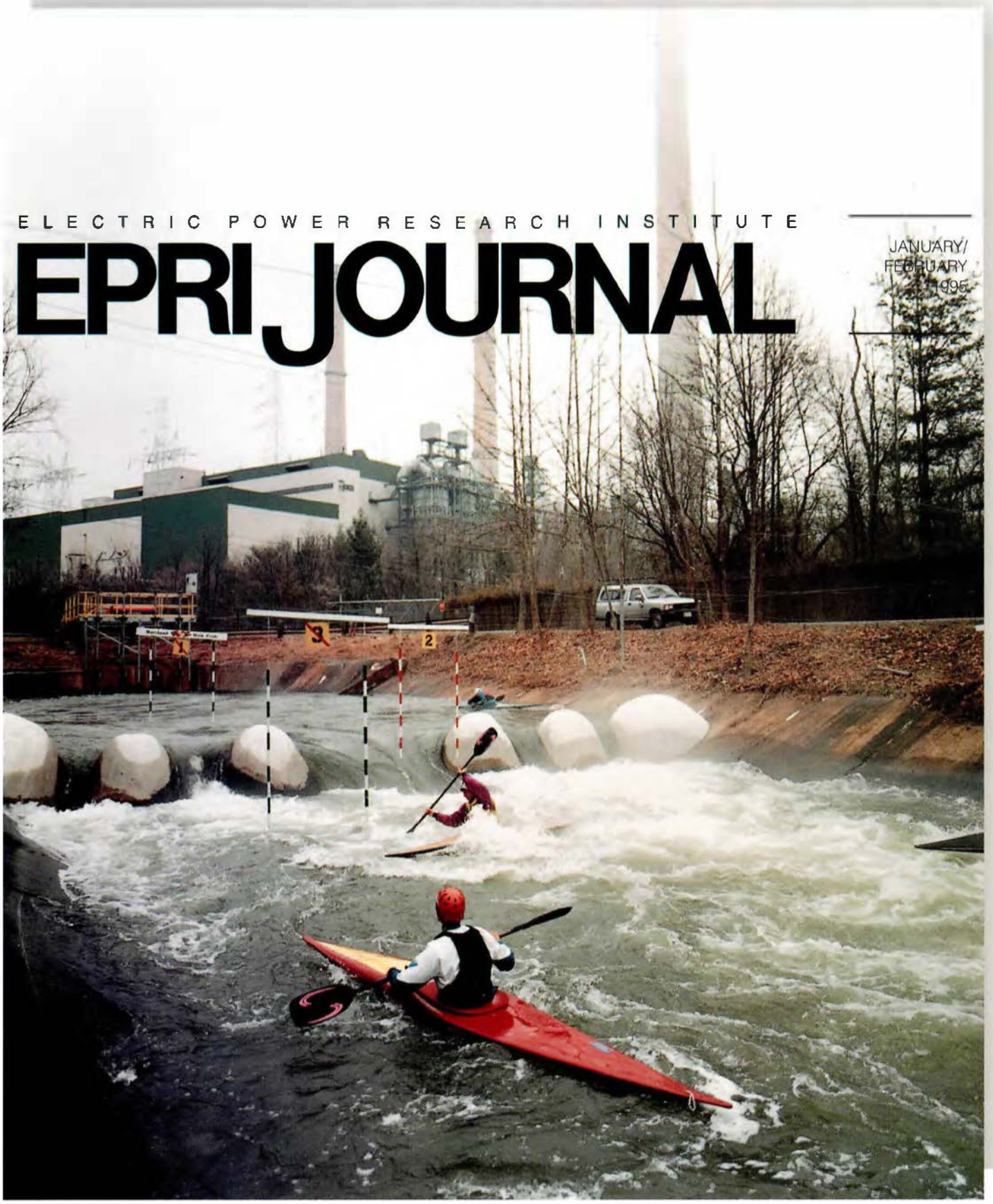
Health Risks of Trace Substance Emissions

Also in this issue • Information Superhighway • Fish Protection • Ozone Research



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Cover: Whether we're physically active outdoors or relaxing inside our homes, many of us are exposed to trace amounts of chemical substances released from the stacks of fossil-fueled power plants. EPRI research has quantified the health risks of such exposure. (Photo courtesy of PEPCO/Rick Giammaria)

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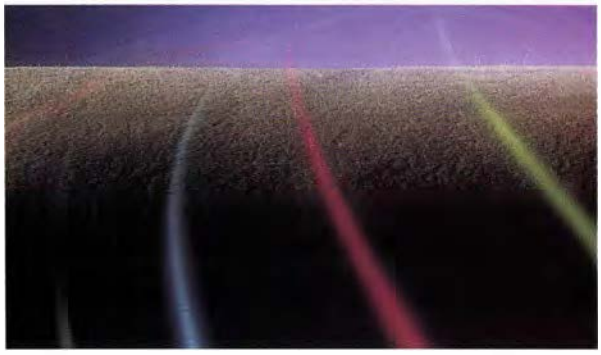

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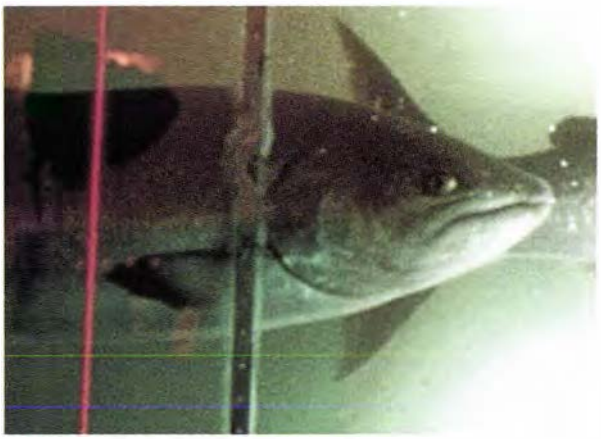


30 Fish protection

Pollution Prevention Video

In recent years, pollution prevention has become a priority for federal, state, and local regulators. Utilities with successful pollution prevention programs have benefited from significant savings and positive community relations. This video (AP-104116) introduces the process of pollution prevention and shows a utility pollution prevention team at work identifying, prioritizing, and implementing new activities. The video describes each step in the pollution prevention process and helps motivate employees to become participants. An accompanying workbook offers greater detail on approaches to pollution prevention and the steps involved in designing and implementing pollution prevention programs.

For more information, contact Mary McLearn, (415) 855-2487. To order, call the EPRI Distribution Center, (510) 934-4212.

GasPlan

The restructuring of the natural gas marketplace has provided utilities with more options for managing their natural gas supplies. The challenge of evaluating these options in the face of uncertain gas demand, prices, and reliability prompted EPRI to develop the GasPlan model. GasPlan is a software tool that offers an analytical approach to solving the problem of short-term gas planning under uncertainty. The model helps utilities make decisions regarding contracts, storage inventory, pipeline imbalances, and other factors related to short-term gas procurement and operations. An accompanying report offers an overview of the short-term gas problem and provides guidance to GasPlan users.

