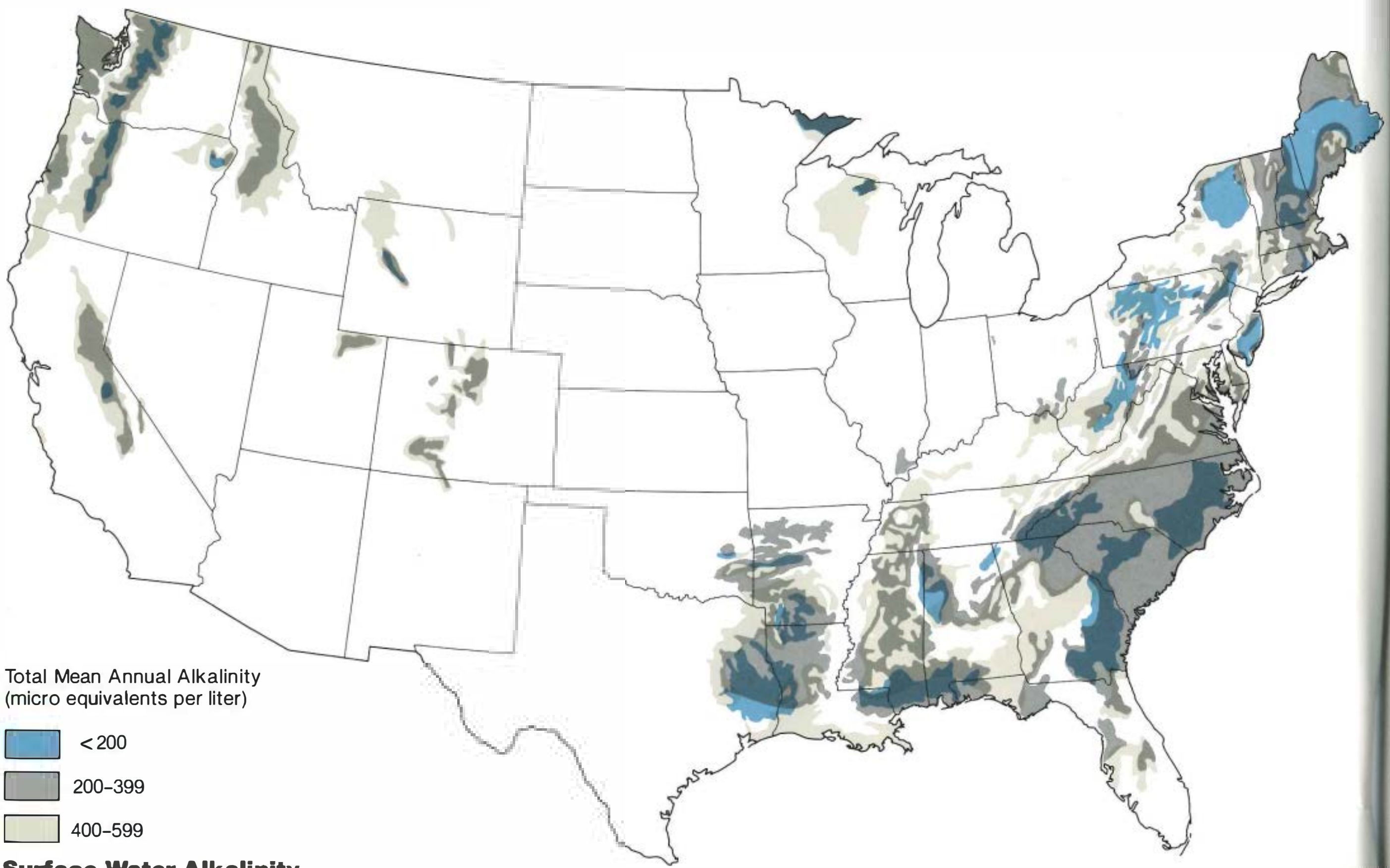
Although acidic deposition by itself appears to do no harm to crops, it may possibly work in combination with other atmospheric pollutants, such as ozone, to damage plants. Both the EPA and EPRI have research under way to study this possibility. Results are very preliminary, but it seems that the ozone and acid rain doses required to have an effect on crops are so large as to be unlikely to occur in nature.

As for agricultural soils, acid rain is apparently only a drop in the agricultural bucket. Routine applications of fertilizers appeared to dwarf any acid input that rain might provide, and the lime that farmers regularly added to their soils to counteract fertilizer-induced acidity also overwhelmed any rain-borne acid. Further, researchers found that acid rain depositions of sulfur and nitrogen compounds can even prevent sulfur and nitrogen deficiencies in certain soils. All in all, researchers seem reasonably confident that the nation's agriculture industry is safe from acid rain.

Statues and cisterns

Two last areas of acid rain effects under investigation are materials and human health. Both are relative newcomers to the research agenda, so even fewer data are available for these areas than for lakes, fish, forests, and crops. The effects of acid rain on materials and human health may be even harder to quantify, so these subjects promise to be under research scrutiny for some time to come.

Reports are frequently made that acid rain is chemically corroding all kinds of materials, from the Statue of Liberty to the Washington Monument. Calcareous building materials, such as limestone, marble, cement, concrete, and masonry, would seem to be acid rain's particular



Surface Water Alkalinity
Whether or not a particular lake or stream is susceptible to acidification is a question that defies easy answers. For example, this EPA map illustrates the alkalinity of surface waters across the United States. At first glance, the darkest (least alkaline) areas might be seen as the ones most susceptible to acidification processes. But many other factors—including the soil, bedrock, and vegetation of the surrounding watershed—play an important role in determining whether the surface water of an area is susceptible to acidification, and there are no maps available today that reflect all those factors for any given region.

Watershed Management: Mitigation at the Site

Selective watershed management may be the fastest and most direct way to deal with acidified lakes and streams, at least with respect to the effects on fisheries. There are both chemical and biologic aspects to be considered. The first step is to control water chemistry; the second step is restocking.

Resource management of this type has been used for a number of years to restore and maintain fisheries. Restocking is a long-established practice, and fishery managers have even begun to introduce new species where possible and desirable. A notable example is the Great Lakes, where salmon have replaced the lake trout and whitefish depleted by the lamprey eel.

With respect to acidification, however, the most important experience has been gained in matters of water chemistry control. For example, lakes near the nickel smelters at Sudbury, Ontario, suffered from severe acidity and a high level of toxic metals—the results of both direct deposition and drainage from slag dumps. Treating a number of those lakes with lime and limestone restored the lakes to a neutral chemical state and precipitated the metals into the bottom sediments. Active fisheries again prevail in some of the lakes, although long-term effects of the original damage are not yet known.

In Sweden the aim was to restore fisheries in hundreds of lakes. Watershed management was the only course of action in this instance because the pollutants believed to cause the acidification originate beyond the country's borders. The Swedish government itself took on the job in 1977, initiating a liming program that now costs more than $5 million annually. Besides improving pH levels, Sweden's effort provides a broad test of a number of treatment methods. Not only are chemicals (typically lime or limestone) distributed from conventional airplanes, helicopters, and boats, but limestone is often deposited along lake shorelines. In addition, silos are being used to dispense lime or limestone into influent streams automatically, based on acidity or flow measurements by monitoring instruments.

Here in the United States a number of Adirondack lakes have been chemically managed in these ways for many decades. Also, some coal mining areas are routinely treated to counter the acidity of mine tailings; lime or limestone deposited on and around the dumps acts to control the chemistry of runoff that drains or leaches into streams. Pennsylvania, with a particularly aggressive program, has even built limestone weirs in streams to neutralize the flowing waters. Altogether, agencies in at least seven states are liming lakes and streams as a matter of either research or watershed management. Seen in a nationwide context, however, the activity is spotty, and the associate data acquisition efforts are inconsistent, casualties of the need to stretch budgets.

The role of natural acidification is also becoming recognized, and effective management may have to encompass still further techniques. For example, with some combinations of topography and drainage, bogs tend to form in the shallows of lakes. Bogs are extraordinary producers of acids and of themselves can progressively acidify previously neutral settings. Dredging may be the only way to counter this eventuality.

Forest cover is also influential; coniferous trees create much more acidity than deciduous, and forests of any kind, more than grasslands. Reforestation practices thus are important; ironically, pines planted for their commercial and esthetic value may have upset the chemistry of some watersheds and their aquatic systems.

Motivated by the Canadian and Swedish experience and by the U.S. need, EPRI is accelerating the pace and sharpening the precision of research with a $2.5 million, three-year program that will focus on three lakes in New York state. Different liming regimens and consequently different patterns of change in the lakes' characteristics should provide more substantive bases for conclusions than are now available. What liming agent is best and how should it be applied? Where, in what dosage, and how often? With what effects on metals, other trace elements, and the biota of the system?

The overall objective is an information base from which to predict the results of chemical treatment. Treatment does not do away with acid deposition, of course; but it mitigates at least some of the effects more quickly and cost-effectively than emissions controls. Also, raising pH levels can restore lake fisheries more assuredly than can be expected from reduced acid deposition alone. □

prey, although metals, paints, plastics, and other substances may also be affected. Acidic deposition could certainly corrode these materials, but researchers are up against two problems when they attempt to quantify the link between acid rain and materials.

First, materials damage occurs naturally to some extent, a product of temperature, humidity, precipitation quality and frequency, wind velocity, and other everyday factors. Second, materials damage may be attributable to many other kinds of pollution, such as ozone and particulate matter. To link acid rain with materials damage, the researcher has to be able to distinguish materials effects caused by acid rain from effects caused by other pollutants and natural weathering.

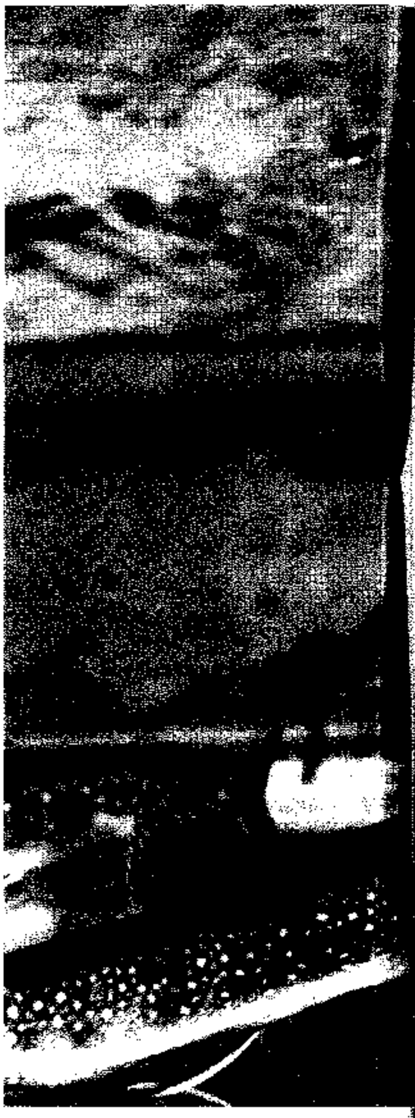
Unfortunately, even though a sizable amount of industrial research has been done over the years to evaluate the susceptibilities of materials to airborne damaging agents and to develop more resistant materials, little has been done to identify which causes are having which effects. There is, in fact, no available method for distinguishing what causes any given instance of degradation.

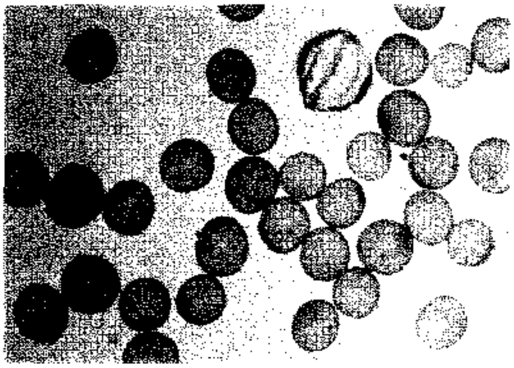
To remedy the situation, the federal government's National Acid Precipitation Assessment Program is planning and beginning several studies to define the role of acid rain in materials degradation. These studies will include assessing which portion of materials damage can be attributed to acid rain, specific rates of damage, and amount of damage in economic terms. Based on this information, better-informed decisions can be made as to how to deal with the problem.

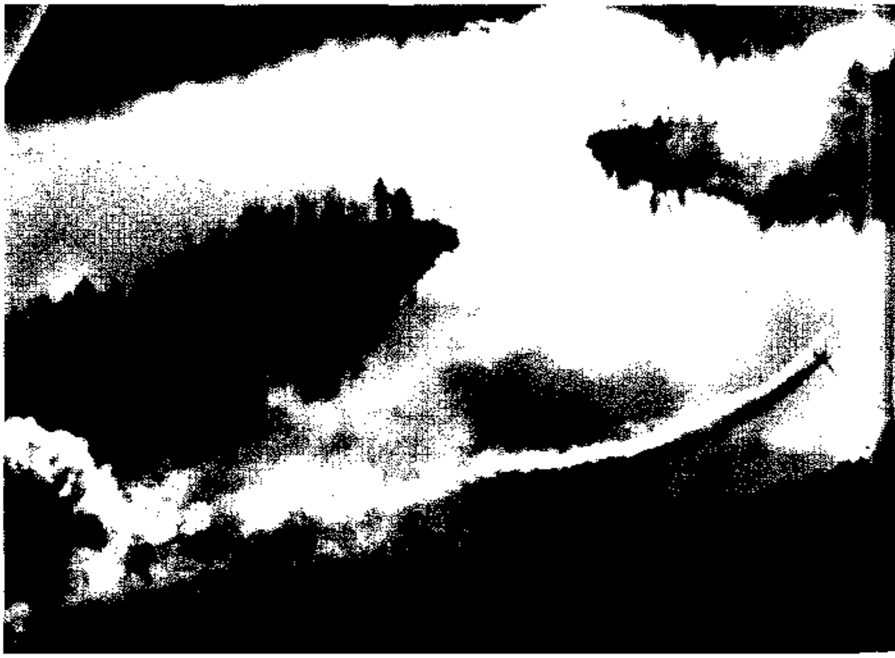
The effects of acid rain on human health are similarly unknown. Some researchers contend that acid rain can indirectly contaminate drinking water with toxic heavy metals. Some of these metals, such as lead and copper, may be leached out of plumbing systems by the rain; still others, such as aluminum, may be leached out of soil by acid rain.

No definite connections have yet been made between acid rain and human health,

Researchers have yet to establish a direct connection between lake acidification and fish losses, but studies are continuing. Here, brook trout eggs collected from pristine streams are incubated and grow to adulthood under varying acidity conditions, providing researchers at the University of Wyoming at Laramie with the opportunity to study the entire fish life cycle.







ecent studies, such as these at Cornell Uni-
rsity's Boyce Thompson Institute, have led
searchers to conclude that acid rain gener
ly poses minimal threat to agricultural crops
d soils; the lime that farmers routinely add
soil to counteract fertilizer-induced acidity
pears to overwhelm any acid rain contribu-
ns. Meanwhile, lime is being applied to
idified lakes by airplane or other means
ecifically to reduce their acidity.

but the few data available suggest that if there is a problem, it would apply under limited conditions. Householders who draw their water unmonitored and untreated from rainwater cistern systems may be exposed to metals that the rain corrodes out of water pipes. Those who draw their water from shallow wells may also be at risk if aluminum or other metals leached from the soil by acid rain find their way into the groundwater supply. All these possibilities will require further study.

Answers yet to come

Further study is, of course, the key to quantifying acid rain's environmental effects, whether they concern lakes, forests, crops, materials, or human health. The work of recent years was the first attempt of governments, research organizations, utilities, and universities to understand these effects. In what were once broad areas of uncertainty, the ongoing research effort has added, slowly and painstakingly, the bits and pieces that will eventually add up to definitive answers.

Researchers are not quite at the point where they can look at any lake and say whether or not it is susceptible to acid rain. They still cannot say for certain why fish are disappearing or what is decimating trees in West Germany and New England. They cannot point to a crumbling statue and pick out acid rain as the cause. They are beginning, however, to understand the complex interaction of precipitation, geology, and vegetation that predisposes lakes to acidification and are learning what fish populations are normal for a given lake. They are examining the forests for dieback clues. They are confident that crops will not suddenly wither from acid rain and reasonably certain that acid rain is not a large-scale public health problem. "We've narrowed the boundaries of what we don't know about acid rain's effects on lakes, forests, crops, materials, and human health," concludes Brocksen. And as the research continues, the boundaries of the unknown will continue to narrow. ■

Further reading

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This article was written by Nadine Lihach. Technical background information was provided by Robert Brocksen, Robert Goldstein, John Huckabee, Robert Kawaratani, Jack Mattice, Ishwar Murarka, and Ralph Perhac, Energy Analysis and Environment Division.

Acid Rain: Control Technology

DEVELOPING THE OPTIONS FOR EMISSIONS CONTROL

Today's options for reducing power plant emissions are costly and limited. R&D efforts are attempting to broaden the field of choice and improve the cost-effectiveness of pollution control.

