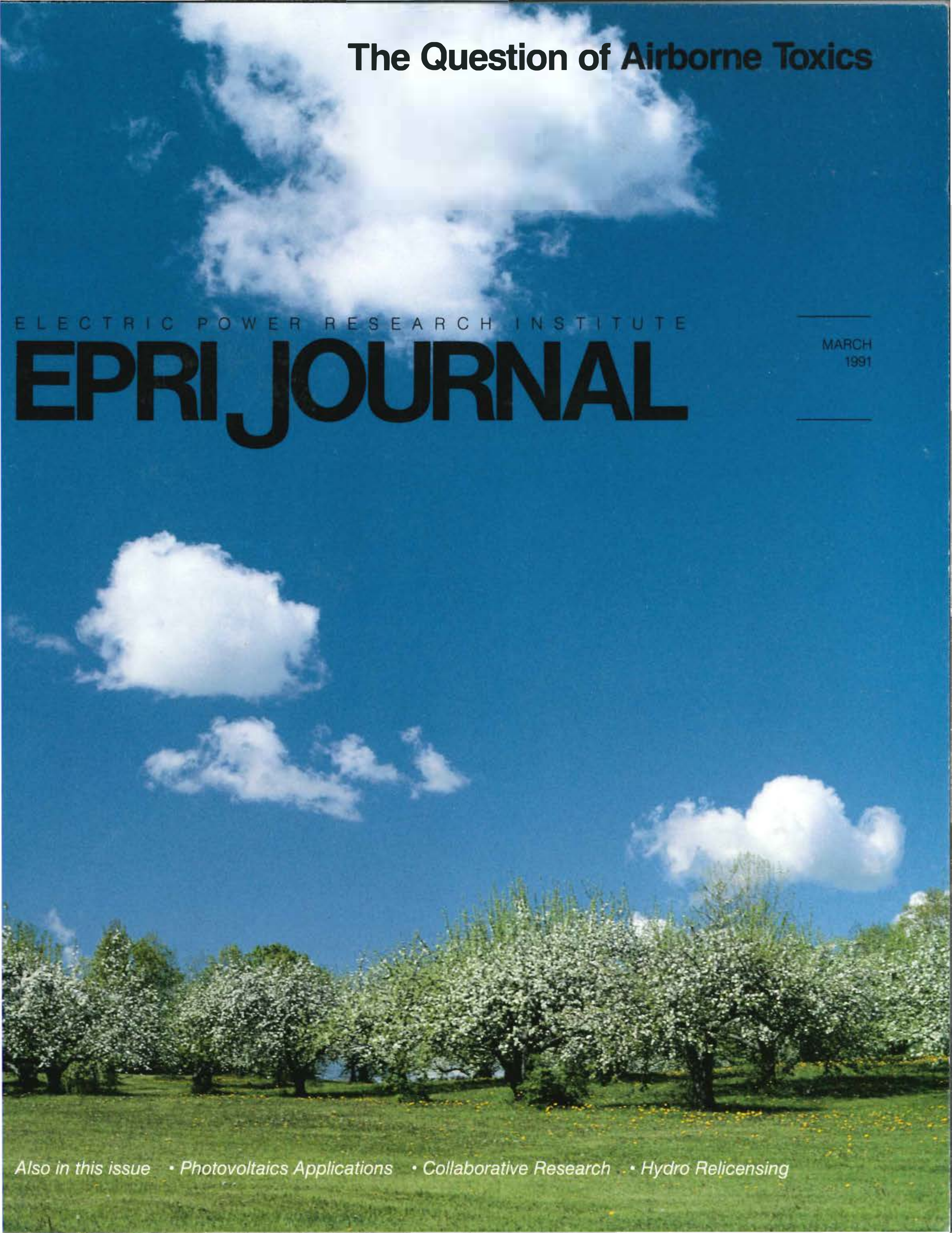

The Question of Airborne Toxics

ELECTRIC POWER RESEARCH INSTITUTE

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Cover: While a number of industries are now subject to new regulations for airborne toxics, the EPA has not yet decided whether utility sources of these substances pose a significant threat to health and the environment.

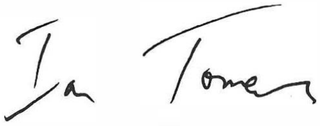
Managing Air Toxics

The decade-long clean air debate in Congress culminated last fall in new Clean Air Act amendments. As the dust settles, however, questions remain for the utility industry regarding a key portion of the legislation that deals with industrial emissions of a group of hazardous air pollutants commonly called air toxics.

Utilities were not the primary target of the air toxics provisions. However, the new legislation calls for the Environmental Protection Agency and the National Institute of Environmental Health Sciences to study the potential health and environmental risks from utility emissions of these substances. The EPA is then to decide whether additional controls are needed for fossil plants.

This study interval provides an opportunity for EPRI and the utility industry to bring to fruition research in progress that is aimed at resolving the key uncertainties surrounding this complex issue. Three years ago, EPRI foresaw the need to improve the industry's understanding of utility toxics emissions. Our initial work in this area, in the ongoing PISCES project, indicated that the available electric utility air toxics data are limited in both quantity and quality. We are now obtaining more precise field data for the PISCES database and computer model, which will enable utilities to predict emissions and discharges from their plants on the basis of fuel type and plant configuration. EPRI has also been developing a better understanding of how these chemicals are transported and transformed after leaving the stack, and has been clarifying the level of risk to public health and the environment. And as a clearer picture emerges from our field measurements, we will develop control technology guidelines to inform utilities of their technical options should controls be necessary. Member utilities will soon be better equipped with the information and tools needed to develop management strategies that are effective, environmentally sound, and economically prudent.

The need for better scientific data on utility emissions and impacts, as confirmed by PISCES and other EPRI work in this area, was a factor in the congressional decision to allow more time for specific study. This outcome is consistent with a healthy relationship between policy and science. The Institute and its utility advisers are now working closely with the Utility Air Regulatory Group, the EPA, and the Department of Energy on how the respective research efforts will be coordinated, thereby enabling the industry and the government agencies to make decisions based on the best scientific and technical information available. This model for cooperation can help ensure a sound science/policy interface on other major environmental issues confronting utilities.



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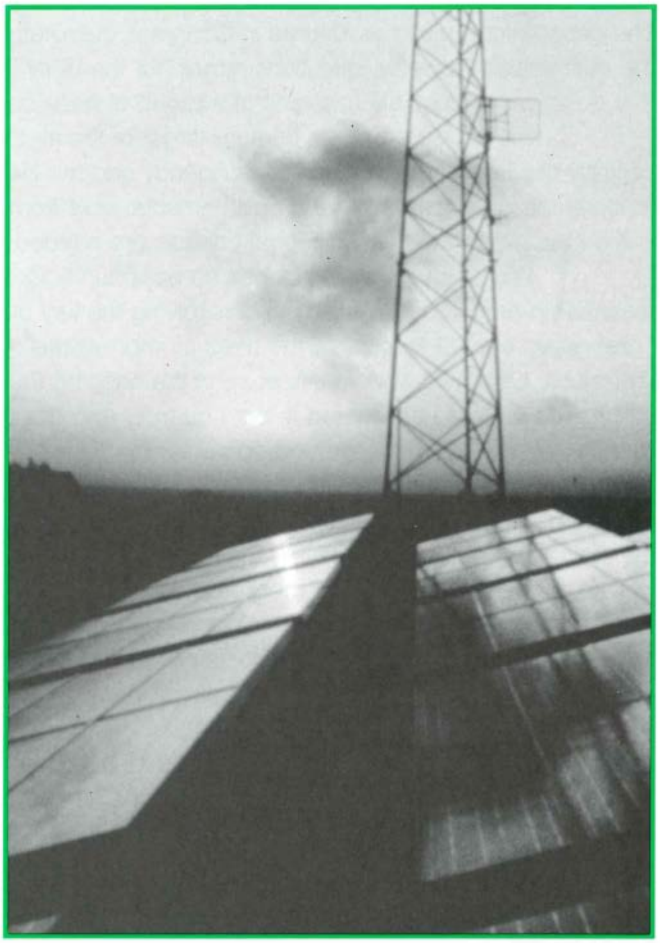

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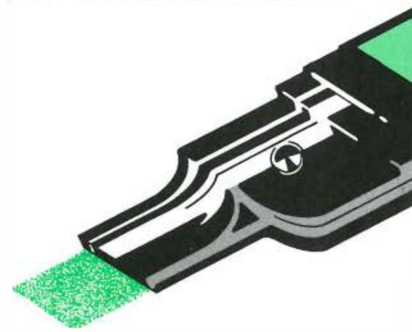
New Focus on Air Toxics



THE CLEAN AIR ACT

CTION 112 (n.A). The Administrator shall perform a study of the hazards to public health reasonably anticipated to occur as a result of emissions by electric utility steam generating units of pollutants listed under subsection (b) . . . The Administrator shall report the results of this study to the Congress within 3 years after the date of the enactment of the 1990 Clean Air Act Amendments. The Administrator shall develop and describe . . . alternative control strategies for emissions which may warrant regulation under this section. The Administrator shall regulate electric utility steam generating units under this section, if the Administrator finds such regulation is appropriate and necessary after considering the results of the study required by this paragraph.

The passage of new amendments to the federal Clean Air Act last November may have brought a decade-long legislative debate to an end, but for the industries that must comply with the law's provisions, and the agencies that regulate those industries, the amendments marked a new beginning.

Reducing atmospheric concentrations of the sulfur and nitrogen oxides blamed for acid rain was a major issue of the debate and a major focus of the 1990 amendments. But the new legislation also aims to reduce emissions of 189 substances that it designates as hazardous air pollutants—commonly called air toxics. These are chemicals, including heavy metals and organic compounds in both particulate and gaseous form, known or suspected to pose a risk to human health or to the environment. How to manage these substances may be a new challenge for the electric power industry.

Some of these substances, mercury and nickel, for example, are found in trace quantities in fossil fuels such as coal and oil and are liberated during their combustion in power plant boilers. Many fossil plants are already equipped with emission control systems that may capture some of these substances before they leave the plant stack, but the degree to which they are removed with existing technology has not been definitively established.

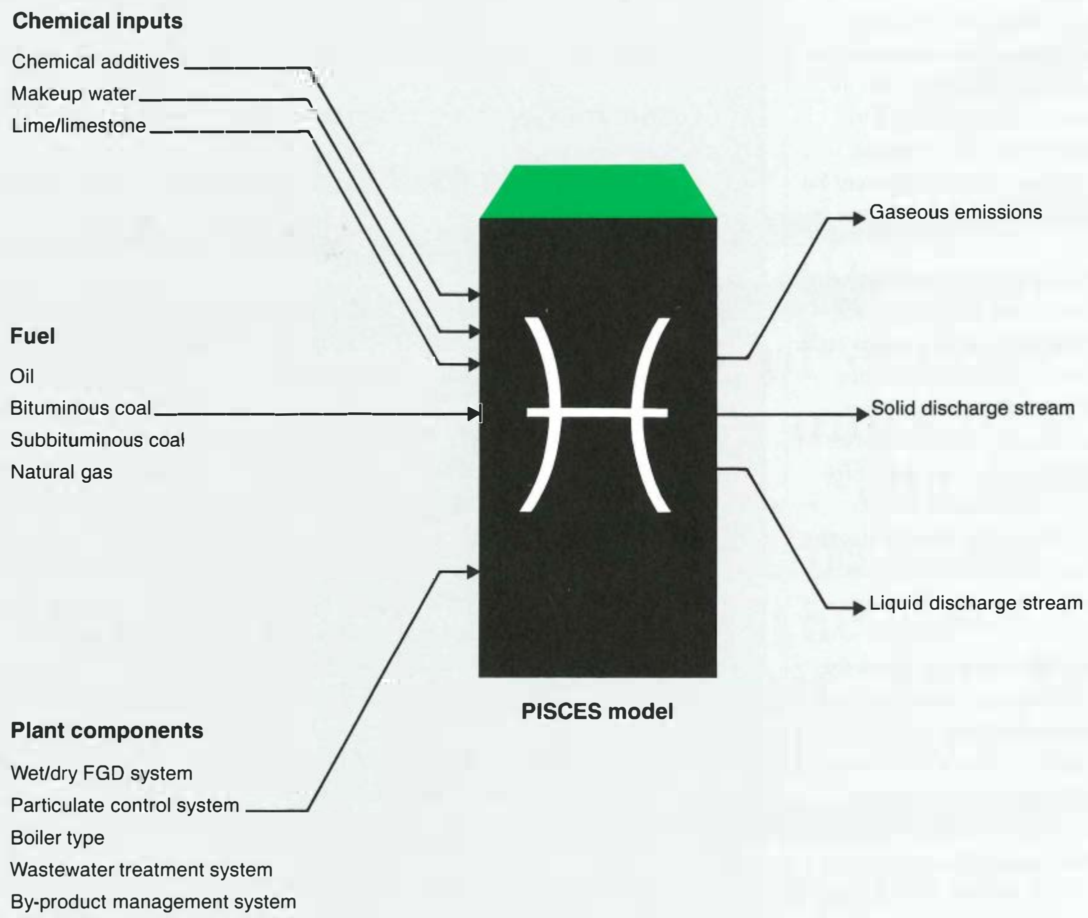
The electric utility industry is not the primary focus of the new air toxics provisions. Environmental Protection Agency (EPA) studies have shown that utility emissions of potential cancer-causing substances pose small threat to the public—less than one excess cancer per year, or a 1-in-1-million chance per year of contracting cancer from exposure to utility emissions. (By comparison, the risk of death from using motor vehicles is 240 in 1 million per year.) This 1-in-1-million value, the agency notes, is a rough estimate that reflects considerable

THE STORY IN BRIEF

New amendments to the federal Clean Air Act include provisions to reduce emissions of airborne toxic substances considered to pose a risk to human health or the environment. While the petrochemical and metals industries are the primary focus of the new air toxics provisions, some of these substances—mercury and nickel, for example—have been identified as present in fossil plant flue gas. The legislation calls for the Environmental Protection Agency to conduct a three-year study of the potential health risks specific to utility sources, after which the EPA administrator will decide whether controls are needed for power plants. To complement the EPA research and help utilities prepare for all possible outcomes, EPRI is developing methods to predict how fuel type and plant configuration affect levels of air toxics emissions, is studying how these substances are chemically converted after leaving the plant, and is assessing the risk they pose to public health and the environment.

PISCES: The Multimedia Approach

EPRI R&D is crafting a comprehensive approach to managing not only gaseous discharges from power plants but the solid and liquid discharges as well. Under a project called PISCES (power plant integrated systems: chemical emissions study), Institute researchers are assessing the source and fate of chemicals in the process streams of fossil plants. This multimedia approach can be likened to an accounting system: it considers how chemical inputs to a power plant (fuels and additives) are transformed within the plant and partitioned into chemical outputs—gaseous, solid, and liquid discharge streams. This approach has been incorporated into a computer model that tracks the pathways of chemicals through the plant and predicts emissions levels. This tool will enable utilities to make operational changes or apply controls with full knowledge of their impact on all plant process streams.



uncertainty. Consequently, utilities have not been directly regulated at the federal level for air toxics, as they have been over the past 18 years for sulfur dioxide, oxides of nitrogen, and particulate emissions.

But the EPA has changed its approach to regulating air toxics. In the past, the agency generally used a risk-based approach to regulation, as required under the 1977 amendments to the Clean Air Act. This meant the agency had to estimate the risk to human health posed by exposure to a substance before it could be regulated—a slow process that resulted in emission standards for only seven substances over a 12-year period. Under the new amendments, however, the EPA has gained greatly expanded authority for regulating air toxics. For industries—not necessarily utilities—deemed to be significant emitters of these substances, the agency will identify and automatically require sources to apply maximum achievable control technology if they emit 10 tons per year or more of any one of the 189 listed substances, or 25 tons per year of any combination of substances. Moreover, the legislation directs the EPA to evaluate the public health risk after the controls are applied; if residual risk remains, further controls may be required.

Dealing with uncertainty

Some industries, including petrochemical processors and metals producers, are likely to be affected immediately under the new legislation. For utilities, however, the requirement to apply controls is not so automatic. The EPA will first study the health and environmental hazards of utility emissions; then the EPA administrator will decide whether controls are needed for fossil power plants. The EPA acknowledges that data for air toxics emissions from power plants should be viewed with caution. As stated in a report prepared for the EPA on the subject (*Summary of Trace Emissions from, and Recommendations of Risk Assessment Methodologies for, Coal and Oil Combustion Sources*, Radian Corporation, July 1986), "There is considerable uncertainty in these estimates due to the wide variability in trace element levels in coal, variations in the design and operating parameters of boilers and control devices, and uncertainty in sampling and analytical methodologies for detecting trace pollutants."

In recognition of such uncertainties, the air toxics provisions of the new clean air legislation call for the EPA to perform a three-year study of possible health risks from utility emissions of air toxics. Mercury, a substance of special concern, was singled out for a separate four-year study that will examine emissions from utility and other sources; health and environmental risks; and control technologies, including their cost. Another mercury study, to be conducted by the National Institute of Environmental Health Sciences, will define threshold mercury exposure for adverse human health effects. The EPA has been directed not to regulate the electric utility industry for air toxics until these studies are completed.

Such regulations could have large economic and operational effects on the electric utility industry. An analysis prepared by the management consulting firm Temple, Barker & Sloane for the Edison Electric Institute estimated that compliance with provisions similar to those in the 1990 clean air amendments could cost $7.8 billion per year—on top of the costs to utilities of complying with the acid rain provisions of the legislation.

"The complexity and uncertainties surrounding these substances make this issue difficult to understand and manage," says EPRI's Michael Miller, who heads the Waste and Water Management Program in the Environmental Control Systems Department. "There are critical gaps in the scientific information on the effects on humans of low-level exposure to these substances, and we don't have firm data on emissions levels yet. Nor do we know what control technologies could be implemented to reduce emissions in a cost-effective manner."

EPRI is pursuing an interdisciplinary and proactive approach to bring the best science and technology to bear on this complex issue, with the aim of giving utilities the information, knowledge, and tools necessary to develop reasoned and informed strategies for managing air toxics. In a coordinated effort on the part of the Institute's Generation and Storage Division and Environment Division, EPRI project managers are addressing the issue on several fronts. They are developing tools that will enable utilities to estimate the levels of emissions from their power facilities, given the types of fuels burned and plant characteristics; developing a better understanding of how emissions are transported and transformed before they encounter humans and ecological systems; and assessing the risk to public health and the environment posed by utility releases of these substances.

EPRI intends this research to complement the studies being conducted by the EPA and is working with the agency, with the Department of Energy, and with utility representatives to determine how and to what degree the research might be coordinated. This cooperative approach should help both the agencies and the utilities to better understand the issue. And if science supports the need to reduce emissions of some of these substances, all the parties will be better prepared to develop strategies for doing so in the most cost-effective manner.

"The Institute is providing scientific and technical information on air toxics that will complement other research to allow decision makers at utilities and regulatory agencies to make knowledgeable decisions," says Miller. "EPRI studies have laid the groundwork for understanding air toxics, and our ongoing projects will help put the industry in a better position for managing these substances."

A holistic approach

A key component of EPRI's air toxics effort is a Generation and Storage Division project called PISCES (power plant integrated systems: chemical emissions study). The PISCES project is developing a comprehensive assessment of the source and fate of chemicals in the process streams of fossil plants. According to project manager Winston Chow, the idea is to take a holistic approach to understanding and quantifying how various chemical inputs to the plant—the fuel and additives—are chemically transformed within the facility and partitioned through plant components into various chemical outputs—the gaseous, aqueous, and solid discharge streams.

"The principles of mass balance show that if a substance is removed from one discharge stream, it will show up in another," says Chow. "Removing trace metals from the flue gas, for example, transfers the products to the liquid or solid phase. Are we exchanging an air quality problem for a liquid or solid waste management problem? Looking at a power facility from a comprehensive, multimedia perspective allows us to see the forest rather than the trees, and to develop cost-effective strategies for managing chemical discharges to minimize risks to public health and the environment while avoiding unnecessarily expensive control requirements."

Understanding how chemicals are partitioned, transformed, and discharged in power plant streams requires knowledge of several variables, Chow notes. The PISCES project has compiled a database that includes descriptions and concentrations of chemicals in power plant process streams, as well as applicable regulations and information on health and environmental effects. "The PISCES database allows one to explore the relationships between chemicals, process streams, and plant components," explains Chow. One type of information in the database, for example, is the concentrations of specific substances in various power plant fuels; this information can provide insight into the efficacy of fuel switching or blending as a way to manage the discharge of these substances.

Another key product from the PISCES project, and one that's intended to be used in conjunction with the database, is a power plant chemical assessment model that runs on a personal computer. The model, which will be available for utility testing this spring, enables a utility engineer to specify the type of fuel burned and the plant's configuration. The model then tracks the pathways of chemicals through the plant and predicts emissions levels.

Explains Chow: "The PISCES model will allow utilities to predict emissions and discharges from any given set of chemical inputs and generation configuration. Thus, operational changes or controls, if necessary, can be applied with full knowledge of their impact on other plant process streams."

A unique feature of the PISCES model is its ability to operate in a probabilistic mode; that is, it incorporates the uncertainty in the input data and displays the probability of various outcomes. This makes it especially valuable for characterizing the emissions of trace substances, whose concentrations are often not precisely known. This feature enables utilities to assess the likelihood of emitting a substance at a specific rate with a given confidence level, notes Chow.

Field measurements

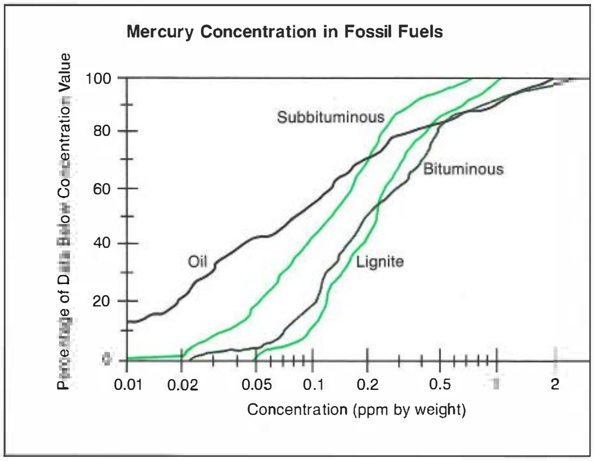
A database and a computer model can be only as good as the data contained in them, and before the PISCES tools can be fully operational, data gaps must be filled. Of particular importance are data on the performance of emission control devices—which were developed to remove sulfur dioxide, nitrogen oxides, and particulate matter—in removing trace chemicals from flue gases. "In compiling the PISCES database, we obtained a lot of data points for plant emissions of various chemical species, that is, what was actually going up the stack," says EPRI's Miller. "But there was very little in the way of paired data sets—what goes in and what comes out—for a given control device like a precipitator. Consequently, we don't know what the species-specific removal efficiencies are for these devices. And the data that were available exhibited wide variability. We realized that the existing literature just did not allow us to come to good conclusions in terms of how well current technology removes air toxics, so it was necessary for us to go out in the field and start collecting better data."

To this end, a field monitoring project was started in May 1990 to measure 24 inorganic and organic substances in the process and discharge streams of several power plants representing different mixes of fuel type, configuration, and environmental control systems. Emissions will be measured for several control devices, including electrostatic precipitators, fabric filters, dry and wet flue gas desulfurization systems, low-NO_x burners, and postcombustion NO_x systems. Plant mass balances are being conducted for all the relevant chemicals to determine their sources, their pathways, and how they are partitioned in the power plant. The data obtained in this project will be put to dual use: they will fill gaps in the database and will be used for model validation to see how well the model's predictions correspond to what's occurring in the real world.

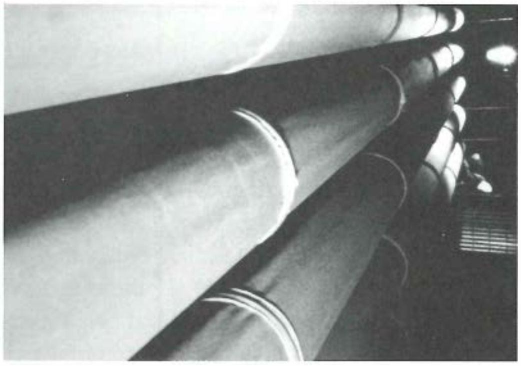
Building on the foundation provided by the database, the model, and the field monitoring project, EPRI's PISCES team is beginning to develop control technology guidelines to inform utilities of their options for managing air toxics if risk assessment supports the need for additional controls. As well as defining the capabilities of existing devices, the project team is scouring the technical literature for information on the potential of emerging or innovative technologies for controlling emissions of air toxics. This

Tools for Managing Air Toxics

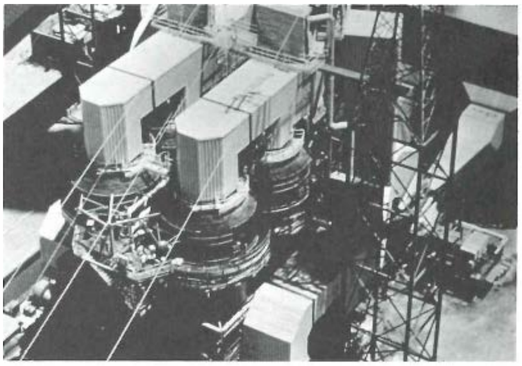
Information and tools developed by EPRI researchers will help utilities better understand and manage emissions from power facilities. The PISCES database, for example, contains information on the concentrations of specific substances in power plant fuels and the effectiveness of existing and emerging control devices in reducing emissions of particular substances. As results come in from studies in progress, EPRI researchers will prepare control technology guidelines to inform utilities of their technical options for removing substances from flue gas. These options may include postcombustion controls, such as baghouses and scrubbers, and precombustion control measures, such as coal cleaning, blending, or switching.