For more information, contact Richard Goldberg, (415) 855-2397. To order, call the Electric Power Software Center, (800) 763-3772.

CHECWORKS

The Chexal-Horowitz Engineering Corrosion Workstation, or CHECWORKS, is the latest in the CHEC family of computer software developed by EPRI. CHECWORKS integrates the capabilities of the CHECMATE, CHEC-NDE, and CHEC-T programs, which are already in use at all U.S. nuclear plants as well as some fossil plants. The software provides plant owners with a powerful new capability to evaluate and manage flow-accelerated corrosion, which affects piping and other plant components. Users can determine the structural adequacy of each inspected component through susceptibility evaluations and the interpretation of nondestructive evaluation data. CHECWORKS is also being used to quantify the benefits of changes in water chemistry, piping materials, and system operation to reduce corrosion rates.

For more information or to order, contact Bindi Chexal, (415) 855-2997.

CLEAN

With EPRI's new CLEAN (Comprehensive Least Emissions Analysis) software, utilities can easily compare the environmental impacts of various residential, commercial, and industrial technologies. CLEAN contains a database of nearly 200 technologies—from electric and gasoline vehicles to electric and gas cooktops. Users can calculate emissions resulting from competing technologies—for instance, a gas heater and an electric heat pump—on the basis of daily load profiles and fuel source. Nitrogen oxides, carbon monoxide, reactive organic gases, particulates, and sulfur oxides are just some of the emissions estimated. Utilities can input emissions data from generation units in their own service territories. Version 2.0 of CLEAN, released last December, offers enhanced features.

For more information, contact Perry Sioshansi, (415) 855-2329.
To order, call the Electric Power Software Center, (800) 763-3772.

Successful DSM Programs

Demand-side management programs, which can encourage improvements in the efficiency and timing of electricity use, often provide utilities financial benefits while enhancing customer relations. But designing successful DSM programs is a challenging task. That's why EPRI published *50 Successful DSM Programs* (TR-103463). This report offers a comparative review of DSM programs at 27 North American utilities, providing utilities and other agencies with ideas for planning, marketing, monitoring, and evaluating their own programs. The programs discussed cover a wide range of financing mechanisms, a mixture of targeted customer types, and a variety of technologies, from lighting to farming equipment.

For more information, contact Paul Meagher, (415) 855-2420. To order, call the EPRI Distribution Center, (510) 934-4212.

Environmentally Benign Refrigerants Perform Well

Ever since the discovery, in the mid-1970s, that chlorine-based refrigerants can deplete the ozone layer of the atmosphere, scientists have been searching for more environmentally acceptable alternatives. To test the performance of potential substitutes in a standardized manner, EPRI joined an interindustry consortium—the Alternative Refrigerant Evaluation Program (AREP)—coordinated by the Air-Conditioning and Refrigeration Institute (ARI). The first results of this evaluation program are now available, and they indicate that nonchlorinated refrigerants can, indeed, perform as well as the original materials in critical heat transfer tests.

Specifically, test data have recently been reported by teams at two universities that subjected several alternative refrigerants to heat transfer tests on tubes of experimental refrigeration systems. A Lehigh University team tested boiling and condensation performance on tube exteriors, and a team at the University of Illinois at Urbana-Champaign tested condensation on tube interiors. In both cases, several alternative refrigerants were found to have heat transfer coefficients that were quite similar to those of the materials they were designed to replace. Still to come are results from tube-interior boiling experiments conducted at Iowa State University. (Most home refrigerators and air conditioners pass air over tubes with the refrigerant inside; large commercial units pass water through tubes with refrigerant on the outside.)

Unlike the original, single-component refrigerants, however, most of the candidate replacements are mixtures, which means that factors other than heat transfer capacity will also have to be considered in making the changeover. Refrigerant blends may, for example, require higher operating pressures. If leaks occur, components may leave the mixture at different rates, thus changing its composition. Some of the new mixtures may also be more flammable. For reasons like these, manufacturers will have to reoptimize and perhaps redesign equipment to use the new refrigerants—at the very time they are also trying to meet increasingly tight efficiency standards.

R-32
R-125
R-134a
R-143a

"The search for new refrigerants is very important to the electric power industry, since air conditioning and refrigeration account for nearly a quarter of all electricity used, which translates into $50 billion in annual kilowatthour sales," says EPRI research manager Sekhar Kondepudi. "The recent test results are very promising in that they show it is possible to find non-chlorine-based refrigerants that have good heat transfer capability. But more work will be needed on how to use them to best advantage."

■ *For more information, contact Sekhar Kondepudi, (415) 855-2131.*

New Process for Coal Tar Remediation

Many electric utilities own, or are otherwise partially responsible for, sites where manufactured gas plants once stood and where potentially toxic and carcinogenic residues may be found. Of particular interest are complex mixtures of organic chemicals in coal tar called polycyclic aromatic hydrocarbons (PAHs). Now researchers have discovered a process with promise for reducing the hazard of PAH compounds while producing a useful product.

Whether a hazardous material actually causes an adverse human health effect depends not only on its inherent toxicity but also on the body's capacity to absorb the material. Activated charcoal is known to bind with PAHs and thus reduce their bioavailability, for example, but its cost is too high for practical, large-scale use. The new process uses petroleum coke—a solid, high-carbon waste product from oil refineries—to bind the PAH compounds in coal tar. The resulting product is relatively benign from a toxicological standpoint and can be formed into briquets for use as a utility fuel.

The effectiveness of this process has been demonstrated through two innovative experiments. In the first, the ability of PAH compounds to be absorbed through the skin was measured before and after treatment with petroleum coke. Using cadaver skin, researchers found that the PAH flux rate was reduced 68-fold when one part of coal tar was mixed with nine parts of petroleum coke. In the second experiment, the bioavailability of ingested PAH was determined by measuring the amount of genetic damage to the DNA of stomach cells of mice fed coal tar mixtures. Treatment of the coal tar with petroleum coke in a 1:9 ratio reduced the amount of genetic damage by more than 99%.

"EPRI and Mobil Oil have recently applied for a patent on both the treatment process and the use of cadaver skin to measure bioavailability," says research manager Larry Goldstein. "Next year we expect to conduct field-scale studies to determine whether these laboratory findings can be used to develop a process for practical use. I believe that such a process could have a major effect on remediation efforts at manufactured gas plant sites, since you are essentially combining two waste streams to get a high-Btu feedstock for utility boilers."

■ *For more information, contact Larry Goldstein, (415) 855-2725.*

How Dams Respond to Earthquakes

Until very recently, design guidelines for concrete dams had changed little in nearly half a century. Although these traditional guidelines were very conservative in many ways—as reflected in the fact that there has never been a catastrophic failure of a modern concrete dam—newly developed advanced failure analysis techniques have shown that some prevailing assumptions may be seriously flawed. Of particular interest is the effect of water pressure on crack propagation in dams during an earthquake.