Control strategies aimed at reducing power plant emissions have shifted in the last decade from a focus on new plants to a concern over existing plants. The Clean Air Act of 1971 established tight federal standards on the combustion emissions of new plants with the assumption that as older plants were retired, their replacements would constitute a higher and higher percentage of utility generating capacity. However, with rising capital costs and a sharp reduction in historical load growth, plant turnover has stalled, sparking renewed legislative and regulatory efforts toward increased controls on pre-1971 plants.

This recent push introduces a fundamental choice of investment strategies for decision makers—whether to increase the investment on older, less-efficient plants where controls are not an integral part of the design or to reserve investment capital for systems now under development that combine superior environmental performance with improved energy and operational efficiency.

In response to the current politically charged issue of acid rain, proposed legislative and regulatory action has targeted coal-fired plants because of their large role in SO_2 emissions. Collectively, they exhaust about 14.4 million tons of SO_2 each year—91% of the total from utility plants of all kinds and about 60% of what comes from all man-made sources in the United States. Coal-fired plants are also a significant source of NO_x, although the greatest percentage comes from cars and trucks. The annual volume of 4.6 million tons from coal-fired plants is 82% of all utility NO_x and almost a quarter of the NO_x from all U.S. sources.

Whether or not widespread action is taken against coal-fired plant stack emissions, no single solution is expected to satisfy the widely varying fuel and design conditions of existing coal-fired plants. There are several basic control approaches and any number of technical variants under development or in use today. They encompass restricted plant operation; the use of different or cleaned coals; altered firing practices, burners, and combustion conditions; and the introduction of reagents to inhibit or capture pollutants in combustion gases.

Plant retirement is not a process or hardware control, but it does have a direct effect on emissions. Of course, this option implies an investment in replacement power and, depending on its source, the continued emission of SO_2 and NO_x at some level.

The same is true of a less drastic step, environmental dispatch: plant use only when weather conditions mitigate the transport and conversion of SO_2 and NO_x. The usual practice is economic dispatch, responding to increased demand with the unit or plant that generates electricity most cheaply among all those available. Therefore, environmental dispatch would imply higher operating costs.

Both of these options are likely to be choices of last resort, when site-specific analyses show that process or plant changes are impossible or uneconomic. Retirement and environmental dispatch are not inherently cheap options; they mean forgoing the recovery of some portion of a plant's capital cost. In addition, they both may affect the reliability of electricity supply and hence be unacceptable to utility regulatory bodies.

Other alternatives, such as coal switching and cleaning, modification of combustion process and equipment, and postcombustion exhaust treatment, turn to technologic advances to achieve their goal. But even aside from differences in their development status, these options are not interchangeable in application.

In the first place, they differ significantly in how much SO_2 and NO_x they are capable of removing. This is illustrated by the broad range between 5–10% SO_2 removal at the low end of coal cleaning to over 90% removal at the high end of flue gas desulfurization. Even the retrofittable combustion measures for NO_x reduction range from 5–10% to more than 50% removal.

The second point is that capital and operating costs do not neatly match the progression of pollutant removal efficiency. There is a sharp change in the curve of cost-effectiveness (cost per ton of pollutant removed) for SO_2 control, and performance above about 35% SO_2 capture becomes disproportionately expensive.

The third obstacle to interchangeability of emission control options is the great number and variety of functional criteria that determine their applicability: fuel type, plant design, furnace geometry, component capacities, duct configuration, land area, water availability, and many others.

Because the technology options are not interchangeable for the three reasons cited, direct comparison of options based on a specific factor is not useful. Rather, each technology is important because of its combined score, actual or potential, in performance, cost, and applicability to today's coal-fired power plants.

Coal switching

One basic approach to emissions control involves simply altering the fuel that is burned in a plant through switching, blending, or cleaning. Changing the source of incoming coal, referred to as switching, may involve relatively little capital outlay and outage time by a utility. This is why it is potentially important among the apparent, quick fixes for acid rain.

In addition to its potential for SO_2 control, switching fuel has historically been a way to improve combustion properties—to deal with variable or declining coal quality and still maintain consistent grindability, heat rate, slagging potential, ash production, and so on.

As a matter of emissions control, coal switching means substituting for one raw coal or blending it with another that has a higher sulfur content. The practice can cut emissions by 30–80%, depending on the blend, but it has several major ramifications. One, obviously, is cost. Low-sulfur blending coal typically carries a price premium of up to 30%; but if coal switching becomes so popular that it creates heavy competition for low-sulfur sources, that premium could increase significantly. Also, when low-sulfur coal is transported a long distance from its southern Appalachian or western source, transportation cost can account for three-fourths of its delivered price.

Another issue is the impact on overall plant operability of burning a grade of coal for which the plant was not designed. For most U.S. utility boilers, severe fuel changes may require lowered temperatures, degraded heat rates, reduced generating capacities, and major modifications to the electrostatic precipitator used for particulate emissions control. Blending in lower-sulfur coal therefore involves plant-specific analyses to maintain economical and reliable plant performance. In some instances where plants were designed to burn high-sulfur midwestern coal, blending in more than 30% of a low-sulfur western coal, with its fundamentally different ash composition, can produce intolerable slagging and fouling unless the plant is operated at less than its rated capacity.

From a technical standpoint, coal blending and switching for SO_2 reduction are attractive and broadly applicable. But there remain awkward conflicts that center on regional economics and politics. For example, switching to low-sulfur fuel that must be shipped long distances could have a major impact on the local coal supply industry, particularly in northern Appalachia and the Midwest. Such an abrupt change could put thousands of local people out of work. Long-term take-or-pay coal supply contracts would have to be renegotiated and penalties paid where past decisions no longer fit future plans.

The technical attractiveness of coal switching is therefore in check until institutional agreements make possible its broad use. In the meantime, switching is likely to involve no more than about 50 million tons annually, potentially reducing SO_2 emissions by about a million tons. The necessary capital equipment is estimated to cost $40/kW and the low-sulfur coal to carry a premium of $15–$20 a ton.

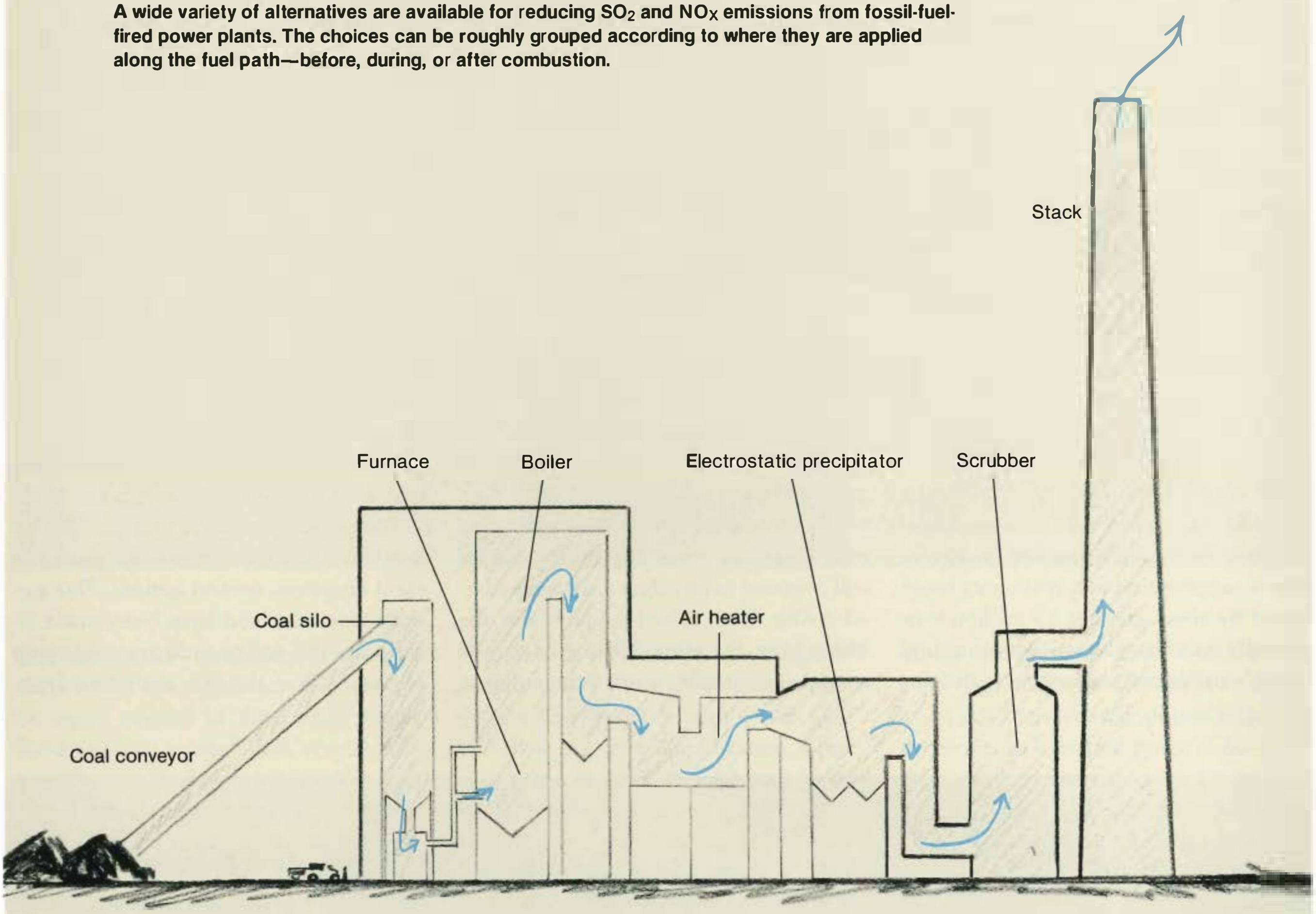
Coal cleaning

Coal cleaning is another way to alter the quality of the fuel stock for better emission characteristics. The process was once a special treatment restricted to fuels used in high-value industrial processes, such as steelmaking. It has come to be economically feasible for steam coal as a means of reducing transportation costs and of improving firing properties by reducing the ash and inorganic (pyritic) sulfur content.

Today's coal beneficiation is categorized as physical coal cleaning. Coal is crushed to break apart the particles of coal and impurities. Further processing takes advantage of the different specific gravities of coal and mineral impurities to separate them in a liquid medium. This can reduce the sulfur content of many northern Appalachian and midwestern high-sulfur coals by 30% or more. Chemical cleaning, while potentially capable of higher sulfur removal, is far from ready for use, and early estimates show it to be very expensive; it is not likely to be suitable for com-

Cleanup Along the Fuel Path

A wide variety of alternatives are available for reducing SO_2 and NO_X emissions from fossil-fuel-fired power plants. The choices can be roughly grouped according to where they are applied along the fuel path—before, during, or after combustion.



Precombustion Control
Options for emission reduction begin outside the power plant with fuel change—outright switching, blending, or cleaning coal to lower the incoming sulfur content. These options are limited in terms of sulfur reduction, partly by the processes themselves and partly by the narrow range of fuel characteristics that utility boilers are designed to accept; but they entail the least capital investment and are far and away the most cost-effective.

In Situ Control
Several new technology options focus on the power plant boiler, where changes in the combustion process itself can suppress the formation of pollutants or capture them before exhaust gases proceed through the rest of the system. These changes are dictated by the configuration of equipment and the manner in which coal and combustion air are combined. Notable examples are low-NO_X burners, the fluidized bed for burning coal in the presence of limestone, and the injection of limestone into the furnace.

Postcombustion Control
The best-known SO_2 emission control is postcombustion treatment—flue gas desulfurization in scrubbers just ahead of the power plant exhaust stack. Scrubbers are capable of high performance in SO_2 removal, but they are expensive as retrofit equipment because of installation cost and provisions for their reliable operation. R&D addresses this problem and also explores other postcombustion exhaust treatments.

mercial application in the utility industry unless its cost can be reduced substantially.

Even when it is regarded only as a means to reduce SO_2 emissions, coal cleaning is attractive for two main reasons. One is that it requires only minimal power plant modification; the other is that it may lead to a number of collateral benefits. With reduced ash and sulfur content, clean coal costs less to transport and causes less wear and tear on pulverizers and other coal-handling equipment. It imposes less burden on ash removal and flue gas cleanup systems, and its firing properties may be better (higher Btu content and generally reduced potential for fouling and slagging).

Even today, about one half of high-sulfur utility coal is cleaned to some degree, primarily for economic reasons. Much more could be cleaned, however. An EPRI assessment based on cleanability analyses by DOE and the Bureau of Mines suggests that SO_2 emissions could be cut by about another 1.5 million tons annually in this manner, concentrating on high-sulfur coals amenable to this approach. The effort would involve capital costs of about $40/kW, affecting 100 million tons per year of high-sulfur northern Appalachian and Midwest coal production. The overall yearly cost might thus be $1 billion.

Although coal cleaning is cost-effective for what it offers, under most legislative proposals it could be only a partial solution. Still, cleaning would reduce the level of performance required of other emissions control hardware installed at the power plant.

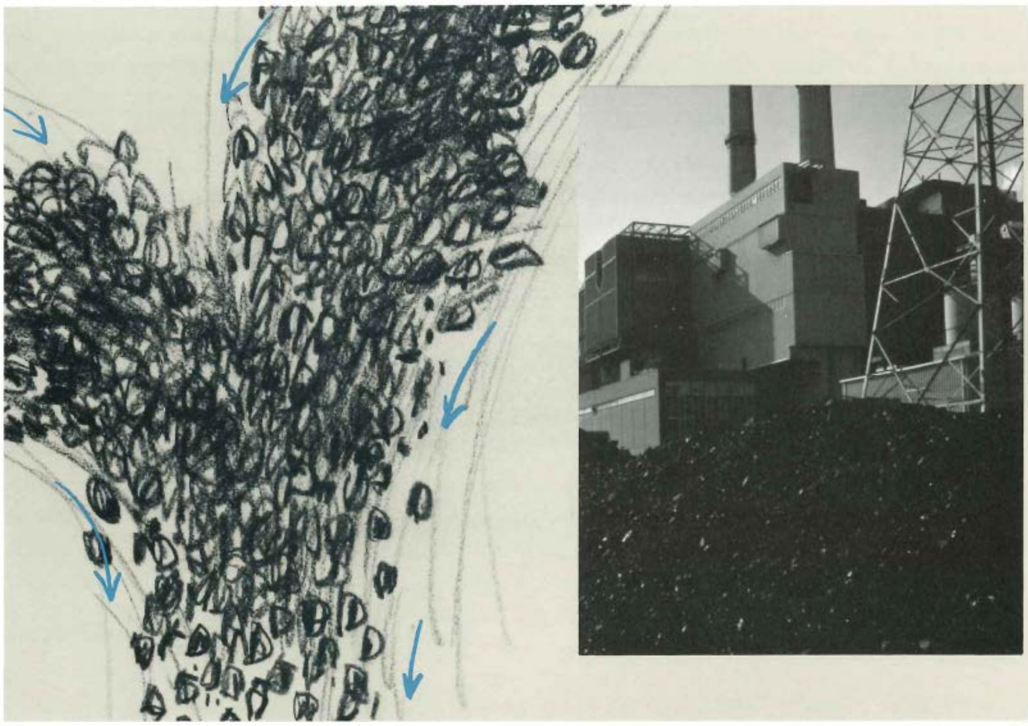
The focus of R&D and testing of various physical cleaning methods and their applicability to different coals is the two-year-old Coal Cleaning Test Facility, conceived and cosponsored by EPRI at Homer City, Pennsylvania. Research there is aimed particularly at the qualities of coal as an electric utility fuel.

Despite utility interest in coal-cleaning technology, in most instances utilities will continue to buy their coal, cleaned or otherwise, from a fuel supplier. For the utility user, therefore, clean coal carries a market-controlled price rather than a technology-controlled cost, and that fact will figure prominently in economic decisions about this option for emissions reduction. The present incremental cost for coal cleaning is in the range of $4–$9 per ton of clean product coal; the incremental price to the user for cleaned coal, on the other hand, is typically $6–$12 per ton.

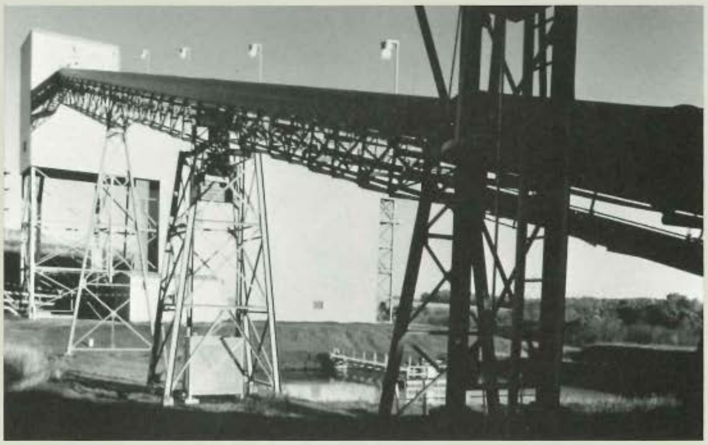
Flue gas desulfurization

Feed stock modifications, such as coal switching or cleaning, can contribute a significant reduction in power plant emissions, but they are solutions that are external to the plant itself. To achieve the higher SO_2 and NO_x removal levels in some proposed legislation, utilities will almost certainly have to turn to internal options—modifications in the plant itself or new processes for cleaner combustion.