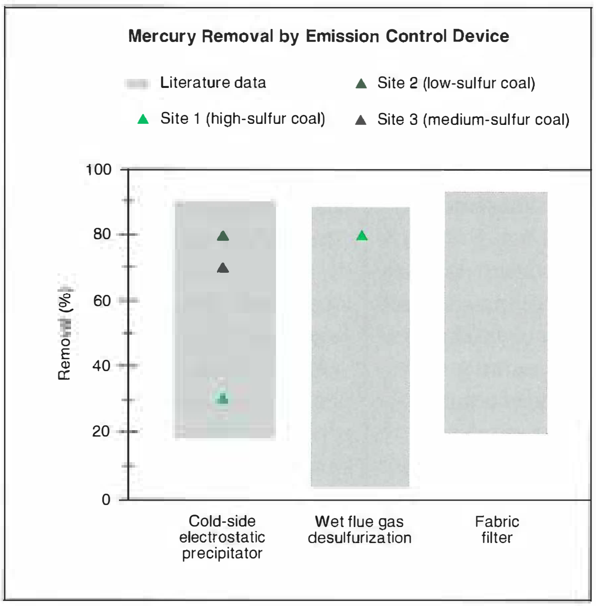


Baghouse



Scrubber





Coal cleaning

Compounds of Concern

The new clean air legislation designates 189 chemical compounds as hazardous air pollutants, commonly called air toxics. Some 37 of these, listed here, have been detected in fossil power plant flue gas. EPRI researchers are working to assess the risk that power plant emissions of these substances pose to human health and the environment. In addition, a field monitoring project is under way to measure many of these chemicals in the process and discharge streams of several power plants to determine how well current emission control devices (such as those developed to reduce emissions of particulates, sulfur dioxide, and nitrogen oxides) reduce emissions of air toxics.

- Acetaldehyde
- Antimony compounds
- Arsenic compounds*
- Benzo-a-pyrene
- Benzene*
- Beryllium compounds*
- Biphenyl
- Bis-(2-ethylhexyl)-phthalate
- Cadmium compounds*
- Carbon disulfide
- Carbon tetrachloride
- Carbonyl sulfide
- Chlorine*
- Chlorobenzene
- Chloroform
- Chromium compounds*
- Cobalt compounds*
- Dibenzofurans
- 1,4-Dichlorobenzene (p)
- Formaldehyde*
- Hexachlorobenzene
- Hydrochloric acid*
- Hydrofluoric acid*
- Lead compounds*
- Manganese compounds*
- Mercury compounds*
- Naphthalene
- Nickel compounds*
- Pentachlorophenol
- Phenol
- Phosphorus*
- Selenium compounds*
- 2,3,7,8-Tetrachlorodibenzo-p-dioxin
- Tetrachloroethylene
- Toluene*
- Trichloroethylene
- 2,4,5-Trichlorophenol

*Included in EPRI field monitoring project.

search involves tapping the experience of other industries that may be applicable to electric utilities—such as experience with municipal waste incinerators—as well as learning about advances in other countries. The research has revealed, for example, that Germany and Japan have reported some success in reducing mercury emissions, primarily from municipal waste incinerators at pilot scale, by using additives and modifying existing technology.

Assessing the risk

In parallel with the Generation and Storage Division's PISCES project, EPRI's Environment Division is conducting studies aimed at improving our understanding of what happens to air toxics after they leave the power plant stack. Each of the projects is developing knowledge aimed at helping answer the central question around which the whole air toxics issue revolves: What risk does the emission of these substances from power plants pose to public health and to the environment?

A key step toward answering that question is finding out which substances are of most concern. Of the 189 substances designated as hazardous air pollutants, 37 are known to be emitted from power plant stacks. With limited R&D resources and a short amount of time available to do the research, EPRI project managers are trying to narrow the list to a half dozen or so priority substances that warrant detailed analysis.

Assessing the potential health risks of toxic substances in the environment is a demanding task. There's a big difference between a large, direct exposure—such as could occur, for example, if a tank containing a toxic substance ruptured near people—and exposure to a minute, diluted amount of the same substance. Also, humans can be exposed to substances by different routes: inhalation, absorption through the skin, or ingestion of food and water containing the substances. To further complicate matters, the substances emitted from power plant stacks may be chemically transformed in the atmosphere by exposure to sunlight and water vapor or may be transformed by their interaction with the ecosystem. These transformed substances may be either more or less toxic than what was originally released from the stack. All of this must be taken into account in risk assessment.

Leonard Levin, a project manager in EPRI's Environmental Risk Analysis Program, is applying a series of computer models and using data developed in other EPRI research programs, including the PISCES project, to determine the risk to human health from air toxics emissions. Explains Levin, "We are using the models to address several key questions: How can EPRI assist a utility in calculating its contributions to concentrations, to public exposure, and to human health risks? How significant are these contributions? What is the relative effect of uncertainties? And are there cost-effective risk management steps that a utility might consider?"

The first of the models Levin is applying, the Airborne Emissions Risk Assessment Model (AERAM), is used to represent individual sources. It uses a set of modules to calculate plant emissions, the transport and dispersion of emissions in the atmosphere, human exposures, and, ultimately, the human health risks from a particular power plant. By varying input data on fuel characteristics and the efficiency of pollution control technologies, the user can evaluate the impact of various control options on potential health risks.

Another model, called AirTox, expands on the capabilities of AERAM. It permits multiple decisions on controls to be analyzed and provides information on a range of outcomes, including cost. AirTox also allows utilities to explicitly incorporate uncertain information on such factors as current ambient concentrations of substances, utility emissions, control efficiency, and the relationship between exposure and health effects. The model can help a utility put in perspective its contribution to air toxics emissions, explore trade-offs between acting soon and waiting for key research results, and evaluate the implications of changes in emissions levels over time.

Test versions of AERAM and AirTox are available to utilities, and a third model is being developed that will expand on those models to allow consideration of routes of exposure besides inhalation. Called Risk PISCES, this multimedia risk evaluation model will link existing models for multiple exposure pathways and will perform a screening evaluation of multiple chemical species under a common framework to identify significant species; these species will then be subjected to detailed risk analyses. Many of the input data for this model are products of the PISCES project sponsored by the Generation and Storage Division.

"The PISCES project is giving us much better data on emissions than we've had before," says Levin. "That allows us to do a multimedia assessment of risk that takes into account not only the inhalation pathway but also food intake, drinking water, and other ways that humans might be exposed. PISCES will eventually give us information not only on air emissions but also on water and solid discharges and their potential to contain toxics. We can use all that information in the model to determine the overall exposure to humans and their overall risk from power plants."

Although Levin's risk assessment project relies on PISCES data, it will in turn develop information that will be used by the PISCES project. Once the risk assessment identifies priority substances, the PISCES team will be able to incorporate this information into the control technology guidelines. "Absent a list of priority pollutants, these guidelines need to be interim, robust, and broad," says Chow. "If specific substances are identified that pose concern, we can target those substances and begin developing control technologies that will effectively protect human health and the environment at a reasonable cost."

The analytical challenge

Although the list of air toxics that will be subject to detailed analysis by EPRI's risk assessment project has not been completed, one substance is sure to be on the list. Mercury was singled out for a special EPA study for several reasons. It's known to be toxic in large exposures, and environmental groups have voiced concern that environmental concentrations are increasing, at least in part because of air emissions from sources that include municipal waste incinerators and coal-fired power plants. Incinerated trash may contain numerous mercury sources, including batteries, paints, plastics, and fluorescent lights. Mercury is also present in trace quantities in coal.

Once released into the atmosphere from natural or anthropogenic sources, mercury vapor can travel long distances before settling in soil and water. It then moves up the food chain, ultimately accumulating in the tissues of fish and presenting a risk to fish-eating predators, including birds, bears, and humans. At least 20 states have issued human health advisories to limit consumption of fish caught in waters with high mercury levels.

The mercury situation serves to illustrate the complexity and challenges of evaluating and managing air toxics. Mercury enters the environment from many sources. In addition to releases from human activities, mercury vapor is released into the atmosphere from such natural sources as volcanoes, ocean water, forest fires, and mineral deposits. Human sources account for about 30–55% of global atmospheric mercury emissions, and about half that amount is attributable to fossil fuel combustion. U.S. utilities contribute about 5% of the global total. The trouble is that the material is present in only minuscule amounts, which are difficult to measure accurately. In ecological systems such as lakes, for example, mercury concentrations are typically expressed in the parts-per-trillion range. In a 25-acre lake, such concentrations might add up to just 0.3 gram of mercury for the entire lake. Getting accurate measurements can be challenging because samples are easily contaminated by contact with human hands, sampling equipment, or laboratory apparatus not kept scrupulously clean. Adding to the analytical challenge is the fact that mercury exists in a variety of forms, with different toxicities. The three major chemical forms are elemental mercury, or mercury-0 [Hg(0)], which is relatively nontoxic; inorganic mercury-2 [Hg(II)]; and methyl mercury, which is the most toxic form and is of most concern because it accumulates in fish tissue.

In the early 1980s, EPRI began sponsoring the development of vastly improved equipment and analytical techniques for measuring mercury in the environment. Using these tools, clean sampling methods, and ultraclean laboratory apparatus, EPRI contractors have been able recently to improve the accuracy of environmental mercury measurements 500-fold, according to Don Porcella, a project manager in EPRI's Ecological Studies Program. "Our contractors have revolutionized the way we think about mercury," he says, "because now we can measure it accurately in the concentrations in which it exists in nature."

Porcella manages a study on mercury in temperate lakes, which is working to quantify terrestrial and atmospheric sources of mercury and the processes that influence the accumulation of mercury by organisms. The researchers have incorporated their results into a computer model that simulates mercury transformations in aquatic environments and the accumulation of methyl mercury by fish. A potential application for the model is evaluating management options—that is, simulating how an ecosystem would respond to alternative emission control measures. The model will also be used in Levin's risk analysis project.

"We now have a very good mass balance of mercury in lakes," says Porcella, "but we don't yet know the mechanisms that are responsible for distributing it. We need to understand the processes that transport and transform the different species of mercury." To that end, Porcella has teamed up with Chuck Hakkarinen of EPRI's Atmospheric Sciences Program on a project that will go to the field to gather ambient air data for mercury. EPRI contractors will take air samples from ground stations and from aircraft to identify the chemical forms in which mercury from power plants exists in the atmosphere and to determine what types of reactions convert the mercury into the forms picked up by ecological systems. Although mercury is the initial focus, the project will also sample for other air toxics as priority pollutants are identified by the Risk PISCES project.

The Pieces of the Air Toxics Puzzle

Health Effects Some of the substances designated as air toxics exist in several chemical forms, which may have different effects on human health. EPRI's Health Studies Program is sponsoring research that aims to fill gaps in the health effects data on several substances, notably arsenic, so that accurate toxicity data are available for use in computer modeling for risk assessment.

Atmospheric Transformation Substances emitted from plant stacks can be chemically altered in the atmosphere, and the resulting compounds may behave differently than those originally emitted. A field monitoring project is under way to improve our understanding of these atmospheric transformations and to determine in what forms and concentrations emitted substances are deposited.

Risk Assessment EPRI-sponsored researchers are using a series of computer models and results of laboratory studies to calculate the potential risks to human health and the environment posed by utility emissions of air toxics. A key component of EPRI's risk assessment research on air toxics is identifying priority pollutants and subjecting them to detailed risk analysis.

Ecological Processes EPRI's Ecological Studies Program is focusing initially on mercury and has developed new analytical and sampling techniques that have allowed researchers to obtain much more accurate measurements of mercury concentrations in ecological systems. EPRI mercury research is using a new computer model to simulate mercury transformations in aquatic environments and the accumulation of methyl mercury by fish.

Health effects

Air toxics are, by the EPA's definition, substances that pose a hazard to human health. But as shown by the mercury example, some of these substances exist in various chemical forms, and as Ron Wyzga, who manages EPRI's Health Studies Program, points out, "The form of a substance for which health data exist may be quite different from the form that comes out of a power plant stack. For air toxics to be managed effectively, the effects of these different forms on human health need to be better understood." Wyzga is heading up a series of projects to investigate the health effects of air toxics, focusing initially on arsenic.

Like mercury, arsenic is a substance of serious concern and a challenge to assess. It is classified as a human carcinogen and is present in trace amounts in emissions from coal plants and in fly ash, to which plant workers may be exposed. It exists in two valence states: arsenic-5 [As(V)], believed to be prevalent in power plant emissions, and arsenic-3 [As(III)], which is released from smelters. The evidence for human carcinogenicity, Wyzga explains, is provided by epidemiological studies of smelter workers, who inhale arsenic-3, and of populations who drink water contaminated with arsenic-5. "The relevance of the health risk data derived from the arsenic-3-exposed smelter population to utility emissions is unclear because of the difference in valence states," he says. "The relevance of the drinking-water studies to utility emissions is also unclear, owing to the difference in the routes of exposure—inhalation versus ingestion."

To add to the challenge, says Wyzga, "there is no animal model for arsenic carcinogenesis; hence animal studies are not available to resolve this issue. Arsenic is generally accepted to be carcinogenic in humans, yet researchers have not been able to induce cancer in laboratory animals from arsenic exposure."

Researchers looking at toxicity mechanisms for arsenic have found that the body handles arsenic-3 differently than it does arsenic-5, notes Wyzga. "Our studies will look at toxicity and carcinogenesis mechanisms of both arsenic-3 and arsenic-5 to find if they are different and whether we can extrapolate from one to another," he says. "We are also considering pharmacokinetic studies to better understand how exposure through oral ingestion relates to exposure through inhalation."

Says Wyzga: "The objective of this research is to reduce uncertainties so that utilities and regulatory agencies can protect the public health." Reducing uncertainties in the health effects data, he points out, in turn helps reduce uncertainties in the risk assessment models to make them more accurate predictive tools.

Future directions

EPRI's response to the large and complex air toxics puzzle involves a coordinated effort among many project managers and researchers working on separate parts of the puzzle. Over the next couple of years, the knowledge being developed through computer models, field measurements, risk assessments, and health effects studies will give the industry and regulatory agencies the best scientific information available for dealing with the air toxics issue.

But although EPRI project managers are focusing on air toxics, they aren't ignoring the fact that removing a substance from one discharge stream may merely shift it to another. In anticipation of the industry's future needs, EPRI R&D is aiming to develop integrated approaches to managing all the by-products that leave a power facility through the various discharge streams. By improving our understanding of the sources, internal pathways, and exit routes of the chemical species in a power facility, the PISCES project is laying the groundwork for the development of comprehensive approaches to managing the by-products of power generation in the twenty-first century—approaches that aim to minimize, even eliminate, potentially hazardous chemicals from the utility facilities of the future.

PISCES project manager Winston Chow envisions a day, perhaps as early as the mid-1990s, when the many computer programs now used for assessing risk, for modeling atmospheric transport and chemical transformations, and for predicting plant emissions can be brought together into an integrated computer workstation for environmental assessment. "At one console," says Chow, "a utility environmental manager could call up the PISCES model; air, water, and soil transport models; and even risk assessment models to inform and support the risk manager's judgment of the most environmentally compatible and cost-effective operating strategy." The ultimate goal of such a strategy, and the direction of EPRI's multidisciplinary R&D on overall toxics management, is to move beyond the current practice of simply capturing and disposing of power facility by-products and toward the practice of recovering and reusing them or reselling them to outside markets.

These are ambitious goals, especially in light of the many uncertainties that now surround the issue. But EPRI is building the knowledge base and the tools that will meet the industry's long-range needs to protect human health and the environment while meeting its primary mission of producing power. ■

This article was written by David Boutacoff. Background information was provided by Michael Miller and Winston Chow, Generation and Storage Division, and Don Porcella, Leonard Levin, Ron Wyzga, and Chuck Hakkarinen, Environment Division.

THE FUTURE OF COLLABORATIVE RESEARCH

by Brent Barker

The global economy is helping to rewrite the basic ground rules of American industry. Barred from direct collaboration for over a century by the Sherman Antitrust Act of 1890, U.S. business competitors are now seeking new, unprecedented alliances—initially overseas—to ensure their economic survival on the new playing field. Joint ventures, partnerships, and other forms of collaboration among otherwise fierce competitors are springing up around the world. The new international alliances represent one of the quickest and cheapest ways to combine strengths, to gain access to unfamiliar markets, and—most important—to gain both a global presence and a global strategy.

In this freewheeling global linkup, the lingering hold of separatism in U.S. corporate law and culture is looking more and more like a handicap. Although the original intent of antitrust law was to ensure that domestic competitors actually competed and didn't simply gang up on the marketplace, the need for consumer protection of this type now seems less relevant in a worldwide market crowded with competitors. Some knowledgeable observers now argue that U.S. antitrust laws are actually leaving American industry vulnerable to the larger competitive forces now aggregating in the global economy.

Remarking on the new global reality, Jack Urquhart, senior vice president for industrial and power systems at General Electric, said, "I remember just a few years ago when GE's major competitor lived over in Pennsylvania, at the fork of the Allegheny, Ohio, and Monongahela rivers. Today, our competitors live throughout the world and are joining forces to challenge GE, which they recognize as the team to beat. Over the next 10 years we will see, in power systems supply, the emergence of four or five global megacompanies—technology centers—around which manufacturers will align. GE intends to be one of them."

Although collaboration among domes-

THE STORY IN BRIEF

Relaxation of U.S. antitrust laws over the past two decades has allowed the formation of consortia for the purpose of carrying out collaborative "precompetitive" research. But fierce global competition has brought its own changes, both in the formation of new consortia and in the orientation of older ones. Representatives from the four original U.S. research consortia—EPRI, the Gas Research Institute, Bellcore, and the Microelectronics and Computer Technology Corporation—were among the 10 speakers at the Institute's latest summer seminar, which offered lively debate on the past, present, and future of collaborative research. The discussions illuminate how consortia are finding it necessary to change their missions and management styles to meet client needs and strengthen the coupling of R&D to actual applications. As the delivery of value speeds up, consortia will play an increasingly important role in the economic fate of the nation.

tic competitors is still rare, it is not quite the anathema it once was. Cracks are in fact beginning to appear in the aging U.S. antitrust wall. One of the first and most intriguing areas of the new collaboration has been research. The 1984 National Cooperative Research Act opened the doors to joint action in those areas designated as "precompetitive research," and in the last six years hundreds of consortia of mixed scope, permanency, and success have sprung up. They have joined the older R&D consortia set up by the regulated industries—electric, gas, and telephone—which, freed from threats of antitrust action and encouraged and cajoled by various legislative and regulatory bodies in the 1970s and 1980s, were the first to embrace the notion of industrywide collaboration in science and technology.

Consortia catching on

The hypercompetitive global economy that has emerged in the last decade has had a profound impact on the research consortia. It has become not only a driving force in the formation of new consortia but also a catalyst for change in the older ones. In both the old and the new, it is changing the speed, style, values, and orientation of research. And coming full circle, consortia themselves are upping the global ante, propelling technological change and with it the competitive requirement to keep up. One way to keep up is to form a strategic alliance—in many cases a consortium—to gain speed and leverage in technological development. As a result, research consortia have become both a driver of and a response to the growing kinetic energy of the global economy.

Nevertheless, appreciation of research consortia has come rather late to the United States. According to Rocco Marano, president of Bellcore, the nation's largest research consortium, "There was a time not long ago when I had to explain collaborative research and defend consortia whenever I spoke. I had to gain converts to the idea that competing American corporations might cooperate upstream from the marketplace. Today, collaborative research in general and consortia in particular are catching on in this country. We're discovering what our counterparts in Japan and Europe have known for some time."


Rocco Marano

"We don't do work anymore just because it is interesting or because it advances the frontiers of knowledge. We do it because our customers need it to take care of their customers. As a result, a new Bellcore culture is taking shape—one where we define quality as client satisfaction."

Marano and Urquhart were two of ten speakers who kicked off two days of spirited discussion among the 60 participants of the EPRI seminar "Collaborative Research in a Competitive Environment." The speakers included utility executives and representatives from four of the leading research consortia in the United States today—Bellcore, EPRI, the Microelectronics and Computer Technology Corporation (MCC), and the Gas Research Institute (GRI). The participants included members of EPRI's Board of Directors and members of EPRI's Advisory Council and their guests, representing a broad cross section of leadership from government, industry, the universities, and the regulatory community.

Origins of four consortia

The original four consortia were created by private interests within a relatively brief, 12-year span, from 1972 to 1984. Although the consortia were formed under widely different circumstances, and for quite different reasons, the origins of each bear the strong imprint of the federal government.

EPRI was the first. Although the idea of a central R&D organization for electric utilities had been under discussion and study for a number of years, the organization emerged suddenly, in something of a "cesarean birth," according to its founding president, Chauncey Starr. The Senate Commerce Committee had given the industry just one year, 1972, to develop an alternative to a proposed federal agency for electric power R&D, one that would be supported by a nationwide tax on electric utility sales. Starr succeeded not only in creating EPRI under deadline but in stamping it with his own particular vision. Starr's conviction that "electricity is the mainspring of social and economic development" helped set the course for a research agenda with a strong sense of national purpose.

Next came GRI. The stimulus in this case was not the Senate but the Federal Energy Regulatory Commission (FERC), which was seeking to compensate for the fact that low regulated gas prices had for years discouraged significant R&D in the natural gas arena. Gas utilities and the interstate pipeline carriers brought together 107 charter members in establishing GRI in 1976 and drew upon the organizational model Starr had created at EPRI.

MCC was established in 1982. By the early 1980s, the federal government was growing restive about how to keep the United States ahead in the global computer race. Responding to the new challenges posed by the many government-assisted research consortia being established in the information area in Europe and Japan, the U.S. government sanctioned the formation of MCC. MCC became the first of many information-based

Barry Whalen

"MCC is trying to build a strategy for no-limit poker. Many of our companies and industries are now essentially playing for this kind of global stakes. Our members understand that in no-limit poker the guy with the largest bankroll almost always wins."

consortia to emerge in the 1980s. It drew together 21 diverse shareholders, ranging from Hewlett-Packard and Honeywell to Westinghouse, Boeing, and 3M.

Bellcore was born of the judicial branch of the federal government rather than the legislative or the regulatory branch. As Marano put it, "Our birth was unique. We were the product of an explosion—the breakup of the Bell system. Our creation was specifically authorized in the court order that governed the breakup." Bellcore now serves the seven unaffiliated regional telephone companies with a staff of 8300 and a budget of $1.1 billion.

Despite widely divergent origins, missions, and technologies, the four consortia have taken remarkably parallel paths in their evolution over the last decade. Each has become much more tightly tied to its members' needs. Competitive forces, emanating directly and indirectly from the global economy, have brought new expectations for research on behalf of the client companies. Speed, value, choice, and delivery have become priorities, adding new pressures to shorten the research horizon and to show immediate and continuing proof of value. One result is that the culture and climate of research are also undergoing change. A second result is that the issues and problems of commercialization have moved to the forefront of American research concerns. No longer is it sufficient for a research organization to pride itself on advancing the frontiers of science; the results must be linked to application—delivered and put to use in sufficient time to make a difference to the client.

Nowhere has the cultural change been more deep-seated than at Bellcore, which according to Marano has undergone "seven tumultuous years" trying to adapt to the new demands of its client-owners, the seven regional telephone companies. "The cultural heritage of the old Bell system is a powerful influence. We're proud of it. At the same time we know that it isn't enough anymore, and sometimes it gets in the way. We don't do work anymore just because it is interesting or because it advances the frontiers of knowledge. We do it because our customers need it to take care of their customers. As a result, a new Bellcore culture is taking shape—one where we define quality as client satisfaction."

Focus on the client

Getting there has been difficult. Bellcore has stated its reorientation toward the client in a body of written values and principles and has sought every opportunity to communicate its redefined mission. But it takes time, and a bit more. "This can't be done by decree," said Marano. "Statements don't make the culture; organizations must breathe life into these principles. New cultures create themselves over time out of shared experiences."