A preliminary investigation of this problem was recently conducted at the University of Colorado as part of a comprehensive EPRI-sponsored research program on crack analysis in concrete dams. The experiments involved applying cyclic uplift pressure, under both wet and dry conditions, to an instrumented block of concrete with cracks. This cyclic loading was conducted first with constant amplitude and then, to simulate earthquake conditions, with pressure spikes.

The most important observation to emerge from this work was that the propagating crack front travels at a faster rate than the water front, so dynamic uplift pressure from water is not a major concern as a crack opens in response to earthquake movement. During crack closure, however, some water may become trapped and act as a wedge, resulting in large tensile stresses on the downstream side of a dam. The results of these tests are currently being incorporated into a computer model so that, for the first time, engineers can quantify possible earthquake effects on crack propagation in dams.

■ *For more information, contact Douglas Morris, (415) 855-2924.*

A recently released EPRI assessment concludes that the trace emissions of chemical substances from fossil-fired power plants appear to pose no significant health risks to humans. The assessment brings together the results of a decade of Institute research on these substances, sometimes referred to as air toxics or hazardous air pollutants. The U.S. Environmental Protection Agency is expected to consider the findings in determining whether utilities should be regulated for such emissions.

During the years since the Clean Air Act Amendments of 1990 were signed into law, the EPA has conducted its own studies on utility emissions of air toxics. Under Title III of the amendments, U.S. industrial facilities that emit certain levels of specified hazardous air pollutants are required to employ specific pollution control technologies. Utilities are exempt from regulation of this sort, pending the outcome of the EPA's own studies. By November, the agency is to recommend to Congress whether utilities should be regulated for such emissions.

The EPRI assessment focused on 16 of 189 hazardous air pollutants targeted by the 1990 Clean Air Act Amendments. These 16 were selected on the basis of their presumed presence in the exhaust of power plant stacks in quantities believed significant enough to be of regulatory concern. They are arsenic, benzene, beryllium, cadmium, chlorine, chromium, dioxins/furans, formaldehyde, lead, manganese, mercury, nickel, polycyclic aromatic hydrocarbons, radionuclides, selenium, and toluene. Only fossil-fired steam-generating units with a rated capacity of at least 25 MW are targeted by the law. In all, 594 power plants in the United States, comprising some 1700 individual coal-, oil-, and gas-fired generating units, fall into this category.

EPRI's assessment examined the pollution control technologies already employed at these fossil-fired plants and concluded that certain controls—most notably, those for particulates and, to a lesser degree, those for sulfur dioxide—capture significant amounts of the substances of concern. The assessment concludes that the overall health risk posed by inhaling emissions from the fossil-fired power plants studied is, under worst-case assumptions, 0.08 of a cancer occurrence per year for the entire U.S. population. (By comparison, the risk due to all emissions sources—from motor vehicles to industrial operations—was estimated in a 1990 EPA report to be as high as 2700 cancer cases per year.) EPRI's assessment accounts for the overlapping of exhaust plumes from the stacks of multiple power plants. Even under worst-case assumptions, 99.5% of the power plants analyzed pose no inhalation cancer risks above the 1 in 1 million level. Under more-realistic assumptions, for all individuals living in the vicinity of each of these plants, the chances are lower than 1 in 1 million that there would be a cancer occurrence from inhaling the emissions during a typical human lifetime.

"The risks are very small," says Ian Torrens, EPRI's issue manager for air toxics. "They are all below the index of 1 in 1 million that's typically used by the EPA to justify regulation for cancer risks." Noncancer risks associated with the power plants—such as respiratory ailments and developmental problems—also fall below the relevant federal guideline levels.

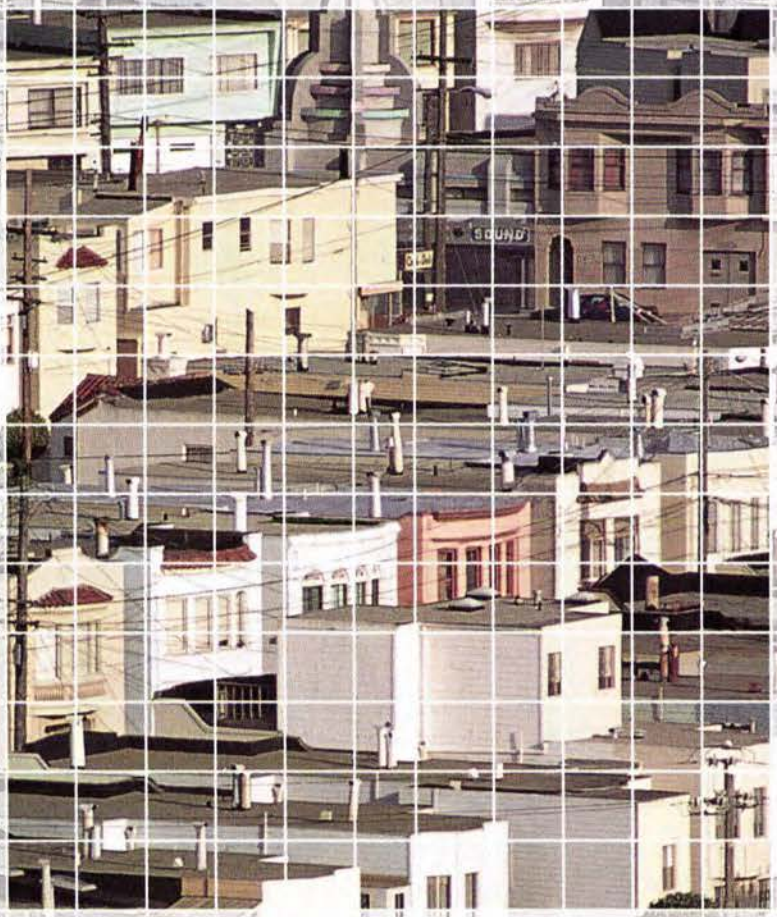
EPRI's researchers examined all variables contributing to risk—such as emission rates, the height of power plant stacks, and the size of fossil-fired units—and found that no one variable determines which power plants pose the highest risk. "This is significant in that it shows you need to consider all these variables in order to accurately assess risk," says Leonard Levin, who coordinated EPRI's comprehensive research effort. "You have to do site-specific studies." EPRI's research revealed some previously accepted figures to be inaccurate. For example, the assessment concluded that the cancer risk posed by a given exposure to arsenic is one-third the level estimated by the EPA for the same exposure. Also, mercury levels in coal burned by power plants were found to be 50% lower than previously believed.

Determining the potential carcinogenic and noncarcinogenic health risks posed by the 16 substances was a complex, multistep task. The researchers examined many factors to complete their risk assessments.