Today, flue gas desulfurization has to lead the list of commercially available plant emissions control options. Flue gas scrubbers exist and have been made to work by the utility industry, removing at least 90% of the SO_2 emissions from



Coal Blending
Changing coal can be as drastic as a complete switch to a low-sulfur source. But to maintain practical combustion and handling properties, the more likely solution is a blend of high- and low-sulfur coals. Widespread changes in fuel mix could have important implications for patterns of coal demand and supply across the country.



Coal Cleaning

Separating coal from mineral matter takes advantage of different specific gravities, as coal particles are floated or centrifuged free from the ash, which is heavier. Because clean coal is cheaper to transport and burns more evenly, EPRI's Coal Cleaning Test Facility seeks more economical and thorough separation processes.

high-sulfur-coal combustion on new plants. This has important implications for entire regions of the United States that are fueled by such coal. As noted in connection with coal switching, the coal, electric power, and other industries in those regions are economically interdependent to such a degree that there is great incentive to make practical use of local coals. Flue gas desulfurization provides one solution to the problem.

In this process, the flue gas produced in coal combustion is typically sprayed with a slurry made up of water and an alkaline reagent—usually lime or limestone. The SO_2 present in the flue gas reacts chemically with the reagent in the slurry, forming calcium sulfite and/or calcium sulfate, which is removed and disposed of in the form of a wet sludge.

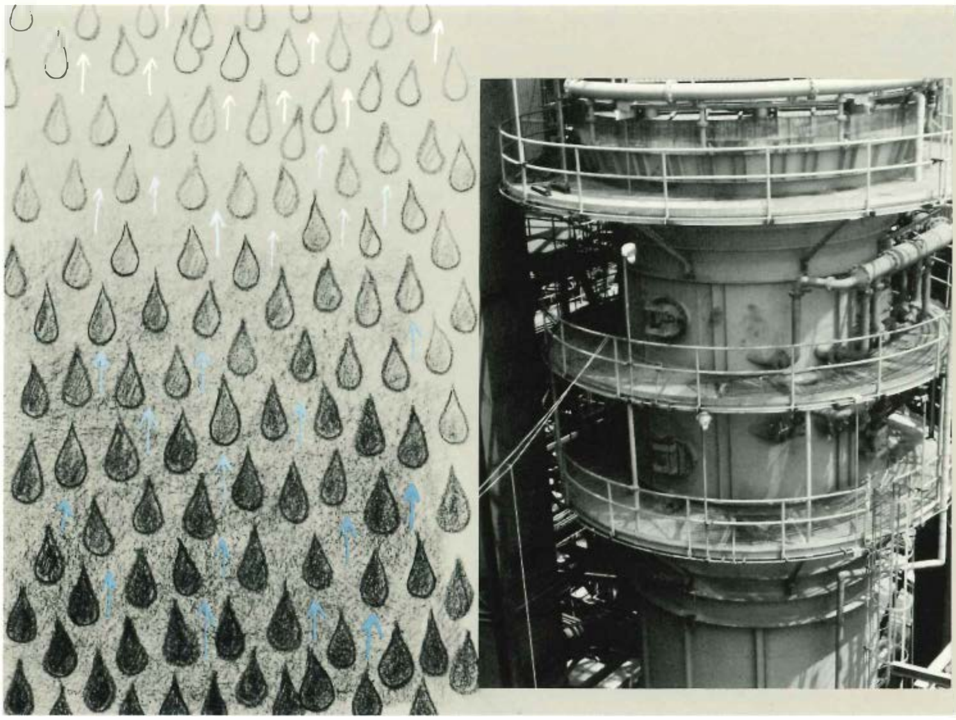
Although wet scrubbers offer large percentage reductions in sulfur, they are usually the least cost-effective control in terms of cost per ton of SO_2 removed. At high removal rates, this means high capital cost, especially undesirable for a retrofit item that may have to be squeezed into place in an older plant with limited remaining life. In a new power plant, the scrubber will commonly cost \$140–\$175/kW. In a retrofit application, it typically costs 10–40% more, but this premium may be as high as 110%.

High cost derives from more than design and construction. Scrubbers yield large volumes of wet waste, thereby requiring extensive land area for ponds or landfills (or, alternatively, expensive transportation for waste disposal elsewhere). Scrubbing uses huge amounts of water (500–2500 gal/min [0.03–0.16 m^3/s] for a 500-MW plant), and many processes still have problems with plugging and fouling of the equipment and corrosion of fans and ductwork downstream, matters that add to operating costs and cut away at reliability. Finally, scrubbers extract a penalty of about 3–8% of plant output energy, simply to run pumps, fans, and flue gas reheat systems.

Scrubber R&D focuses on better reliability, lower cost, and less waste. In the shorter term, redundant components (which can be brought into service while others are down) have boosted average high-sulfur-coal scrubber availability by 20–25 percentage points in the last five years, to a current range of 80–90%.

Reliability comes from better process chemistry and simplified equipment. One new scrubber configuration, for example, increases the contacting (of SO_2 molecules and scrubber reagent) by bubbling the flue gas through the reagent slurry instead of spraying the reagent slurry into the flue gas stream. The scrubber consumes less energy because the scrubbing liquor need not be pumped through spray nozzles. Also, its chemistry yields a relatively dry gypsum waste that is potentially marketable.

Another variant in both configuration and chemistry, the double alkali scrubber, absorbs SO_2 from the flue gas with a clear aqueous solution, usually sodium sulfite, so as to minimize the scale and plugging problems that can plague conventional lime or limestone slurry scrubbers. Lime or limestone in the recirculating tank fixes the sulfur in solid form for disposal. Double alkali scrubbing successfully mini-



Flue Gas Desulfurization
Lime or limestone in a finely sprayed slurry is the standard shower bath that scrubs SO_2 from power plant flue gases today. Stainless steel vessels like this one — equivalent to 100 MW of plant capacity — use multilevel sprays to remove more than 90% of the sulfur from high-sulfur coal combustion gas.

mizes scale and is being applied to high-sulfur combustion gases.

Another advanced concept, spray-dry scrubbing, is of special interest because of its suitability for retrofit applications, where equipment size and water availability may be special problems. In this option, the reagent (usually lime) slurry is injected into an absorber vessel in finely atomized form; the droplets evaporate in the hot gas, leaving only dry, reacted particles for collection by conventional baghouses or electrostatic precipitators. The simplicity of the process lends reliability and economy to spray drying, and the waste may be easier to handle than that from wet scrubbing.

In an overall assessment, there is much to be said for flue gas desulfurization. It is an established technology for high-efficiency SO_2 removal and can be used in new or retrofit applications. In fact, FGD is the only technology that currently can satisfy federal emission standards for new plants. However, its high cost is a problem that is likely to become an even greater handicap in the future. Its application to existing plants is an expensive add-on solution, extending the life of these older, relatively inefficient units rather than encouraging their replacement by newer technology.

For a decade scrubbers have been in the position of being the only devices that can produce major reductions in high-level sulfur emission; soon, as new technologies are developed that—alone or in combination—can compete technically, the cost of FGD will have to be reduced if it is to compete economically.

Low-NO_x combustion

NO_x is formed in the furnace from nitrogen in both the coal and the combustion air. The chemical reactions involved depend strongly on the rate of fuel-air mixing and on the resultant temperatures in and around the flame zone. NO_x formation is thus encouraged or inhibited by firing practices, burner design, and furnace geometry. All are important because man-made NO_x emissions, unlike those of SO_2, are projected to increase in coming years.

Three combustion modifications are most attractive for coal-fired boilers: low-excess-air combustion, overfire air ports, and low-NO_x burners. All are ways to control the amount of oxidant made available in the combustion process and limit its peak temperature, essentially by the timing and location of air injection.

Low-excess-air operation is a change that can yield up to 15% lower emissions for a very small capital cost—about \$0.40/kW. Overfire air ports can reduce NO_x as much as 30–50%, depending on how the burner pattern shapes the flame zone, at a capital cost of about \$2/kW. However, only a limited range of boilers can be modified for these options.

The technology under development that is expected to be least affected by such limitations is the low-NO_x burner. This device differs from conventional burners in that it delays the mixing of fuel and air in the boiler. Such control creates a very fuel-rich mixture in the combustion zone that limits formation of NO_x from nitrogen bound in the coal molecules.

Low-NO_x burner designs are being pursued for all four of the basic furnace types now in utility use. Although they seem to be more amenable to use with some systems than others, it is expected that low-NO_x burners will be a retrofit option for a majority of U.S. coal plants. On the basis of pilot-scale testing with U.S. coals, the NO_x reduction capability and capital cost of some advanced burners are projected at about 45–60% and \$8–\$16/kW, respectively.

Firing practices and burner designs are clearly the main candidates for retrofit improvements. Altering the furnace itself is a matter of replacement, not retrofit. Even so, furnace configuration remains important in assessing the applicability of other combustion modifications. EPRI is therefore inventorying utility boilers according to such factors as rating, age, firing pattern, burner type, manufacturer, and coal. The data are expected to provide solid information on the nationwide potential for reduction of utility NO_x emissions.

It is estimated that about 60% of U.S. coal-fired capacity (units of 100 MW and larger) is retrofittable in some way to reduce NO_x emissions. But only about 38% can foreseeably use the low-NO_x burners now commercially available or under development. The R&D incentive is to close that gap with a full range of combustion staging devices.

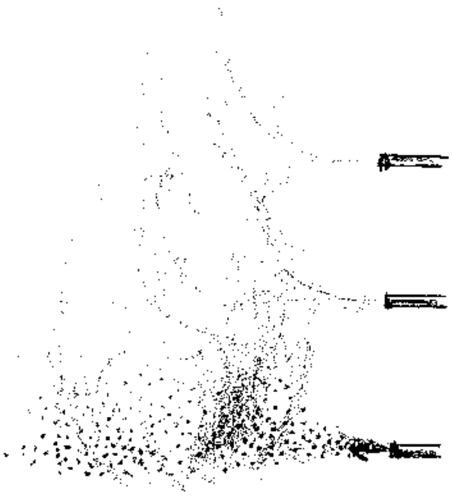
NO_x can also be removed from flue gas with very high efficiency, but the principal scheme, called selective catalytic reduction (SCR), does not appear economically attractive. Capital cost alone, for example, appears to be 10 times that of combustion modification to suppress NO_x. Also, high temperature requirements of the process require the SCR equipment to be immediately adjacent to the boiler itself, upstream from the furnace air heaters and particulate removal equipment, whose functions are affected by the SCR byproducts. These problems appear technically surmountable, but the high capital and operating costs of the process do not provide an incentive to do so.

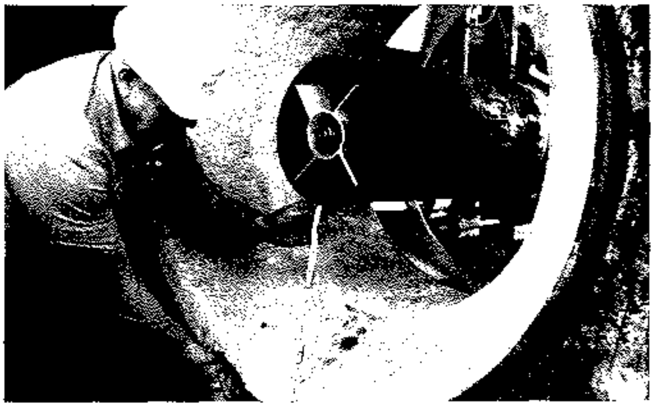
Furnace limestone injection

Attempts to capture SO_2 by injecting limestone into the furnace date from the 1960s, but because the process chemistry was not well understood or controlled, it was ineffective. The potential costs of retrofit SO_2 control call for a second look at limestone injection, as does the finding that favorable furnace conditions for the process may be similar to those required for suppression of NO_x formation. Within the past five years, therefore, the research goal has become one of developing a single technology capable of significantly reducing SO_2 and NO_x simultaneously.

In this process, dry pulverized limestone ($CaCO_3$) is fed into the furnace, where it calcines to lime (CaO) and reacts with SO_2 to form dry, solid calcium sulfate ($CaSO_4$), or gypsum. These reactions are now known to proceed most effectively in gradual combustion at reduced temperature, which is a desirable environment for NO_x suppression. By contrast, a conventionally hot, high-heat-release flame zone seems to fuse and seal

Low-NO_x Combustion
NO_x is an inherent combustion product because nitrogen comes from the combustion air as well as from the coal itself. Reduced flame temperature and slower combustion are key mechanisms of NO_x suppression. Retrofit burners feature coal pipe and air passages shaped to lengthen the flame zone by the relatively gradual introduction and mixing of air.





(sinter) the limestone particles, cutting off their reactivity. This fundamentally limited the effectiveness of the earlier attempts at SO_2 reduction by this method.

EPA has sponsored development of a combustion configuration called the limestone injection multistage burner (LIMB), which combines the features needed for both SO_2 and NO_x control. EPA's target for SO_2 removal alone is 50–70%; work to date has been limited, however, to laboratory-scale research. In a separate development, Japanese researchers have tested limestone injection at pilot scale with low-NO_x burners and achieved as much as 50% SO_2 removal.

Meantime, other tests show a range of 20–50% SO_2 removal, this performance variation being largely a function of limestone injection rate (as well as combustion conditions) and thereby closely controllable. Cost-effectiveness draws attention to the technology, completely apart from the implications for NO_x control. It appears capable of 40–60% SO_2 capture, roughly half that of a lime/limestone scrubber. Capital cost may be only \$15–\$50/kW, one-tenth to one-quarter of scrubber cost. The operating cost advantage is not as striking; the much larger quantity of limestone required results in a busbar electricity cost impact typically about half that of a wet scrubber.

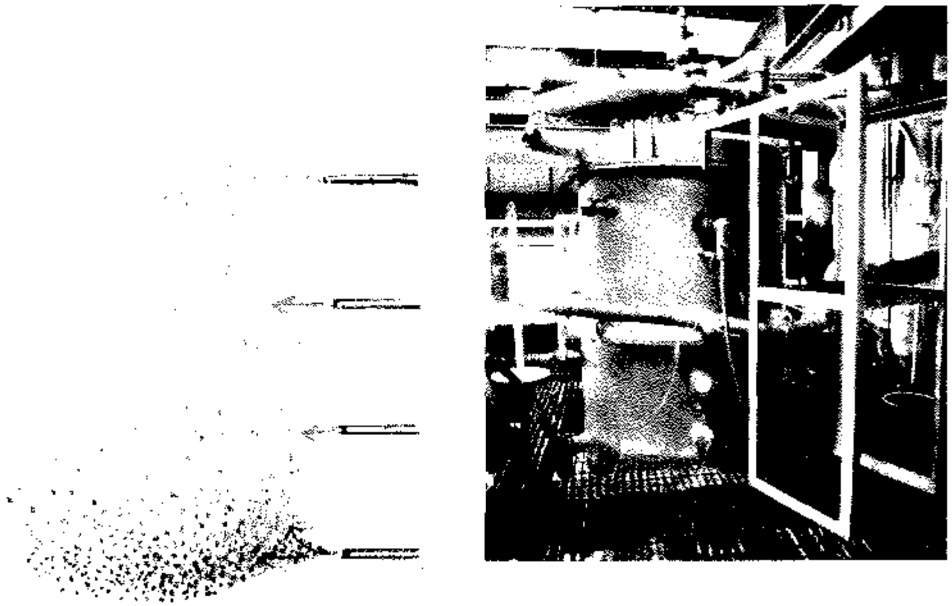
Limestone mass also causes a technical problem. It results in a high loading of solid particles in the flue gas, which could alter slagging and fouling behavior, produce erosion in the convection zone of the boiler, cause plugging of air heaters, and easily double the task of baghouse or precipitator, where the calcium sulfate particles are collected. The ash handling and disposal system could also be overloaded. Modifications necessary to resolve these problems can add substantially to the cost of installation. Although the possibility of improved SO_2 removal exists when the process is used in conjunction with low-NO_x conditions, the fouling, erosion, and corrosion problems that plagued earlier attempts at limestone injection remain to be resolved before commercially acceptable reliability can be assured.

A 300-MW demonstration by a German utility began nearly a year ago, and a 700-MW demonstration by a German boiler manufacturer is planned to start by the end of 1983. The latter incorporates a low-NO_x burner. Both programs seek SO_2 removal better than 60%, but such results, even if achieved, will not be directly transferable to U.S. experience because of differences in furnace designs and coal properties. German coal, for example, contains 1% or less sulfur, substantially reducing the limestone loading relative to U.S. high-sulfur coal, which contains 2–4% sulfur or more.

Taking full advantage of the German and Japanese results, and also of LIMB and other concepts for combined emissions control, EPRI-sponsored development of furnace limestone injection is planned to include laboratory work through 1984, prototype testing at 20–100 MW in 1986, and if successful, the startup of a 400-MW or larger utility demonstration in 1988.