A major concern has been holding on to top talent. The cultural shift implicit in the number one value at Bellcore—that "customer needs drive us"—may in fact drive away the very best scientific

Stephen Ban

"Concrete and quantitative evidence of benefits is now essential to keeping member support. We must now compete well with alternative marginal investments. And to do this we must increase the flow of benefits to our customers. Clearly, technology transfer is central to making consortia work."

minds if carried out insensitively or too abruptly. Bellcore's second value explicitly recognizes that "people are our strength." Bringing home the point, Marano said, "We function on brainpower. We don't manufacture; intellectual property is our product. And good people don't fall out of the sky. We simply must keep the very best people at all levels to be successful."

A key reason for keeping the best people is to stay ahead of the marketplace. Marano added that looking after the true interests of his clients requires him not only to respond to what the market wants today but to envision and create the market requirements of tomorrow. It takes topflight talent to lead the market—to know just when and where to provide technological leadership far enough ahead of today's commercial requirements to keep clients continually at the cutting edge. Marano cited optical electronics and voice synthesis as two examples of critical, high-payoff areas to which

Bellcore is committing resources of its own for the future.

The secret of success in the long term, said Marano, "is that we must be the best at what we do—innovative, creative, cost-effective, and timely. From our clients' standpoint we must be easy to do business with. We must not only do excellent work, we must *deliver* excellence."

The delivery of excellence has been tagged as the third value of the new Bellcore culture. It exemplifies the new struggle of research consortia everywhere to improve the downstream pickup of research results, what many organizations today call technology transfer. Why the emphasis on delivery? "Because we are now in a position," said Marano, "where we must prove over and over that the consortium has value—to our owner-clients, to our regulators, even to the public at large."

Enhancing value through better delivery was a theme picked up and amplified in various ways by a number of participants. Richard Balzhiser, president and CEO of EPRI, concluded a discussion of EPRI's mission by saying that "delivering value is the key to success in R&D today." Stephen Ban, president and CEO of GRI, agreed, adding that "concrete and quantitative evidence of benefits is now essential to keeping member support." The reason, continued Ban, is that "with deregulation [of gas] have come new, demanding standards for returns on cooperative R&D. We must now compete well with alternative marginal investments. And to do this we must increase the flow of benefits to our constituencies. Clearly, technology transfer is central to making consortia work."

Barry Whalen, senior vice president for plans and programs at MCC, said flat out that "the first attribute of a successful consortium is that it must provide high value." Whalen prefaced his comment with some of the turbulent history of his own organization and the fast-paced industries it represents. Through hard-won experience, Whalen now extends his list of essential attributes of consortium success to five. "First, the consortium must prove its value. Second, it must create new business opportunities for the participants. Third, it must have a direct impact on the critical path of the business, even in some cases down to producing breakthroughs on schedule. Fourth, it must find a way to balance short- and long-term benefits. And fifth, it needs a mechanism to accelerate the process of commercialization." And here, in the key commercialization area, Whalen added, "we have a poor track record."

Whalen pointed to the difficult process of getting MCC launched and the impact this had on the rapidly evolving organization. It took two years to put the organization in place, and it took another three years to develop the first commercial product. The five years total from startup to the first evidence of tangible value was, in Whalen's opinion, "totally unacceptable, with the rate of change today, and one of the reasons MCC has gone to the 'instant consortia' mode."

Bruce Merrifield

"Everyone now understands that technology is the engine that drives the world economy, and everyone wants to participate. To compete, we need to build strategic alliances—collaborative ventures of all types—as a means of structuring ourselves for the management of continuous change."

Linked consortia

In addition to the 21 shareholding companies, MCC now has grown to include 26 associate members and 3 government agencies that participate in individual research programs. These programs constitute what Whalen calls instant consortia in dozens of critical technological areas, ranging from electronic packaging to CAD software, to solid-state optical storage, to enabling technology for computer visualization.

The end result, said Whalen, is that "MCC is not a consortium. It is a collection of linked consortia. We have a diversity of companies from many sectors—computers, defense, communications, semiconductors, consumer products, finance, insurance, manufacturing—with a common mission of competitiveness in information technology. Since we now have pervasive technologies, such as laser diodes, that are finding their way into all kinds of products—office, entertainment, information storage, etc.—we need some new way to link companies in different businesses that are using these core technologies. MCC can fill the gap for companies that are not horizontally integrated."

The impetus is competition, particularly among the large, horizontally integrated organizations now emerging on the world stage. Nowhere has the international competition been more fierce, and nowhere have the stakes been higher, than in the exploding information field, where MCC is concentrating. "MCC is trying to build a strategy for no-limit poker," said Whalen. "Many of our companies and industries are now essentially playing for this kind of global stakes. Our members understand that in no-limit poker the guy with the largest bankroll almost always wins."

Whalen sees the competitive issues associated with the race for high-definition television (HDTV) symbolically at the heart of the problem. To compete, parallel

Jack Urquhart

"Today, our competitors live throughout the world and are joining forces to challenge GE. Over the next 10 years, we will see the emergence of four or five global megacompanies—technology centers—around which manufacturers will align. GE intends to be one of them."

investments must be made in disparate industries, markets, and technologies—consumer electronics, computers, semiconductors, cable, telephone, movies, banks. "The investment is staggering," he said. "We need hundreds of millions for each of these major markets, and this investment must occur simultaneously. Large foreign companies are now establishing these relationships to make all of these investments in lockstep."

His proposal to meet the global HDTV competition is to create a linkup of interrelated consortia for both research and investment. One consortium to develop receiver prototypes. One to develop standards for programmers, distributors, transmission companies, and so on. And still others to demonstrate interactive services using fiber-optic cables and to manage a trial cities market assessment. The cost of this kind of demonstration is high; it would take about $40–100 million, he estimates, to "fiberize" a small city. Nevertheless, the eventual stakes are so enormous that the opportunity should not be lost. According to Whalen, recognition of the market potential is widely evident. "A consortium is now forming at MCC of telephone, newspaper, and advertising companies to develop simulations of interactive services."

The organizational implications of what Whalen is saying may in the long run become more important to the nation than the particular outcome of the HDTV race. Under the duress of global competition, MCC has evolved faster than most other research consortia, and the forces and form of its evolution may hold some clues to the future for other research consortia. It is perhaps telling that Whalen described MCC's current organization as "a management vehicle for research and business collaboration that can lead to investment and technology exploitation." The key phrase is *business collaboration*.

Dominant trends

Overall, three broad trends are likely to impact the research consortia of the future. First, as MCC's Whalen clearly implied, the barriers distinguishing R&D activities from downstream investment will continue to blur; and the concept of consortia is likely therefore to broaden well beyond research. MCC's experience with HDTV collaboration already demonstrates the advantages of moving the concept of collaboration into the business arena, even though collaboration in the future will be constrained by the remaining antitrust laws. The second broad trend is that consortia are likely to become more inclusive over time, broadening their membership base while offering their members greater selectivity in the R&D program. And third, technological change will become a major force itself, pressuring change in both the character of the consortia and the lineup of participants.

Stephen Ban of GRI provided clear evidence of the second trend, the expanding membership base of consortia, and clearly spoke to its advantages. "GRI has gone through two big structural changes in its history: adding a new constituency and moving aggressively into technology transfer. Both have their origins in the deregulation of gas. Deregulation made gas producers awaken to the fact that they were paying part of the bill for research [through netback pricing], and at the same time it became clear both to the producers and to us that GRI's program would improve with their involvement. Gas producers joined us in 1988."

James Ferland

"We in this industry still think too much of competition in terms of nonutility generators and each other, and not enough in terms of the larger world. [We must be able] to produce electricity at rates competitive with Japan and Korea and others—because that's where a lot of jobs and customers are going to go if we are not effective."

As a result, GRI has expanded from 107 charter members in 1976 to approximately 300 members today and now represents about two-thirds of gas energy sales in the United States. According to Ban, GRI has successfully delivered 150 commercial products to market in the last 10 years and provides a solid 4:1 benefit-cost ratio for its enlarged membership.

Like GRI, each of the other consortia continues to explore the pros and cons of expanding its membership base, and each is now moving, whether quickly or incrementally, toward providing greater

Mason Willrich

"If we move the generation side of our business into a more competitive structure, we'll unleash forces that will accelerate technological innovation. This is crucial to economic success in this industry—and to putting this country back in a mode where we are competitive in global markets."

choice for members. In opening up its research menu completely, MCC has certainly gone the furthest. Bellcore's program is now about two-thirds elective. And EPRI has just introduced a program of "tailored collaboration," designed to give its members greater flexibility in directing a portion of their research funds.

The broad consensus among the seminar participants was that the trend toward membership expansion and greater research selectivity would continue. Most saw it as a natural evolution—a long-term necessity as their various industries and markets evolve and as the existing memberships come to recognize the benefits of drawing upon the larger pool of technical expertise outside their own industrial core.

But what of technology itself? If it is in fact a dynamic process, how can the industries and consortia now arrayed around today's technologies remain constant? This was clearly an issue of concern to the participants, one they came to view as the third major trend affecting the future of research consortia. The clear implication is that technological change will alter the "natural boundaries" of today's industries, and with them the very construct of an industrywide consortium.

"In the old days," said Marano, "we had the illusion of control over the pace of technology change. But technology is changing faster every day. Technologies once considered distinct are now merging. The merger of telephony, computers, and television is now inevitable—no one can stop it. And everyone must come to terms with it."

As some type of new cluster emerges from today's separate telecommunications industries, it seems to follow that Bellcore will have to seek broader research alliances; and anticipation of the merger of telephone, computer, and television technologies may well have been a factor in Bellcore's decision to become a shareholder of MCC. Although Marano stopped short of speculating on the future direction of Bellcore, he does believe that "within 5–10 years the nation will begin the tremendous investment of moving toward a totally digitally oriented network. Eventually we will have two fibers for everything that now requires separate circuits—video, telephony, data, fax, etc." The result, which Marano described as an "intelligent network," will allow the unbundling of software for new services from the basic switching capacity. The portent of this unbundling is a vastly accelerated service revolution in telecommunications.

In a similar vein, Whalen talked about the ever-expanding information industry and the likelihood and necessity of the formation of a new consortium of information users. "The biggest change in consortia will be a movement from the manufacturer's side to the user's side," he commented. "Open system architecture is forcing computers down to the commodity level. Information users are now completely disaggregated and may really benefit from an EPRI-type organization someday."

William Berry

"Technology is key to the future of this industry regardless of what its structure is—key to either its success or failure. This is not all upside potential; there are a lot of technological threats out there."

Technology is also changing the face of the energy industries. The impetus toward greater efficiency in resource utilization and waste control, for example, carries with it the implication that today's energy, chemical, and manufacturing industries will find common ground in integrated approaches to resource processing—complexes capable of producing a full spectrum of chemicals, feedstocks, and electricity from a hydrocarbon stream such as coal. As many participants pointed out, electricity generation has, in fact, already begun a long-term trend toward attracting a number of new players, ranging from independents firing natural gas to equipment suppliers and mainstream chemical and oil companies.

A global race

Across the spectrum of modern technologies, from microelectronics to energy, the speed and sweep of technological change has taken on a life of its own. Capturing the opportunities implicit in this change

Jim Jura

"EPRI has been struggling with the issue of greater membership choice for a long time. The needs we are trying to address are, first, a fair funding mechanism and, second, a way to work with changes in the industry, including new players. As EPRI gets closer to its members, I think we will see it move in this direction."

has become a global race, one that places a premium on unifying the entire innovation process, from research to final product. The conclusion, at least in the mind of Bruce Merrifield, professor of management at the University of Pennsylvania's Wharton School of Business, is that "we must meet the worldwide technological explosion by collaborative efforts—by pooling our resources, skill, and capital to pull our major developments into the pipeline. Everyone now understands that technology is the engine that drives the world economy, and everyone wants to participate. To compete, we need to build strategic alliances—collaborative ventures of all types—as a means of structuring ourselves for the management of continuous change."

A number of the participants saw the global imperative and the need for change management as having particular import for the utility industry. According to James Ferland, who is chairman of the board, president, and CEO of Public Service Electric & Gas and also chairman of EPRI's Board of Directors, "We in this industry still think too much of competition in terms of nonutility generators and each other, and not enough in terms of the larger world. I don't think there is adequate appreciation for the macro issue we are dealing with, namely, the importance of technology in allowing us to produce electricity at rates competitive with Japan and Korea and others—because that's where a lot of our jobs and customers are going to go if we are not effective."

Keeping the U.S. utilities competitive with their counterparts on the world stage is something of a novel concept but one that Ferland implied could become a central issue in the 1990s. Jack Urquhart of GE pointed to the growing disparity in global investment and to the fact that his markets, as well as the test beds for his advanced technology, have essentially shifted overseas in the last decade.

"The result is that the most efficient combined-cycle plant in the world is now in Tokyo, as is the world's largest nuclear reactor," said Urquhart. "We must face the fact that we have a relatively old utility system here in the U.S. The Koreans, Taiwanese, and Japanese have new systems. We have added less new equipment percentage-wise than any other major country except maybe England and Italy. There is a lot of work ahead for us rebuilding what we have—making it environmentally acceptable and improving its efficiency." Urquhart sees a particularly pressing need for both R&D and a wave of investment in nongeneration areas: transmission and distribution, systems work, and environment.

But restructuring within the utility industry may also become part of the answer to the global challenge. Mason Willrich, president and CEO of PG&E Enterprises, is one of a number of utility executives who see genuine advantage in opening the utility industry to greater competition. "As yet there is no common vision about where our industry is going. As a country we are tremendously fragmented by our 50-state setup, and the

Chauncey Starr

"The opportunity is there for this industry to take a leadership position in the whole spectrum of national issues. The big issue is not the alternative structure of EPRI funding but whether the funding is sufficiently large to tackle the major problems that the nation wants addressed."

utilities mirror that fragmentation. But it is clear to me that if we move the generation side of our business into a more competitive structure, we'll unleash forces that will accelerate technological innovation. This is crucial to economic success in this industry—and crucial to putting this country back in a mode where we are competitive in global markets."

Willrich laid out his own vision of the future of the utility industry, a vision around which he hopes "a consensus might be built." Utilities, he said, "will increasingly become more distribution and transmission companies and less generation companies." By this he means they will make major efforts to modernize their distribution systems, including widespread use of smart meters to transmit price signals and market options. He also believes utilities will join together in broad regional groupings to plan, build, and operate long-distance transmission systems and will go on to optimize these regional grids so that bottlenecks become a thing of the past. With all that in place,

Debating the Structu

As competitive forces continue to reshape the utility industry, the role of technology and the research that spawns it will almost certainly become more important. William Berry, chairman of the board, Virginia Electric & Power, drove home this point at the seminar when he said, "Technology is key to the future of this industry regardless of what its structure is—key to either its success or failure. This is not all upside potential; there are a lot of technological threats out there."

How best to meet the new opportunities and threats posed by technology and whether to meet them individually or jointly were the issues that galvanized the discussion for the last half of the seminar. Should the industry pull apart or continue to support its collaborative research program, begun 18 years ago with EPRI? And if the answer is collaboration, how can the individual needs of a rapidly diversifying membership be accommodated? Throughout the tug and pull of discussion, the trends driving other research consortia toward expansion of strategic alliances, toward greater inclusiveness in membership, and toward providing members greater selectivity in the research program were clearly evident.

"The day of individual R&D in utilities is behind us, for reasons of cost alone," said Jim Jura, administrator of Bonneville Power. "The leveraging and pooling of funds is more a part of our future." James Ferland, chairman of the board, president, and CEO of Public Service Electric & Gas, agreed. He included among the practical benefits of collaboration economies of scale, leveraging of investment, risk sharing, cost sharing, and continuity, as well as "one much less obvious benefit, but one we have come to truly appreciate at PSE&G—that is, the value of technical networking. The individual contacts and ongoing communications have value well beyond what we can measure."

Moreover, Ferland stressed, "Collaboration in the future will increasingly mean working with government, private organizations, international suppliers, and foreign utilities. It is critical that EPRI play a leadership role in these broader collaborative activities."

The most heated discussion of the day revolved around the issue of EPRI membership choice. Bill Berry took the strongest stand, calling for the virtual unbundling of EPRI's program. "EPRI needs to be changed," Berry said. "EPRI is attempting to meet the research needs of the 1990s with a membership structure and a funding arrangement that belong to a bygone era. IPPs [independent power producers] have become an important factor in this industry and yet are excluded [from full membership]. And EPRI has a one-size-fits-all program that assumes a homogeneous industry. That may have worked in the 1970s, but today we have a very diverse and variegated industry."

Berry proposed that EPRI be divided into four broad categories. The first would be a core program, aimed at universal participation, that would include environmental issues, transmission and distribution, and long-range, basic research. The other three pieces—generation, end use, and advanced generation—would be broken into still finer categories, each of which would be entirely discretionary. In Berry's view, "The result would be that payments would be fairer, and EPRI's priorities would change for the better."

George Maneatis, president of Pacific Gas and Electric, took exception. "Bill Berry's proposal is cherry picking. How can we do this and sustain a national research program? What is to keep it from fragmenting further?" But Maneatis went on to say that "what Berry proposes may be accomplished over time."

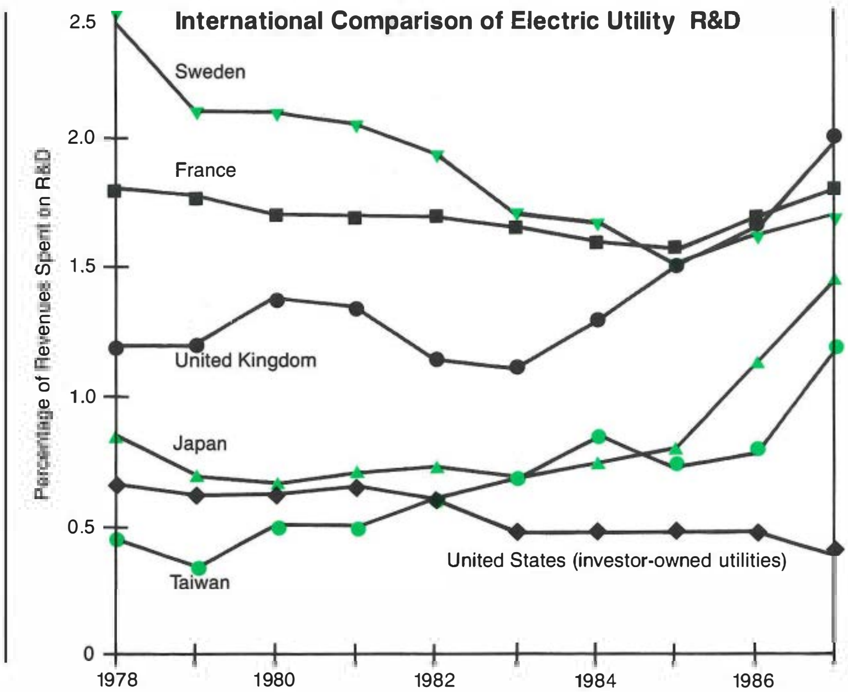
Jura, picking up on Maneatis's point, said, "The key word here is *transition*. This is not entirely new; the management of EPRI has been struggling with this for a long time. The specific needs we are trying to address are, first, a fair funding mechanism and, second, a way to work with changes in the industry, including new players. As EPRI gets closer to its members, I think we will see it move in this general direction."

Mason Willrich, president and CEO of PG&E Enterprises, joined in by saying, "I like Berry's proposal. It responds to structural changes in the industry. *A la carte* means people are more involved in the pieces that they choose, and as a result you are more likely to get a coupling of R&D to actual innovation. That's the bottom line—not, are we producing R&D, but whether the work we are doing is leading to new products and services for the industry."

In James Ferland's mind, the evolutionary trend is being fueled by competition. "It's not really a question of *if*, but *when*. In the future, I'm sure there will be more latitude for members to place funds. I'm even getting substantial pressure from my own organization. The reason is that we are trying to run our organization more like a busi-

Shared Research

During the 1980s, foreign electric utilities consistently spent more on R&D as a percentage of total revenues than their counterparts in the United States. Over the long term, this lack of investment in innovation may put the competitiveness of U.S. electric utility customers in jeopardy.



ness than a regulated monopoly. As we do this, we find our employees poking into all sorts of corners and finding out that the places where we have been sinking our capital as a regulated monopoly are not the kinds of investments that bring something down to the bottom line. I'm getting pressure to earmark EPRI funds to areas where it is more profitable, like T&D."

Ric Rudman, senior vice president for business operations at EPRI, described a new initiative to provide a mechanism for greater choice. Called "tailored collaboration," the policy initiative emerged from a survey of utility attitudes toward membership issues and options. "In our survey, we found a strong base of support, good return on investment, but a desire for more flexibility in directing a portion of their membership dues," said Rudman. "Tailored collaboration is an important start—it will allow members to begin to tailor programs to their specific needs, and it will allow regional and state groups to come to EPRI to manage research on their behalf. Overall, it provides some needed market signals to EPRI; and in the longer term, it provides a pathway to evolutionary change."

The long-term promise of tailored collaboration will be to speed and enhance the targeted delivery of value to individual members while preserving EPRI's collaborative nature. It opens the door for pockets of collaboration within a larger collaborative framework, a concept not dissimilar to the linked consortia undergoing trial at MCC. Although the idea was widely endorsed by the participants, support over the issue of an enlarged research effort was split. Some said we can't afford it; others said we can't afford not to do it.

Chauncey Starr, president emeritus of EPRI, helped to bridge the long discussion about membership options by reminding the participants of the broad national purposes of the electric utility industry. "My enthusiasm for electrification is based on the fact that it is the way to improve the gross cross section of environmental, public, and social issues that we are faced with today. The opportunity is there for this industry to take a leadership position in the whole spectrum of national issues, and I encourage you to take it on as a national responsibility. The big issue is not the alternative structure of EPRI funding but whether the funding is sufficiently large to tackle the major problems that the nation wants addressed."

Bruce Kenyon, then senior vice president of Pennsylvania Power & Light and chairman of EPRI's Research Advisory Committee, agreed. "Investor-owned utility research as a percentage of revenue is one-half what it was 15 years ago, while foreign utilities are increasing R&D as a percentage of revenue. This raises a fundamental question: are we putting enough money into R&D to fund our future competitiveness?" □

Profile of Four Consortia

	Year Founded	Members	Annual Budget	Staff	Mission
EPRI	1972	720 electric utilities	$400 million	760	To apply science and technology to the benefit of EPRI members and their customers
GRI	1976	300 gas producers, pipelines, and utilities	$185 million	270	To plan, finance, and manage R&D to benefit member companies and gas ratepayers
MCC	1982	21 shareholders and 26 associate members from diverse industries	$65 million	540	To enhance competitiveness in information technology
Bellcore	1984	7 regional telephone companies	$1100 million	8300	To provide technical support and services needed by shareholders in providing exchange telecommunications and exchange-access services

he reasons, they will be in a good position to become smart buyers on both sides of the meter—smart buyers of power on the open market and smart buyers of efficiency on the customer's premises.

"Eventually, we will resort to all-source bidding as the most efficient procurement approach," he said. "Twenty-one states have already adopted competitive bidding, and 13 more are considering it. As it spreads, the wholesale markets will become intensely competitive. There will be room for a wide variety of firms—large, small, broad-based, narrowly specialized, and those affiliated with utilities and other industries. Ultimately, however, competition will weed out any incompetents."

Expanding the consortia

Bruce Merrifield went further than any other speaker in predicting, and advocating, the expansion of the consortium concept beyond research, an extension at odds with current antitrust law but entirely consistent with Merrifield's own history, deeply held views, and personal mission. As assistant secretary of commerce for productivity, technology, and innovation in the Reagan administration, he went aggressively after the U.S. antitrust laws as early as 1981, "because they were killing us internationally."

As part of his crusade, he spearheaded the drive for the National Cooperative Research Act of 1984, which in turn opened the floodgates for research consortia, and he subsequently championed the Technology Transfer Acts of 1984 and 1986 to help the United States "capture our own technology—the billions in federally sponsored research that we have been giving away for 40 years."

Merrifield believes we must gird ourselves for the global competition of the 1990s by a series of coordinated policy steps: mobilizing our advanced technology, reforming monetary policy to reduce the cost of capital to stimulate investment, and modifying the U.S. antitrust laws and regulatory barriers that "currently inhibit the collaborative efforts needed for industrial competitiveness."

He pointed out that we have arguably the most entrepreneurial culture in the world, one that creates between 600,000 and 700,000 new businesses every year, of which more than 70% survive for longer than 5 years. These new businesses have been the primary generator of the 20 million new jobs created in the United States in the last decade and the primary source of most "next-generation technology."

"Ours is a bottom-up revolution," said Merrifield. "We have 15 million companies in the U.S., and yet only 5% are publicly traded. The other 95% represent the great invisible strength of the U.S. economy, a diversity and depth that no other nation can match. Coupled with our lead in basic research of $18 billion per year, this gives us a permanent leading edge in next-generation technology."

The real question in his mind is whether the leading edge in innovation is enough. Our highly creative businesses are also highly fragmented, unable to join forces except through outright merger and acquisition, and generally starved for capital. He acknowledged that "90% of the cost of innovation is involved in translating basic discoveries into useful commercial products and services. And the climate for this translation in the U.S. is just not adequate. As a result, the U.S. advantage in advanced technology is not being effectively exploited."