THE STORY IN BRIEF

Currently, electric utilities do not fall under federal regulation for emissions of air toxics—a category of air pollutants that includes both carcinogenic and noncarcinogenic substances. But the Clean Air Act Amendments of 1990 ordered the U.S. Environmental Protection Agency to determine whether such regulation is warranted on the basis of health risk. The EPA has been studying the issue, and its final recommendation to Congress is due in November. EPRI recently completed its own comprehensive study, an intensive four-year effort that caps a decade of research on power plant emissions. The study, carried out in close collaboration with the Utility Air Regulatory Group and the U.S. Department of Energy, concludes that the nationwide utility emissions of the chemicals targeted for study pose no significant health risks to humans. Throughout EPRI's investigation, researchers kept the EPA abreast of findings as they emerged; a final, detailed report—now available to EPRI members—has been delivered to the EPA, which is expected to consider the data in making its recommendation.

Assessing

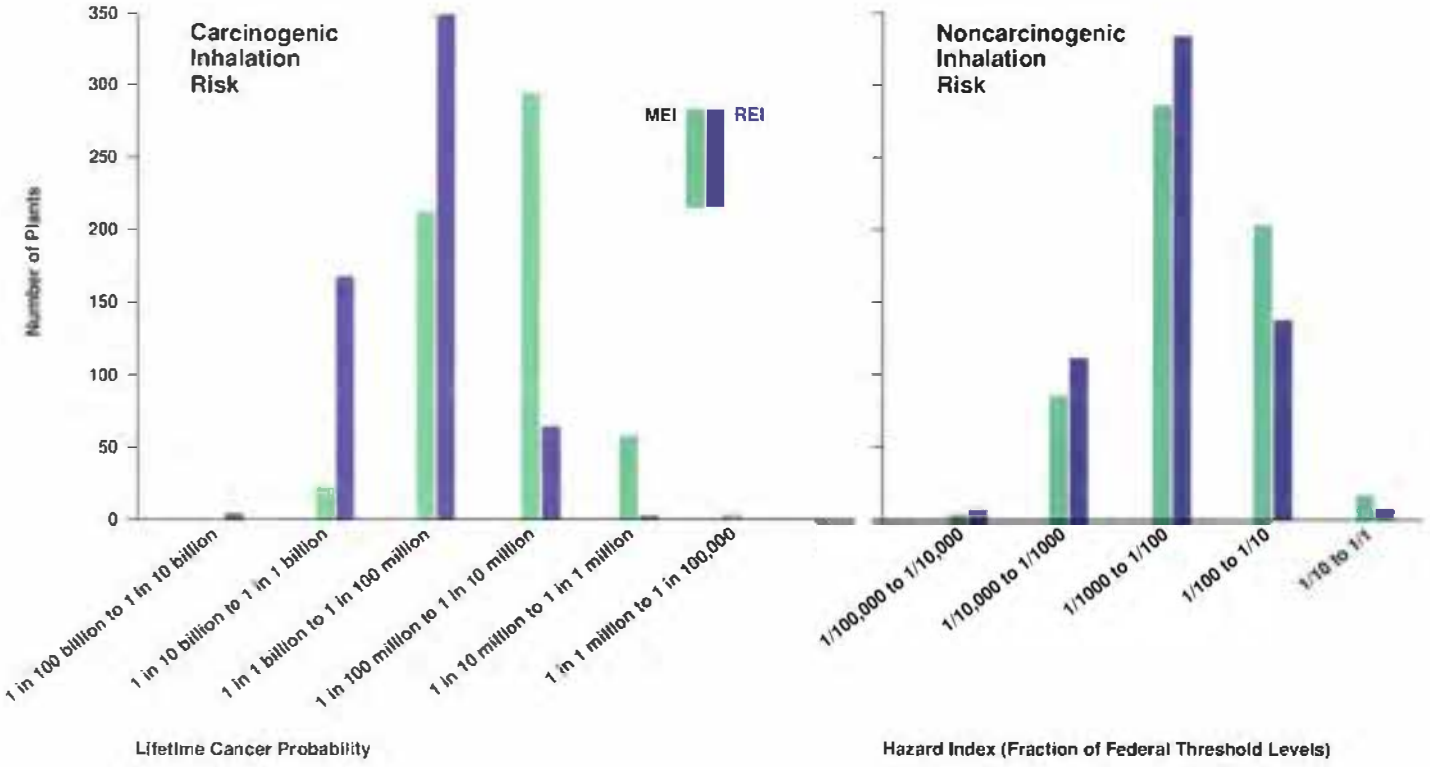


THE Risks

OF UTILITY HAZARDOUS AIR POLLUTANTS

by Leslie Lamarre

INHALATION RISK **EPRI's study explored the health risks posed by inhaling both carcinogenic and noncarcinogenic substances. Carcinogenic risk is expressed in terms of the probability of a cancer incident, with a risk of 1 in 1 million typically indicating to regulators the need for closer scrutiny. Noncarcinogenic risks, such as respiratory and neurological ailments, are expressed in terms of a hazard index—the ratio of an individual's actual exposure to the federally defined maximum level of exposure considered safe. An index of 1 or greater indicates a risk level of potential concern. As these charts indicate, the bulk of the 594 power plants studied show minimal carcinogenic and noncarcinogenic risks, falling far below the indexes of concern to regulators, even under worst-case (maximally exposed individual, or MEI) assumptions. Given the MEI assumptions, the carcinogenic risk to individuals in the vicinity of all but three plants is below 1 in 1 million; the highest risk posed is less than 2 in 1 million. Under the more realistic, reasonably exposed individual (REI) assumptions developed by EPRI, none of the plants poses a risk greater than 1 in 1 million. In fact, the highest REI-based risks are posed by only two plants showing probabilities greater than 1 in 10 million. For noncarcinogenic risks, none of the plants has a hazard index greater than 1, and about two-thirds of the plants have indexes below 0.01. The highest MEI-based hazard index is 0.5, while the highest REI-based index is 0.3.**



They combined data from the direct measurement of the 16 substances at power plants with results from fuel studies, demographic and meteorological information, estimates of human exposure to the substances, and data on the health effects of such exposure. The effort, which involved extensive collaboration with the Utility Air Regulatory Group (UARG) and the U.S. Department of Energy, led to the development of new methodologies and produced some of the best data sets currently available.

Over the course of EPRI's comprehensive study, researchers met quarterly with EPA officials to share information on the methods and tools used for analysis. The results, which were reviewed by about 30 technical experts from utilities, research laboratories, and government agencies, are detailed in a four-volume report (*Electric Utility Trace Substances Synthesis Report*, TR-104614) released late last year.