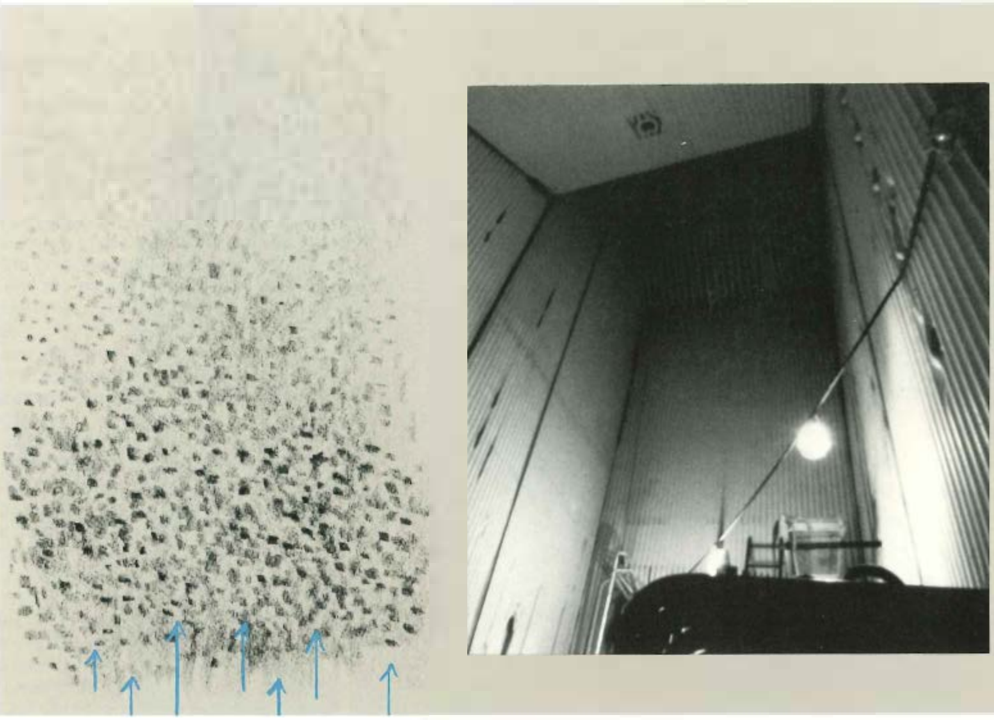
Fluidized-bed combustion

Fluidized-bed combustion (FBC) is important because of its inherently low SO_2 and NO_x emissions. The technology is



Furnace Injection of Limestone

Finely pulverized limestone can capture SO_2 from the gases in a conventional furnace when combustion conditions are controlled to suppress NO_x. Such combined reduction of boiler emissions is the subject of international R&D that ranges from pilot-scale combustor experiments to full-scale boiler tests.



Fluidized-Bed Combustion
Both SO_2 and NO_X emissions are curtailed in a fluidized combustion bed, where upwelling air suspends the burning coal among limestone particles. Rapid heat exchange holds the temperature down to suppress NO_X, and the churning limestone captures SO_2 as $CaSO_4$. Process development is moving from 20-MW pilot to 140-MW demonstration scale, and boiler retrofit criteria are being carefully considered.

not yet commercial at large-utility scale, but a 160-MW demonstration by EPRI with TVA, Duke Power Co., and the state of Kentucky will begin construction by 1985 at TVA's Shawnee station, near Paducah, Kentucky. Other utility demonstrations in the 100–200-MW range are also being considered.

The technology features a special furnace configuration in which a mixture of fuel and limestone is suspended and churned about in an upwelling flow of air. In terms of weight, the fluidized-bed particles exceed the fuel particles by 99:1, improving and stabilizing the heat transfer. Steam generator tubes are submerged directly in the fluidized bed, and heat exchange there is more efficient than at the water walls of a conventional boiler.

Just as with limestone injected into a pulverized-coal furnace, the limestone of a fluidized bed reacts to capture the evolving SO_2—in this case, 90% or more. Combustion can be maintained at about 1500°F (816°C), instead of twice that figure, which precludes slagging and also inhibits NO_x formation. This results in a design that has much greater fuel flexibility, thus reducing dependence on expensive high-quality coal.

The feasibility of converting existing pulverized-coal boilers to FBC offers an attractive opportunity to reduce emissions while providing increased fuel flexibility and generating capacity. EPRI studies furnish examples. Analysis of a 500-MW boiler six years ago showed that the cost of furnace modification then (including the outage time to do it) was greater than the cost for adding a retrofit scrubber.

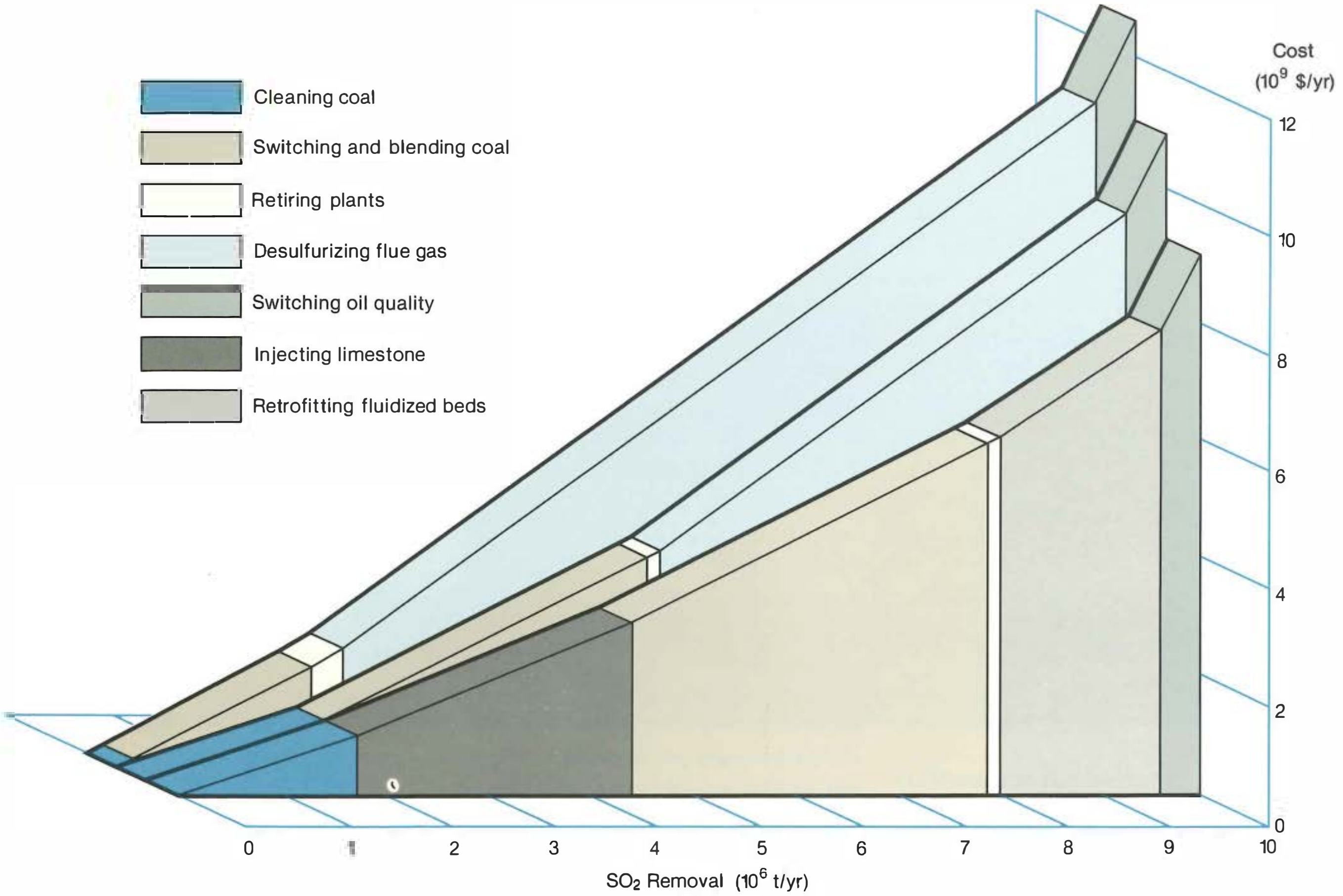
Since then, however, changing cost conditions plus improvement in FBC technology have led to reexamination of this option. Another boiler is now being studied that may benefit from these different circumstances. To cut SO_2 emissions, this 100-MW pulverized-coal unit on the Northern States Power Co. system was switched from an eastern bituminous to a low-sulfur western coal. The lesser heating value of the new fuel has forced a unit derating to 85 MW. Analysis is now under way to establish whether this boiler can be practically retrofitted with a fluidized bed to restore or even exceed the original 100-MW rating.

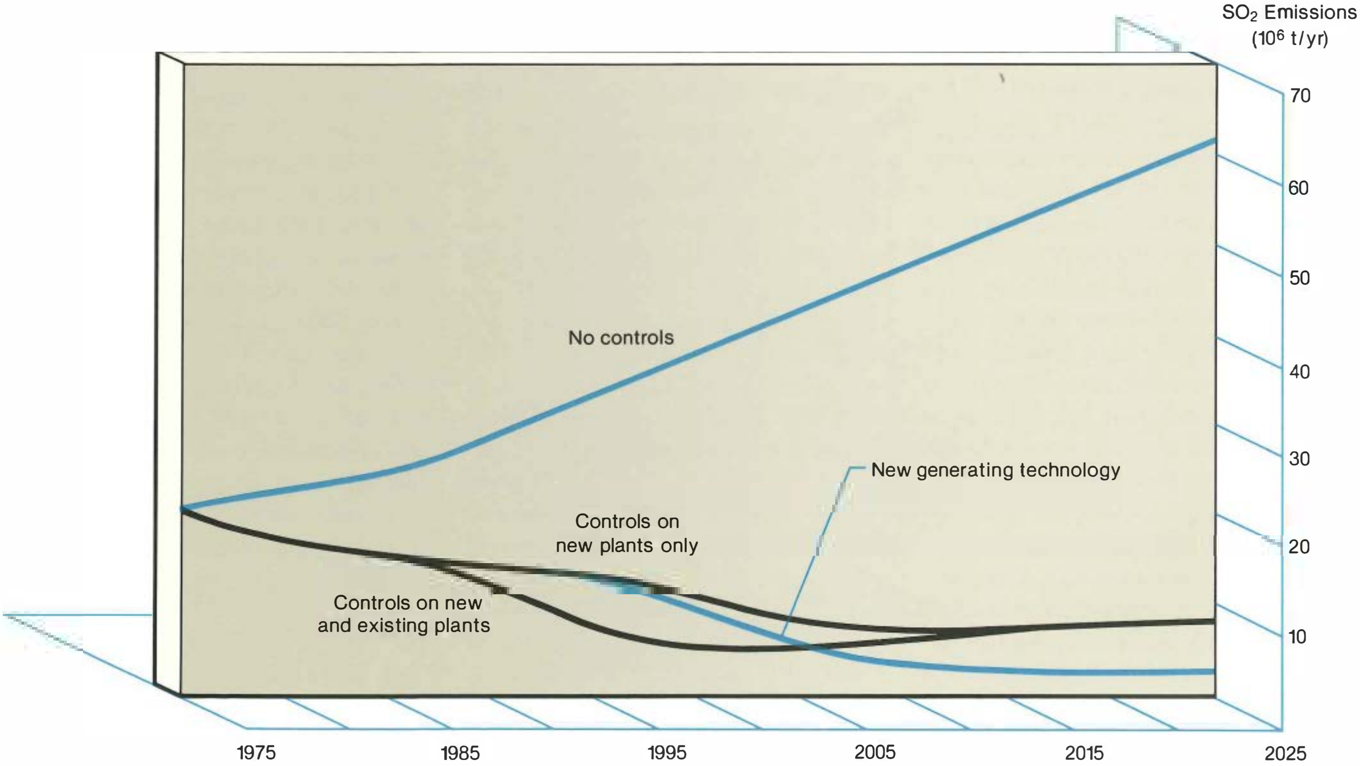
The key technical difference in these two cases appears to be the physical size of the boiler relative to its rated capacity. The 500-MW boiler was a late 1960s product, tightly designed for economy and therefore small, with a high heat release rate. The 100-MW boiler dates from the 1950s; it is a looser, more-conservative design, proportionately larger and therefore better suited to fluidized-bed conversion.

As these examples illustrate, retrofit is very plant-specific. In turn, this suggests that only a portion of coal-fired boilers can be modified with fluidized beds at reasonable capital cost. The greater promise for this option is as an alternative furnace-boiler design in new coal-fired power plants or as a replacement boiler to repower existing steam turbines.

Options in time

From the modification of the coal combustion process itself to the removal of


Cleaning coal
Switching and blending coal
Retiring plants
Desulfurizing flue gas
Switching oil quality
Injecting limestone
Retrofitting fluidized beds
Cost
(10^9 $/yr)
12
10
8
6
4
2
0
0
1
2
3
4
5
6
7
8
9
10
SO2 Removal (10^6 t/yr)


SO2 Emissions
(10^6 t/yr)
70
60
50
40
30
20
10
No controls
New generating technology
Controls on
new plants only
Controls on new
and existing plants
1975
1985
1995
2005
2015
2025

SO_2 and NO_x from the flue gas, the possibilities for retrofit emissions control span a variety of alternatives. Depending on the degree and urgency of what is decided for acid rain cleanup, the nation's pre-1971 coal-fired power plants will be subject to quite different combinations of corrective action, even including the outright retirement of plants that do not justify retrofit.

If, for example, the nation's decision makers choose to deal with the problem by electing an arbitrary and rapid reduction in SO_2 emissions of 10 million tons per year (as proposed by legislation), the control options become effectively limited to those currently available: plant retirements, low-sulfur-coal blending, coal cleaning, and flue gas scrubbers. This approach would involve plants totaling about 200,000 MW of capacity. Making allowance for many kinds of uncertainty, it might cost \$11–\$15 billion a year to execute, even if various institutional and contractual limitations can be resolved. The large out-of-pocket costs imposed by this approach are primarily due to heavy reliance on scrubbers for more than half of this capacity.

Alternatively, strategies that allow for more gradual reductions in emissions would both open the range of retrofit control options and encourage the use of those that cost least—particularly retirements, blending, and cleaning. Retrofit options under development, such as limestone injection and low-NO_x burners, may provide somewhat more cost-effective control but are probably limited in application and therefore have less potential for emission reduction.

Both of these scenarios offer something of a Band-Aid solution, and an expensive one at that. Besides the tremendous capital costs of add-on equipment or internal plant modification, most of the options incur additional penalties in efficiency and/or reliability.

A still longer-term view would include the approach of preserving capital to speed the development and transition to new coal generation systems that are inherently clean and more energy-efficient than current plants. New systems, such as fluidized-bed and gasification–combined-cycle plants, represent the concept that the use of coal for power generation is not fundamentally in conflict with a clean environment, and thus they have strong appeal as an ultimate solution. The potential for these new types of generation is great enough to introduce another trade-off consideration for decision makers: although they are at least several years from commercial readiness, they allow emission reductions to follow naturally from the current economic and environmental evolution of coal-fired plants. This would eliminate costly Band-Aid approaches that serve to freeze technology in today's plants and would, in the long run, provide improved emissions control in a more cost-effective manner.

The actual steps that the utility industry takes toward emissions control, and when and how they come about, will flow from R&D success and from the form of policy regulation that may be adopted. Whatever the future holds, the industry has a wealth of research results to apply to the acid rain problem. A successful solution will involve continued research and judicious choices among the answers now at hand and within reach. ■

Further reading

Kurt E. Yeager. Testimony prepared for a joint hearing on acid rain (Implications for Fossil Energy R&D). Subcommittee on Energy Development and Applications and Subcommittee on Natural Resources, Agricultural Research, and Development, House Committee on Science and Technology, September 20, 1983.

Michael W. McElroy. "Status of Retrofit Low-NO_x Combustion Control for Coal-Fired Utility Boilers." 76th Annual Meeting of the Air Pollution Control Association, Atlanta, Georgia, June 1983.

"Scrubbers: The Technology Nobody Wanted." *EPRI Journal*, Vol. 7, No. 8 (October 1982), pp. 6–15.

"Trade-offs in NO_x Control." *EPRI Journal*, Vol. 7, No.1 (January/February 1982), pp. 19–25.

This article was written by Ralph Whitaker. Technical background information was provided by Kurt Yeager, Callixtus Aulisio, Robert Carr, Stuart Dalton, Michael McElroy, Thomas Morasky, George Preston, Richard Rhudy, and Robert Row, Coal Combustion Systems Division.

The Costs of Control Strategies

Various strategies have the potential for controlling SO_2 emissions from existing fossil-fuel-fired power plants. Governed by different assumptions, the three strategies shown here call for different emphasis on different technologies to remove about 10 million tons of emissions annually—a total much under discussion today. In each case, the option at the left yields the greatest reduction of emissions per dollar spent, and the progressively steeper ramp portrays the cumulative annual performance and cost of other options.