If Merrifield had his way he would extend the consortium concept all the way to manufacturing; in fact, he believes that a collaborative manufacturing law is imminent in the United States. With this law in place, he foresees, there would be a rapid shift to the shared ownership and shared use of the "flexible, computer-integrated manufacturing" (FCIM) system. The idea here is that a shared, central facility would be reprogrammed continuously by individual companies that would buy time to develop prototypes and carry out short production runs.

"The transition to FCIM is now beginning," he said. "Eventually, it will trans-

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form manufacturing to a largely service function in which a given facility can make hundreds of different products for different companies in different industries. It optimizes investment and reduces the cost of labor in manufacturing from an average of 18–20% to less than 5%."

Most important in Merrifield's mind is the likelihood that FCIM offers the United States a strategic alternative, one that can be used to counteract the "targeted industries strategy" that has decimated so many U.S. industries in recent decades. As he explained it, targeting—as carried out by the newly industrializing nations—relies upon two steps: first, being able to carry a negative cash flow while pricing below cost until the market is captured, and second, recovering cost with a dominant and stable design after the competition is gone. But FCIM allows a targeted competitor to leapfrog step two with sudden innovation, eliminating the cost recovery period of the targeter and, with it, the basic incentive of targeting. As Merrifield summed it up, "FCIM introduces a new global strategy that favors companies and countries that can continuously develop next-generation technology. The creative culture of the U.S. should prosper."

If Merrifield's sense of the strategic importance of FCIM is correct, the pace of technological change will only accelerate in the next century. Product development cycles will shorten, production runs will get smaller, and products will be much more highly tailored to the customer's needs. As tailoring to the customer grows ever more sophisticated, production will, in fact, begin to emulate service.

FCIM goes to the heart of our national vulnerability in global competitiveness. It is emblematic of the need for new synergy between basic research and downstream technical activities, as well as for new modes of collaboration. The consortium is likely to play a larger role in helping the United States cope with the issues of adopting, adapting, and diffusing advanced technology. ■

ON-SITE UTILITY APPLICATIONS FOR PHOTOVOLTAICS

Photovoltaic solar cells that turn sunlight directly into electricity have been around since the 1950s, when the first modern cells powered satellites in orbit. Since then, researchers and manufacturers in half a dozen countries, mainly in the United States and Japan, have steadily pursued the scientific breakthroughs and engineering development needed for higher energy conversion efficiencies and lower cost. These are the long-sought twin goals that could make the ultimate vision for photovoltaics—providing a significant fraction of the country's electricity in widespread central station and distributed grid-connected systems—a reality.

Such a vision is still being pursued in continuing research and development by manufacturers, much of it sponsored by the federal government, some of it sponsored by EPRI. But while the quest continues for inexpensive, high-efficiency solar cells that can compete with conventional means of generation, something more than just R&D funding has been sustaining the photovoltaics business.

That something is now a $300-million-a-year worldwide commercial PV market—representing annual sales of some 50,000 kW (at peak rating) worth of cells and modules, and growing about 25% a year recently. In the United States, less than a fifth of the almost 15,000 kW of PV modules (peak rating) that one expert reports were made in 1989 went for use in familiar consumer products, such as solar calculators and watches. Virtually all the rest were used in a wide range of off-grid installations generically called remote power applications or were exported for similar uses to markets abroad (including growing markets in the developing world). Applications include lighting of various kinds, electronic communications equipment, corrosion protection, agricultural water pumping, remote monitoring, and even powering isolated homes for which the cost of extending conventional utility service is prohibitive.

THE STORY IN BRIEF

As photovoltaic solar cells prove economical for a growing number of niche applications in markets here and abroad, utilities are discovering a widening range of uses within their own internal operations. In many cases, PV modules can meet operational requirements for low-power utility applications more economically than extending distribution lines or adding step-down transformers. EPRI has launched new initiatives, including market studies and technical assistance, to help utilities develop such early uses of PV, both on their systems and for some specialized customer applications. This could help open significant new markets for solar-electric modules while providing important learning experiences for potentially major users. Utilities that put PV to work for special applications today will be in a better position to effectively apply solar cells to bulk power generation in the future as cell costs and efficiencies continue to improve.

The so-called remote power market for PV—which in this country accounted for some $80 million of industry revenue last year, according to one analyst—now counts operating installations in the several thousands in the United States alone. The systems are small in terms of power rating, typically ranging from a few tens of watts to as much as a few kilowatts. As stand-alone systems, they usually also involve battery storage. Thanks to a sustained federal government procurement program during the 1980s, some of the largest users of photovoltaic systems today include the nation's armed forces (particularly the Coast Guard) and the national park and forest services, as well as the weather and aviation agencies.

Electric utilities are also becoming a significant sector in the remote PV power market as they discover within their own operations the cost-effective, low-power applications in which PV competes handily with conventional approaches. More than 20 utilities today are using PV modules and arrays in low-power service applications, including warning sirens; beacon, buoy, and security lights; water-level sensors; communications links; backup generator starters; special switches on transmission lines; and even remote customer loads. And while no utility yet uses PV for all of these applications, California's Pacific Gas and Electric (PG&E), with over 700 documented in-house installations it calls cost-effective, comes close.

Recognizing the critical role that early, low-power PV installations can play in building confidence and establishing an experience base among utility operations and engineering personnel, EPRI has launched a major initiative to assist utilities in finding, evaluating, and installing such cost-effective applications of PV. Some of the activity is being coordinated with the Photovoltaic Design Assistance Center at Sandia National Laboratories in New Mexico and the Solar Energy Research Institute in Colorado.

EPRI's effort has included a series of regional workshops to introduce utility distribution engineers to the technology and to spread awareness of the many low-power applications of PV, both for utilities' own use and at customer sites. Along with a straightforward methodology to help identify the applications, a customized computer spreadsheet program is being developed that allows engineers to evaluate the relative economics of applying PV at a particular load versus the cost of extending a conventional utility distribution line. The Institute has also begun assisting in the development of specific PV applications, including some that may offer new business opportunities for utilities.

New perception of photovoltaics

According to John Bigger, a project manager in EPRI's Solar Power Program, the new thrust in cost-effective, early applications of PV in utility operations "represents a break from the typical past perception of utility PV, which was largely centered on the development of technology for large-scale, multimegawatt generating stations in deserts or other areas with very good solar resources. The more recent perception is that while today's PV technology is not economically competitive with bulk power generated by conventional means, PV can be quite competitive with alternatives in many low-power applications where the actual amount or cost of energy involved is less important than reliable and trouble-free remote operation.

"There is a new focus on fostering the cost-effective use of PV to power equipment routinely used by most utility transmission and distribution departments. Many utilities are also interested in using PV as a way to serve distant or uneconomical customer loads or loads they have been unable to serve before."

Bigger says such small-scale utility applications of PV for internal operations as well as remote customer service represent an important new market for small, distributed PV systems—despite the typically low power ratings of most installa-

PV at Electric Utilities: Cost-effective Applications Abound

Two dozen U.S. utilities of various sizes and ownership types are using photovoltaics for low-power loads in their own operations, having found the technology to be more economical than frequent battery replacement or extending a utility service line. As documented in a recent EPRI study, many such applications involve maintaining charged batteries for remote lighting, monitoring, and communications equipment. Some utilities are also exploring the cost-effective use of PV in customer service applications, including livestock water pumping, remote residences, and outdoor lighting. Small, remote loads of industrial and institutional customers represent a virtually untapped utility market for PV.

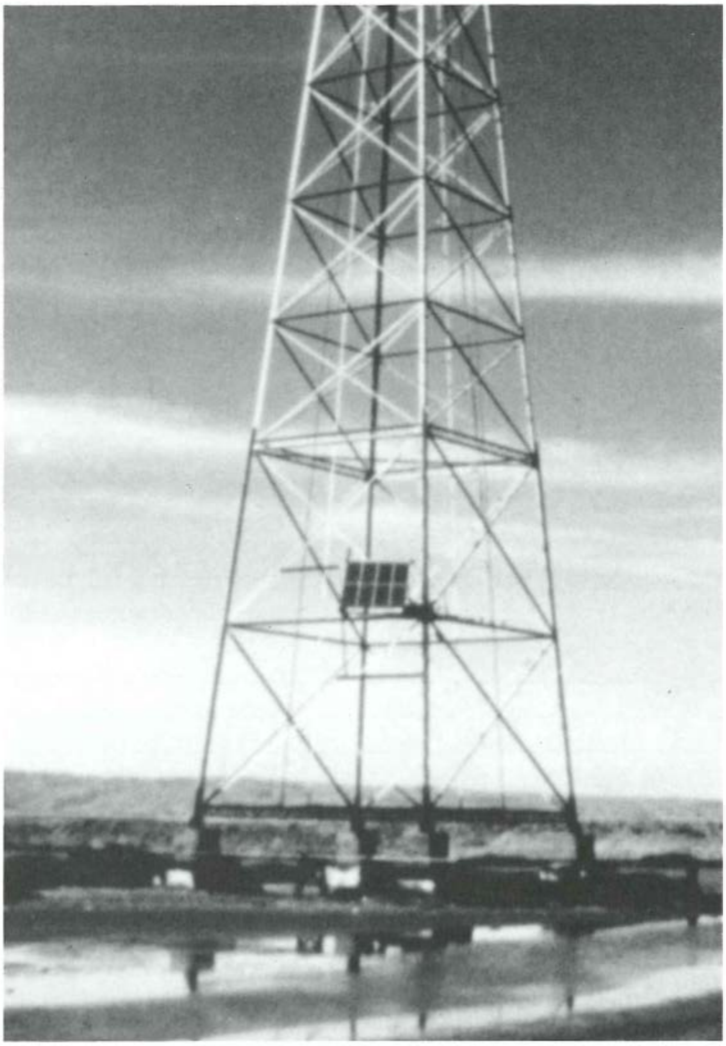
Utility Operations Area/ PV Application	Alabama Power	Arizona Public Service	Bonneville Power Administration	Boston Edison	Carbon Power & Light	Duke Power	Florida Power Corporation	Georgia Power	Gulf Power	Houston Lighting & Power	Indiana Michigan Power	K.C. Electric Association	Lower Colorado River Authority	New York Public Power Authority	Niobrara Electric Association	Northwest Rural Public Power District	Pacific Gas and Electric	Public Service of Colorado	Public Service of New Hampshire	San Isabel Electric Services	Savannah Electric and Power	Southern California Edison	Southwestern Electric Power	West Texas Utilities
Transmission and distribution																								
Tower obstruction beacons	■		■							■	■						■				■			
Sectionalizing switches		■						■									■							■
Cathodic protection							■																	
Power plants and facilities																								
Plant warning sirens		■		■													■							
Navigation aids							■						■											
Backup generators																	■							
Cathodic protection	■							■	■															
Automatic gate openers																	■							
Lighting																							■	
Communications																								
Microwave repeaters		■	■														■	■	■					
Remote metering																								
Emergency call boxes																								
Environmental monitoring																								
Remote weather stations																	■							
Water quality monitors						■																		
River level gauges	■																■							
Water temperature monitors																	■							
Cloud seeding																	■							
Insolation monitors														■										
Residential/commercial customer service																								
Remote residences																								
Water pumping and control					■						■	■			■	■				■				
Lighting					■															■		■		
Gas pipeline systems																								
Flow meters																	■	■						
Valve actuators																	■							
Cathodic protection																	■							
Gas flow computers																	■							
SCADA remote terminals																	■	■						

tions—because of the potentially very large numbers of installations across the country. As more utilities become familiar with PV and provide information to manufacturers and other utilities, companies that produce integrated PV power systems will be better able to develop effective, packaged systems tailored for utility use.

On the basis of input from engineering and operations department representatives of six utilities that already use or are considering using PV, EPRI contractor Ascension Technology of Lincoln Center, Massachusetts, recently estimated the potential near-term annual market for six applications. The contractor conservatively forecasts that over 7700 installations, representing yearly additions of over 3100 kW in aggregate peak capacity, are possible over the next five years. The utilities that participated in the in-depth application survey and market assessment were Alabama Power, Atlantic City Electric, Lower Colorado River Authority, New Braunfels (Texas) Utilities, PG&E, and Southwestern Electric Power.

T&D Applications of PV

Several utilities are using PV panels to charge batteries that keep aircraft warning beacons operating atop high-voltage transmission towers. PV is also being used in several cases to charge batteries that operate remote sectionalizing switches on transmission and distribution lines. PV-powered cathodic protection systems for tower footings (not shown) are also in use.



Tower obstruction beacon

T&D sectionalizing switches

Most of the potential installations and capacity identified in the study fall in the domain of customer service applications—streetlights, rest area fans and lights, and remote residences. The other applications involve utilities' own internal load requirements—powering tower obstruction beacons, charging batteries that operate transmission and distribution (T&D) sectionalizing switches, and providing voltage and energy support on heavily loaded distribution feeders.

But the six applications for which the utility market potential was estimated only begin to scratch the surface of possible near-term utility uses for PV. A database compiled by Ascension Technology from published references and utility and manufacturer responses to a broader survey for the project identified 65 specific uses of PV by utilities; most are based on at least one actual installation, and most, though not all, are considered cost-effective today. They span applications in agriculture, corrosion protection, communications, control, lighting, monitoring, pumping, residences, security, and signaling.

Investigators noted that the largest numbers of uses of PV involve the sending or receiving of information. Indeed, many of the earliest terrestrial applications of PV involved powering mountaintop radio and microwave repeater stations. Most major utilities operate their own mobile radio and microwave systems for voice communications and for supervisory control and data acquisition (SCADA) signals. Over the last 10 to 15 years, some utilities and telecommunications companies have pioneered the use of PV for such communications links.

For example, Public Service Company of New Hampshire has operated a PV-powered microwave repeater for over 10 years in the state's White Mountains. PG&E operates several as part of its far-flung communications and operations network in California. Nationwide, the EPRI applications database indicates hundreds of existing PV-powered communi-

More PV Possibilities for Customer Service

EPRI's studies have identified a number of cost-effective PV applications on the customer side of the service meter in areas where utility lines already exist, as opposed to remote, stand-alone installations. Line-connected residential applications include dusk-to-dawn security lights and electric gate openers. Commercial customer uses include cathodic protection, actuation of pipeline valves, lighting of parking lots, and powering of remote pumps for watering livestock.

In the case of pumping water for livestock, many utilities in the western United States have substantial numbers of these low-power, intermittent loads scattered throughout their service territories at the ends of long extensions of single-phase distribution line. The pump systems typically are less than 1 hp (750 W) and consume only 500–1000 kWh in a year. Very often, the cost to utilities to maintain distribution service to the pumps, particularly if utility lines are damaged in winter ice storms or summer tornadoes, can far exceed the revenue the loads represent.

To demonstrate the use of PV in this promising agricultural application, Sandia National Laboratories funded the installation of two PV-powered pump systems at a watering location in the service area of K.C. Electric Association, a rural electric cooperative in eastern Colorado. K.C. Electric reports that it serves at least 100, and possibly as many as 200, such remote pumping loads with distribution lines. In addition to Sandia, the Western Area Power Administration supported the project and EPRI provided support via a contract with Lakewood, Colorado, consultants NEOS Corporation.

NEOS documented the installation design and assessed the opportunities for utilities to offer PV water-pumping systems as a new customer service option and a lower-cost alternative to extending or rebuilding distribution lines. The NEOS study identified significant potential for utilities of all sizes and ownership types in 16 of the 26 major western livestock-grazing states. The application gives utilities the opportunity to offer PV-powered electric service as an option that also offers to reduce the utility's cost of service to those loads. NEOS also examined utility considerations with respect to customer service, operations, regulation, business objectives, and program implementation.

As part of the project, NEOS conducted a telephone survey of 25 rural electric co-ops in Colorado, Nebraska, and Wyoming about potential opportunities. On average, over 250 remote water-pumping installations were reported for each cooperative's service area. Assuming a PV system size of 500 W for such installations, the survey indicated a potential market of over 3000 kW.

Potential industrial applications of PV include powering such special remote equipment as the pumps at oil stripper wells, pipeline monitoring systems, or gas well meters. Institutional customers such as public agencies are already beginning to use PV for lighting highway signs and operating signals; for operating park and rest area lights, fans, and water pumps; for lighting streets and structures; and for operating irrigation meters and controls. In California, thousands of emergency roadside call boxes that were formerly served by electric utilities are now PV-powered. □

cations installations ranging from 400 W to 1 kW, with an aggregate installed power of over 1900 kW. (Most are owned by parties other than utilities, such as telecommunications companies.)

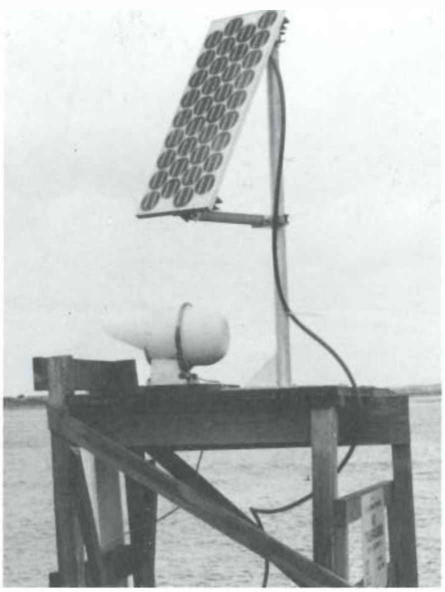
According to Sandia, the most widespread PV application is for warning devices, including transmission tower lights, navigational beacons, plant warning sirens, railroad signals, and highway signs. Over the last decade, the Coast Guard has converted over 11,000 of the navigational aids it maintains to PV power. Examples of utility applications in this area include Florida Power Corporation, which has outfitted more than 65 navigational buoys with PV panels.

At least three of the country's nuclear power plants—PG&E's Diablo Canyon, Arizona Public Service's Palo Verde, and Boston Edison's Pilgrim—use PV to maintain charged batteries on some of the warning sirens around the plants' perimeters. Sirens located a significant distance from a distribution circuit, where the alternative might be extending the line or frequent battery replacement and testing,

Providing Customer Service Without the Wire

Some utilities are exploring the use of PV as an alternative approach to serving remote customers and loads in situations where extending distribution lines would be prohibitively expensive. Such applications include remote residences, safety and security lighting, and remote, low-power pumps for livestock watering. Many industrial and institutional customers also use cathodic protection systems that could be candidates for PV.

Navigation beacon



Remote residence

Area and security lighting

Area and security lighting

Livestock water pumping

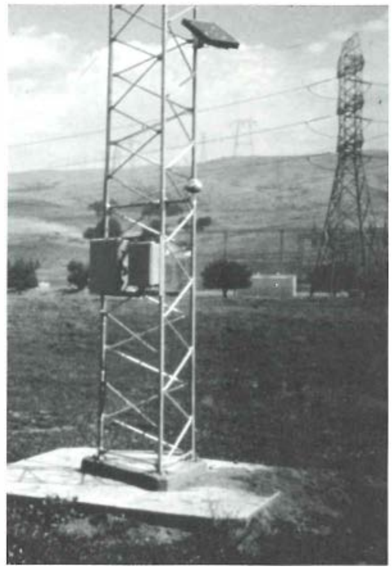
Remote residence

PV Spans a Spectrum of Other Utility Uses

In addition to T&D uses, PV offers a cost-effective alternative to distribution line extension in a wide variety of applications in routine utility operations. These include powering all sorts of communications equipment (e.g., microwave repeaters), remote terminal units, and meteorological and hydrologic monitoring stations. Power plant warning sirens and security lights are also being equipped with PV. Underground tank and pipeline cathodic protection systems, widely used by utilities, are beginning to be powered by PV.

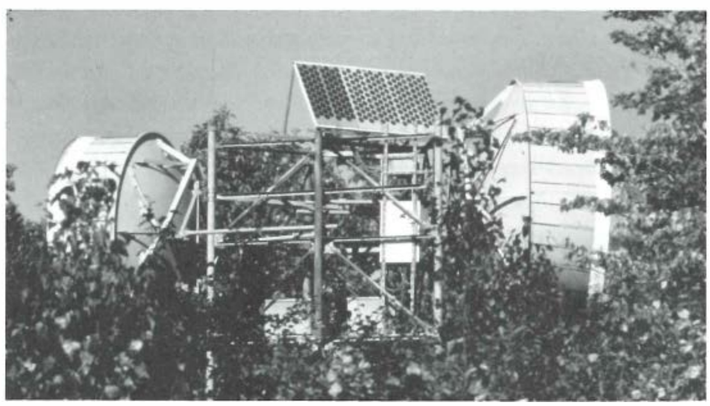
Water-level sensor

Weather instruments



Power plant warning siren

Microwave repeater



are good candidates for PV application.

Utility use of PV for transmission tower aircraft warning lights points up that many so-called remote applications are not necessarily geographically remote, just remote from an existing utility service line of the desired voltage. Low-voltage beacons on a tower carrying high-voltage conductors can't economically tap onto the transmission line. Typically, a utility must either string a distribution circuit to a transmission line tower or install costly transformers to step down the voltage for service use. The initial capital cost and the recurring maintenance costs for either conventional approach can be steep.

Several utilities have substantially reduced the recurring costs with standalone PV-battery systems mounted on the transmission towers. PG&E has done it with several 190-foot towers for 115-kV lines along mud flats on the southern end of San Francisco Bay. Bonneville Power Administration similarly lights several towers for its high-voltage circuits, including some that cross the Columbia

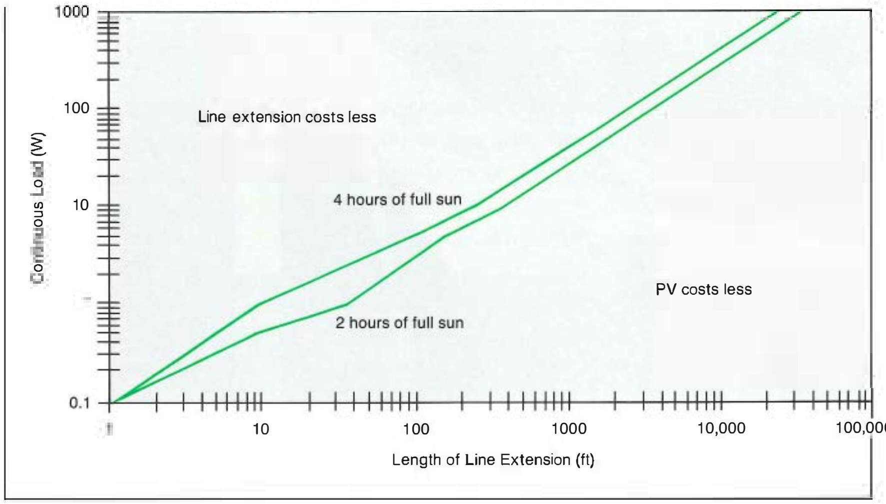
River. The federal utility calculates that PV is cost-effective compared with stringing a distribution line more than a couple of miles and is more reliable than remote engine generators.

Alabama Power recently installed six PV-powered beacons on two transmission towers at the edge of Mobile Bay, replacing service-voltage transformers that were susceptible to failure due to lightning strikes. "Because the towers are in a marshy area that is inaccessible by truck, replacing the transformers meant they had to be carried some distance by hand, and the cost of maintenance was also high. We expect the PV arrays will virtually eliminate the cost of replacing and maintaining those distribution transformers," says Herbert Boyd, Alabama Power's director of technology management.

Among other utilities applying PV for beacon power, Savannah Electric and Power uses photovoltaic panels at the foot of a 270-foot, 115-kV transmission tower on Hudson Island, off the Georgia coast. Indiana Michigan Power uses PV for beacon power in one instance, and Houston Lighting & Power recently installed two systems.

Software Shows Where PV Economics Cross the Line

The economic advantage of using a PV-battery unit to serve a remote, low-power load rather than extending a utility distribution line depends on the application's load level and its distance from an existing line. An EPRI PC-based computer spreadsheet program under development will help utilities make the best choice in evaluating the relative economics of PV systems in a wide range of applications. Note in this typical plot that the duration of full sunlight has relatively little effect on the outcome.



Other cost-effective applications

The EPRI study also documented installations and estimated the market potential for five other PV applications. Those selected were judged to offer utilities the most significant opportunities for operating cost savings and to have the widest applicability throughout the industry.

Like the tower beacon, four other applications are battery-coupled, stand-alone (non-grid-connected) uses of PV: powering T&D sectionalizing switches, streetlights, rest area fans and lights, and remote residences. The sixth application detailed in the study is grid-connected: using PV for voltage and energy support on thermally limited, but heavily loaded, utility distribution feeders.

Utilities use sectionalizing switches on both transmission and distribution lines to isolate parts of a circuit for maintenance or to control power flow for other reasons. The switches must be operable even when the power line is out of service. A sectionalizing switch is typically installed every 20 miles on a transmission line and every 10 miles on a distribution line.