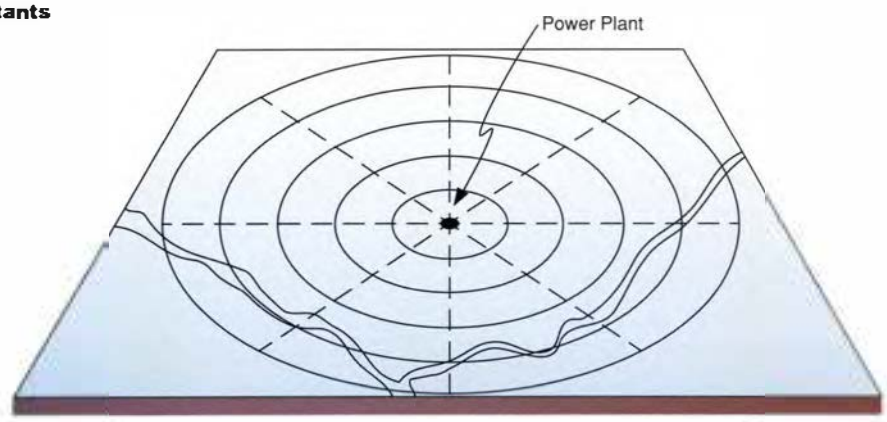
Although EPRI's research into air toxics got under way about 10 years ago—well before the passage of the 1990 Clean Air Act Amendments—the bulk of the research that produced this report was conducted over the past 4 years. (For more information on the earlier stages of EPRI's research, see the January/February 1994 *EPRI Journal*, p. 6.) "By anticipating the potential for a utility component in the 1990 clean air law, we were able to be proactive," says Torrens. "Getting an early start on our research enabled us to provide the EPA with the best possible data in plenty of time for them to perform their analyses and draw their own conclusions."

The emissions factor

The first major task was to find out what quantities of the 16 substances were emitted into the atmosphere by the 1700 generating units. These are not easy figures to

LAYERING DATA FOR A COMPLETE PICTURE

Assessing the health risks of hazardous air pollutants involved four basic phases of research.

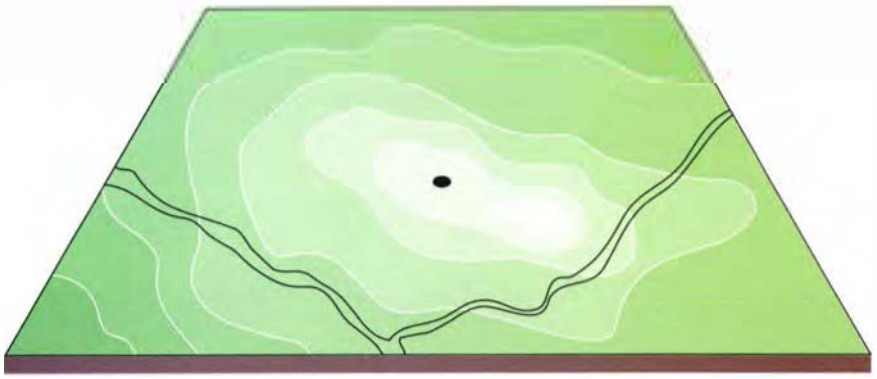


Quantifying emissions

In the first phase, researchers directly measured the substances emitted by some of the plants and developed methodologies to extrapolate to the entire industry.

Characterizing dispersion

In the second phase, researchers combined site-specific data on stack height, wind velocity and direction, and other factors to determine the direction and manner in which exhaust plumes spread through the atmosphere and to estimate the concentration of the air pollutants at various ground locations within a 50-kilometer radius of each stack.



Estimating human exposure

The third phase, exposure assessment, required the incorporation of population and other data indicating where and how people live over a 70-year lifetime within each 50-kilometer radius.

Assessing health risks

The fourth phase, health risk assessment, combined information from all the previous phases to come up with risk estimates for the general population and for individuals in particular locations.

get at. However, EPRI and DOE had taken direct measurements at 43 operating units. To fill the gaps in the measurement data, EPRI researchers conducted extensive fuel analyses and studied the effectiveness of environmental controls. All of this information was considered in the context of the utility industry's generation makeup in the year 2010, when compliance with the nitrogen oxide and sulfur dioxide provisions of the Clean Air Act Amendments is expected to be complete. (The EPA's study is also to be based on the assumption of full compliance with the Clean Air Act.)

Since coal-fired capacity makes up about 65% of the total industry capacity under study, EPRI analyzed this fuel type in the most detail. One major conclusion was that mercury levels in ready-to-fire coal are, on average, 50% lower than the levels listed in a database developed by the U.S. Geological Survey. (Mercury is a substance of particular concern, since reports of mercury-contaminated fish have been issued by public health officials in several states.) The main reason for the significant difference in mercury levels is that the USGS data are based on samples of coal taken from the ground. These samples included some rocks and minerals that would not be present in the coal that utilities burn. The USGS data also do not account for coal washing, which typically occurs after mining and removes significant amounts of trace elements.

By comparison, EPRI's conclusion regarding mercury levels is based on 154 samples of ready-to-fire domestic coal obtained from actual power plants. EPRI's findings are reinforced by another set of fuel data—data from the coal industry, which keeps records of the chemical concentrations in the coal it sells. EPRI has reported its findings to the EPA, which had initially stated its intention to use the figures from the USGS database to project emissions resulting from coal combustion.

Data on emissions of the 16 substances from oil- and gas-fired plants were somewhat limited: emissions from only 12 oil-fired plants and 2 natural-gas-fired plants had been fully measured. However, EPRI researchers developed methodologies that enabled them to calculate the amount of each substance emitted per Btu at these plants, and they extrapolated these values to the entire industry. Generally, natural gas plants are not of significant concern, since most trace elements in the stack exhaust from these plants are below the detection limits of the sampling and analysis methods used for all plants. The data from the oil-fired plants are considered to represent a good, though limited, cross section of the industry.

In developing forecasts of the utility in-

INDIVIDUAL EXPOSURE—TWO VIEWS **Knowing the quantity and type of emissions released by power plant stacks does not provide enough information to estimate the exposure of individuals to these substances. Breathing rates, activity patterns, and time spent indoors and outdoors will all influence a person's exposure. To estimate exposure, the Environmental Protection Agency has relied on a standard assumption called the maximally exposed individual (MEI). However, the EPA has acknowledged that the MEI standard considerably overestimates individual exposure. As a more realistic alternative, EPRI developed the reasonably exposed individual (REI) measure of exposure. In both cases, the exposed individual lives in an area with the highest concentration of power plant emissions.**

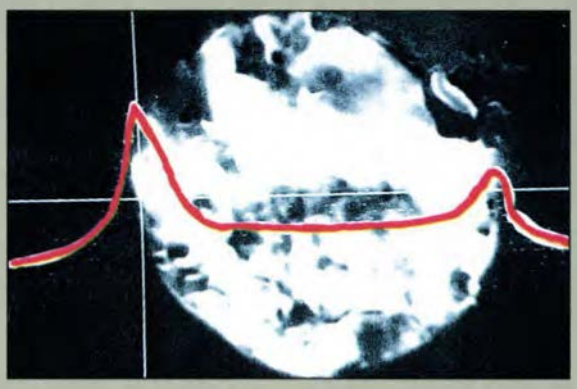
The MEI measure assumes that the individual is sedentary, breathes at a steady rate, and lives outside any structure for his or her entire lifetime.