The graph in back represents possible control responses assumed in the context of several recent congressional proposals. Annual performance and cost increments for each option have been estimated for the aggregate capacity (megawatts) of power plants likely to use that option. The combination of proposed federal law and present state laws and economic policies tends to discourage lower-cost options and encourage flue gas desulfurization. The total cost could be more than \$12 billion a year.

A more flexible approach, shown in the middle graph, would use the most cost-effective options to the fullest possible extent before more expensive options were called into play. Cleaning coal of all kinds would not reduce the emission rate to the same value at every plant, and increased switching to low-sulfur coal could have awkward implications for the economies of high-sulfur coal mining areas; but the otal technology cost for this strategy is somewhat ess, at about \$11 billion a year.

The more varied mix of options in the front graph vould be a possibility perhaps four or five years from now. Predicated on utility industry and federal R&D, t relies heavily on new technology—in this example, urnace-injected limestone and fluidized beds in retrofitted boilers, which together reduce overall emisions by as much as flue gas desulfurization can oday. The greater cost-effectiveness of the two new ptions reduces the overall cost of this strategy to erhaps \$9 billion a year.

tility Emission Trends

ontrols imposed on new power plants, beginning in e early 1970s, have yielded significant reductions in O_2 emissions at a cost of about \$6 billion a year. nese emissions are continuing a decline and by the ar 2000 are expected to be only about a third of what ey would have been without controls. Proposed legisation to extend control measures to the rest of the nan's existing fossil-fuel-fired plants could decrease O_2 further, but at a likely cost of \$12 billion a year. In years, the next generation of coal plants, based on nerently cleaner technologies, such as fluidized-bed mbustion and gasification–combined cycle, will offer eater emission reductions than achievable by retrofitg today's plants.

Federal Acid Rain Research

Providing a coordinated response to an issue of national concern is the objective of the federal Interagency Task Force on Acid Precipitation, charged with administering a national acid rain research program.

The U.S. Interagency Task Force on Acid Precipitation is taking the lead to plan, implement, and manage the federal government's acid rain research program—the National Acid Precipitation Assessment Program. Resulting from the Acid Precipitation Act of 1980 and commencing in 1981, the national program represents a concerted, nationwide research effort to improve our understanding of the causes, effects, and possible answers to the acid rain question. The program involves over 200 projects and hundreds of scientists in government, academia, and the private sector.

Truly an interagency effort, the statutory task force is chaired jointly by three federal entities: the National Oceanic and Atmospheric Administration (NOAA), the Department of Agriculture (USDA), and the Environmental Protection Agency (EPA). In addition, nine other federal groups participate, each represented by the highest ranking person responsible for the research program in that agency. They include the departments of Commerce, Energy (DOE), Health and Human Services, Interior (DOI), and State (DOS); the Council on Environmental Quality; the National Aeronautics and Space Administration; the National Science Foundation (NSF); and the Tennessee Valley Authority.

These federal groups work in close cooperation with one another to integrate preexisting acid rain research, to assess current findings, and to coordinate and plan future efforts. But this cooperation is not limited to just the federal government. The program also seeks the involvement of other groups concerned with acid rain, such as private industry, environmental groups, academia, state and local government, other federal activities not funded under the national program, and other countries.

To facilitate this public and private cooperation, President Reagan appointed three members of the private sector to the task force: Ralph Perhac, director of the Environmental Assessment Department of EPRI's Energy Analysis and Environment Division; John McKetta, professor of chemical engineering at the University of Texas; and James Mahoney, senior vice president of Environmental Research and Technology, Inc. Each appointee offers a unique perspective. Perhac comments, "I can contribute some very detailed knowledge of what is going on in acid rain research at EPRI. In so doing, I can alert the task force about duplication or gaps in the research and seek to coordinate our efforts."

Other participants, rounding out the 20-member task force, include the directors of Argonne, Brookhaven, Oak Ridge, and Pacific Northwest national laboratories.

Research Coordination

Of the twelve federal agencies and departments involved in the U.S. Interagency Task Force, five provide virtually all the program's core acid rain budget—$22 million for FY1983. These five are coordinating the research: EPA (51.3%); DOI (16%); USDA (13.3%); NOAA

(10.1%); and DOE (9.2%). Although the remaining seven departments do not perform research under the program's core budget per se, their involvement is integral, as each has expertise in specific areas relevant but not limited to acid rain research. For instance, NSF sponsors about $1.5 million in basic research germane to the core national program but not specifically focused on the program's applied objectives. This provides a pool of funding for important research whose immediate relevance to solving the problem is not yet evident.

Coordination is needed in instances where research under way is considered germane to understanding better the acid rain phenomenon but is not funded directly under the national program. In fact, the success of the long-term program depends heavily on the ability to integrate the work of many groups, most of which have been performing acid rain research of different kinds for several years. This requires continual interaction between the task force and research participants.

The national program has a 10-year authorization, after which time Congress will review the need for continuing the coordinated research effort. However, the task force is responsible for reporting annually to the president, Congress, and the nation on the program's progress, state of the science, and policy implications.

J. Christopher Bernabo from NOAA serves as executive director of the national program. With the help of his program coordination staff, he serves as a liaison for all the groups involved. "As executive director, I do not represent any one agency but am responsible for the program's overall direction and implementation. The program coordination office is the focal point for planning and managing the national program. We manage the day-to-day activities of the task force and perform other functions, such as developing management plans, budgets, and annual reports. We are funded by all the agencies involved and report to the joint chairmen but are physically located at the Council on Environmental Quality."

As highlighted in its 1982 annual report, some of the accomplishments already achieved during the national program's first year of research are the creation of a nationwide map illustrating regions where surface waters are thought to be most vulnerable to acidification; production of a critical assessment document defining the status of scientific knowledge on the causes and effects of acid rain; development of models to predict cost and emission changes for utilities and industries on the basis of various control strategies; and testing of the limestone injection multistage burner (LIMB) system to simultaneously reduce sulfur dioxide and nitrogen oxide emissions from utilities by 50%.

With guidance from the joint chairmen and Bernabo, the task force sets research goals, identifies projects needed to meet those goals, and decides which agencies are best suited to perform the needed work. According to Bernabo, "First we look at how to apportion the resources in the abstract—what research is needed, rather than who does it. Then we go through a negotiation procedure to decide who performs the needed work." What makes this federal program unique is that during the process each agency must justify its proposed work on the basis of the national objectives, rather than on the agency's more parochial mission needs. "By working together in developing a single interagency budget, we are avoiding unnecessary duplication and crucial gaps in the total federal effort," Bernabo adds.

To plan and implement an integrated research effort addressing the goals of the national program, the task force has established nine research categories. The percentage of the FY1983 $22 million budget total spent on these nine categories is as follows: natural sources (3.1%); man-made sources (6.1%); atmospheric processes (23.5%); deposition monitoring (19.3%); aquatic effects (15.1%); terrestrial effects (19.9%); effects on materials and cultural resources (4.5%); and assessments and policy analysis (8%). The remaining research category, control technologies, is not included in the total budget, as the funds for the general development of SO_2 and NO_x control hardware are appropriated under preexisting programs. This task group coordinates its efforts with the assessment and research activities of the national program.

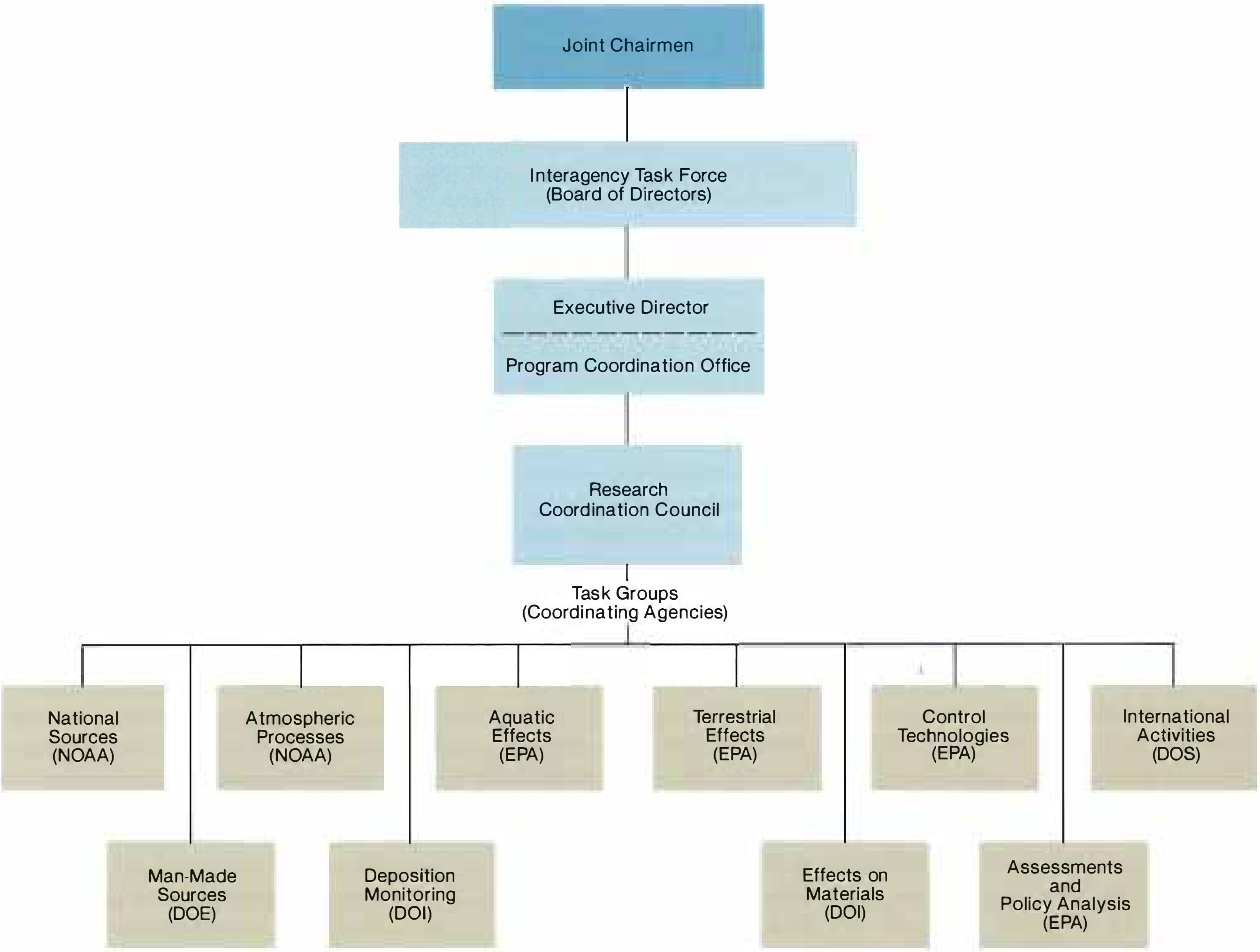
Organization and Funding

Assigned to each research category is a working-level task group. Although one agency has been given charge of each task group, program managers and experts from all the participating federal entities and national laboratories are detailed to these areas to perform research as directed. For instance, several agencies are involved in atmospheric processes research; even though NOAA is the lead agency, EPA, DOE, and DOI all participate.

These task groups meet several times a year to plan research and assess progress. Peer review panels composed of outside scientists evaluate the plans and progress of each group on the basis of its scientific merit and how well the research addresses the goals of the national program. In addition, the leaders of each of the task groups sit on a research coordination council chaired by Bernabo, which in turn reports to the entire task force. This ensures that the people performing the work are also involved in the planning of the program.

As Bernabo explains, "Instead of making a large central bureaucracy, we de-

National Acid Precipitation Assessment Program



pend on the involvement of both the generals and the troops with a lean staff. The up side is that plans are more easily implemented because those responsible for their implementation had input into their creation. The down side is, of course, that it is a slow process as there are many actors." By many actors, Bernabo refers to the 70 or so individuals who sit on the various task groups in addition to about 20 task force members. Each task group relies heavily on contractors to perform the work, which in turn adds to the number of people involved.

In addition to contributing to the overall planning process, each task group presents its interagency budget proposal to the task force. Appropriate acid rain research budgets for each federal entity are established and ultimately sent to the Office of Management and Budget for approval. Through coordinating and approving the interagency budget, the task force exercises control over how that money will be spent and how a project should be directed. "A problem we face, however, is that funds cannot flow directly through the task force, as a task force cannot be authorized to spend dollars. Rather, the funds flow through each of the agencies. So the spigot, if you will, has many different heads," Bernabo notes.

The problem is exacerbated when each agency's budget goes to Congress for authorization. Because Congress does not see the acid rain budget as a whole, changes imposed in the budgeting process can cause fragmentation of the overall program. Suddenly the integrated effort becomes unbalanced. "The point is, the closer the integration, the more interdependence. If one participant, for any reason, falls out, there's a definite hole. It's like someone not showing for a potluck dinner. If that person was supposed to bring the dessert and he doesn't show, everyone's out of dessert," Bernabo remarks. Overall, however, Bernabo believes that this kind of integrated framework can work effectively. "Congress mandated that we work in an interagency mode because no single agency has the research breadth or funding to cover all aspects of the acid rain issue. Given this interagency structure, I don't see any better way to pull the pieces together and squeeze down the information in a form useful to the policy people."

Policy Assessment Activities

The need for this distilled information is the justification for the Assessments and Policy Analysis Task Group. Composed of individuals from all the task force agencies, this group attends all the task group review sessions to ensure that the groups' work is compatible and consistent. The assessment group also pulls all the data together in a format from which an integrated assessment can be made. According to Bernabo, "The first integrated assessment, due in FY1985, will look at the scope of the damage from acid rain in both ecologic and economic terms. And we're going to quantify the level of uncertainties in areas where we're unable to give definitive answers." By 1987 Bernabo hopes the assessment group will have enough information about these uncertainties to begin to say more in terms of models and projections. Ultimately, the assessment group is expected to present policy options based on its findings to the administration, Congress, and the public. A full-time interagency acid deposition assessment staff has been established to ensure the work gets done in an integrated manner. This group reports through the research coordination council to the executive director and joint chairmen.

The difficulty arises when the task force tries to translate the science into policy options. By law, EPA, not the task force, is responsible for promulgating any emissions regulations to abate acid rain. The task force is charged with improving the scientific basis for informed decisions by EPA, Congress, states, and private sector managers. Bernabo explains that thorough scientific research cannot be done overnight. He notes, "There are a lot of questions that science cannot yet answer. Some may never be adequately answered. But we feel that within the next 5 to 10 years we should be able to provide a firmer basis for policy decisions and specify the range of uncertainties for the still unanswered questions."

Some of the questions the national program is specifically addressing are, What are the current and potential effects of acid deposition on a regional basis? What is the relative contribution of man-made versus natural sources of acid-forming material? What is the quantitative relationship between the release of precursor pollutants into the atmosphere and the deposition of acidic materials? What are the costs and environmental impacts of these effects, as well as the economics of controlling pollutant emissions?

The search for answers to these questions, however, is not unique to this task force. Acid rain is an issue of international concern as well, and the task force is looking at data collected overseas.

Additional Research Cooperation

To assist in answering these concerns, an additional task group, international activities, exists and is chaired by the Department of State. One of the chief objectives of the group is to establish a basis for increased cooperation between the United States and Canada on research and monitoring activities. Although the Canadians do not have a formal, national acid rain plan, since 1981 they have had in place the Research and Monitoring Coordinating Committee, which is quite similar to the U.S. Interagency Task Force. This committee pulls together research efforts under way, with the Canadian provinces sponsoring about 50% of the total acid rain research funding, and the remainder provided by the Canadian federal government. This contrasts with the U.S. research program, where the federal government is the largest sponsor of the research and the states sponsor much more modest efforts.

Interestingly, Bernabo cites, "A little known fact is that the Canadians are spending $20 million per year in research, too. That's almost as much as we are, and per capita, nearly 10 times what we are spending." According to Bernabo, the Canadians and Americans have an excellent working relationship and build on each other's programs. In some cases, Canada and the United States are pursuing research jointly. For example, they are cooperating on a cross-Appalachian tracer experiment (CAPTEX) to help determine long-range pollutant transport patterns and facilitate evaluation of atmospheric models. Another partner in the CAPTEX project is EPRI, whose involvement in acid rain research predates the coordinated national effort.

EPRI's environmental acid rain research program is second only to the federal government's, amounting to nearly $15 million a year. Bernabo commends the cooperation existing between EPRI and the national program on all levels: as researchers, scientists, and reviewers. "We feel very confident in the areas where EPRI is funding research. We don't have to duplicate its research; on the contrary, we draw on the results of its program." Perhac also comments, "EPRI's research program and the federal government's are quite compatible, even though we may take a slightly different approach in specific research areas. Our two programs have been complementary from the very beginning, and representatives from DOE and EPA have been part of EPRI's advisory structure ever since we started our acid rain program. I work with many of these same people now through the task force." Such complementary work is commonplace with the federal government's acid rain research program.