The PV application market is for those remote switches, far from utility substations, where it is more economical to use a PV-charged battery with a motor or pump to open and close a switch in response to a radio or telephone SCADA signal from the utility than to send a line crew. Other options for charging the batteries are to install a step-down transformer to provide service voltage for the switch or to extend a nearby distribution line if the switch is on a transmission line.

On average, a distribution line costs about $25,000 to $27,000 a mile to install, compared with $3000 for a step-down transformer (at a 34.5-kV installation) and $1700 for an appropriately sized PV system. The 30-year-levelized annual revenue requirement is about $700 for adding the transformer and about $400 for adding the PV system, versus about $8300 for a line extension. As a general rule, distribution line extensions of more than 500 feet for low-power loads will be less economical than applying PV, the study found.

Adds Bigger, "The smaller the load and the farther it is from an existing distribution line, the more likely that a PV system would be cost-effective, for any application." And compared with installing a transformer just to operate a sectionalizing switch, PV offers advantages that include reduced electrical losses and improved reliability.

Georgia Power has used PV for six years to charge batteries that power eight motor-operated sectionalizing switches on 115-kV transmission lines and one switch on a 46-kV line. The PV panels also power the communications links that allow remote operation of the switches. In California, PG&E has installed two new

PV-powered remote switches on a 115-kV transmission line. West Texas Utilities has operated three 69-kV switches with PV for over two years.

Arizona Public Service installed seven radio-controlled sectionalizing switches powered by PV at three locations on its 69-kV subtransmission system. The switches are actuated by compressed nitrogen, with PV powering a hydraulic pump and radio control link. But reliability problems were encountered that stemmed from undersizing the PV panels and from the sometimes below-freezing operating temperatures that required battery-draining equipment heaters. The PV systems at two locations were replaced with step-down transformers, according to the utility.

The market for PV power in street lighting is in new installations because retrofitting existing lighting systems generally is not economical, the study indicates. The new street-lighting installations that are most appropriate for PV include new communities and subdivisions or cases where an alternative to underground distribution cable is desired. As might be expected, about three-quarters of the potential market is in southern and western states.

Several packaged PV-battery streetlight systems are available off the shelf from specialty producers as well as from original manufacturers. In a related application, Southern California Edison has developed a PV-powered high-pressure sodium lamp system for use in area lighting that is marketed commercially through an SCE subsidiary.

For parks and roadside rest areas, PV is an attractive alternative for providing minimal lighting and ventilation power at facilities that may be remote from existing distribution lines, particularly in scenic areas. And the market, which includes nature walks and boat launches as well as remote areas in parks, is growing. The electricity needs of a typical rest area can be met with a 200-W PV array and 240 amp-hours of battery capacity.

Remote residences represent a now relatively small but potentially significant new market for utilities that want to serve customers who would not otherwise be customers for cost reasons; that is, extending grid power to them is prohibitively expensive, either for the utility or for the customer.

Every year, utilities whose service areas border on remote regions—such as PG&E—turn down many requests from would-be customers who live too far from an existing utility distribution line. Many remote homes are used only seasonally, as hunting or vacation cabins. PG&E estimates that there are over 3500 stand-alone residential PV systems already installed in northern California, averaging 300 W each, and most have motor-generator backup. Given the recent rate of growth in new installations, PG&E estimates that as many as 1000 additional systems were installed in 1990.

"There are many services a utility can provide without the wire just as well as with the wire," says Carl Weinberg, PG&E's manager of research and development. "If utility services can be provided to customers more cheaply by using photovoltaics, then that's the way we ought to do it, instead of just automatically running a wire to them."

The study for EPRI puts the national market potential for remote residential PV at 3000 systems a year (three times PG&E's estimate for its service area last year). Researchers say this is most likely a conservative figure because it represents only 1.8% of the estimated 168,000-plus owner-occupied homes in the United States that either do not now use electricity or use less than $10 worth a month. On the basis of surveys of the motivations of existing remote residential PV users, the study projects that as many as half of those 3000 systems could be supplied by utilities with PV systems.

In addition to the many off-grid uses of PV, some utilities are recognizing the value of small line-connected installations

Market Forecasts for Utility-Owned PV Systems

On the basis of surveys and interviews with utility operations and customer service personnel, EPRI estimates that the potential utility market in seven key applications from 1991 to 1996 will be some 40,000 installations. Coupled with estimates of the typical system power rating for the seven applications, the five-year market forecast represents installed PV capacity of over 11 MW. All of the applications but one—voltage and energy support on a utility distribution feeder—represent low-power uses of PV and are considered cost-effective today.

Application	PV System Size	Installations (units/year)	PV Capacity Installed (kW/year)
Transmission tower beacons	500 W	50	25
Transmission sectionalizing switches	100 W	60	6
Street and security lights	100–400 W	2000	500
Rest area lights and fans	200 W	4000	800
Distribution feeder support	100–500 kW	1	300
Remote water pumping	500 W	200	100
Remote residences	300–500 W	1500	525
1991–1996 Market Forecast		Five-year total: 40,000	Five-year total: 11,500 kW

to their systems in roles other than as central station generating plants. PG&E has extensively investigated PV for distribution feeder support and has identified a test case where PV—at today's cost of the technology—would be slightly more economical than upgrading part of an existing distribution system. By offsetting localized peak daytime current flows on a feeder with solar-generated electricity that correlates well with customers' demand for power, distributed PV installations offer to help relieve thermal overloads of transformers and conductors.

PV can thus increase the overall utilization of existing T&D capacity by deferring the need to reconductor lines, upgrade substation transformers, or add circuits. It also offers other potential benefits, including reduced electrical losses, reactive power support, and increased feeder reliability.

Daniel Shugar, an engineer in PG&E's R&D department, calculates that the value of such distributed-generation benefits of PV for this application are about equal in magnitude to the system energy and capacity values that are traditionally evaluated. Shugar says that while his test-case analysis for PG&E found PV marginally economical at today's costs and tax incentives compared with conventional alternatives for distribution support, "what's important is that it is in the ballpark, and as the cost of PV falls while its local and system value increases, this application could become increasingly economical. The magnitude of the distributed benefits implies that the advantages of decentralized, modular PV generation could even outweigh the economies of scale of central station PV generation."

In its study for EPRI, Ascension Technology estimated the market for PV-powered distribution feeder support in those locations where PV output would match well with distribution peak loads, where load growth is relatively slow, and where land is available for siting PV plants of as much as 1 MW (which would require about 10 acres). Another potentially at-

Stepping-stones to Energy Significance

Substantial reductions in cost and continuing gains in energy conversion efficiency will be needed before PV technology is able to provide economical bulk power in the United States. But researchers view the many cost-effective low-power utility applications of PV identified in recent studies as important stepping-stones on PV's path to becoming a significant energy source.

Present applications of PV to serve small loads fit well within a longer-term technology integration scenario. In the past, most PV facility installations were demonstration projects, and their costs were often shared by utilities, government agencies, and EPRI. Projects ranged in size from less than a kilowatt to several hundred kilowatts and generally were not commercially cost-effective.

Today's cost-effective applications range from a few watts to only a few kilowatts, and most serve isolated, off-grid loads. In the near term—say, the next five years—researchers anticipate that some utilities will install commercial-size, grid-connected PV generation facilities of up to 1 MW. These would include applications for distribution feeder support. By the latter part of this decade, experts believe, one or more larger commercial-scale utility power generation projects—at the scale of several hundred kilowatts to several megawatts—may be installed. Truly energy-significant use of photovoltaics could then begin to develop.

"Such a scenario, coupled with the growing use of PV in developing countries for villages and islands not served by utility distribution systems, suggests paths for the orderly business and technology development of photovoltaics over the next two decades," says Edgar DeMeo, who heads EPRI's Solar Power Program. "Some of the early applications within electric utility systems will be instrumental in establishing technical credibility for PV in the eyes of utility operating engineers. As applications become established and progress toward larger systems, a stable supplier-industry base can develop."

Adds DeMeo, "The key challenge for photovoltaics today is to continue to serve ever-expanding niche markets, driven by continuing system cost reductions, while sustaining focused R&D to achieve the cost and performance needed to break into worldwide energy-significant power markets. We believe this will occur most readily through cooperative alliances of suppliers, users, researchers, and national and international programs whose common goal is to thrust PV technology into the bulk power mix. If this goal is achieved, society will enjoy one of the very few energy technologies able to decrease adverse global environmental impacts even as people increase their electricity use." □

tractive approach would include customer roof-mounted installations—for example, up to 8 kW on residential roofs and as much as 50 kW on the roofs of large commercial buildings.

Demonstrations of line-connected PV systems have been installed in power ratings from 1 kW up to 6 MW in several U.S. locations by a number of utilities and private organizations. EPRI has documented the performance of a number of these demonstrations for many years.

But because this distributed-generation application is still considered to be in the demonstration stage, the study's estimate of the near-term market potential assumed only one utility installation a year—most likely beginning with PG&E—over the next five years. When one does occur, other utilities can be expected to follow developments closely.

Identifying cost-effective PV applications

Beyond the six early utility uses of PV that were analyzed, EPRI's studies have identified 65 applications that utilities either already fill with PV systems or have suggested in project surveys as candidates. In the T&D area, possible new applications include the operation and transmission of data from sensors that monitor current flows on T&D lines. Another use could be to provide service power at isolated transmission substations for switching, security, and data transmission.

In power plant operations, PV is applicable for such diverse security-related functions as special lighting, video surveillance, and remote-gate access control. Some utilities already use PV for low-power cathodic protection systems that inhibit corrosion in transmission towers, underground tanks, and pipelines.

Several utilities also use PV for powering data acquisition and communications equipment used in remote monitoring of meteorological or other environmental conditions, such as stream flows, water levels, and water quality. In the communications area, there are new possibilities in remote meter reading systems and roadway emergency telephones and in the fiber-optic communications systems that many utilities are now installing. Utilities could also use PV for lighting facility signs and for trickle-charging service vehicles prone to battery drain.

In addition to the previous studies of early utility PV applications, EPRI is conducting a series of applications workshops and projects both to help utilities identify specific cost-effective installations in their service areas and to support group installations of PV applications. The effort includes the development of a computer spreadsheet–based methodology for analyzing the use of PV in specific applications. With user-defined, utility-specific inputs, the program can determine general PV system design and costs and calculate levelized annual revenue requirements for a PV system or a distribution line extension. The use of the spreadsheet has been demonstrated in the utility applications workshops.

New and planned activities in which EPRI is participating include group installations by several utilities in selected PV applications. Results are to be analyzed and reported consistently throughout the utility industry. The work is being cosponsored by the various groups of utilities, EPRI, and Sandia National Laboratories. Each group application involves selected PV manufacturers, system integrators, and utility equipment suppliers, says EPRI's Bigger.

The first group application under way involves a dozen utilities in seven states that will install PV-powered T&D sectionalizing switches by about the middle of 1991. Once the switches are operating, a year's worth of performance data will be analyzed and reported, along with design specifications, to the industry for use by utility personnel.

Further ahead, Bigger says, PV-powered cathodic protection systems for tanks, pipelines, and transmission towers are a likely area for a second round of group installations. Beyond that, research managers hope to organize a group installation of PV-powered livestock-watering pumps by utilities and cooperatives in a number of western states in 1991.

"These applications projects represent a low-cost, low-risk way for utilities to get early experience with PV," says Bigger. "For just a few thousand dollars each, utilities can get their own design, operations, and procurement people using and gaining familiarity with the technology."

A technology destined to grow

As a result of factors independent of the interplay of conversion efficiency and energy cost in the larger economic equation that limits the use of photovoltaics for bulk electricity generation, PV is finding important niches for everyday use in utility companies' own operations as a reliable, cost-effective source of remote power. And it is already being considered as a new way to serve new customers and special loads. As PV gains familiarity and acceptance among utility engineering and operations personnel, its specific advantages can be better understood and exploited. The technology seems destined to turn up in ever more diverse uses on both sides of the utility meter as it evolves toward its ultimate realization as a ubiquitous, low-cost, solid-state power source. ■

Further reading

Early Applications of Photovoltaics in the Electric Utility Industry. EPRI final report for RP1975-6, prepared by Ascension Technology. Forthcoming.

Early Applications of Photovoltaics in the Electric Utility Industry: Livestock Water Pumping. EPRI final report for RP1975-7, prepared by NEOS Corp. Forthcoming.

U.S. Department of Energy, Sandia National Laboratories. *Photovoltaic Systems for Utility Companies.* June 1990. SAND90-1378.

J. E. Bigger and E. C. Kern, "Early Applications of Photovoltaics in the Electric Utility Industry"; C. Jennings, "PG&E's Cost-Effective Photovoltaics Installations"; and D. S. Shugar, "Photovoltaics in the Utility Distribution System: Evaluation of System and Distributed Benefits." Papers presented at the 21st IEEE PV Specialists Conference, Kissimmee, Florida, May 22, 1990.

This article was written by Taylor Moore. Background information was provided by John Bigger, Generation and Storage Division.

TECH TRANSFER NEWS

New Center Promotes Tech Transfer

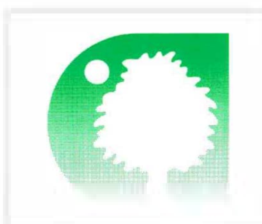
EPRI's Customer Systems Division is establishing a new customer support center to help member utilities apply the division's technology and knowledge to solve problems. The Customer Assistance Center will offer a range of services—including seminars and workshops, assistance in customizing EPRI-developed products, and "jump-start" consulting designed to help utilities launch their own studies and projects.

The new center reflects an Institute-wide effort to place more emphasis on technology transfer, according to EPRI's Larry Lewis, manager of the center. "In developing a product," he says, "you're not really finished until you've put that product into the hands of end users, then trained them to use it to solve problems." The center, he says, was established to provide quick access to EPRI products and reduce the time needed to learn how to use them.

According to Lewis, the center aims to fill a niche in the marketplace that has been vacant up to now—rapid response to short-term utility problems. "Many utilities often encounter problems whose solution may require only a day or a few days of a contractor's time," he says. "But contractors aren't always available to work on short-term projects on short notice. We've set up the center to enable utilities to call us and tap into our stable of contractors who have expertise in specific areas and will be available to resolve short-term problems." According to Lewis, such services may be offered on a retainer basis: utilities interested in having access to such support may provide the center with a retainer, which could be drawn against for future projects.

The center will offer several levels of service, Lewis explains. "One level consists of free consultation, either over the telephone or at the member utility's office. This provides fast access to technical information or product support; it also allows the center staff to assess a member's needs and determine how much work will be required to solve the problem. If a project requires more time, the center will provide services on an at-cost basis."

Training will be a core offering, according to Lewis. "We are establishing a remote training service, called RemoteLink, to teach utility staff how to use EPRI products—a new software package, for example—over a computer connection." Via computer and telephone connections, an EPRI contractor will take the trainee step by step through the operation of the software.



The center has already helped several member utilities solve problems. Iowa Southern Utilities, for example, turned to the center when it needed assistance in calculating marginal costs to evaluate demand-side management options. The center provided a consultant who had the skills Iowa Southern was looking for. Over a four-day span, the consultant assessed the utility's current and forecast costs, interviewed key utility employees, and identified the resources needed to perform a marginal cost study. The consultant next developed a preliminary set of marginal electricity costs for 1991, made a presentation, provided a written report explaining how the marginal cost study was performed and outlining the steps that remained, and then recommended refinements. Iowa Southern took it from there, using the consultant's recommendations to complete the study itself. "The center provided help that was right on cue," says Tim Eibes, manager of energy services for Iowa Southern. "The work product provided results that we needed right away, and it was easy to participate. We have found a very valuable resource in the center."

Currently located at EPRI headquarters in Palo Alto, the center will move to a site in the central United States by midyear. "A central U.S. location provides several benefits," notes Lewis. "Perhaps the most significant is that we'll be closer to most of our members. We are aiming to provide a very quick response to solving utility problems—sort of a SWAT-team approach. Being centrally located will cut down the amount of travel time required to reach any member that needs our services. It will also minimize any disparity in office hours between us and our members due to different time zones."

Lewis notes that these services are just a phone call away. Member utilities can reach the center through a toll-free number: 1-800-776-EPRI. ■ *EPRI Contact: Larry Lewis, (415) 855-8902*

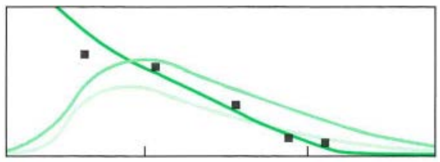
MYGRT Code Proves Its Value

An EPRI-developed computer code that simulates how chemicals move through groundwater recently helped Duke Power save more than $1.4 million. The utility was planning construction at two company-owned properties. Both locations were formerly sites of manufactured gas plants (MGPs), and both are suspected of having unknown amounts of buried by-products. Site data collected by Duke Power's environmental engineering subsidiary suggested that organic contaminants might move to off-site areas via groundwater flow, but it wasn't possible to determine whether this had in fact occurred or might still occur in the future. The utility needed a way to simulate conditions over long periods in underlying aquifers, to determine the extent of migration of contaminants, and to report findings in detail to state environmental regulators.

Using EPRI's computer code MYGRT™ (Version 2.0), Duke engineers determined that organic contaminants from the MGPs would not affect off-site drinking-water quality. MYGRT projected insignificant migration of contaminants, indicating that the best course of action was to leave the buried by-products alone. Consequently, Duke Power was able to avoid the cost of excavating the sites and of drilling more wells off-site to monitor water quality.

The MYGRT code was developed by EPRI's Land and Water Quality Studies Program to model the concentrations of groundwater contaminants from buried by-products at various distances over time. The MYGRT code runs on IBM-compatible personal computers. MYGRT begins with inputs of measured concentrations of constituents from the lower edge of the contaminant source. Alternatively, the program accepts data from geochemical and biochemical database tables. Program computations use hydrological data from the site in question. Site-specific groundwater velocity, retardation, dispersion, and degradation data are required inputs. Once these are entered, the user selects the type of analysis needed, determines whether multiple simulations are desired, and provides information on sources, time, and the graphic "views" required. In three to five minutes, the program begins to print out tabular data, draw contours, and map x-y plots. Multiple overlays of the data are easily generated, so different slices can be examined over different periods of time.

In their reports to state environmental agencies, the Duke engineers included MYGRT projections of concentrations over long periods of time at various distances.



The reports satisfied regulators that concentrations of organic constituents from sources at the two sites would remain below the levels set in federal water quality standards well into the distant future. According to Duke's David Anderson, the MYGRT code "has really turned out to be a useful instrument for everyone involved —for the scientific community as well as the regulatory bodies." As he points out, MYGRT provides results that would otherwise be unavailable. "You could put in a hundred [sample] wells, and if they weren't in exactly the right places, you still wouldn't get the right picture of what's happening under there." With MYGRT, Anderson notes, the right picture emerges.

MYGRT works by combining methods from hydrology, geochemistry, and biochemistry, explains EPRI's Ishwar Murarka, manager of the Land and Water Quality Studies Program. "The program results have been validated in both lab and field trials," says Murarka, "and ongoing validation research is reducing the uncertainties further." Murarka, who has overseen the code's development from its inception, recently learned of its use in federal Environmental Protection Agency applications: the EPA Office of Solid Waste and Emergency Response has prepared a draft report listing MYGRT as one of the groundwater transport/fate codes in use in agency offices. ■ *EPRI Contact: Ishwar Murarka, (415) 855-2150*

New Report, Video on Dual-Fuel Heat Pump

A recently released EPRI report describes the dual-fuel heat pump (DFHP) and the results of a field evaluation that tracked the performance of five prototype units for more than two years.

Designed for commercial space conditioning, the Fuelmaster dual-fuel heat pump teams an electric heat pump with a gas furnace in a single package. The heat pump provides high-efficiency heating and cooling, and the gas furnace provides economical supplementary heating during cold snaps. The Fuelmaster can be programmed to automatically choose the optimal mix of electric and gas operation. "The DFHP offers customers the lowest possible operating cost while providing utilities with a means of satisfying their winter load shape objectives," says EPRI's Morton Blatt, manager of the Customer Systems Division's Commercial Program.

According to the project report (CU-7084), the field evaluation successfully demonstrated the operation of the prototype units and yielded performance data that closely matched manufacturer specifications. In one application, a 2700-square-foot restaurant in Portland, test results showed that the customer saved $432 per year in heating-season energy bills by using the DFHP instead of a current-model gas-electric unit.

A new EPRI video produced by Lennox Industries (CS90-04) highlights the Fuelmaster's features. The video also describes how the DFHP can help utilities efficiently expand their share of the U.S. space-heating market—a market traditionally dominated by natural gas suppliers. EPRI member utilities can order the video through their technology transfer managers. ■ *EPRI Contact: Morton Blatt, (415) 855-2457*

Hydroelectric Systems

Evaluating Hydro Relicensing Alternatives

by James Birk and Charles Sullivan, Generation and Storage Division

The relicensing of 300 hydroelectric plants in the next decade will involve a total capacity of about 4000 MW—a $10 billion value. Applicants are likely to face strong challenges to their plans from resource agencies and environmental groups. Extreme differences in agendas make it unlikely that win-win solutions will be attained easily; trade-offs and compromises will be a reality. Opposing parties may find a common framework for discussion, however, in a recently developed EPRI methodology.

The methodology evaluates the effects of relicensing alternatives on the power and nonpower values of water resources (Figure 1). Power values include the value of capacity, energy, operating flexibility, and voltage control. Nonpower values include energy conservation, fish and wildlife populations, recreational opportunities, flood control, navigation, irrigation, and water quality. Properly implemented, the EPRI methodology will help a plant owner determine the following:

- The preferred relicensing alternative from a public perspective
- The power and nonpower value components of each alternative
- The important (as well as unimportant) areas of uncertainty in power and nonpower values
- The value of additional information gathering to resolve uncertainties

Need for a methodology

The Electric Consumers Protection Act (ECPA) of 1986 states that the Federal Energy Regulatory Commission (FERC) must give "equal consideration" to power and nonpower values of water resources when licensing and relicensing hydroelectric plants. The legislation did not specify how to do so, however, and subsequent FERC rulemakings have not defined an approach. FERC's *Hydroelectric Project Relicensing Handbook* (April 1990) frames the requirement this way: "Equal consideration *does not mean* treating all potential purposes equally or requiring that an equal amount of money be spent on each resource value, but it *does mean* that all values must be given the same level of reflection and thorough evaluation. . . ." Given this situation, EPRI decided that exploring the issue of how to provide equal consideration to power and nonpower values would be useful for all parties involved in the relicensing process. In 1988, therefore, the Institute contracted with Decision Focus Incorporated to develop a logical methodology for addressing the issue. The project's final report (GS-6922), released last August, describes the new methodology in detail and summarizes the results of applying it to three actual utility relicensing cases. EPRI plans to release a software tool for the methodology this fall and is seeking utilities to participate in a beta test this spring. In addition to automating the methodology, the software will provide an extensive database of nonpower values collected from many sources.

EPRI's methodology evaluates hydro relicensing alternatives from a broad social perspective; that is, it quantifies the effects of relicensing alternatives on the total social value

ABSTRACT *Hundreds of U.S. hydroelectric plants are due for relicensing by the year 2000. Since the Electric Consumers Protection Act has mandated that equal consideration be given to power and nonpower values in the licensing process, utilities must address a wide range of issues in developing relicensing proposals. The challenge is to maximize the benefit of water resources to the public. EPRI's commitment to exploring the issues of equal consideration and the public interest has produced a methodology to aid utilities in making relicensing decisions; software to automate the methodology is scheduled for release later this year. The methodology is formally supported by the Federal Energy Regulatory Commission.*

of a water resource by considering the interests of all parties affected by the resource. The methodology uses decision analysis to complement cost-benefit analysis: cost-benefit analysis provides the means for determining resource values and comparing alternatives; decision analysis identifies the important assumptions (including their uncertainty), determines the preferred alternative under uncertainty, and determines the value of additional studies on the assumptions.

While many parties in the relicensing process may be uncomfortable with assigning dollar values to the nonpower aspects of a water resource, the reality is that license conditions imply making value judgments and making trade-offs between power and nonpower, or between competing nonpower, aspects. Employing the EPRI methodology to explicitly analyze these trade-offs to determine whether they are reasonable in the public context can provide useful insights for applicants.

For example, a license condition that costs $1 million but increases a fish population by only 100 fish would require that each fish be worth at least $10,000 to society. An increase of 100,000 fish, however, would require a value of only $10 per fish. Obviously, the reasonableness of these values depends on the specific circumstances. Using the methodology can help applicants clarify their circumstances and the trade-offs implied by various license conditions. They can then determine whether those trade-offs are consistent with social values and determine the significance of the uncertainty in social values.

In addition, the methodology helps applicants approach relicensing in a proactive mode. The increased pressure to settle issues during the consultation process should motivate applicants to develop strong arguments to support their proposals. Engaging in dialogue early in the process with resource agencies, environmental groups, and other interested parties helps applicants learn about the issues that concern these groups, explore those issues, and present justifiable rationales for their own preferred alternatives. By listening carefully and investigating all reasonable alternatives, applicants can make compromises to win support from opposing parties before facing FERC.