The REI measure accounts for time spent indoors (where exposure to some pollutants is reduced), time spent working in distant areas, residential relocations, physical activity (and hence varying breathing rates), and even the replacement of fossil-fired generation units after 45 years of operation.

A Closer Look at Arsenic

Among the most significant findings of EPRI's air toxics study is the conclusion that a standard value used by the Environmental Protection Agency to calculate the cancer risk of inhaled arsenic overestimates that risk by a factor of 3. EPRI has requested a revision of the EPA's value, which is contained in the agency's Integrated Risk Information System database.

The EPA's number was based on the results of two studies of U.S. workers exposed to copper smelter dust, which contains arsenic. One study looked at workers in Montana; the other, workers at the ASARCO copper smelter in Tacoma, Washington. The findings of the Tacoma study were revised in the late 1980s when the researchers updated the exposure calculations. The EPA has not yet amended its risk value for arsenic to reflect this new information.



This composite micrograph shows that the arsenic in a fly ash particle lies primarily on the particle's exterior surface. EPRI researchers are investigating the extent to which such arsenic is available within the human body to interact with cells and tissues. (Courtesy of Center for Electron Microscopy, Technical University, Graz, Austria)

EPRI used the EPA's own method for calculating the cancer risk of inhaled arsenic—that is, the risk associated with inhaling a given unit of arsenic concentration. Included in EPRI's calculations were the results of the studies used by the EPA. However, EPRI also accounted for the modified findings of the Tacoma study and used the results of a well-documented, recently released study of copper smelter workers in Sweden—a study that was not available when the EPA performed its calculations. The final EPRI result is a unit risk of 1.43×10^{-3} per microgram per cubic meter, compared with the EPA's figure of 4.29×10^{-3}.

In the meantime, three significant questions remain about the underlying assumptions of this risk calculation. At the most basic level is the question of whether the arsenic species in fly ash are the same as those in copper smelter dust. The second question is whether the bioavailability—the extent to which the arsenic is available within the human body to interact with cells and tissues—is the same for arsenic in fly ash as it is for arsenic in copper smelter dust. Finally, there's the question of whether the arsenic exposure-response relationship is a linear relationship—one that allows researchers to extrapolate from high exposures to low exposures, as is the common practice.

EPRI's research indicates that there may be some serious flaws in these assumptions. Regarding the chemical state of arsenic, researchers have determined that the major arsenic species in fly ash is arsenic(V), present principally as calcium arsenate, while the arsenic in copper smelter dust is most likely present as arsenic(III) species, which are known to be at least 10 times as acutely toxic as arsenic(V) species.

Regarding bioavailability, EPRI's laboratory studies suggest that lung retention is slightly higher for the arsenic in copper smelter dust than it is for that in coal fly ash. Also, arsenic that is bioavailable from copper smelter dust appears to be excreted from the body at slightly slower rates than arsenic from fly ash. An even more significant initial finding is that copper smelter dust containing arsenic causes inflammation in the lungs; inflammation is known to promote cancer growth. EPRI's investigation of the bioavailability issue continues and includes a study of workers at a coal-fired power plant in central Slovakia who are exposed to fly ash from a coal that has a very high arsenic content.

Regarding linearity, research indicates that there may be significant differences between the health impact of arsenic at low doses and that of arsenic at high doses. A study of two communities in Mexico where arsenic is naturally present in drinking water has shown that people who ingested higher levels of arsenic excreted certain metabolites of the substance at lower rates than did those who ingested lower levels of arsenic. Similar results emerged from a recent animal study. Notes Janice Yager, the manager of EPRI's arsenic research, "The capacity of individuals to detoxify arsenic may be inhibited after high exposures to the material. This leads to nonlinearity in the exposure-response relationship."

Other ongoing EPRI studies are assessing the impact of particle loading to determine whether the number and mass of the particles inhaled can influence retention. The results of these studies will be incorporated into a sophisticated model currently under development—a physiologically based pharmacokinetic model. Unlike other models available, this one will account for chemistry and biology to more accurately assess the health effects of arsenic over a wide range of exposures. The model is expected to be released by mid-1995. □

dustry's generation makeup in 2010, the researchers accounted for a number of variables that can influence emissions levels. These variables include electricity demand, the type of coal burned, the replacement of older generation units, the addition of new coal plants, and the particulate removal technologies employed. Indeed, particulate control technologies alone can make a significant difference, since the bulk of the trace substances under study are contained in fly ash particles. EPRI's fly ash sampling data show that properly designed electrostatic precipitators and baghouses can remove more than 99.5% of a power plant's particulates.

A UARG-funded survey, which drew a 40% response from 286 utilities with steam-generating units, provided information on particulate controls already in place and any additional controls planned for the next few years. These data enabled EPRI to develop more realistic estimates of particulate emissions.

In projecting emissions, EPRI used three 2010 scenarios—one developed by an EPA contractor, which served as the base-case scenario, and two forecast by EPRI. Jeremy Platt of EPRI, the developer of the two alternative scenarios, says that they reflect the range of assumptions in industry forecasts made by other groups, including the Energy Information Administration and the Gas Research Institute. The alternative scenarios straddle the demand assumed in the EPA's forecast, with one based on a higher demand assumption and the other based on a lower one.

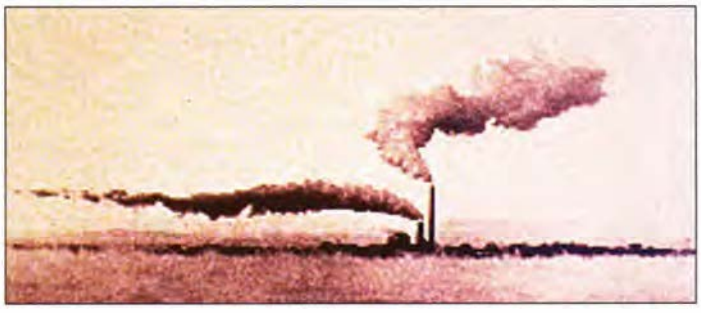
The survey information on planned particulate controls was used with all three scenarios, but other factors varied. For instance, the high-demand scenario assumed a greater use of existing units to meet that demand, while the lower-demand scenario assumed extensive use of clean coal technologies.

The people factor

Once EPRI researchers learned more about emissions levels in 2010, they had to determine the extent to which people will be exposed to the emissions. To accomplish this aim, the researchers modeled the exhaust plumes from the stacks of the 1700 coal-, oil-, and gas-fired units and calculated the concentrations of emissions at various ground locations downwind of the stacks. Then they combined these data with information on residence patterns, obtained from the U.S. Census Bureau.