Other Studies

There are several major acid rain studies already completed, each assessing different aspects of the acid rain phenomenon. Confusion can exist in distinguishing between the roles of these various acid rain groups, and although seeming to overlap, each group has quite a distinct role.

For instance, the National Academy of Sciences (NAS) has already completed two studies relevant to acid rain. The first, dedicated to studying the effects of energy technologies on the atmosphere and biosphere, devoted one chapter to acid deposition. "It only looked at one portion of the acid rain issue—from the ecology standpoint. How is acid deposition affecting aquatic systems? The report did not address the question of what happens in the atmosphere between the time pollutants are emitted from a stack and deposited on the ground," Bernabo explains.

To further examine this question, NAS created a panel, on its own initiative, to assess the current state of knowledge about atmospheric processes that could assist in better understanding the relationship between emissions and deposition. A third study is planned by the academy to examine long-term trends in such areas as precipitation and atmospheric chemistry.

The Office of Science and Technology Policy, on the other hand, commissioned a review panel headed by William Nierenberg, director of Scripps Institution of Oceanography, to analyze the science in the working group reports prepared under the Memorandum of Intent between Canada and the United States. Under this bilateral agreement, several acid rain reports were jointly produced by scientists from each country. Among other studies in progress focusing on different aspects of acid rain are work by Congress's Office of Technology Assessment on long-range transport of pollutants, and the Congressional Research Service's study on current and potential emission mitigation technologies.

Outlook for Research

Although there are an enormous number of acid rain studies completed, in progress, or planned, there are also many acid rain bills currently before Congress. In fact, to date over 10 pieces of legislation have been introduced. If acid rain legislation is passed in the near future due to widespread congressional concern, would there be a need for the nation's acid rain research program? Bernabo answers, "We're spending on the federal level about $22 million a year in acid rain research. That amount is trivial compared with the cost of controls and the cost of potential damages. Any solution to the acid rain problem is going to require both additional research and some form of mitigation action. Unfortunately, the research is not to the point where it can pinpoint what action would be most effective and least costly." He also points out, "Our inability to really specify the nature of the acid rain problem is because the government wasn't doing long-term research earlier. If it had, we might be able to answer many of the questions today." ■

This article was written by Ellie Hollander, Washington Office.

New Contracts

Advanced Power Systems

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP714-5	Agglomeration Demonstration and Production-Run Test	5 months	134.4	Allis-Chalmers Corp. *W. Weber* *H. Lebowitz*
RP986-12	CO_2: Ocean-Atmosphere Interaction	1 year	69.7	Scripps Institution of Oceanography *W. Reveal*
RP1597-1	Evaluation of Irradiated Metal Samples for Use in Fusion Components	10 months	194.9	McDonnell Douglas Astronautics Co. *K. Billman*
RP1597-2	Radiation Damage and Performance Analysis of Ferromagnetic Steels for Fusion Applications	11 months	100.0	University of Wisconsin—Madison *K. Billman*
RP1897-2	Workshop: Fuels and Combustion Problems of Oil- and Gas-Fired Utility Boilers	6 months	30.0	Energy Systems Associates *W. Rovesti*
RP1990-2	Additional Studies on Water/Steam Rankine-Cycle Solar Central Receiver Power Plants	5 months	75.6	Bechtel Group, Inc. *S. Kohan*
RP1996-12	Turbulent Response of Wind Turbines	7 months	154.1	Battelle, Pacific Northwest Laboratories *F. Goodman*
RP1996-13	Wind Turbine Test Support	1 year	68.5	Oregon State University *F. Goodman*
RP2003-4	Test Plan Preparation: Solar Total Energy Project	5 months	88.3	Rockwell International Corp. *J. Cummings*
RP2048-5	Materials Evaluation and Development for CGCC Plants	27 months	102.6	Tennessee Valley Authority *W. Bakker*
RP2102-1	High-Temperature Measuring System for Gas Turbines	30 months	278.6	Kaman Instrumentation Corp. *C. Dohner*
RP2147-8	Investigation of Deleterious Coking Mechanism	6 months	39.6	Air Products and Chemicals, Inc. *H. Lebowitz*
RP2196-2	10-MW (e) Solar Pilot Plant; Evaluation of Colorgraphic Display and Digital Control Systems	9 months	173.3	Honeywell, Inc. *J. Bigger*
RP2387-1	Product Feasibility Assessment: Advanced Power Generation Technology	5 months	82.2	Decision Focus, Inc. *A. Cohn*
RP2524-1	Requirements for Gasification-Based Plant Simulation, Using Advanced Microprocessor Systems	10 months	98.4	Esscor, Inc. *G. Quentin*
RP2532-1	Evaluation of Liquid Phase Methanol Demonstration	6 months	142.1	Chem Systems, Inc. *H. Lebowitz*

Coal Combustion Systems

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP983-15	Workshop: CONAC Technology	9 months	40.0	Raymond Kaiser Engineers, Inc. *O. Tassiker*
RP1184-4	Startup Strategy: Analytic Evaluation Technique	14 months	192.9	Babcock & Wilcox Co. *F. Wong*
RP1260-41	SO_2–NO_x Emission Reduction Requirements, Phase 1	4 months	72.8	KVB, Inc. *M. Miller*
RP1870-4	Full-Scale Spray Dry FGD Evaluation	5 months	264.8	Radian Corp. *R. Rhudy*
RP2422-2	Properties of Concrete Containing Fly Ash	7 months	27.3	University of California at Berkeley *D. Golden*
RP2428-1	PFBC Turbocharged Boiler Design and Economic Study	10 months	266.5	Fluor Engineers, Inc. *S. Drenker*

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager

Electrical Systems

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP1095-16	Field Testing: Galloping Control	2 years	191.4	VTC Industries Inc. *P. Landers*
RP1142-3	Development of a 38-kV Current-Limiting Protector	22 months	268.8	Phoenix Electric Corp. *J. Porter*
RP1290-3	Amorphous Steel for Transformers	18 months	2168.3	Allied Corp. *E. Norton*
RP1529-2	Electric Generation Expansion Analysis System	14 months	105.0	Stone & Webster Engineering Corp. *N. Balu*
RP1717-6	Operations: TLMRF Structural Development Program	5 years	5912.5	Sverdrup Technology, Inc. *P. Lyons*
RP2016-3	Research Tasks: TLMRF Structural Development Program	41 months	2142.1	Sverdrup Technology, Inc. *P. Lyons*
RP2335-1	Research: Unexplained Outage	38 months	276.8	Sierra Pacific Power Co. *R. Kennon*
RP2444-2	Development and Evaluation: Interactive Protection System	10 months	44.8	University of Washington *J. Mitsche*
RP7897-1	Basic Dielectric Materials Research: Characterization of Insulation Materials	25 months	423.9	University of Connecticut *B. Bernstein*
RP7897-3	Development of Moisture Barriers for Extruded Dielectric Cables	22 months	231.5	Springborn Laboratories, Inc. *B. Bernstein*

Energy Analysis and Environment

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP799-18	Design and Testing of a Small-Animal Electric Field Exposure Facility	8 months	151.4	Electric Research & Management, Inc. *R. Kavet*
RP1616-27	Plume Model Development and Evaluation—Hybrid Approach	28 months	760.7	Environmental Research and Technology, Inc. *G. Hilst*
RP1813-5	Assessemnt: Acidic Precipitation Effects Data Base	5 months	41.6	A.S.L. Associates *R. Kawarantani*
RP1826-13	PCB Exposure Assessment for Making Risk Assessment	17 months	121.0	Anderson Nichols & Co. *A. Silvers*
RP2045-3	Demonstration: Market Penetration Analysis Methods	10 months	40.5	Applied Decision Analysis, Inc. *E. Beardsworth*
RP2141-6	Decision Framework for CO_2 Research	5 months	50.0	Applied Decision Analysis, Inc. *D. Fromholzer*
RP2198-7	Specialized Analysis of Environmental Settings Data Base	7 months	29.8	Envirosphere Co. *I. Murarka*
RP2369-22	Petroleum Coke Markets for Utilities	6 months	30.0	The Pace Co., Consultants & Engineers, Inc. *H. Mueller* *S. Alpert*
RP2369-30	Regional Electric Utility Fuel Markets (California and Northeast)	4 months	99.5	Charles River Associates *J. Platt*
RP2369-40	Analyzing Natural Gas Market Uncertainties	8 months	75.0	Applied Decision Analysis, Inc. *J. Platt*
RP2381-3	Planning Research in Conservation Analysis	6 months	25.00	Union Carbide Corp. *S. Braithwait*
RP2381-5	Innovative Rate Design Survey	2 months	53.0	Ebasco Services, Inc. *J. Chamberlin*
RP2441-1	Model Development in Support of the Planning and Evaluation Division	1 year	140.0	Applied Decision Analysis, Inc. *L. Rubin*

Energy Management and Utilization

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP1081-4	Feasibility Analysis: Mini-CAES Cycle	5 months	69.7	Gibbs & Hill Inc. *R. Schainker*
RP1081-5	Energy Storage: Technical Support Services	6 months	25.0	Bechtel Group, Inc. *R. Schainker*
RP1136-20	Evaluation, Test, and Procurement of Advanced Zn-CL_2 Battery-Powered Electric Van	9 months	211.5	Energy Development Associates *B. Askew*
RP1833-2	LOADSIM Technology Transfer	6 months	99.7	ECC, Inc. *T. Yau*
RP1967-8	Assessment of Membrane Technology Applications	8 months	50.0	SRI International *A. Karp*
RP1967-9	Potential Utility Impact of Supercritical Fluid Separation Processes	4 months	39.9	Arthur D. Little, Inc. *A. Karp*
RP2034-6	Utility-Sponsored Residential Conservation Program Effectiveness: Low-Income Customer Weatherization	4 months	25.0	ICF, Inc. *G. Purcell*
RP2034-9	Commercial Refrigeration Research Plan	8 months	87.5	Science Applications, Inc. *A. Lannus*
RP2035-6	Evaluation: Commercial Building Energy Management	7 months	65.6	JRB Associates, Inc. *G. Gurr*
RP2285-5	Lighting Effectiveness Research Plan	4 months	87.5	Lighting Research Institute, Inc. *A. Lannus*

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP2416-16	Plasma Mesabi Metal	6 months	50.0	Minnesota Power & Light Co. *L. I. Harry*
RP2418-2	Improved Luminaire Calorimetry	3 months	32.5	Building Acoustics and Lighting Laboratories, Inc. *A. Lannus*

Nuclear Power

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RPX101-1	Zircaloy Corrosion Properties Under LWR Coolant Conditions	26 months	750.0	Centre d'Etudes Nucléaires de Cadarache *A. Machiels*
RP1166-4	High-Temperature Aqueous Cracking of Ni-Cr-Fe Alloys	1 year	149.7	Massachusetts Institute of Technology *A. McIlree*
RP1252-9	Incorporation of EPRI–CELL Data Libraries in EPRI/CMP	16 months	93.6	S. Levy, Inc. *O. Ozer*
RP1393-8	Reliability Analyses of Refueling Outages	9 months	138.1	Westinghouse Electric Corp. *T. Law*
RP1628-6	Poolside Examination of B&W-Type Ag-In-Cd Rods	43 months	119.1	Duke Power Co. *J. Santucci*
RP2135-11	Aerosol Formation and Transport in LWR Primary System	1 year	79.8	Argonne National Laboratory *F. Rahn*
RP2180-9	Distribution Characterization for Pressurized Thermal Shock	6 months	80.5	Materials Research & Computer Simulation, Inc. *D. Norris*
RP2184-2	Use of CRT Display Guidelines	13 months	42.1	Search Technology. Inc. *J. O'Brien*
RP2225-2	Industry Piping Design Practice and Large-Diameter Piping Test	6 months	98.8	Tennessee Valley Authority *Y. Tang*
RP2227-3	Verification of Simplified Piping Design Handbook	5 months	59.3	Duke Power Co. *R. Nickell*
RP2290-1	Analytic Modeling: Two-Phase Pump	21 months	186.2	Tetra Tech, Inc. *J. Kim*
RP2290-2	Two-Phase Flow Testing of a Flow Visualization Pump	13 months	71.1	Davis Engineering, Limited *J. Kim*
RP2290-3	Pump Trip Criteria and Transient Identification Technique for PWRs	10 months	99.0	EG&G Idaho, Inc. *S. Divakaruni*
RP2394-8	Task Order: Probabilistic Risk Assessment and Safety Assessment	11 months	30.0	Nucon, Inc. *W. Sugnet*
RP2405-3	Physically Based Crack Sizing Method for Use with AMAPS Data	6 months	50.2	Ultrasonics International, Inc. *S. Liu*
RP2405-4	Development of Signal Processing Technique for Automated Crack Sizing	5 months	50.5	Southwest Research Institute *S. Liu*
RP2406-2	Thermal Analysis of Consolidated Fuel	10 months	65.0	Battelle, Pacific Northwest Laboratories *R. Lambert*
RP2407-1	Guidelines: Nuclear Power Performance Data Aquisition	7 months	131.0	Combustion Engineering, Inc. *N. Hirota*
RP2409-1	Project Planning: Field-Hardened Instruments and Electrical Components for Nuclear Plant Applications	4 months	54.2	Science Applications, Inc. *R. Kubik*
RP2430-10	Financial Simulation Model: Large-Scale Prototype Breeder	1 year	50.0	Argonne National Laboratory *D. Gibbs*
RP2430-11	Demonstration of Flow Coupler for the LMFBR	6 months	158.5	Westinghouse Electric Corp. *D. Gibbs*
RP2430-15	Robots for Maintenance, In-service Inspection, and Maintainability of Large Components, Large-Scale Prototype Breeder	9 months	184.5	Westinghouse Electric Corp. *D. Gibbs*
RP2451-1	Instrumented Steam Generator at Palo Verde-1	23 months	225.0	Combustion Engineering, Inc. *L. Williams*
RP2471-1	Guidelines: Surveillance Testing of Standby Emergency Pumps	1 year	95.7	Mollerus Engineering Corp. *J. Matte*
RP2507-1	Software Development: Probabilistic Risk Assessment	5 months	29.9	Science Applications, Inc. *D. Worledge*

Planning and Evaluation

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP2342-3	Changes in Customers' Load Shapes in Response to Utility Load Management Programs	6 months	51.1	Angel Economic Reports *K. Miller*

R&D Staff

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP128-9	Degradation Mechanisms of Beta Alumina Electrolytes	1 month	43.3	Department of Energy *W. Bakker*
RP2426-3	Mechanical Properties of Novel High-Temperature Alloys Capable of Forming Protective Silica Scales	9 months	85.8	Battelle Memorial Institute *J. Stringer*

New Technical Reports

Each issue of the *Journal* includes information on EPRI's recently published reports.

Inquiries on technical content may be directed to the EPRI project manager named at the end of each summary: P.O. Box 10412, Palo Alto, California 94303; (415) 855-2000.