Figure 1 The recreational use of water resources is an example of the nonpower values that, according to federal law, must be considered in developing hydro relicensing applications. A new EPRI methodology helps utilities and other interested parties assess relicensing alternatives in terms of their overall net public benefit.

Using the methodology

The methodology has four steps: determining the scope of the analysis, synthesizing available data, evaluating alternatives, and evaluating assumptions.

In the first step, an applicant identifies the relicensing alternatives and the power and nonpower values affected by each alternative. The alternatives should represent the potential outcomes of the relicensing process and, to the extent possible, examine the objectives of all interested parties. For example, if the state fish and wildlife agency is requesting an increase in the minimum flow, the applicant analyzes that scenario. Also in this step, the applicant investigates opportunities to combine the objectives of multiple parties and create new alternatives. For example, an alternative to increase the minimum flow could be combined with a plant upgrade, thereby addressing both power and nonpower needs. Similarly, drawing a reservoir down to improve flood control could also address the needs of downstream boating, rafting, and fishing.

To determine the scope of the power and nonpower values affected by the various alternatives, the applicant selects a reference alternative. (Current operations is a logical and convenient reference alternative, but the choice is immaterial to the results.) The reference alternative, with its associated power and nonpower values, serves as a standard against which other alternatives are compared. The applicant identifies the power and nonpower effects of each alternative vis-à-vis the reference alternative. If none of the alternatives has an effect on a particular power or nonpower value component, that component does not have to be quantified. For example, if all the parties involved agree that neither a minimum flow nor a turbine upgrade will affect upstream wildlife, no effort need be spent on that issue.

In the second step, the applicant gathers information on the extent and value of the power and nonpower water uses being considered. To analyze recreational use, for example, the applicant assembles all relevant information about the number of days anyone would use the resource for recreation (the user days) and how much each user would be willing to pay to use the resource (the willingness to pay). The total recreational value is determined by multiplying the number of user days by the user willingness to pay. If the available information is incomplete, the applicant must develop a way to estimate the required information. The EPRI report contains detailed guidelines on how to do this. In addition to estimating best guesses for the various components, the applicant develops a range of uncertainty for each assumption to reflect opposing viewpoints and/or the lack of data.

In the third step, the evaluation process begins. First, working on the assumption that the best guesses are correct, the applicant totals the power and nonpower values of each of the relicensing alternatives. The difference in total value between an alternative and the reference is that alternative's incremental social value, which could be negative. (By definition, the incremental social value of the reference alternative is zero.) The applicant then ranks the alternatives by incremental social value. This process, illustrated qualitatively in Figure 2, provides a baseline from which to investigate the importance of uncertainty.

By analyzing the ranking results, an applicant can understand how similar or different the various alternatives are in terms of overall social value. Further, it is possible to compare the applicant's preferred alternative with the alternative that maximizes net social value (they may be the same).

Examining the power and nonpower components of social value provides insight into how different parties might view the alternatives. For example, if a project owner is interested only in power value, the alternatives can be ranked according to this priority. Similarly, if a state fish and wildlife agency is concerned only with maximizing the value of a fishery, the alternatives can be ranked according to that value. Uncovering this information could be useful in negotiations with interested agencies and, subsequently, with FERC. If the difference between the preferred alternative of the applicant and that of an agency is small, expensive arguments against the agency's alternative may not be worthwhile for the project owner. Conversely, if the difference in power value is great, the applicant may want to devote considerable resources to influencing the choice of relicensing alternative.

Figure 2 In the EPRI methodology, the effects of each relicensing alternative on the relevant power and nonpower values of the water resource are determined in relation to a reference case. This matrix shows the results of such an evaluation qualitatively. (A plus sign indicates a positive impact; a minus sign, a negative impact; and a zero, no impact.) The user then quantifies the impacts in dollar terms and ranks the alternatives according to overall net social value. Sensitivity and decision analyses are conducted to determine the robustness of the ranking and the value of obtaining additional information.

Values / Alternatives	Power	Reservoir fisheries	Wildlife at reservoir	Recreation at reservoir	Down-stream fisheries	Down-stream recreation
Higher minimum flow	+	0	0	0	+	+
No minimum flow	+	0	0	0	–	–
No midsummer drawdown	0	+	+	+	0	0

In the fourth step, the applicant isolates the most important issues by using decision analysis techniques to capture and determine the importance of uncertainty in the input assumptions. The results of this analysis may contribute to the consultation process, since they pinpoint issues worthy of further consideration. If an initially controversial issue is shown to be unimportant, for example, then adopting the opposition's viewpoint and perhaps using it as a bargaining tool may benefit the applicant. (The forthcoming software tool will automate much of the decision analysis process and facilitate this step for those who are not expert decision analysts.)

The decision analysis process involves varying each assumption through its uncertainty range to determine whether that variation changes the ranking of alternatives. The assumptions that are found to affect the ranking are then treated probabilistically; that is, probabilities are assigned to various values in the range of uncertainty. This may be done by means of a formal probability encoding process, or the applicant may rely on the informal judgment of in-house staff and perform additional analyses to determine the importance of a precise probability distribution.

Related to identifying the important uncertainties is determining the value of information analysis. This involves quantifying an upper bound on the social value of further information gathering. When the result is compared with the cost of performing the information gathering, the applicant can determine which, if any, further studies are justified. The applicant can use these findings in the first-stage consultation to appeal study requests to FERC.

Quantifying power and nonpower values

The application of cost-benefit analysis to relicensing alternatives in step two of the methodology requires an accounting of the costs and benefits to society of each alternative. It is necessary to include the impacts on all who benefit from the water resource so that each alternative can be examined in terms of its value to society as a whole. Power values are relatively straightforward to quantify, since markets exist where they are bought and sold. Most nonpower values, in contrast, are not found in any market. Nevertheless, people are clearly willing to pay to use and/or conserve these resources, as evidenced, for example, by sales of recreational equipment and by contributions to environmental organizations.

The impacts of relicensing alternatives on power values typically result from a change in the amount or timing of hydropower generation that changes the utility's operating cost. Under traditional regulatory practice, this change in cost is passed on to ratepayers, as are capital and operation and maintenance costs. Economists use the concept of consumer surplus to quantify the impact of price changes on social value, or welfare. Consumer surplus is the difference between the total amount consumers are willing to pay to consume a given quantity of a good and the amount they actually pay. It can be shown (see GS-6922) that the change in cost experienced by a utility as a result of relicensing conditions is a reasonable approximation of the change in consumer surplus.

To assess how the nonpower impacts of relicensing alternatives affect social value, it is necessary to consider two types of nonpower values: use and nonuse. Use value refers to the willingness to pay for the actual consumption of a good (e.g., a day of fishing). Nonuse value refers to value derived purely from the knowledge that the good exists. There are at least three types of nonuse value: option value, existence value, and bequest value. Option value is the willingness to pay to retain the option to use the resource in the future. Existence value is the willingness to pay simply to preserve the existence of the resource for one's lifetime. Bequest value is the willingness to pay to preserve the resource for future generations.

Relicensing alternatives typically affect the amounts of nonpower goods available to society. It is important to quantify the change in the supply of a nonpower good, since the willingness to pay for the good may be a function of its supply. For example, the willingness to pay for a day of rafting may increase with increasing river flow but then decrease for dangerous flow. Similarly, society may be willing to pay more per fish to improve a mediocre fishery than a good fishery.

Two commonly used approaches for determining the willingness to pay for nonmarket goods are creating hypothetical markets (contingent valuation) and assessing implicit prices from existing, related markets (e.g., hedonic pricing and the travel cost method). Both approaches have advantages and disadvantages. Contingent valuation typically entails using a survey to determine the largest fee people would be willing to pay to use and/or preserve the existence of a resource. While this approach has the advantage of eliciting willingness to pay directly (and while it is the only means of assessing existence value), bias can be introduced by the way the survey questions are asked.

The hedonic method relies on the availability of a related market from which to assess use values; for example, real estate values around a lake could be used to estimate the recreational value of a stable lake level. This method is open to criticism because of the statistical assumptions it requires or the lack of closely related markets. The travel cost method is based on a statistical relationship between travel costs and resource use. Because travel expenditures may overestimate or underestimate the use value, depending on the number of sites visited on a given trip, or because travel costs may be small relative to the other sacrifices made to use the resource, this method's results may not be accurate.

To apply the EPRI methodology, the applicant must estimate the willingness to pay for each nonpower resource use being considered in the analysis. Since the methodology explicitly assesses the value of gathering further information, the analysis should use estimates based on the available data, whatever the source (e.g., a contingent valuation survey, a travel cost analysis, or records of expenditures for recreational equipment). For each nonpower component, the analysis should use a reasonable base-case value and then determine larger and smaller values that reflect the range of uncertainty. This procedure can account not only for the error introduced by the assessment approach but also for the inherent uncertainty in the value. The decision analysis process uses this range of values to determine the importance of the input assumption and the need for a more detailed assessment.

For example, data from a study of daily expenditures for fishing can be used as a lower bound on the willingness to pay to go fishing, since that willingness is at least as great as the cost. The analysis can then look at successively higher reasonable willingness-to-pay values and determine whether the uncertainty affects the ranking of relicensing alternatives. If it does, a probability distribution should be assigned and the social value of refining the information should be determined.

Identifying creative alternatives

Retrospective analysis of the conditions imposed by FERC for relicensed hydro plants has shown that the relicensing process tends simply to trade off power for nonpower values. Instead of cutting up the existing pie differently, the goal—according to the ECPA—should be making the pie bigger. Achieving this goal should lead to an outcome that is in the best interests of all parties—the public, the applicant, the resource agencies, and FERC.

Identifying creative relicensing alternatives is the key to maximizing social value. In many instances where the EPRI methodology has been applied, creative new alternatives have led to increased social value from increased power and/or nonpower benefits. For example, in one of the case studies performed as part of the methodology development process, the analysis showed that the net value of the plant could be enhanced by 50%, primarily through greater recreational use of the reservoir and through increased power values. In another utility study, applying the methodology showed that an alternative involving the restoration of wetlands at the project would have considerable social value if the restoration made it unnecessary to restore wetlands in areas with higher real estate values.

By providing a ranking of options and uncertainties based on social values, the EPRI methodology helps utilities make considered relicensing decisions. Still, it is not a cookbook for decision making. Other factors may influence the applicant's proposal. For example, the ranking may suggest relicensing alternatives that contradict resource agency recommendations. Since the ECPA does not require an explicit social valuation approach, the extent to which the applicant uses such results in the relicensing process will depend on the overall relicensing strategy.

The methodology may be most useful for developing a greater understanding of the issues involved, gaining further insights, and examining new ideas. Fred Springer, director of FERC's Office of Hydropower Licensing, believes that it "can offer insights in developing a relicensing strategy and can help identify the key variables that deserve examination and discussion." He adds, "Inherent in the relicensing process is the expectation that, whenever possible, public benefits will increase beyond those currently being realized. The EPRI methodology is one tool applicants can use to identify alternatives that have a strong probability to increase public benefits."

Safety Margins Evaluation

Design-Basis Accident Methodology

by Lance Agee, Nuclear Power Division

A comprehensive reload-licensing analysis capability requires a methodology for analyzing design-basis accidents (DBAs) with multidimensional core effects. Through its DBA methodology project (RP2941), EPRI has been developing and demonstrating methods for analyzing three hypothetical accident scenarios: a PWR control rod ejection, a PWR steam line break, and a BWR control rod drop. When concluded, this project will complete the reload-licensing capabilities and guidelines (except for loss-of-coolant accidents) developed for EPRI's Reactor Analysis Support Package (RASP).

The primary tools being used in the DBA methodology effort are the following EPRI-developed codes: ARROTTA, for three-dimensional space-time neutronics calculations; VIPRE-02, for thermal-hydraulic calculations; and RETRAN-03, for system pressure response calculations.

Project plan

A steering committee of highly knowledgeable utility engineers was formed in 1987 to develop functional specifications for the analysis of each of the three accident scenarios being considered. The committee represents a spectrum of nuclear utilities, including those that have developed their own safety analysis capabilities. The members are Paul Bergeron, chairman (Yankee Atomic Electric), Sam Forkner (Tennessee Valley Authority), Terry Garrett (Wolf Creek Nuclear), Larry Matthews (Southern Company Services), Kevin Ramsden (Commonwealth Edison), Toni Roscioli (Pennsylvania Power & Light), and Gregg Swindlehurst (Duke Power).

The committee recommended a direct three-dimensional approach to the analysis of the accidents, concluding that this approach would be relatively easy to justify, could reduce conservatism, and could minimize engineering and computer resource requirements. The committee further recommended that the development of the three-dimensional methodology be based either on capabilities already included in the EPRI-developed code ARROTTA (advanced rapid reactor operational transient analysis) or on capabilities that could reasonably be added to it. ARROTTA is a three-dimensional, space-time neutronics code that uses advanced nodal methods developed at the Massachusetts Institute of Technology under EPRI funding.

The committee's recommendations were incorporated into three licensing options and functional specifications documents, one for each of the transients. The next phase of the project defined methodologies that minimize licensing exposure and gain plant margin, evaluated computer codes and defined necessary enhancements, and tested the methodologies for the desired analysis applications. More recently, project efforts have focused on validating and benchmarking the methodologies; a major part of this work has been performed by utilities. The final stage of the project will involve helping utility groups obtain regulatory acceptance for each methodology.

Close cooperation between EPRI and member utilities is a key element of the project. For each of the three accident analysis efforts, EPRI is incorporating computer code benchmarking into a report that supports licensing, provides assistance for model preparation, and supports demonstration of the difference in conservatism between existing licensing calculations and calculations with ARROTTA. Participating utilities have responsibility for guideline development, model preparation and testing, and completion of licensing documentation. The overall goal is to formulate and demonstrate a methodology for analyzing the three accident scenarios with ARROTTA, VIPRE, and RETRAN.

PWR control rod ejection

The rod ejection accident (REA) scenario is fully described in EPRI report NP-4498, *Reactor Analysis Support Package (RASP)*, Vol. 3: *PWR Event Analysis Guidelines*. Briefly, the scenario postulates the mechanical failure of a control rod mechanism housing such that the reactor coolant system pressure rapidly ejects a control rod assembly and drive shaft to a fully withdrawn position. This would require a complete and instantaneous circumferential rupture of the control element drive mechanism housing or of its nozzle. The consequence of such a mechanical failure would be a rapid positive reactivity addition, resulting in a core power excursion with a large localized relative power increase.

It is necessary, for plant licensing, to analyze such an accident to conservatively predict the possibility of any fuel damage and to determine the magnitude of the challenge to the integrity of the reactor coolant system pressure boundary as a result of the power surge. A sufficient number of initial reactor states must be analyzed to completely bracket all potential operating conditions and to ensure that the upper bounds on possible damage have been evaluated. To model an off-center ejected rod and consider the effects of a tilted power distribution, a three-dimensional neutronics code is necessary. Thus ARROTTA was chosen to analyze the REA transient.

Duke Power agreed to serve as the lead utility for the REA effort and to participate in the initial application of ARROTTA to REA analysis. The EPRI-Duke joint effort was part of a larger effort at Duke to develop a methodology for multidimensional reactor transients and safety analysis physics parameters. Duke has submitted an application to the Nuclear Regulatory Commission (NRC) to obtain a safety evaluation report for using ARROTTA to analyze hypothetical REA scenarios at its Catawba and McGuire nuclear stations.

EPRI's tasks were to complete a specific code validation for the REA application and to incorporate it into a report that supports licensing of the methodology; to complete the checkout of ARROTTA for the intended application; and to provide assistance in applying ARROTTA to REA analysis. Duke had full responsibility for guideline development, model preparation and testing, and completion of licensing documentation to qualify the application methodology. This work involved several functional groups within the utility's nuclear engineering section; a project management approach was used to plan and coordinate the efforts of the various groups.

EPRI developed ARROTTA for solving LWR transient problems in which spatial effects in the reactor core are significant. Because core power distributions and other parameters are not amenable to measurement under reactor transient conditions, computer predictions of such events are usually verified against calculations made with other, similar computer codes. For the REA validation the researchers chose HERMITE, one of several industry codes available for comparison, because it has an NRC-approved topical report and has been used in several licensing applications.

The comparative study found that ARROTTA can be reliably used for any rod ejection–type transient, including transients up to hot, full-power conditions. The good agreement between the two codes for the event studied verified ARROTTA's treatment of the transient neutronics, fuel temperatures, control rod motions, and cross sections. An EPRI report, *ARROTTA–HERMITE Code Comparison* (NP-6614), documents this comprehensive verification effort and establishes an industry benchmark for this type of analysis.

EPRI has completed several other studies that support the validation of the REA application of ARROTTA. A standard benchmark set verifies the basic capabilities of ARROTTA to calculate static and transient power distributions for homogeneous nodes. These capabilities are described in a draft report on EPRI's activities in the REA effort under RP2941. Another EPRI study has examined the sensitivity of ARROTTA REA results to axial and radial mesh spacing, steady-state convergence, time-step size, control rod worth, and Doppler coefficient. A third study, reported in NSAC-135, compared ARROTTA with PDQ-7E for several PWR beginning-of-life core configurations. The PDQ-7E solutions represent full assembly heterogeneities on a pin-by-pin basis.

Now that EPRI has completed the verification of ARROTTA against a similar industry code for a PWR control rod ejection accident, member utilities have a methodology for performing multidimensional analyses in-house without having to rely on vendor calculations. ARROTTA has state-of-the-art algorithms that have been shown to produce excellent results much faster and much less expensively (by a factor of about 10) than the other codes of its class.

PWR steam line break

The main steam line break accident is one of several hypothetical severe transients addressed in the final safety analysis report for any plant. It is described in detail in NP-4498, Vol. 3. Briefly, a double-ended rupture in a main steam line in the secondary system causes a sudden cooling of the water in the corresponding primary loop. The cold water flowing into part of the core represents a positive reactivity insertion that must be contained by the control rods, which are scrammed into the core almost immediately. Later in the scenario, soluble boron enters from the emergency core cooling system. The critical aspect of the analysis is the hypothesis that the cold water would bring the reactor back to criticality despite reactor scram and before boron reached the core.

ABSTRACT *In cooperation with several nuclear utilities, EPRI has been evaluating the overly conservative assumptions used by LWR vendors in analyses of design-basis accidents. The project goal is to apply state-of-the-art analytical tools to reduce the excess conservatism found in vendor calculations. The resulting methods will permit utilities to improve plant performance by modifying technical specifications, to improve operational flexibility, and to respond quickly to safety-related issues at or before the time they attain licensing significance.*

As in the case of the REA analysis, the possibility of a localized return to power calls for the use of a methodology capable of handling three-dimensional effects. Also, the ability to consider the effects of cross-flow between adjacent core regions (cross-flow resulting from differences in coolant density) would contribute to a more realistic simulation of the accident scenario. It was concluded that these capabilities could be realized by linking ARROTTA with VIPRE-02, a six-equation thermal-hydraulics code developed by EPRI. VIPRE offers a flexible core model (applicable to both PWRs and BWRs) that permits the detailed calculation of fuel temperatures and moderator conditions.

EPRI has coupled the ARROTTA and VIPRE-02 codes; a paper describing this coupling was presented at the Sixth International RETRAN Conference (NP-6949). Further, a reactor vessel model is being incorporated into VIPRE in order to handle thermal mixing for both the steam line break and BWR stability (RP3156) analyses.

The Wolf Creek Nuclear Operating Corporation has cooperated with EPRI in the PWR steam line break effort. Wolf Creek conducted RETRAN analyses of a hypothetical steam line break accident to obtain the thermal-hydraulic response needed by EPRI to perform the more detailed VIPRE–ARROTTA analysis. The results were reported at the RETRAN conference. This presentation, which is also published in NP-6949, described the modeling approaches used and compared the RETRAN results with the results in the Wolf Creek updated safety analysis report. Wolf Creek intends to present a steam line break analysis to the NRC in a topical report.

BWR control rod drop

This accident scenario is described in NP-4498, Vol. 2: *BWR Event Analysis Guidelines*. It postulates the dropping of a fully inserted and decoupled control rod at its maximum velocity. The control rod is assumed to be the maximum-incremental-worth rod consistent with the constraints on control rod patterns. Rapid removal of a high-worth control rod could result in a potentially significant excursion, which could affect the fuel cladding and the reactor coolant pressure boundary.

The BWR rod drop accident was assigned a lower priority by the DBA steering committee and will be addressed at a later date. EPRI is currently looking for a utility to take the lead in this licensing effort.

Ecological Studies

Effects of Acidic Deposition on Forest Nutrients

by Louis Pitelka, Environment Division

For the past decade, scientists, policymakers, and the general public have been concerned about the possible effects of acidic deposition on forests. The issue first arose with the recognition of the role terrestrial ecosystems play in controlling surface water acidification. As early as 1971, there were predictions that forest growth would decline as a result of soil acidification and nutrient leaching. The level of concern increased greatly in the early 1980s with reports of actual cases of forest decline in West Germany and in the northeastern United States. The coincidence of high levels of atmospheric deposition and marked forest decline led many to conclude that there was a direct cause-and-effect relationship.

EPRI forest study

Several EPRI projects have focused on aspects of the problem of forest decline. The largest of these projects is the Integrated Forest Study on Effects of Atmospheric Deposition, or IFS. Initiated in 1985, the IFS tested several hypotheses concerning the relationship between atmospheric deposition and the nutrition of forest ecosystems. The project focused on the possibility that acidic deposition causes the gradual loss of such essential nutrients as calcium, magnesium, and potassium from the soil.

EPRI was joined by Southern Company Services and the Empire State Electric Energy Research Corporation in funding the IFS. The National Acid Precipitation Assessment Program (NAPAP) independently funded two sites in the study. Researchers from the Environmental Sciences Division at Oak Ridge National Laboratory designed and coordinated the project. Investigators from 13 universities, two federal agencies, two foreign countries, and several other research organizations participated in the effort.

The IFS was an ecosystem-level study of the processes of nutrient flux that link the atmosphere, vegetation, soil, and soil water. Its objective was to quantify the deposition and soil processes that act together to determine a forest's nutrient status. The research was conducted at 15 sites in the northeastern, southeastern, and northwestern United States and at sites in Canada and Norway (Table 1). The sites differ in terms of climate, air quality, soils, and vegetation. Research sites were operated for three to four years between 1985 and 1989.

At each site, investigators characterized the cycling processes that control the flux of more than a dozen chemical constituents of deposition as well as elements important for plant nutrition. This involved measuring the mineral content of major ecosystem components (overstory vegetation, understory vegetation, roots, litter, and soil) and monitoring the annual flux of elements within the ecosystem. For example, the scientists recorded input through wet and dry deposition, canopy interactions, litter fall, plant uptake, movement through the soil, and leaching or loss through the soil. In addition to these monitoring activities, the project included a variety of experimental tasks and the development of a personal computer-based nutrient cycling model called NuCM, which simulates the long-term effects of deposition or changes in deposition.

Results

The fieldwork phase of the IFS has been completed, and investigators are analyzing the results. While publication of results is still several months away, the IFS findings have been presented at numerous international meetings and have been incorporated into NAPAP's assessment efforts. Since the IFS constitutes the main effort in North America to evaluate the effects of acidic deposition on forest nutrient status, its results have been important to the NAPAP work. Additionally, NuCM has been useful in evaluating the long-term effects of different patterns of acidic deposition (see EPRI report EN/GS-7132, *Analysis of Alternative SO_2 Strategies*).

ABSTRACT *Much research over the past decade has focused on determining how acidic deposition affects forests and whether it is responsible for certain cases of forest decline in North America and Europe. A comprehensive, four-year EPRI field study examined the hypothesis that acidic deposition can cause important plant nutrients to be leached from forest soils, thereby creating nutrient deficiencies. The results confirm that acidic deposition accelerates nutrient leaching but indicate that many other factors also affect forest soil nutrient status. At the sites monitored in the study, nutrient leaching rates did not correlate closely with deposition rates or with the severity of forest decline.*

Table 1
IFS SITES

Code	Location	Forest Type
ST	Smoky Mountains, NC	Spruce-fir
SS*	Smoky Mountains, NC	Spruce-fir
SB*	Smoky Mountains, NC	Beech
DL	Duke Forest, NC	Loblolly pine
LP	Oak Ridge, TN	Loblolly pine
GL	Grant Forest, GA	Loblolly pine
CP	Coweeta, NC	White pine
CH*	Coweeta, NC	Mixed hardwood
FS	Gainesville, FL	Slash pine
WF	Whiteface Mountain, NY	Spruce-fir
TL	Turkey Lake, Ontario	Mixed hardwood
MS	Howland, ME	Red spruce
HF	Huntington Forest, NY	Mixed hardwood
DF	Thompson Forest, WA	Douglas fir
RA	Thompson Forest, WA	Red alder
FL*	Findley Lake, WA	Fir-hemlock
NS	Nordmoen, Norway	Norway spruce

*Site without intensive deposition monitoring.