To model the exhaust coming out of the stacks, EPRI employed the EPA-supported ISCLT2 model for long-term exposure. A version of the Industrial Source Complex model, ISCLT2 is recommended for the analysis of emissions only within a 50-kilometer radius of a source. Although power plant emissions can spread farther, any significant risks posed by the emissions are believed to be limited to this area (on the basis of quality control checks performed by EPRI). The model divided each 50-kilometer area into a grid and produced estimates of the average long-term concentrations of the various emitted chemicals within each cell of the grid. The data input included meteorological information like wind direction and speed, the height and diameter of each power plant stack, and the temperature and velocity of the gas emitted from each stack. The model also investigated the impact of overlapping plumes from multiple sources in densely populated areas. Greater New York City showed the largest number of overlapping plumes from utility stacks.

National census data enabled researchers to determine how the population is distributed within a 50-kilometer radius of every power plant. The researchers focused on exposure through inhalation—rather than through ingestion or skin contact—since exposure to most of the substances



ENSR Consulting and Engineering

MEASURING COMMUNITY EXPOSURE **As these plumes indicate, stack emissions of hazardous air pollutants and other constituents can be dispersed erratically, making estimates of actual human exposure a challenging task. To better estimate community exposure, EPRI researchers have employed instruments—such as the one pictured here—for directly measuring chemical concentrations in a given area.**

under study occurs in this way.

In calculating exposures, EPRI researchers initially relied on the EPA's standard assumption of the maximally exposed individual (MEI)—that is, a person who lives entirely outdoors for a 70-year lifetime in the populated area with the highest concentration of power plant emissions. The MEI standard assumes a body weight of 70 kilograms and a constant inhalation rate of 20 cubic meters per day. Leonard Levin points out that the MEI standard does not represent reality very closely. "In real life, people are moving around more and spending about 80% of their time indoors; they may even move to different residential areas."

Indeed, the EPA's own exposure guidelines have noted that the MEI measure of exposure is so extreme that it lies outside the range that any individual is going to experience. As a more realistic alternative, EPRI researchers developed a measure of exposure they term the reasonably exposed individual (REI). The REI measure still assumes that the individual lives in the area of highest emissions concentrations, but it uses the results of research by EPRI and others to account for time spent indoors (where exposure to many exterior substances decreases); time spent commuting to and from work; residential relocations; physical activity patterns (which affect breathing and, hence, the rate at which emitted substances are taken in); and even the replacement of fossil-fired generation units, after 45 years of operation, with units that meet or exceed the 1994 federal New Source Performance Standards for particulate emissions.

Most of the new assumptions used for the REI standard lower the exposure for individuals. But a few can increase exposure rates. One of these is the REI's body weight of 62.5 kilograms, compared with the MEI's body weight of 70 kilograms; equal exposure to the same chemical is likely to have a bigger impact on a lighter person than on a heavier one. EPRI's researchers opted for the lower average body weight because the exposures are being assessed over a lifetime; 70 kilograms is an average adult body weight and does not account for a person's lower weight in childhood.

Overall, REI exposure rates are 20–75% lower than MEI exposure rates. Differing population groups and the different substances emitted by the various power plants account for the wide range. Among the biggest factors affecting exposure rates is the replacement, over time, of older power plants, which makes REI exposures an average of 14% lower than MEI exposures. The researchers note that neither the MEI nor the REI exposure measure accounts for the bioavailability of emissions in the body—that is, the extent to which inhaled emissions are actually absorbed by the body and available to do harm. Accounting for bioavailability would have further lowered REI exposures, since certain amounts of the substances inhaled can be excreted through natural biological processes.

The risk

In order to determine the inhalation risk posed by the MEI and REI exposures, EPRI researchers still needed to know the health impacts of these exposure levels. Insight is afforded by the use of standard factors, such as those posted in the EPA's Integrated Risk Information System (IRIS) database. One such value is the unit risk factor. A unit risk factor indicates the relative carcinogenic effect of a given unit of concentration of a certain chemical.

The researchers relied on the IRIS values to estimate the lifetime carcinogenic and noncarcinogenic risks of all the chemicals that pose health risks through inhalation. The exception here was arsenic, which EPRI studied more closely. Results from these studies show values for the carcinogenic unit risk of inhaling arsenic that are one-third the value listed in the IRIS database. EPRI has issued a formal request for a revision of the arsenic unit risk value in the IRIS database. (The sidebar on p. 11 offers more information on EPRI's arsenic research.)

Inhalation risks were calculated for each chemical and each plant. Individual carcinogenic risk is expressed in terms of the probability of a cancer incident from the inhalation of the highest concentration of an emitted substance. Noncarcinogenic risk is expressed in terms of a hazard quotient—the ratio of the actual exposure of an individual to a defined maximum exposure level that is considered safe for an individual. A hazard quotient of 1 or greater indicates a risk level of potential concern, requiring a more detailed assessment; a value of less than 1 is generally not considered hazardous.

As previously stated, the carcinogenic risk to the entire U.S. population posed by emissions from the 594 fossil-fired plants studied is estimated to be less than 0.08 of a cancer occurrence per year. The cancer risk to individuals in the vicinity of all but three of the plants is below 1 in 1 million. The highest risk among those three plants (an oil-fired plant with no emissions controls and two bituminous coal plants with particulate controls, all in different parts of the country) is 1.7 in 1 million. These estimates are based on MEI, or worst-case, assumptions; risks based on REI exposures range from 2% to 19% of the MEI risks. None of the REI risks is greater than 1 in 1 million, and only two REI risks are greater than 1 in 10 million.

Of the 30 plants with the highest MEI-based risks, 23 are coal fired, 5 use multiple fuels, and 2 are oil fired. One interesting finding is that while the emissions of the highest-risk plant are close to the median emissions for all plants, this plant has comparatively short stacks and is situated in an urban setting. As might be expected, gas plants show the lowest MEI risks—about 1 in 10 million for the median plant. For coal plants, arsenic is the largest contributor to MEI-based risk, representing 48–59% of the risk (depending on the coal type), followed by hexavalent chromium at 23–33%. For controlled and uncontrolled oil plants, arsenic and chromium contribute 55% and 20%, respectively.

Regarding noncarcinogenic health risks, none of the 594 plants generates emissions resulting in a hazard quotient greater than or equal to 1 for any substance. The risk is similarly low for all substances considered together. The highest MEI-based hazard index is 0.5, and the highest REI-based index—for the same plant—is 0.3. About two-thirds of the plants have hazard indexes below 0.01. Coal plants with only particulate controls show the highest overall MEI hazard indexes; controlled oil-fired

Mercury Studies

The mercury emitted from power plant stacks can accumulate in fish muscle tissues.

As with arsenic, EPRI undertook an in-depth study of the health effects of mercury both because it is a major contributor to the risk associated with power plant emissions and because its nature is not well understood. Organic methylmercury is the primary concern, since this compound accumulates in fish muscle tissues; ingestion of methylmercury in fish is the primary means of human exposure to mercury from power plants.

Methylmercury is a neurotoxin that can be deadly at extremely high doses. At somewhat lower doses it can cause problems like paresthesia (a numbness and tingling in the extremities) or—in the case of children who were exposed in utero—psychomotor retardation.