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ADVANCED POWER SYSTEMS

Coal Gasification Systems: Guide to Status, Applications, and Economics

AP-3109 Final Report (RP2207); $31.00

This report contains current and consistent information about the status, potential utility applications, and economics of coal gasification technologies that have already been demonstrated at commercial scale or that are close to commercial practice. EPRI-developed capital and operating costs are presented for these technologies. For comparison, performance and cost estimates are also provided for coal-fired steam plants, oil-fired steam plants, and oil- and gas-fired combined-cycle and combustion turbine plants. The contractor is Synthetic Fuels Associates, Inc. *EPRI Project Managers: M. J. Gluckman and A. E. Lewis*

Interconnecting DC Energy Systems: Responses to Technical Issues

AP/EM-3124 Final Report (Special Issues Assessment 82-412); $11.50

This report summarizes the viewpoints of more than 80 organizations and individuals involved in the integration of dc power systems into utility distribution systems by means of solid-state power-conditioning equipment. Functional utility interface requirements are presented for isolation, grounding, and interconnection; and various operational issues (e.g., startup, loss of utility, harmonics, reactive power, feeder balancing, and safety) are discussed. The contractors are Systems Control, Inc., and James B. Patton. *EPRI Project Managers: R. W. Taylor and R. J. Ferraro*

EDS Coal Liquefaction Process Development

AP-3128 Annual Report (RP778); $43.00

This sixth annual report on Exxon Donor Solvent (EDS) process development covers the period from July 1, 1981, to June 30, 1982. Project activities focused on EDS pilot plant operations conducted with bottoms recycle under liquefaction conditions of increased severity. The report summarizes test runs with both subbituminous and bituminous coals. The necessary information is now available to design a commercial-size EDS process plant that can be operated on these two coals. The contractor is Exxon Research and Engineering Co. *EPRI Project Manager: N. H. Hertz*

Shell-Based Gasification–Combined-Cycle Power Plant Evaluations

AP-3129 Final Report (RP239); $28.00

This report describes a detailed engineering and economic evaluation of Shell-based integrated gasification–combined-cycle (IGCC) power plants using current-technology combustion turbines (2000°F firing temperature). A consistent cost and performance comparison is presented for a Shell-based IGCC plant firing Illinois No. 6 coal and a Texaco-based IGCC plant operating under equivalent conditions. The results indicate that the performance and costs of these plants are comparable. The contractor is Fluor Engineers, Inc. *EPRI Project Managers: M. J. Gluckman and A. E. Lewis*

COAL COMBUSTION SYSTEMS

6- × 6-ft AFBC Development Facility: 1980 Test Results

CS-3115 Interim Report (RP718-2); $26.50

This report, the second in a series, presents the 1980 test results from the 6- × 6-ft atmospheric fluidized-bed combustion (AFBC) test facility. In 1980 significant data were developed in the areas of fly ash recycling, coal and limestone particle size, fluidization velocity, and lignite combustion. The contractor is Babcock & Wilcox Co. *EPRI Project Manager: C. J. Aulisio*

Wet-Dry Cooling-System Assessment Program

CS-3130 Final Report (RP422-10); Vol. 1, $8.50; Vol. 2, $11.50; Vol. 3, $17.50

This report documents the development of a program for assessing the performance of a commercial wet-dry cooling installation. Volume 1 is an executive summary. Volume 2, the management plan, presents the program task descriptions and reporting requirements and discusses project control. Volume 3, the program execution plan, addresses the testing, computer modeling, and engineering analysis efforts. The contractors are United Engineers & Constructors, Inc.; Environmental Systems Corp.; and Public Service Co. of New Mexico. *EPRI Project Manager: J. A. Bartz*

Laboratory Fire-Side Corrosion Evaluation of Improved Superheater Tube Alloys and Coatings

CS-3134 Final Report (RP644-1); $10.00

Tests were conducted to examine possible solutions to fire-side corrosion of superheater and reheater tubes exposed to high-alkali coal-burning systems. These laboratory tests involved several promising new alloys and coatings identified in an earlier study. The objectives were to optimize alloy composition and to evaluate corrosion resistance in longer-term cyclic exposures. The contractor is Foster Wheeler Development Corp. *EPRI Project Manager: John Stringer*

Detection of Water Induction in Steam Turbines: Field Evaluation

CS-3135 Final Report (RP637-1); $13.00

This report describes the second phase of a study to determine the suitability of various instrumentation systems for detecting the presence of water in steam pipes. In this phase, temperature, pressure, and acoustic sensing systems were installed at a power plant and their outputs monitored on a dedicated digital data acquisition system. The temperature and acoustic systems operated satisfactorily, but the dynamic pressure system was too fragile for routine utility operation at elevated temperatures and pressures. The contractor is Westinghouse Electric Corp. *EPRI Project Managers: J. B. Parkes and T. H. McCloskey*

Development of Low-Pressure Turbine Coatings Resistant to Steam-Borne Corrodents

CS-3139 Interim Report (RP1408-1); Vol. 1, $14.50; Vol. 2, $13.00

This report documents the screening-test phase of a project to identify one or more coatings that will prevent or reduce corrosion-related failures of blades and disks in low-pressure steam turbines. Volume 1 describes laboratory salt spray tests and fatigue tests of the candidate coatings. Volume 2 presents results from field tests of coated U-bend specimens in a low-pressure steam turbine; it also summarizes the laboratory tests and discusses the status of experiments initiated to study the most promising coatings in more detail. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: B. C. Syrett*

Coal-Oil Mixture Test at Florida Power & Light Co., Sanford No. 4

CS-3155 Final Report (RP1895-5); $14.50

This report summarizes a one-year demonstration test of coal-oil mixture (COM) fuel at Florida Power & Light Co.'s Sanford Unit 4. It discusses the construction and operation of a 10,000-bbl/d COM preparation plant, the burning of COM with a maximum coal concentration of 50 wt%, and an analysis of the test results. The report concludes that from a technical point of view, COM is a viable alternative fuel for use in a liberally designed utility steam generator. The contractor is Florida Power & Light Co. *EPRI Project Manager: R. K. Manfred*

Preliminary Feasibility Analysis of Shop-Assembled, Barge-Shipped PFB Steam Generators

CS-3156 Final Report (RP1180-15); $16.00

This report discusses the feasibility and economics of assembling 500-MW (e) pressurized fluidized-bed (PFB) steam generators in a shop and shipping them by barge to a job site. The investigation revealed that similarly sized vessels are transported and erected relatively frequently in the process industry and that barges carrying these vessels can travel over a significant portion of the U.S. inland waterway system. The contractor is Foster Wheeler Development Corp. *EPRI Project Manager: S. G. Drenker*

Solid-Particle Erosion of Utility Steam Turbines: 1980 EPRI–ASME Workshop

CS-3178 Proceedings (RP1885-1); $23.50

This report contains the proceedings of a workshop on solid-particle erosion of utility steam turbines that was held in Atlanta in May 1980. Utility, boiler manufacturer, and turbine manufacturer viewpoints are presented, and recommendations for further work are included. The contractor is Wood-Leaver and Associates, Inc. *EPRI Project Manager: John Stringer*

Proceedings of 1982 Joint Symposium on Stationary Combustion NO_x Control

CS-3182 Proceedings (TC82-920); Vol. 1, $50.50; Vol. 2, $35.50

This report documents the 1982 EPA-EPRI Joint Symposium on Stationary Combustion NO_x Control, which was held in November 1982 in Dallas. More than 50 papers are presented that address utility boiler field experience; NO_x flue gas treatment; limestone injection SO_x control; industrial process combustion; industrial, commercial, and residential systems; and fundamental combustion research. *EPRI Project manager: M. W. McElroy*

ELECTRICAL SYSTEMS

Probabilistic Approach to Stability Analysis

EL-2797 Final Report (RP1764-4), Vol. 2; $16.00

This executive summary discusses background, conclusions, and recommendations of a project to investigate the application of probabilistic methods to power system analysis and to develop preliminary computer methods for evaluation and testing. A stochastic approach to stability analysis, a probabilistic model of system disturbances, a probabilistic description of the protection system, and methods of probabilistic stability evaluation are detailed. The contractor is Arizona State University. *EPRI Project Manager: N. J. Balu*

High-Pressure Dielectric Strength Tests on PPP (PPLP) Insulation

EL-3131 Final Report (RP7876-20); $11.50

This report presents the results from 136 tests on high-voltage paper–polypropylene film–paper (PPP) insulation. (In Japan this material is called polypropylene-laminated paper, or PPLP.) The results are compared with previously established and published data for paper-oil cable insulation. The tests and analyses explored the exceptionally high dielectric strength of PPP laminate, oil-pressurized cable insulations. The contractor is Sumitomo Electric Industries, Ltd. *EPRI Project Manager: Stephen Kozak*

Phase-to-Phase Switching Surge Design

EL-3147 Final Report (RP1492); $23.50

This report—an addendum of the *Transmission Line Reference Book: 115 138-kV Compact Line Design*—provides phase-to-phase switching surge design information. The effects of several parameters on flashover probability are discussed, including alpha and atmospheric factors, waveshapes and timing of phase-ground components, and line dimensions. Advanced statistical methods are also discussed. The contractor is Power Technologies, Inc. *EPRI Project Manager: R. E. Kennon*

Power System Planning: Research Needs and Priorities

EL-3152 Proceedings (WS82-116); $16.00

This report contains the proceedings of a workshop held in August 1982 in Minneapolis to identify and rank research needs in power system planning. Ten areas for near-term EPRI research are presented. These were developed from a much larger list of topics suggested during workshop discussions. The contractor is Detroit Edison Co. *EPRI Project Manager: N. J. Balu*

ENERGY ANALYSIS AND ENVIRONMENT

Control of Nitrogen Oxides: Assessment of Needs and Options

EA-2048 Final Report (RP1375), Vol. 5; $29.50

This volume is part of a six-volume reference set designed to provide the information required by utilities in dealing with several pending NO_x-related regulatory changes. The volume describes available emissions control technologies for both utility and nonutility combustion devices that are significant sources of NO_x. The costs and control levels of these technologies are discussed, as well as their impacts on efficiency, operation, and other pollutants. The contractor is KVB, Inc. *EPRI Project Manager: R. E. Wyzga*

Ammonia in Precipitation and Plumes: Solubility and Effect on SO_2 Oxidation

EA-2998 Final Report (RP858); $14.50

The solubility of ammonia in water at low concentrations was studied under controlled laboratory conditions simulating actual atmospheres, and the results were applied to the aqueous-phase oxidation of SO_2 in power plant plumes. Measurements of ammonia solubility in the presence of CO_2 were compared with classical solubility theory predictions. A numerical precipitation-scavenging model was used to study the aqueous-phase oxidation of SO_2, and various postulated mechanisms for the oxidation process were considered. The contractor is Battelle, Pacific Northwest Laboratories. *EPRI Project Manager: Charles Hakkarinen*

Relationship Among Acidifying Depositions, Surface Water Acidification, and Fish Populations in North America

EA-3127 Final Report (RP1910-2); Vol. 1, $17.50; Vol. 2, $25.00

Volume 1 of this report assesses the state of scientific knowledge about the relationship between acidic deposition and freshwater aquatic resources. The evaluation addresses working hypotheses in these areas: atmospheric deposition and effects on surface water; surface water acidification and effects on fish populations; and measures to mitigate impacts of surface water acidification. Volume 2 is an annotated bibliography containing nearly 1500 citations on the responses of fish and aquatic ecosystems to acidifying depositions and related acid stresses. The contractor is Western Aquatics, Inc. *EPRI Project Manager: R. W. Brocksen*

Estimation of Uncertainty in Coal Resources

EA-3133 Final Report (RP1367-1); $16.00

This report describes the development of a methodology for providing coal resource estimates and quantifying their associated uncertainty. Sources of uncertainty are identified, and the application of the methodology over several major coal-producing regions is detailed. The calculation of coal resources by manual, computer, and geostatistical methods is reviewed. The contractor is the Texas Energy and Natural Resources Advisory Council; the subcontractor is the University of Texas at Austin. *EPRI Project Manager: Jeremy Platt*

Weather Normalization of Electricity Sales

EA-3143 Final Report (RP1922-1); $25.00

This report discusses (1) methods for quantifying the relationship between electricity sales and weather, and (2) techniques that utilities can use to adjust their sales data for abnormalities in weather. An appropriate method for matching weather data and sales was specified, and models incorporating this method were shown to verify the procedure. A nonparametric method was developed for identifying the nonlinear response of sales to weather. The contractors are Cambridge Systematics, Inc., and Quantitative Economic Research, Inc. *EPRI Project Manager: Ahmad Faruqui*

Legionnaires' Disease Bacterium in Power Plant Cooling Systems: Phase 1

EA-3153 Interim Report (RP1909-1); $13.00

This report documents Phase 1 of a two-phase study of Legionnaires' disease bacteria. It presents the results from a survey of nine power plants that examined the distribution, density, viability, and infectivity of *Legionella* in plant cooling systems. A new species identified at two sites is discussed. The contractors are Oak Ridge National Laboratory, the University of Tennessee, and Savannah River Laboratory. *EPRI Project Manager: J. S. Mattice*

Industrial Use of Cogeneration Under Marginal-Cost Electricity Pricing in Sweden

EA-3157 Final Report (RP1212-1); $13.00

This report reviews Sweden's experience with industrial cogeneration in order to gain insights into cogeneration applications in the United States. It focuses on pricing issues, discussing Sweden's marginal-cost electricity pricing practices in depth. A set of hypotheses about the implications of the findings for U.S. policy on electricity pricing and industrial cogeneration is included. The contractor is The Rand Corp. *EPRI Project Manager: Ahmad Faruqui*

ENERGY MANAGEMENT AND UTILIZATION

1981 Survey of Utility Load Management, Conservation, and Solar End-Use Projects: Selected Technologies and Case Studies

EM-2649 Final Report (RP1940-1), Vol. 2; $31.00

A survey was conducted to document ongoing utility activities in the areas of load management, energy conservation, and solar end-use technologies. This volume contains 16 detailed case studies of utility project activity in eight end-use technologies. The contractor is Energy Utilization Systems, Inc. *EPRI Project Manager: V. A. Rabl*

COPE: Cogeneration Options Evaluation

EM-3126-CCM Computer Code Manual (RP1276-8); Vol. 1, $13.00; Vol. 2, $16.00

This report discusses the computer model COPE, which can help management examine attractive cogeneration options and choose an option best suited for specific sites, given the relevant tax and fuel use regulations. Volume 1, the program descriptive manual, explains the model's structure, applications, and methodology. Volume 2, the user's manual, describes how to access the model, prepare data, and interpret results. The contractor is Synergic Resources Corp. *EPRI Project Managers: S. D. Hu and R. L. Mauro*

Development of Zinc Chloride Battery for Utility Applications

EM-3136 Interim Report (RP226-5); $23.50

This report summarizes work in a program to develop a zinc chloride battery for utility energy storage. Three prototype batteries are described. The first was cycle-tested for 170 complete charge-discharge cycles during 1982; the second was built and tested to verify the design; and the third demonstrated electrochemical energy efficiencies. The report also updates the manufacturing cost analysis. The contractor is Energy Development Associates. *EPRI Project Manager: D. L. Douglas*

Opportunities in Thermal Storage R&D

EM-3159-SR Special Report; $32.50

This report contains the proceedings of two EPRI-sponsored workshops, one on heat storage and one on cool storage, held in January 1983 in Palo Alto, California. All the papers presented at the workshops are included, and extensive panel discussions on promising improvements in thermal energy storage materials, heat exchange technology, thermal insulation, and controls are summarized. Recommendations are included. *EPRI Project Manager: V. A. Rabl*

NUCLEAR POWER

Gamma Scan Measurements at Hatch-1 Following Cycle 3

NP-2105 Final Report (RP130-4); $19.00

A measurement program to obtain relative La-140 gamma-ray intensities for irradiated fuel bundles and rods is documented in sufficient detail to make the data useful for benchmarking three-dimensional power distribution prediction methods and on-line power distribution determination methods. Particular emphasis is given to the gamma in-core monitoring system. The contractor is General Electric Co. *EPRI Project Manager: Odelli Ozer*

VIPRE-01: A Thermal-Hydraulic Analysis Code for Reactor Cores

NP-2511-CCM Computer Code Manual (RP1584-1), Vol. 3; $17.50

This volume is the programmer's manual for the VIPRE code, which was developed for core thermal-hydraulic analysis applications. The manual explains the structure of the code as well as the computer interfaces. The contractor is Battelle, Pacific Northwest Laboratories. *EPRI Project Manager: J. A. Naser*

Low-Level Waste Disposal Site Performance Assessment With the RQ/PQ Computer Program

NP-2664-CCM Final Report (RP2063-1); $11.50

This report presents the RQ/PQ computer program for use in screening and selecting shallow land burial sites for low-level waste (LLW). The code is capable of calculating potential radioactive LLW hazards and the characteristics of the natural and man-made barriers provided by the disposal facility. The bases for modeling nuclide releases from nine potential pathways are described and compared with NUREG-0782 methods. A summary of the equations solved, a FORTRAN listing, and sample problem input and output are included. The contractor is Rogers and Associates Engineering Corp. *EPRI Project Manager: R. F. Williams*

ABAQUS–EPGEN: A General-Purpose Finite Element Code

NP-2709-CCM Computer Code Manual (RP964-5, RP1550-1), Vol. 1, Rev. 1; $13.00

This document presents revisions to NP-2709-CCM, Volume 1, the user's manual for the ABAQUS–EPGEN code. Text changes, deletions, and additions are indicated, along with pagination changes. The contractor is Hibbitt, Karlsson and Sorensen. *EPRI Project Manager: H. T. Tang*

Spinning Turbine Fragment Impacts on Casing Models

NP-2743 Final Report (RP399-5); $14.50

This report presents the results of 10 scale-model turbine missile impact tests. The tests ($\frac{1}{11}$ scale) were conducted to assess turbine missile effects with respect to nuclear plant design. Model tests of spinning missiles with and without blades are compared with full-scale tests of nonspinning missiles without blades. The contractor is Southwest Research Institute. *EPRI Project Manager: G. E. Sliter*

Hydrogen Combustion and Control Studies in Intermediate Scale

NP-2953 Final Report (RP1932-7); $23.50

This report summarizes experiments to examine the combustion behavior of hydrogen under containment conditions that might occur in a postulated degraded core accident. It describes both quiescent (premixed) and dynamic (continuous injection) tests conducted in a vessel 213 cm in diameter and 518 cm high (with a volume of 17,800 liters). Temperature, pressure, flame front propagation, and gas constituent concentration measurements are included. The contractors are Acurex Corp. and NUS Corp. *EPRI Project Manager: Loren Thompson*

Steam Generator Chemical Cleaning: Demonstration Test in a Model Boiler

NP-2990 Final Report (RPS128-1); $25.00

This report presents the results of the final demonstration testing of a generic chemical cleaning process developed to remove steam generator corrosion-product buildup. The effectiveness of the process for high-copper-sludge removal and the cleaning of dented tube–support plate crevices was evaluated. The corrosivity of the process to the generator base metals was also determined. The contractor is Combustion Engineering, Inc. *EPRI Project Manager: C. S. Welty, Jr.*