The IFS results reveal that the nutritional status of forests is affected by many natural and anthropogenic factors. Most important among these are the properties of the soil at a particular site and the overall health and age of the forest. Also, the extent to which acidic deposition influences the nutritional status depends heavily on these and other factors.

The simplest way to explain the role of acidic deposition at the various IFS forest sites is to first compare the deposition regimes at the sites and then discuss soil properties and other site characteristics that mediate the effects of the deposition. The deposition monitoring results (Figure 1) are of great interest in themselves, since they reveal some unexpected patterns within and between sites.

Not surprisingly, there was wide variation among the sites in total deposition of sulfur and nitrogen, with sites in the Pacific Northwest having the lowest levels. Less expected was the observation that, for sites at comparable elevations, deposition levels were higher in the Southeast than in the Northeast. For example, deposition at the Smoky Mountain monitoring site (ST) was significantly greater than deposition at the Whiteface Mountain site (WF) in New York. This result is important in light of the fact that red spruce decline and mortality are much more extensive at the latter site than at the former. Another unexpected result was the importance of dry deposition and, at the high-elevation sites, cloud water deposition. Until the early 1980s, these factors were neglected, even in studies involving the measurement of chemical inputs into ecosystems. It is now known that in many cases they constitute 50% or more of total deposition.

The deposition of sulfur and nitrogen was of particular interest in the IFS, since the sulfate and nitrate ions cause soil acidification and nutrient leaching. The availability of these mobile anions in the soil solution helps to determine the extent to which such base cations as Ca^{++}, K^{+}, and Mg^{++} are leached or Al^{+++} is brought into solution. On the other hand, even when sulfur and nitrogen deposition rates are high, biological processes (e.g., the trees' demand for nitrogen) or physical processes (e.g., the adsorption of sulfate onto soil particles) may cause sulfate and nitrate anions to be removed from the soil solution and may thus preclude cation leaching.

Another factor that determines the extent to which base cations can be leached is their availability in the soil. Base cations can be present in soil in several forms. As components of primary rock minerals in the soil, they become available to be leached or to be used by trees only through the slow process of soil weathering. A large amount of unweathered minerals in a soil represents a long-term nutrient reservoir that can supply the soil at a low rate for thousands of years. Cations released as a result of soil weathering or those that enter the soil from deposition can be retained in the soil by bonding weakly to particles of clay or organic matter. These cations can then enter the soil solution through the process of cation exchange. In this process, free cations in the soil solution exchange with ions bound to the clay and organic matter (called the cation exchange complex). Abundant cations tend to exchange with those in more limited supply. Once in the soil solution, cations are available to be leached or to be taken up by plants. Base cations held on the cation exchange complex represent a second reservoir of nutrients within the soil, and they can be depleted at a much faster rate than the unweathered minerals. The cations in solution represent a third, even more mobile reservoir.

The IFS sites vary widely in the relative sizes of the base cation reservoirs. In general, the young soils (i.e., those at northern or recently glaciated sites) have large amounts of unweathered minerals, since the degree of weathering is a function of soil age. These young soils also tend to have reduced supplies of base cations on the cation exchange complex because this reservoir has been depleted by the natural acidification processes that are characteristic of cold, wet regions. In contrast, older soils, such as those found in the southeastern United States, have much smaller amounts of weatherable minerals as a result of thousands of years of depletion by the weathering process. However, in some cases these soils have greater amounts of exchangeable base cations than the young soils.

With this background information, it is possible to understand the measured net base cation flux patterns observed at the IFS sites (Figure 2). Most sites showed a net loss of base cations from leaching. There was wide variation from site to site in the rate of loss, however, and the patterns did not correlate closely with deposition patterns. While it is impossible to explain in this report all the differences between sites, a few specific examples will illustrate the range of factors involved.

At the two sites with the highest net loss rates of base cations—the Turkey Lake site (TL) in Ontario and the red alder site (RA) near Seattle—high leaching rates can be attributed to natural causes. In red alder, symbiotic

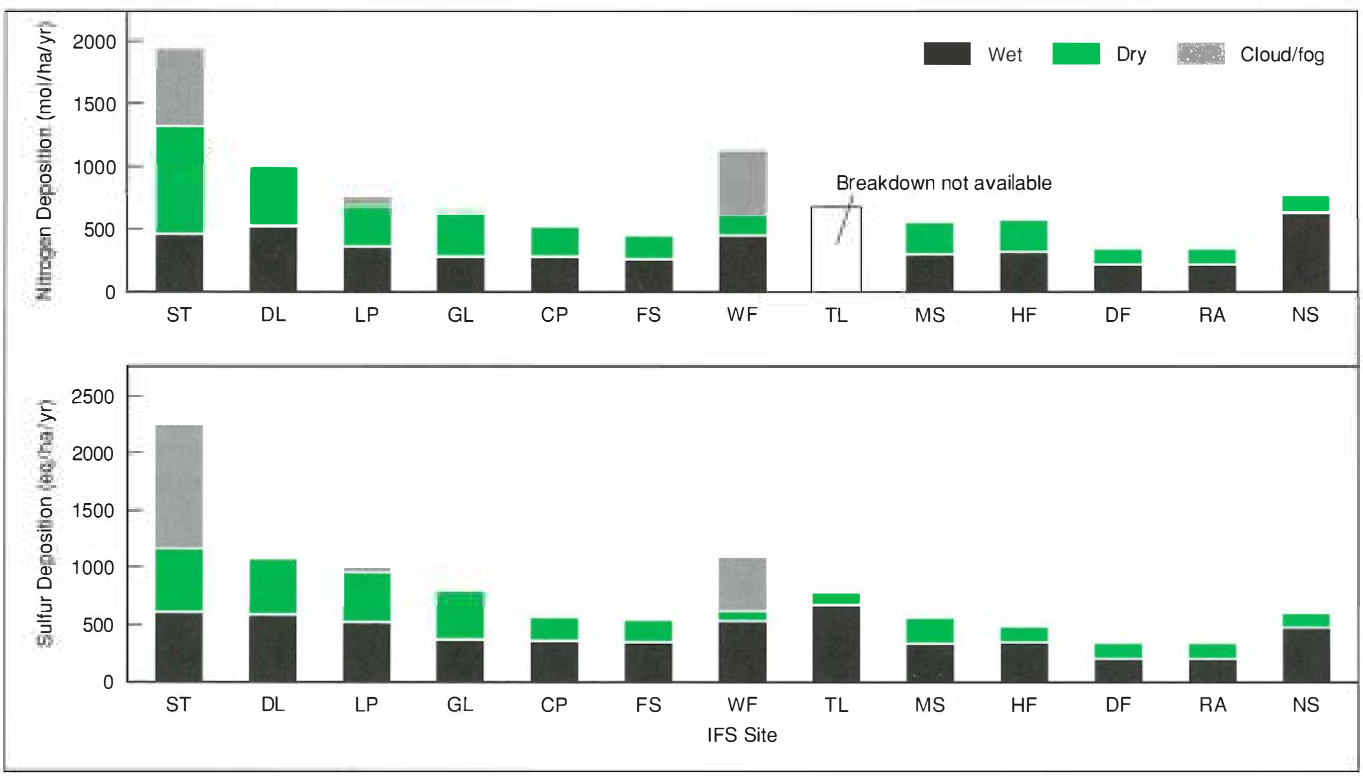
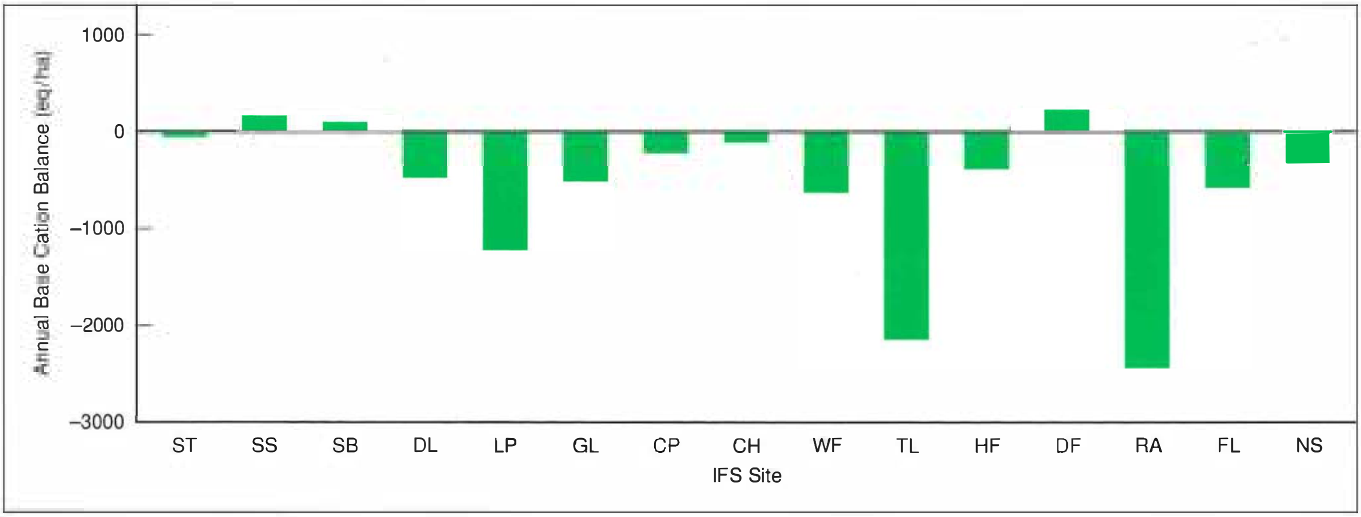


Figure 1 Mean annual deposition of nitrogen (as nitrate and ammonium), top, and sulfur (as sulfate), bottom, at 13 IFS field sites. The data illustrate the importance of dry deposition and cloud water deposition, as well as the differences between southern (first six bars) and northern sites.

Figure 2 Net base cation balances for 15 IFS sites. A value above zero indicates a net influx to the ecosystem (i.e., deposition exceeds leaching); a value below zero indicates a net loss (leaching exceeds deposition). While most sites show a net loss, a comparison with Figure 1 shows that the net balances are not closely correlated with deposition levels.



relationships develop between the plants and certain soil fungi that fix nitrogen gas from the atmosphere. Large quantities of nitrogen are fixed by red alder plantations, and much of this nitrogen eventually is converted to nitrate by bacteria. As noted above, nitrate is a mobile anion that causes cation leaching and soil acidification. In this case, the nitrate does not come from acidic deposition.

Nitrate is also the principal cause of the high leaching rate at Turkey Lake, but here the nitrate is internally generated by the decomposition of stored organic matter in the soil. Because the forest is mature and is growing slowly, there is little demand from trees for the nitrate; hence it is available to leach cations.

The results for the three Smoky Mountain sites are also interesting. At two of the sites (SS and SB), there was a net accumulation of base cations (cation deposition exceeded leaching); the third site (ST) showed close to zero net change. Since the Smoky Mountains received the highest acidic deposition loadings of all the IFS sites, one might expect leaching to be high if acidic deposition is a major factor controlling leaching. The apparent explanation is that the soil is already highly acidic as a result of natural processes and has an extremely small amount of exchangeable base cations. Because cation exchange is an equilibrium process, the direction of the reaction for any particular cation depends in part on the ion's concentration in solution and its concentration on the cation exchange complex. If there are very few base cations on the exchange complex and base cations are being added to the soil solution from atmospheric deposition, the reaction actually can be in the direction of the exchange complex; that is, the complex will take up base cations from the soil solution. Although the high level of acidic deposition may be detrimental to these forest sites in other respects, it is not causing net depletion of base cation reserves.

Forest sites where acidic deposition may be most detrimental in depleting base cations include those that have moderate levels of exchangeable base cations, minimal unweathered reserves, and estimated weathering rates close to zero. The IFS sites of greatest concern in this regard are several of the southeastern sites (Duke Forest, Oak Ridge, and Grant Forest). Acidic deposition at these sites, although not as heavy as at some other sites, could deplete the exchangeable reservoirs over time, and there would be no replenishment of base cations from weathering.

Another way to put in perspective the importance of acidic deposition in depleting nutrients is to compare it with tree harvesting. When tree trunks or entire trees are harvested and removed from the ecosystem, large quantities of base cations and other nutrients are also removed. The amount of base cations annually sequestered by growing trees can exceed the amount leached as a result of acidic deposition. If, after several to many decades of growth, the trees are harvested, the quantity of base cations removed from the site will be substantial. In contrast, if the trees are not harvested, they eventually die and decompose, and the cations are recycled. Thus, timber harvesting represents a significant mechanism by which base cations can become depleted at a site.

This brief summary of IFS results illustrates the complexity of the biogeochemical processes that control forest nutrient status and the effects of acidic deposition. Many of the insights gained from the IFS were possible only because so many sites were compared by using the same protocols and because complete nutrient budgets were determined for all sites. This approach has made it possible to put the effects of acidic deposition in perspective. It must be noted that even if base cations are being depleted by natural or anthropogenic processes, one cannot always predict if or when a forest will be negatively affected. As at the Smoky Mountain sites, the soil will eventually cease to lose base cations and, under those conditions, trees may still be able to thrive.

Value-Based Transmission Resource Analysis

by Neal Balu and Mark Lauby, Electrical Systems Division

ABSTRACT *Electricity consumers in the United States enjoy highly reliable supply service, but several utilities are reexamining the traditional practice of providing all customers with the same high level of system reliability. EPRI's Value-Based Transmission Resource Analysis (VBTRA) Workstation will enable utilities to weigh the value of reliable service to customers against the cost of facility additions. The workstation will include three recently completed tools that offer important new capabilities: a transmission reliability program for large systems; a composite (generation and transmission) reliability program, which is already in use by several utilities; and a method for determining the costs, to utility customers, of power interruptions—information crucial for value-based reliability analyses.*

The high-voltage transmission network in the United States faces tough challenges—challenges that stem largely from a rapid increase in the number and size of interutility power transfers on the network and from the continued steady growth of power delivered directly from utility plants to customers. These trends are expected to continue for the next several years, yet environmental and economic constraints have slowed the construction of new lines to handle the growth in load and in bulk power transfers. As a result, an increasing number of utility systems may often operate close to their reliability limits.

A power system is deemed reliable if it can supply sufficient generation and transmission capacity to meet system load under both normal and contingency conditions. Because power must be reliably transferred to load, effective utility planning requires that the value of a given generating unit be seen as a function of transmission reliability. In fact, given the strains on America's transmission network and the high cost of capital, it is imperative that utilities regard their transmission facilities as flexible resources for increasing reliability and capacity. A utility can use its transmission system as a resource by uprating facilities or adding new facilities to increase power transfer capability—thereby reducing spinning reserves and contingency generation requirements—or by using alternative circuit paths to prevent the onset of unstable situations.

To help utilities realize the benefits of transmission as a resource, EPRI is developing a strategy called the Value-Based Transmission Resource Analysis (VBTRA) Workstation, which focuses on the value of system reliability. In addition to previously available tools for analyzing generation reliability, the workstation will include a recently completed program that can evaluate transmission reliability in large (2500-bus) networks. But transmission and generation interact, so composite (generation and transmission) reliability must also be a part of reliability analyses. The VBTRA Workstation will include the first production-grade software available for utilities to use to analyze composite reliability.

Value-based reliability analysis

In recent years the concept of what constitutes an acceptable level of system reliability has begun to change, and the traditional practice of providing all customers with a very high level of system reliability is being reexamined. Utilities are now considering varying levels of system reliability: residential customers might accept lower levels in exchange for lower rates; industrial and business customers who depend on variable-speed equipment, robotics, solid-state devices, and advanced information systems might pay higher rates for higher levels of reliability.

The VBTRA Workstation is designed to perform value-based reliability analysis (Figure 1). The relative value of reliability to utility customers—as measured in terms of the costs they incur as a result of power interruptions—plays a pivotal role in this kind of analysis. Hence EPRI developed and recently demonstrated a method for determining system interruption costs for various types of utility customers. When these costs are known, the value to a customer of increasing transmission reliability can be quantified. Using this new method, the VBTRA Workstation will enable utilities to plan facilities so that an appropriate balance exists between benefits to customers and costs of providing reliable service.

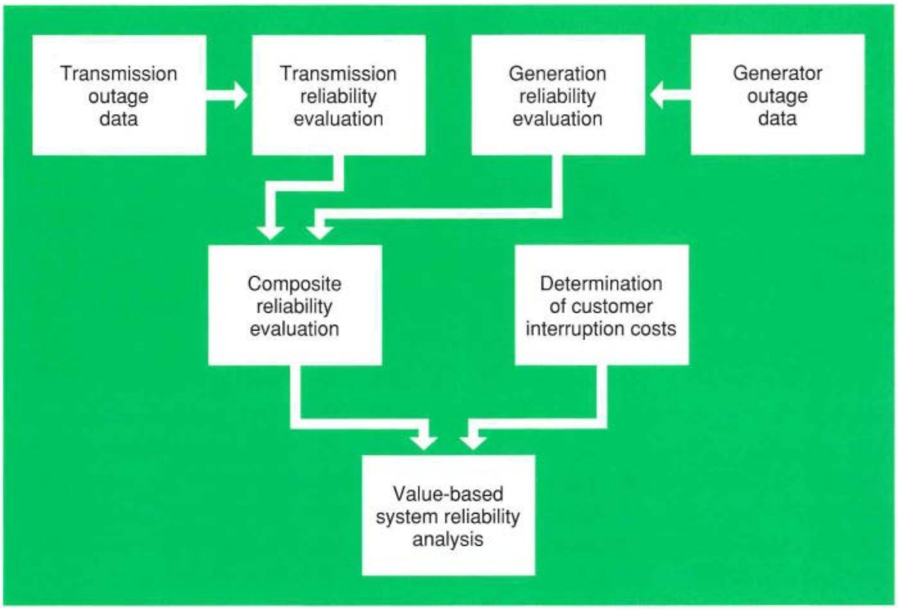
Generation reliability

The evaluation of the steady-state reliability of a bulk power system is an important element in allocating capital resources and in determining trade-offs between cost and reliability. Generation reliability evaluation methods, in which transmission limitations are ignored, were the first tools to be developed for steady-state reliability analyses. These methods are based on the analytical characterization of the probability distribution of the available generation capacity, which is then compared with the load to be supplied.

Efficient methods of computing generation reliability have been available for several years, and the resulting probabilistic indexes, such as loss-of-load probability (LOLP) and expected power not supplied (EPNS), are widely used in planning studies. However, those methods do not explicitly recognize such major influences on the reliability of an interconnected power system as power generation scheduling, policy limits on power transfer, and network capacity. The VBTRA Workstation will include a set of generation reliability programs called GENREL, which incorporate these previously untreated factors.

Developed in RP1534, the GENREL programs accurately model how system reliability is affected by unit and system operating characteristics, intersystem transmission limitations, and the interrelationship of plant duty cycles in different areas. A utility can use these programs to assess alternative operating policies, coordinate power transfers with neighboring utilities, improve generation system reliability, and evaluate the benefits of interconnections. Generation outage data used to drive the analysis can be obtained from the North American Electric Reliability Council's Generation Availability Data System (GADS).

Figure 1 To assess the value of system reliability for planning purposes, utilities need to evaluate composite (generation and transmission) reliability in various scenarios and to determine the costs customers incur as a result of power interruptions. EPRI has completed or is working on several software programs and data development methods to help utilities perform these tasks. The VBTRA Workstation will combine these tools in one convenient package.



Transmission reliability

With the rapid growth of power networks and the increasing interconnection between utilities, it has become clear that transmission networks play a critical role in determining overall system reliability. In fact, having enough generation capacity to handle expected loads cannot ensure system reliability if the transmission system is not adequate. Including transmission makes the task of calculating system reliability much more difficult than when only generation capacity is examined. Generation reliability evaluation entails relatively simple comparisons; when transmission is included, however, the evaluation of supply adequacy for a given scenario (in which load levels, generation availability, and circuit availability are predetermined) usually requires power flow analysis.

Any reliability evaluation of a bulk power transmission system requires outage data for the components that compose the system. In RP1283 and RP1468, EPRI identified what outage data should be collected and developed a way to produce a good statistical database for use in assessing transmission system adequacy. In another project aimed at helping utilities perform transmission reliability assessments (RP3159-1), EPRI recently completed a 2500-bus version of its successful 150-bus SYREL program. The new program is called TRELSS (transmission reliability evaluation for large-system studies). It uses the contingency enumeration method in an initial screening of contingency conditions (i.e., load and generation patterns) to determine the cases in which transmission capability is most critical. TRELSS then examines those cases in detail, indicating the impact that transmission outages at specific load levels have on customer service. The probability of these outages and the resulting inadequacy, as measured by load shedding, can then be used to compare options for transmission system reinforcement.

Composite reliability

Traditional methods for estimating the reliability of generation and transmission systems do not consider interactions between the two types of systems; thus they ignore ways in which a generation outage and a transmission outage that singly do not affect power system performance may together lead to system problems. Case studies of utility-derived systems indicate that such combined outages may contribute significantly to total system unreliability. Evaluating the reliability of combined generation and transmission systems will become more crucial as utilities increase economy interchanges.

In RP2581-2 researchers developed a Monte Carlo simulation technique that defines sample system scenarios in part by using random number generators whose probability distribution matches those of modeled equipment failures and load fluctuations. The researchers then incorporated the technique into computationally efficient software that uses information from separate evaluations of generation reliability and transmission reliability. This software—CREAM (composite reliability assessment by Monte Carlo methods)—is the first production-grade computational tool able to calculate composite LOLP and EPNS indexes. It also performs sensitivity analyses indicating the variation in these reliability indexes with incremental reinforcements of generation capacity at each bus and of transmission capacity at each right-of-way.

As a principal component of the VBTRA Workstation, CREAM will enable planners to perform combined generation and transmission reliability analyses in evaluating how alternative facility-addition decisions would affect overall system reliability. For example, utility planners can use CREAM to determine whether it would be better, in terms of reliability, to add a new generator, to use existing transmission lines to obtain power from another utility, or to build a transmission line that would allow the utility to buy power from a utility with surplus capacity. Planners at several utilities are already using CREAM to compare system designs, justify facility decisions, and identify system weaknesses.

Customer interruption costs

In addition to enhancing their reliability analysis capabilities, EPRI member utilities are interested in incorporating customer values into system planning and into the evaluation of possible system additions. Specifically, utilities recognize the need for information about the value of improved service, in terms of fewer and shorter power interruptions, to various types of customers. Such information is needed if a utility is to perform cost-benefit analyses in which the value of service to customers is weighed against the cost of facility additions designed to increase transmission reliability and available power. Yet most utilities have virtually no customer data on the value of service reliability as measured by the costs resulting from outages.

In RP2878-1 EPRI developed a detailed, step-by-step method for conducting customer surveys, evaluating the results, and obtaining customer interruption cost data for use in cost-benefit analyses. The approach was demonstrated at two large utilities, and any utility can employ it to obtain valid estimates of customer interruption costs. In RP2878-2 EPRI is developing a procedure that will facilitate the comparison of utility-specific customer interruption costs with the costs of power system enhancements. Utilities will also be able to use the procedure to assess the value of reliability provided by adding nonutility generators or independent power producers to the power system.

In summary, the VBTRA Workstation will enable utilities to bring together the necessary analytical tools and data for performing reliability-based cost-benefit analyses as an integral part of overall system planning. With the VBTRA package, utility engineers will be able to measure levels of reliability and rank construction projects on the basis of the relative value they provide to customers. These results will give utilities a new basis for deciding where to spend their "reliability dollars."

New Contracts

Project	Funding/ Duration	Contractor/EPRI Project Manager
Electrical Systems		
Structural Response of Transmission Lines to Hurricane Winds (RP1277-12)	$53,500 4 months	GAI Consultants/*P. Lyons*
Transformer Moisture Detector Development (RP1289-5)	$172,800 19 months	Massachusetts Institute of Technology/*G. Addis*
HVDC Modulation Controller (RP1426-8)	$502,200 16 months	Power Technologies/ *S. Wright*
Development of Preproduction TOMCAT System (RP1497-5)	$399,700 19 months	Foster-Miller/*H. Mehta*
Development and Application of Static Phase Shifters for FACTS (RP2473-42)	$89,600 15 months	University of Toronto/ *D. Maratukulam*
Hourly Load Forecasting Using Neural Networks (RP2473-44)	$102,500 24 months	Southern Methodist University/*D. Maratukulam*
Expert System for Security Analysis (RP2944-6)	$214,200 17 months	General Physics Corp./ *M. Lauby*
Thyristor-Controlled Series Compensation (RP3022-4)	$2,052,500 25 months	General Electric Co./ *B. Damsky*
Environment		
GCM Sensitivity to Atmospheric Carbon Dioxide Concentrations (RP2333-11)	$88,300 13 months	Yale University/ *C. Hakkarinen*
Influence of Vegetation on the Fate of Polycyclic Aromatic Hydrocarbons in Soils (RP2879-10)	$199,800 18 months	Martin Marietta Energy Systems/*J. Goodrich-Mah*
Tropospherical Model Development and Evaluation of Organic Acids and Aerosols (RP3189-3)	$492,700 24 months	California Institute of Technology/*P. Saxena*
Risk Analysis of Contaminated Sites (RP3194-1)	$137,600 17 months	Decision Focus/ *V. Niemeyer*
Exploratory Research		
Mixing in Turbulent Free Shear Flows (RP8006-15)	$117,800 30 months	Cornell University/ *J. Maulbetsch*
Flux Pinning in High-Technetium Superconductors (RP8009-6)	$98,600 12 months	Battelle, Columbus Laboratories/*J. Stringer*
Development of a Computer Program for Analysis of Hydraulic Turbines Under Natural Aspirating Conditions (RP8010-11)	$186,800 14 months	Fluid and Power Research Institute/*M. Merilo*
Regulation of the Ozone Response and Genetic Strategies of Control (RP8011-1)	$541,000 36 months	Pennsylvania State University/*L. Pitelka*
Genetic and Microbial Ecology of Biofilms (RP8011-2)	$752,600 42 months	University of Tennessee/ *R. Goldstein*
Search for Nuclear Products From Condensed-Matter Fusion (RP8012-1)	$149,800 12 months	Colorado School of Mines/*D. Worledge*
Self-Collider Fusion Reactor With Direct Energy Conversion (RP8012-5)	$65,000 6 months	University of Florida/ *D. Worledge*
Generation and Storage		
Life Assessment and Repair of Combustion Turbine Nozzle/Vane Segments (RP2775-8)	$98,500 22 months	Liburdi Engineering/ *J. Allen*
Chiyoda Thoroughbred 121 Process Project at Georgia Power's Plant Yates (RP2827-1)	$7,000,000 50 months	Southern Company Services/*R. Moser*
Application of a Saturator to CAES Systems With Gasification Power Plants (RP2834-1)	$80,000 5 months	Energy Storage & Power Consultants/*A. Cohn*
Guidelines for the Selection and Application of Primary Control Elements (RP2922-3)	$187,400 11 months	Encor-America/*M. Blanco*
Fossil Plant Automation Technical Support (RP2922-5)	$143,800 24 months	WTI/Indus Technologies/ *M. Divakaruni*
Machine Insulation Condition Assessment Adviser (RP2960-3)	$156,700 18 months	Iris Power Engineering/ *J. Stein*
Selective Catalytic Reduction Project at Gulf Powers Plant Crist (RP3004-12)	$2,000,000 47 months	Southern Company Services/*E. Cichanowicz*
Geotechnical Evaluation of a Depleted Gas Reservoir for Siting a CAES Plant (RP3049-2)	$300,000 18 months	Pacific Gas and Electric Co./*B. Mehta*
Amorphous Silicon–Germanium Solar Cells (RP3063-1)	$1,373,500 19 months	Princeton University/ *T. Peterson*
Application of the TRW Slagging Combustor to Utility Boilers (RP3069-1)	$2,200,000 31 months	TRW/*A. Kokkinos*
Economics of Pulse-Jet Baghouses for Utility Applications (RP3083-4)	$214,500 23 months	Sargent & Lundy Engineers/*R. Chang*
Pulse-Jet Baghouse Laboratory Support Work (RP3083-10)	$184,300 34 months	Southern Research Institute/*R. Chang*
Nuclear Power		
Evaluation of Waste Characterization Methodologies for Irradiated Reactor Waste Components (RP2813-31)	$65,100 6 months	Sierra Nuclear Corp./ *R. Lambert*
Role of Trace Impurities in the Classification of Non-Fuel-Bearing Components (RP2813-32)	$62,200 11 months	Battelle, Pacific Northwest Laboratories/*R. Lambert*
In-plant Trial of Cable Indenter Aging Monitor (RP2927-8)	$80,800 4 months	ERC Environmental and Energy Services Co./ *G. Sliter*
Investigation Into the Nature of Irradiation Damage and Its Analysis Using Charpy Impact Data (RP2975-16)	$50,000 12 months	ESEERCO/*T. Griesbach*
Moisture Separation Drain/Demineralizer Evaluation (RP2977-6)	$189,400 16 months	Toledo Edison/*T. Passell*
Supplementary Instrumentation for Garner Valley Seismic Array (RP3014-3)	$78,800 48 months	University of California, Santa Barbara/ *J. Schneider*
Application of Chemical Control for Zebra Mussel Infestation (RP3052-4)	$120,000 7 months	Centerior Service Co./ *N. Hirota*
Waterside-Corrosion Support (RP3114-47)	$134,200 10 months	Altos Engineering Applications/*B. Chexal*
Instrument Air Diagnostic System (RP3114-49)	$113,900 11 months	MPR Associates/ *W. Reuland*
CHEC/CHECMATE Users Group Support (RP3114-53)	$204,800 21 months	Altos Engineering Applications/*B. Chexal*
Development of Nuclear Power Plant Control System Retrofit Adviser (RP3114-56)	$70,100 18 months	Decision Focus/*S. Oh*
Analysis of BWR ATWS With Oscillations (RP3114-57)	$50,000 5 months	Computer Simulation and Analysis/*R. Torok*
Melt-Water Interaction Analysis (RP3130-1)	$70,000 4 months	Argonne National Laboratory/*M. Merilo*
Experiments on Lower-Plenum Response Under Severe-Accident Conditions (RP3130-2)	$459,700 16 months	Fauske & Associates/ *M. Merilo*
Alarm System Redesign in Operating Plants (RP3136-1)	$183,100 14 months	MPR Associates/ *J. O'Brien*

New Technical Reports

Requests for copies of reports should be directed to Research Reports Center, P.O. Box 50490, Palo Alto, California 94303; (415) 965-4081. There is no charge for reports requested by EPRI member utilities, U.S. universities, or government agencies. Reports will be provided to nonmember U.S. utilities only upon purchase of a license, the price for which will be equal to the price of EPRI membership. Others in the United States, Mexico, and Canada pay the listed price. Overseas price is double the listed price, except as noted. Research Reports Center will send a catalog of EPRI reports on request. To order one-page summaries of reports, call the EPRI Hotline, (415) 855-2411.

CUSTOMER SYSTEMS

Residential Energy Usage Comparison Project: An Overview
CU-6952 Interim Report (RP2863-3); $100
EPRI Project Manager: S. Braithwait

Impact of Demand-Side Management on Future Customer Electricity Demand: An Update
CU-6953 Final Report (RP2863-8); $100
Contractor: Barakat & Chamberlin, Inc.
EPRI Project Manager: S. Braithwait

Electric Vehicle Battery Testing and Development at Argonne National Laboratory, 1989 Annual Report
CU-6968 Final Report (RP2216-2); $25
Contractor: Argonne National Laboratory
EPRI Project Manager: R. Swaroop

Geothermal Ground-Loop Preinstallation Project at Walden Pond
CU-6969 Final Report (RP2892-6); $100
Contractor: Public Service Co. of Indiana
EPRI Project Manager: P. Joyner

Radio-Frequency and Infrared Drying of Sized Textile Warp Yarns
CU-7006 Final Report (RP2893-6, -8); $100
Contractors: West Point Foundry and Machine Co.; Auburn University
EPRI Project Manager: K. Amarnath

Proceedings: 1990 Electric Utility Marketing Research Symposium—Preparing for a Market-Driven Future
CU-7010 Proceedings (RP2050-1); $62.50
Contractor: Synergic Resources Corp.
EPRI Project Manager: T. Henneberger

Proceedings: Innovations in Pricing and Planning
CU-7013 Proceedings (RP2343-5); $100 (overseas price the same)
Contractor: Barakat & Chamberlin, Inc.
EPRI Project Managers: W. LeBlanc, P. Hanser

CFCs and Electric Utilities: Making the Transition to a Safer World
CU-7027 Final Report (RP2792-12); $100 (overseas price the same)
Contractor: Bevilacqua-Knight, Inc.
EPRI Project Manager: P. Joyner

ELECTRICAL SYSTEMS

Study of Fault-Current-Limiting Techniques
EL-6903 Final Report (RP2877-1); $40
Contractor: Westinghouse Electric Corp.
EPRI Project Manager: J. Porter

Overload Characteristics of Paper-Polypropylene-Paper Cable
EL-6929 Final Report (RP7880-2); $25
Contractor: Underground Systems, Inc.
EPRI Project Manager: J. Shimshock

Fundamental Research on Metal Oxide Varistor Technology
EL-6960 Final Report (RP2667-2); $25
Contractor: General Electric Co.
EPRI Project Manager: H. Mehta

Field Evaluation of Grillage Foundation Uplift Capacity
EL-6965 Final Report (RP1493-4); $47.50
Contractor: Cornell University
EPRI Project Manager: V. Longo

Space Charge in Polyethylene-Ionomer Blends for DC Cable Insulation
EL-6977 Final Report (RP7897-9); $32.50
Contractor: University of Connecticut
EPRI Project Manager: B. Bernstein

GENERATION AND STORAGE

Compressed-Air Energy Storage Using Hard-Rock Geology: Champagne Effect Model, Vols. 1 and 2
GS-6662 Final Report (RP2488-3); Vol. 1, $47.50; Vol. 2, $40
Contractor: United Technologies Research Center
EPRI Project Manager: R. Schainker

Coal Devolatilization in a Moving-Bed Gasifier
GS-6797 Final Report (RP2525-14); $32.50
Contractor: Hamilton Maurer International, Inc.
EPRI Project Manager: M. Epstein

Southern Company Services' Study of a KRW-Based GCC Power Plant
GS-6876 Final Report (RP2773-5); $32.50
Contractor: Southern Company Services, Inc.
EPRI Project Manager: M. Epstein

Feedwater Heaters: Replacement Specification Guidelines
GS-6913 Final Report (RP2504-5); $1000 (overseas price the same)
Contractors: Sonalysts, Inc.; Powerfect, Inc.
EPRI Project Manager: J. Tsou

Surge Protection of Generators
GS-6936 Final Report (RP2594-1); $55
Contractors: Ontario Hydro; Rensselaer Polytechnic Institute
EPRI Project Managers: J. Edmonds, J. Porter

Proceedings: 1990 SO_2 Control Symposium, Vols. 1–3
GS-6963 Proceedings (RP982); $300 (overseas price the same)
EPRI Project Manager: P Radcliffe

Proceedings: 1990 First International Symposium on the Biological Processing of Coal
GS-6970 Proceedings; $62.50
EPRI Project Manager: S. Yunker

Corrosion in Syngas Coolers of Entrained Slagging Gasifiers
GS-6971 Topical Report (RP2048-1); $32.50
Contractor: Lockheed Missiles & Space Co., Inc.
EPRI Project Manager: W. Bakker

Proceedings: International Cooling-Tower and Spray Pond Symposium
GS-6976 Proceedings; $70
EPRI Project Manager: J. Bartz

FGD Mist Eliminator System: Troubleshooting Manual
GS-6984 Final Report (RP2250-3); $400 (overseas price the same)
Contractors: United Engineers; Radian Corp.; Southern Research Institute
EPRI Project Manager: R. Rhudy

CAES Plant With Steam Generation: Preliminary Design and Cost Analysis
GS-6987 Final Report (RP2676-3); $32.50
Contractor: Energy Storage and Power Consultants
EPRI Project Manager: R. Pollak

Proceedings: 1989 Conference on Technologies for Producing Electricity in the Twenty-First Century
GS-6991 Proceedings; $92.50
EPRI Project Manager: S. Alpert

The Zebra Mussel: U.S. Utility Implications
GS-6995 Final Report (RP1689-24); $25
Contractor: Macrofouling Consultants
EPRI Project Manager: J. Tsou

Proceedings: Coal-Handling Systems, 1989
GS-6996 Proceedings (RP1400-20); $150 (overseas price the same)
Contractor: CQ Inc.
EPRI Project Manager: D. O'Connor

Trace Element Removal by Iron Adsorption/Coprecipitation: Process Design Manual
GS-7005 Final Report (RP910-3); $40
Contractor: Brown and Caldwell
EPRI Project Manager: M. McLearn

Device-Grade Hydrogenated Amorphous Silicon Produced by DC Magnetron Reactive Sputtering
GS-7012 Interim Report (RP2824-1); $100 (overseas price the same)
Contractor: University of Illinois
EPRI Project Manager: T. Peterson

Mass Culture of Algae Using Carbon Dioxide From Stack Gases
GS-7029 Final Report (RP2612-11); $32.50
Contractor: University of Hawaii at Manoa
EPRI Project Manager: J. Berning

A Computer-Aided Diagnostic and Troubleshooting System for Fuel Cell Power Plants
GS-7039 Final Report (RP3061-3); $32.50
Contractor: ARINC Research Corp.
EPRI Project Manager: D. Rastler

Evaluation of the Chiyoda Thoroughbred 121 Flue Gas Desulfurization Process at the University of Illinois Abbott Plant
GS-7042 Final Report (RP2865-1); $500 (overseas price the same)
Contractor: Radian Corp.
EPRI Project Manager: R. Moser

EPRI High-Sulfur Test Center: Wet Flue Gas Desulfurization Baseline Limestone Tests
GS-7043 Final Report (RP1031-9); $500 (overseas price the same)
Contractor: Radian Corp.
EPRI Project Manager: R. Moser

NUCLEAR POWER

Electropolishing Qualification Program for PWR Steam Generator Divider Plates
NP-6618 Final Report (RP2758-3); $25
Contractor: Quadrex Corp.
EPRI Project Manager: C. Wood

Utility Industry Evaluation of the Power Reactor Inherently Safe Module (Revision 1)
NP-6644 Final Report (RP3030); $32.50
EPRI Project Manager: E. Rodwell

Terry Turbine Controls Guide
NP-6909 Final Report (RP2814-14); $21,000 (overseas price the same)
Contractor: Dresser-Rand
EPRI Project Manager: R. Kannor

NUHOMS Modular Spent-Fuel Storage System: Design, Licensing, and Construction
NP-6940 Interim Report (RP2566-1); $32.50
Contractor: Carolina Power & Light Co.
EPRI Project Manager: R. Lambert

NUHOMS Modular Spent-Fuel Storage System: Performance Testing
NP-6941 Final Report (RP2566-1); $32.50
Contractor: Carolina Power & Light Co.
EPRI Project Manager: R. Lambert

Evaluation and Technologic Improvement of an Enhanced Imaging System, Phase 3: Metallurgical Evaluation
NP-6948 Final Report (RPC105-3); $25
Contractor: General Electric Co.
EPRI Project Manager: M. Avioli

Proceedings: Sixth International RETRAN Conference
NP-6949 Proceedings; $85
EPRI Project Manager: L. Agee

Fabrication of Axial Stress Corrosion Cracks in Alloy 182 Weld Materials
NP-6954 Final Report (RP2928-1); $25
Contractor: General Electric Co.
EPRI Project Manager: S. Liu

Investigation of Mechanisms of Environmentally Accelerated Crack Growth in Reactor Pressure Vessel Steels
NP-6958 Final Report (RP1325-9); $25
Contractor: SRI International
EPRI Project Manager: R. Jones

Infrared Thermography Guide
NP-6973 Final Report (RP2814-18); $15,000 (overseas price the same)
Contractors: American Risk Management Corp.; Honeyhill Technical
EPRI Project Managers: G. Allen, A. Wise

On-Site Radiation Exposure in Severe Reactor Accidents: Scoping Study
NP-6978 Final Report (RP2392-26); $25
Contractor: Stone & Webster Engineering Corp.
EPRI Project Manager: I. Wall

Survey of Earthquake-Induced Fires in Electric Power and Industrial Facilities
NP-6989 Final Report (RP3000-42); $25
Contractor: EQE Engineering Inc.
EPRI Project Manager: F. Rahn

Eddy-Current Probe Characterization
NP-6990 Final Report (RPS404-3); $32.50
Contractor: J. A. Jones Applied Research Co.
EPRI Project Manager: C. Welty

Alloy 690 for Steam Generator Tubing Applications
NP-6997-M Final Report (RPS408-6); $25
Contractor: Westinghouse Electric Corp.
EPRI Project Manager: A. McIlree

Laboratory Examination of Tubes R35C70 and R36C67 Removed From the V. C. Summer Nuclear Station
NP-6998-M Final Report (RPS407-34); $25
Contractor: Babcock & Wilcox Co.
EPRI Project Managers: A. McIlree, P. Paine

Operation of the EPRI Nondestructive Evaluation Center: 1989 Annual Report
NP-7007 Final Report (RP1570-2); $32.50
Contractor: J. A. Jones Applied Research Co.
EPRI Project Managers: G. Dau, S. Liu

CALENDAR

For additional information on the meetings listed below, please contact the person indicated.

APRIL

18–19
NMAC Regional Workshop: Small Fasteners
Charleston, South Carolina
Contact: Bob Kannor, (415) 855-2018

24–25
Power Plant Electric Auxiliary Systems
Princeton, New Jersey
Contact: Maureen Barbeau, (415) 855-2127

25–26
Magnetic Field Measurement
Lenox, Massachusetts
Contact: Greg Rauch, (415) 855-2298

25–26
1991 Utility Strategic Planning Forum
Baltimore, Maryland
Contact: Susan Bisetti, (415) 855-7919

MAY

1–3
Evaluation of Demand-Side Management Impacts
Chicago, Illinois
Contact: Bill LeBlanc, (415) 855-2887

1–3
International Symposium: Biological Processing of Coal
San Diego, California
Contact: Susan Bisetti, (415) 855-7919

6–7
NMAC Regional Workshop: Small Fasteners
Scottsdale, Arizona
Contact: Bob Kannor, (415) 855-2018

7–9
Conference: Heat Rate Improvement
Scottsdale, Arizona
Contact: Pam Turner, (415) 855-2010

8
Security Enhancement Users Group
Baltimore, Maryland
Contact: Ram Adapa, (415) 855-8988

14–15
Optical Sensing in Utility Applications
San Francisco, California
Contact: Lori Adams, (415) 855-8763

CONTINUED

CALENDAR CONTINUED

23–24
NMAC Regional Workshop: Small Fasteners
Boston, Massachusetts
Contact: Bob Kannor, (415) 855-2018

JUNE

3–5
ETADS Experienced-Users Workshop
Haslet, Texas
Contact: Paul Lyons, (817) 439-5900

3–5
1st International ISA–EPRI Controls and Automation Conference
St. Petersburg, Florida
Contact: Arvind Agarwal, (415) 855-2773

3–7
Workshop: Distribution Cable
Indianapolis, Indiana
Contact: Harry Ng, (415) 855-2973

3–7
Workshop: Distribution Cable
Washington, D.C.
Contact: Harry Ng, (415) 855-2973

4–6
International Conference: Cycle Chemistry in Fossil Fuel Plants
Baltimore, Maryland
Contact: Maureen Barbeau, (415) 855-2127

12–14
Upgrading Transmission Lines
Haslet, Texas
Contact: Dick Kennon, (415) 855-3211

13–14
NMAC Regional Workshop: Small Fasteners
St. Louis, Missouri
Contact: Bob Kannor, (415) 855-2018

16–19
Workshop: Radwaste
Boulder, Colorado
Contact: Carol Hornibrook, (415) 855-2022

17–21
Transmission Line Electrical Design: ACDCLINE
Lenox, Massachusetts
Contact: Jim Hall, (415) 855-2305

18–20
Workshop: Condensate Polishing
Scottsdale, Arizona
Contact: Lori Adams, (415) 855-8763

20–21
Seminar: Low-Level Waste Management and Radiation Protection
Boulder, Colorado
Contact: Carol Hornibrook, (415) 855-2022

24–26
1991 EPRI Technology Transfer Meeting
Palo Alto, California
Contact: Joanne Peterson, (415) 855-2716

26–28
Conference: Information and Automation Technology
Washington, D.C.
Contact: Pam Turner, (415) 855-2010

26–28
Power Plant Pumps
Tampa, Florida
Contact: Susan Bisetti, (415) 855-7919

JULY

16–18
Steam Turbine Generator Life Assessment and Maintenance
Charlotte, North Carolina
Contact: Tom McCloskey, (415) 855-2655

30–August 1
5th National Demand-Side Management Conference
Boston, Massachusetts
Contact: Bill LeBlanc, (415) 855-2887

AUGUST

13–19
3d Fossil Plant Inspection Conference
Baltimore, Maryland
Contact: Maureen Barbeau, (415) 855-2127

SEPTEMBER

9–11
Expert Systems
Boston, Massachusetts
Contact: Susan Bisetti, (415) 855-7919

18–20
Conference: Fossil Plant Construction
Boston, Massachusetts
Contact: Pam Turner, (415) 855-2010

18–20
International Conference: Use of Coal Ash and Other Coal Combustion By-products
Shanghai, China
Contact: Dean Golden, (415) 855-2516

19–20
Magnetic Field Measurement
Lenox, Massachusetts
Contact: Greg Rauch, (415) 855-2298

25
ETADS Users Group Meeting
Dallas, Texas
Contact: Paul Lyons, (817) 439-5900

OCTOBER

8–11
Coal Gasification
San Francisco, California
Contact: Lori Adams, (415) 855-8763

8–11
PCB Seminar
Baltimore, Maryland
Contact: Maureen Barbeau, (415) 855-2127

15–18
Meeting Customer Needs With Heat Pumps
Dallas, Texas
Contact: Pam Turner, (415) 855-2010

15–18
Particulate Control
Williamsburg, Virginia
Contact: Susan Bisetti, (415) 855-7919

29–November 2
Computer-Aided Control System Analysis: Classical Techniques
Birmingham, Alabama
Contact: Murthy Divakaruni, (415) 855-2409

NOVEMBER

4–6
Managing Hazardous Air Pollutants
Washington, D.C.
Contact: Lori Adams, (415) 855-8763

5–7
Boiler Tube Failure
San Diego, California
Contact: Maureen Barbeau, (415) 855-2127

DECEMBER

3–6
Symposium: SO_2 Control
Washington, D.C.
Contact: Pam Turner, (415) 855-2010

11–13
Generator and Motor Workshop
Scottsdale, Arizona
Contact: Lori Adams, (415) 855-8763

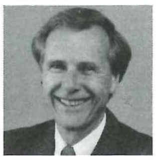
Authors and Articles

Miller

Chow

Porcella

Levin



Wyzga

Hakkarinen

Barker

Bigger

New Focus on Air Toxics (page 4) was written by David Boutacoff, *Journal* feature writer, on the basis of information from several EPRI staff members in the Generation and Storage Division and the Environment Division.

Michael Miller, who heads the Waste and Water Management Program, joined EPRI in 1980 after working with Pacific Gas and Electric. At PG&E, Miller served successively as a consultant on air quality and as administrative assistant to the vice president of planning and research. Earlier, he worked as an air quality analyst for URS Corporation and with Northern States Power Company.

Winston Chow is a program manager in the Waste and Water Management Program. Before joining EPRI in 1979, Chow spent seven years with Bechtel Power Corporation as an engineering supervisor engaged in power plant design. Previously, he worked for Raychem Corporation on polymer research and development.

Donald Porcella, a project manager in the Ecological Studies Program, joined EPRI in 1984, after six years with Tetra Tech, a Honeywell R&D and consulting subsidiary. Before that, he was a professor of civil and environmental engineering at Utah State University and the associate director of the Utah Water Research Laboratory.

Leonard Levin is a project manager in the Environmental Risk Analysis Program. Before coming to the Institute in 1986, he was a senior scientist and senior meteorologist at Woodward-Clyde Consultants. Earlier, Levin served as the director of physical sciences programs at EA Engineering, Science, and Technology and as a senior scientist at Science Applications International.

Ronald Wyzga, senior program manager of the Health Studies Program, has been with the Institute since 1975. Before joining EPRI, Wyzga worked for the Organization for Economic Cooperation and Development in Paris, performing statistical and economic research and analysis on environmental problems. Earlier in his career, he worked as an instructor in the Department of Biostatistics at the Harvard School of Public Health.

Chuck Hakkarinen, technical manager in the Atmospheric Sciences Program, was formerly manager of environmental data analysis. He came to EPRI in 1974 as a project manager for environmental assessment and later served as technical assistant to the division director. ■

The Future of Collaborative Research (page 14) provides illuminating discussion about the origins of research consortia and how these organizations are changing in response to the dynamics of global business. **Brent Barker,** EPRI's manager of corporate information, wrote the article from what was said at the EPRI Advisory Council's most recent annual seminar, held last August.

Barker served as the *Journal*'s editor in chief for 12 years. He came to EPRI in 1977 after working successively as a commercial research analyst at USX Corporation, an industrial economist and staff author at SRI International, and a communications consultant. ■

On-site Utility Applications for Photovoltaics (page 26) was written by Taylor Moore, *Journal* senior feature writer, with guidance from **John Bigger,** a senior project manager in EPRI's Solar Power Program.

Bigger manages projects on early utility applications of photovoltaics and on field testing of high-concentration photovoltaic systems. He joined EPRI in 1976 after 10 years as an engineer with the Los Angeles Department of Water & Power. At EPRI, Bigger first managed work in solar-thermal technology and later coordinated the Institute's role in a hydrogeothermal demonstration plant. ■

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