Steam-Water Separation in a Swirl-Vane Centrifugal Separator

NP-2996 Final Report (RPS173-1); Vol. 1, $8.50; Vol. 2, $19.00

This report describes a study to assess and model the performance of swirl-vane moisture separators used in steam generators. Volume 1 presents the results and implications of vane separation experiments conducted earlier, and Volume 2 details the data and the analyses performed. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: C. L. Williams*

Evaluation and Improvement of PWR Secondary-System Oxygen Control Measures

NP-3020 Final Report (RPS104-1); $37.00

This report documents a study on the design and operation of balance-of-plant systems and components to minimize oxygen-induced corrosion in the secondary systems of PWRs. Recommendations on equipment and design modifications that would correct air inleakage in most plants are presented, along with associated costs. The use of hydrazine to scavenge oxygen in secondary systems is evaluated, and recommendations on operating and maintenance practices are presented. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: R. L. Coit*

Characterization of Single-Tube Model Boiler Dented Intersection Specimens

NP-3024 Final Report (RPS112-2); $11.50

This report describes an analysis of three model boiler specimens that were exposed to a corrosive environment and then either left untreated or (in an attempt to halt the corrosion process) treated with calcium hydroxide or boric acid. The specimens were characterized by using light and scanning electron microscopy and energy and wavelength dispersive X-ray spectrophotometry. Destructive examination of the specimens revealed the presence of multiple layers of oxide products with differences in morphological and chemical features. The contractor is Calgon Corp. *EPRI Project Manager: J. P. N. Paine*

Analysis of Sludge From Indian Point-3

NP-3027 Final Report (RPS136-5); $10.00

This report presents detailed chemical analyses of steam generator sludge samples from the Indian Point-3 PWR. Primary sludge constituents are identified, as well as elements observed at levels of 1–2% and less than 1%. The separation and subsequent analysis of an anion and a cation resin fraction are discussed in detail. The contractor is Rockwell International Corp. *EPRI Project Manager: M. J. Angwin*

Nonproprietary Corrosion Inhibitors for Solvents to Clean Steam Generators

NP-3030 Final Report (RPS148-1); $28.00

This report summarizes a project to develop a corrosion inhibitor for use with solvents for chemically cleaning PWR steam generators. The work addressed inhibitor chemistry, solution chemistry, corrosion mechanism, metallurgy of the metals to be protected, system parameters (e.g., the nature of galvanic coupling), and techniques to monitor corrosion. Various tests of a promising nonproprietary corrosion inhibitor are reported. The contractor is Petrolite Corp. *EPRI Project Manager: C. S. Welty, Jr.*

Steam Generator Data Base

NP-3033 Final Report (RPS160-1); $20.50

This report discusses the development of a data base to provide comprehensive information on the effects of different PWR designs, materials, and operating conditions on various steam generator corrosion phenomena. In the work described here, a logical structure was established for the data base, forms requesting data were sent to the cooperating plants, and computerized systems were set up to deal with the responses. The contractors are S. Levy, Inc., and NWT Corp. *EPRI Project Manager: S. T. Oldberg*

Condensate Demineralizer Performance During Periods of High Condenser Leakage

NP-3035 Topical Report (RPS167-1); $11.50

Laboratory testing was conducted to determine deep-bed condensate polisher performance for sodium chloride removal during periods of high condenser cooling-water inleakage. This report discusses removal efficiency data as a function of a resin equivalence ratio, cation resin form, inlet pH, and pH additive. It also outlines a technique for establishing polisher system design bases and operating procedures relative to boiler water specifications. The contractor is NWT Corp. *EPRI Project Manager: C. S. Welty, Jr.*

Condensate Polishing at Surry Nuclear Power Station

NP-3037 Topical Report (RPS167-1); $13.00

This report presents the results of a detailed study at the Surry nuclear station to evaluate the capability of deep-bed condensate polisher systems to achieve water quality consistent with the PWR secondary water chemistry guidelines of the Steam Generator Owners Group. Polisher performance during normal operation and during periods of simulated condenser cooling-water inleakage is analyzed. The results of less extensive site studies at the Ginna and Trojan nuclear stations are also documented. The contractor is NWT Corp. *EPRI Project Manager: C. S. Welty, Jr.*

Neutralization of Tubesheet Crevice Corrosion

NP-3040 Final Report (RPS183-2); $17.50

Tests were conducted to produce Inconel 600 intergranular attack (IGA), representative of that observed in operating plants. Uniform IGA occurred to a depth of 6–8 mils in 90 days at 650°F in a test environment with 40 wt% NaOH, 10 wt% KOH, and 12 wt% Cr_2O_3. The results show that in 40 wt% NaOH and 10 wt% KOH, sodium nitrate prevented all IGA and stress corrosion cracking in stressed C-ring and isothermal capsule tests. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: A. R. McIlree*

Model Tests of an OTSG for Lane Blocker Assessment and THEDA Code Verification

NP-3042 Final Report (RPS186-1); $37.00

Thermal-hydraulic data were acquired from a 30-tube test section simulating a once-through steam generator (OTSG); a steam-water mixture at prototypical conditions was used as the working fluid. Tests were conducted to assess the feasibility of using lane blockers (plates covering the exposed support plate holes in the inspection lane) to eliminate moisture transport to the upper tubesheet. Experimental data were compared with predictions made by the three-dimensional thermal-hydraulic code THEDA-2. The contractor is Babcock & Wilcox Co. *EPRI Project Manager: C. L. Williams*

Corrosion Performance of Alternative Steam Generator Materials and Designs

NP-3044 Final Report (RPS192-1); Vol. 1, $10.00; Vol. 2, $26.50; Vol. 3, $20.50

This report presents the results of corrosion tests on two model steam generators featuring materials and designs for reducing corrosion damage. One model was faulted with seawater and the other with a simulated cooling-tower water; post-test nondestructive and destructive examinations were conducted. Volume 1 presents the operating data and summarizes the results. Volumes 2 and 3 present detailed results for the seawater-faulted and freshwater-faulted models, respectively. The contractor is Combustion Engineering, Inc. *EPRI Project Manager: C. E. Shoemaker*

Crevice Corrosion of Lattice Support Alloys in Secondary Environments of Steam Generators

NP-3045 Final Report (RPS204-1); $14.50

This report summarizes a study to determine the extent to which galvanic coupling effects are significant for initiating and sustaining corrosion in crevices. Particular emphasis was placed on determining how crevice and bulk water chemistries affect the corrosion rate. Experiments were conducted in a single-pass flow tube containing 14 specimens in different crevice geometries. The corrosion of support alloys was related to alloy content and pH. The contractor is SRI International. *EPRI Project Manager: C. E. Shoemaker*

Evaluation of Condensate Polishers

NP-3046 Final Report (RP623-3); $11.50

A series of high-temperature tests was conducted to evaluate the potential for steam generator corrosion due to the release of resins or soluble impurity chemicals from full-flow condensate polishers. Three soluble impurities—sodium hydroxide, sodium silicate, and sulfuric acid—were tested, and resin ingress was simulated. Sulfate-induced intergranular attack of nickel alloy tubing, as well as instances of wastagelike attack, was observed. The contractor is Combustion Engineering, Inc. *EPRI Project Manager: M. J. Angwin*

Numerical Simulation of Steam Separators Used in Nuclear Steam Generators and Reactor Systems

NP-3063 Final Report (RPS172-1); Vol. 1, $14.50; Vol. 2, $13.00

This report describes the analytic models and the computation techniques for model solution that were used to study two-phase flow-through steam separators. Calculations for the flow-through Combustion Engineering and Westinghouse steam separators are given as examples. Volume 1 describes the analytic development of the SWIRL code, and Volume 2 (designated NP-3063-CCM) is the computer code manual. The contractor is Jaycor. *EPRI Project Manager: D. A. Steininger*

Generic Qualification of Rotary Hand Switches

NP-3095 Final Report (RP1707-8); $10.00

Data were compiled for use in the qualification of safety-related rotary hand switches for operation in mild nuclear plant environments (e.g., the control room). Prior test results, plant experience, materials, environmental stresses, potential failure modes, and surveillance-maintenance procedures are discussed for three switch models. The report also presents an example to demonstrate how these data can be useful in qualifying other, similar switches. The contractor is Power Technical Associates, Inc. *EPRI Project Manager: G. E. Sliter*

Gamma-Ray Exposure Rate Distribution

NP-3107 Interim Report (RP825-2); $11.50

Gamma-ray exposure rate measurements were made with thermoluminescent dosimeters to determine the relative contribution of various surface areas in a steam generator to the overall radiation levels. The measurements were compared with analytic predictions based on discrete ordinates and point kernel techniques, and assessments of the radiation source inventory of the various surfaces were developed. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: R. A. Shaw*

Testing On-Line Leak Sealing Methods

NP-3111 Final Report (RP1328-1); $11.50

A test program was conducted to evaluate the effectiveness of commercial leak repair services with respect to the requirements of nuclear power plants. Three companies commercially engaged in on-line leak sealing demonstrated their sealants, fixtures, and techniques. The results indicate that the effectiveness of an injected-sealant repair is determined by the quality of the initial repair and by performance within the first 48 hours. The contractor is Combustion Engineering, Inc. *EPRI Project Manager: B. P. Brooks*

Criteria Definition for LLW Solidification and Containerization

NP-3112 Final Report (RP2130-1); $13.00

This report describes the methodology and results of a study to define minimum performance standards for low-level waste (LLW) solidification and containerization technologies. Conclusions about the state of the art of the technologies are presented. The contractor is The Analytic Sciences Corp. *EPRI Project Manager: M. D. Naughton*

In Situ Calibration of Nuclear Plant Platinum Resistance Thermometers

NP-3113 Final Report (RP1440-1); $14.50

The feasibility of using Johnson noise measurements for the in situ calibration of reactor platinum resistance thermometers was investigated in tests in the laboratory and at two reactors. Three methods based on Johnson noise measurements were evaluated. Objectives were to determine possible error uncertainties, to quantify their effects, and to identify future research areas in Johnson noise thermometry. The contractor is Oak Ridge National Laboratory. *EPRI Project Managers: S. M. Divakaruni and A. B. Long*

Assessment and Control of BWR Radiation Fields

NP-3114 Final Report (RP819-1); Vol. 1, $10.00; Vol. 2, $41.50

This report describes the work of the BWR radiation assessment and control program from 1978 to 1982. Volume 1 (a summary report designated NP-3114-SY) provides an executive overview of the project and its major findings. Volume 2 contains detailed information on the work performed, which included radiation-field surveillance at several BWRs; assessments of the influence of plant design and operating factors on radiation buildup; and studies of feedwater chemistry, out-of-core corrosion films, fuel deposits, and component recontamination. The contractor is General Electric Co. *EPRI Project Manager: M. D. Naughton*

User's Guide for Demonstration of GADS Analysis Decision Routines

NP-3116 Final Report (RP1391-3); $17.50

This report describes the development and application of software for analyzing the type of data found in the North American Electric Reliability Council's Generating Availability Data System (GADS). This work was performed to demonstrate the remote accessing, retrieval, and analysis of such data. The goal is to support utility decision processes in these areas: design of new units, improvement of existing units, generating-system capacity additions, and R&D program definition. The contractor is Southwest Research Institute. *EPRI Project Manager: J. M. Huzdovich*

Transient Cooldown in a Model Cold Leg and Downcomer

NP-3118 Interim Report (RP2122-3); $14.50

This report describes an investigation of the cooldown transient of water in a cold leg and downcomer due to high-pressure injection in a stagnant loop. Fluid-mixing experiments were conducted in a $\frac{1}{5}$-scale transparent PWR model. The results focus on the phenomena of buoyancy-dominant fluid flow and mixing under stagnant loop flow conditions. The report analyzes the temperature data, summarizes the flow visualization findings, and presents full data traces and tables. The contractor is Creare R&D Inc. *EPRI Project Manager: K. H. Sun*

BWR Spray Nozzle Performance in Steam Environment

NP-3119 Interim Report (RP443-3); $16.00

This report presents measurements of the water distribution below single full-scale BWR spray nozzles under different environmental conditions. Droplet velocities and size distribution were measured as well, and the findings are discussed. The contractor is Dartmouth College. *EPRI Project Manager: K. H. Sun*

Estimate of Primary-System Temperatures in Severe Reactor Accidents

NP-3120 Final Report (RP2135-2); $14.50

This report describes engineering calculations performed to provide estimates of primary coolant system conditions for several risk-dominant LWR severe accident sequences. The specific time span and core locations under consideration are identified. MARCH code predictions of the time histories of core gas temperature, flow rate, pressure, and composition are presented. The contractor is Science Applications, Inc. *EPRI Project Manager: R. C. Vogel*

GO Methodology

NP-3123-CCM Computer Code Manual (RP818, RP1842); Vol. 1, $10.00; Vol. 2, $20.50

This report describes the GO methodology, a probabilistic system performance analysis technique, and its computer software and applications. Volume 1 presents an overview of the methodology and its uses in nuclear system analysis. Volume 2 compares the GO methodology with fault tree analysis by applying both techniques to several examples. The contractor is Energy Incorporated. *EPRI Project Manager: B. B. Chu*

Computer-Calculated Potential pH Diagrams to 300°C

NP-3137 Final Report (RP1167-2); Vol. 1, $8.50; Vol. 2, $13.00; Vol. 3, $11.50

This report documents a program to develop a general computer method for estimating the potential pH diagrams for metals in water at temperatures from 25 to 300°C. Volume 1, an executive summary, presents a program overview and discusses the application of potential pH diagrams to nuclear corrosion problems. Volume 2, a diagram handbook, presents the many diagrams generated in the project. Volume 3 is a user's manual for POT–pH–TEMP, the computer code developed for generating diagrams. The contractor is Babcock & Wilcox Co. *EPRI Project Managers: D. Cubicciotti and T. O. Passell*

PWR Model Steam Generator Corrosion Studies

NP-3138 Final Report (RP623-1); $19.00

A series of high-temperature heat transfer corrosion tests was conducted to examine the effects of water chemistry variations on steam generator material corrosion. The tests—which were carried out in four-tube, low-heat-flux pot boilers and in multitube model steam boilers—focused on the laboratory production of tube denting and the role of specific impurities in the corrosion of carbon steel support structures. The contractor is Combustion Engineering, Inc. *EPRI Project Manager: J. P. N. Paine*

Survey and Analysis of Work Structure in Nuclear Power Plants

NP-3141 Final Report (RP2167-1); $17.50

This report discusses work structure factors at nuclear power plants. It presents the findings of a questionnaire completed at 10 plants and of structured critical-incident interviews. Recommendations for a set of candidate research issues to be considered by EPRI are included. The contractor is BioTechnology, Inc. *EPRI Project Manager: H. L. Parris*

Evaluation of BWR Resin Intrusions on Stress Corrosion Cracking of Reactor Structural Materials

NP-3145 Final Report (RP1563-2); $10.00

This report discusses a study of the stress corrosion and corrosion fatigue behavior of type-304 stainless steel when exposed to off-normal BWR water chemistry conditions. Tests were conducted with normal high-purity BWR water and with impure BWR water that simulated ion exchange resin releases from the demineralizer system. The contractor is Battelle, Pacific Northwest Laboratories. *EPRI Project Managers: M. Fox and D. Cubicciotti*

Effect of Hydrogen Injection on Hydrogen Uptake by BWR Fuel Cladding

NP-3146 Final Report (RP1930-5); $10.00

Reported hydrogen uptake rates for zirconium alloys in BWRs, PWRs, HWRs, and various experimental in-reactor loops are presented. Factors contributing to the variability of these data are discussed, and an attempt is made to estimate the baseline for hydrogen uptake from the outside of good-quality cladding under normal BWR operating conditions. Recommendations are included for a surveillance program for BWRs operated with hydrogen injection. The contractor is Atomic Energy of Canada Ltd. *EPRI Project Manager: D. G. Franklin*

Potential Impact of NRC Safety Goals on the Nuclear Industry

NSAC-56; $14.50

This report presents an assessment of two recently issued NRC proposals—a policy statement defining nuclear power plant safety goals and an action plan outlining the implementation of those goals. The two proposals were studied to identify the range of plausible interpretations of the action plan and to estimate what impact the adoption of the goals and the action plan would have on the nuclear industry. Quantitative estimates of how implementation costs would vary with different interpretations of the action plan were also developed. The contractor is EDS Nuclear, Inc. *EPRI Project Manager: George Sauter*

PLANNING AND EVALUATION

Integration of State-Level Electricity Demand Forecasting Model and the Regional Electricity Model

P-3132-SR Special Report; $16.00

This report describes a project to integrate the State-Level Electricity Demand (SLED) Model and the Regional Electricity Model (REM). More recent data were incorporated into the structural parameters of the SLED model. Six alternative scenarios reflecting different economic growth and electricity price assumptions were specified for the integrated model. SLED and REM appear reasonably compatible and should provide more reliable forecasts of regional electricity demand. *EPRI Project Manager: Keith Brown*

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