The Environmental Protection Agency has estimated a safe level of daily methylmercury exposure; the estimate is based on a 1973 case in which thousands of Iraqis suffered temporary or permanent nervous system damage when they ate bread baked with flour mistakenly milled from seed grain that was treated with methylmercury fungicide. As part of the 1990 Clean Air Act Amendments, the National Institute of Environmental Health Sciences (NIEHS) is required to investigate the mercury issue further to determine a safe threshold for mercury exposure.

EPRI believes that the current threshold level estimated by the EPA is inappropriate for a typical community exposure because it is based on the Iraqi incident, which involved very high exposure over a short period of time. In contrast, the exposure to methylmercury from power plants is a very low exposure over a long period of time. Other problems with the Iraqi data set that complicate its application to community exposures and risks include the fact that nonstandard measures were used to determine the health effects of mercury on children. For instance, researchers simply asked parents how long it took their children to walk and talk. And because the questions were answered in hindsight, there may be a margin of error in the parents' recollection of the children's ages.

EPRI researchers are currently following two studies that were more rigorously designed. In one of these studies, an international team of investigators is examining the neurobehavioral effects of fetal exposure to methylmercury. This study focuses on women and children in the Faeroe Islands in the North Atlantic between Iceland and Scotland—specifically, 1000 mothers and the babies born to them over a two-year period. The mothers were exposed to methylmercury through the ingestion of whale meat. Since the level of mercury in a person's hair is proportional to the level of mercury in his or her blood, researchers have collected blood and hair samples from the mothers and babies in order to gain further insight into the extent of their exposure. The children born during the study are being followed and tested for developmental effects.

The second study of interest is cosponsored by the NIEHS and the Ministry of Health for the Republic of Seychelles, an island group located in the Indian Ocean off the east coast of Africa. The study is investigating 779 mother-infant pairs on the islands, where residents consume a fish diet believed to be high in methylmercury. Researchers will track the exposure of fetuses and of children up to the age of six and a half and will evaluate their neuropsychological development through a series of tests.

Although EPRI researchers believe that the results of these two tests will provide more insight into the nature of methylmercury exposure from power plants, they caution that there are some important differences between the lifestyles and nutritional habits of these island populations and those of U.S. populations. Such differences will have to be accounted for in any conclusions reached.

In the meantime, EPRI has developed a physiologically based pharmacokinetic model to help better predict the health effects of methylmercury. The model details the oral absorption, distribution, metabolism, and excretion of methylmercury in different species, including rats, monkeys, and people. Already the human model has been used to estimate fetal exposure to methylmercury from the known concentration of the substance in maternal hair. Ultimately EPRI will use this model, along with new epidemiologic, experimental, and statistical findings, in a national health risk assessment for methylmercury. (For more information on the full scope of EPRI's mercury research, see two earlier *EPRI Journal* articles—April/May 1994, p. 14, and December 1991, p. 4.) □

plants and plants with mixed units, the lowest. For bituminous coal plants, hydrochloric acid accounts for about 47% of the hazard index, while chromium contributes about 46%.

Beyond the air

Not all power plant emissions are absorbed only through inhalation. Some are ingested—for example, in fish, produce, beef, or drinking water—and others are absorbed through the skin (by swimming or showering, for instance).

To fully account for the risks from all potential routes of exposure, EPRI's study included a multimedia risk assessment—that is, one that estimates the health risks not only of stack-emitted substances traveling through the air but also of substances that are eventually deposited on the ground surface and travel through soil and water. Multimedia risk assessments require many assumptions about chemical and physical processes for which supporting data are often poor. To help increase the reliability of these assumptions, EPRI developed the TRUE (Total Risk of Utility Emissions) model as a framework for multimedia risk assessment, along with accompanying methodologies.

EPRI researchers used TRUE to study all the substances of concern except the radionuclides, for which alternative models and data were used. Inputs required include emissions measurements, the physical characteristics of the environment, data on food and water consumption, and health effects parameters. Outputs include concentrations of the substances in air, soil, and groundwater; the exposure levels of individuals; and human health risks.

As a basis for the multimedia risk assessment, the researchers used emissions measurement data from four fossil-fired power plants considered representative of the industry—three coal-fired plants, two of which are located in rural areas and one of which is in an urban setting, and one oil-fired plant in a coastal region. Because mercury is so complex, it required a closer look. Researchers combined EPRI's Mercury Cycling Model with TRUE to evaluate the noncarcinogenic risks of mercury at the four sites.

The four sites differed with regard to such factors as climate and the proximity of lakes and other bodies of water where people fish. As a result, the risk levels calculated for the individual plants differed dramatically. However, the cumulative carcinogenic risks for all emitted chemicals by all exposure pathways were lower than 1 in 1 million for each of the four sites. Meanwhile, the cumulative hazard indexes for noncarcinogenic substances remained well below 1 for all of the sites and for all subregions within each site. Exposure assumptions for these risks were based on the MEI measure of exposure. For comparison, EPRI calculated REI-based risks for the carcinogenic chemicals and found that they were 24–30% of the risks based on MEI values.

Arsenic was by far the biggest contributor to carcinogenic risk at all sites but the oil site, where beryllium was the dominant contributor. For noncarcinogenic health risks, the top contributors varied, with chromium(III) being most significant at one of the rural coal plants and at the oil plant, mercury ranking highest at the other rural coal plant, and chlorine compounds ranking highest at the urban coal plant. For all sites, the dominant means of exposure for carcinogenic risks were ingestion and inhalation, with ingestion playing the bigger role. For noncarcinogenic risks, inhalation, ingestion, and absorption through the skin all played a role, with inhalation being the main exposure pathway at three sites and ingestion being the main pathway at the fourth.

The risks from radionuclides—naturally occurring radioactive elements, such as uranium and thorium—in fossil fuels were studied separately. Measurements of radionuclide emissions made by DOE at several coal-fired power plants were used in this study, along with a UARG-sponsored analysis of radionuclides in fuel oil samples that were provided by EPRI member utilities. The radionuclide risk model used (CAP-93PC) was developed and supported by the EPA. Modeling was performed for eight representative plants. The results show that humans are exposed to radionuclides primarily through particles deposited on the ground surface and through ingestion of the substances in food. EPRI researchers stress that further study of radionuclides is needed because of the relative lack of data on emissions from oil-fired plants and because of uncertainties in the modeling process. But the preliminary calculations show annual individual doses from the eight plants modeled all to be less than 25% of the levels considered significant.

Leonard Levin of EPRI notes that the multimedia risk assessments incorporate a number of uncertainties. Some of these uncertainties stem from the models used to estimate values input into risk assessments. Others have their origins in the assumptions and simplifications made when models are linked together. The most significant uncertainties remaining are related to mercury. Says Levin, "There's still some basic science that needs to be done. We still do not have a good understanding of how mercury interacts with ecosystems—how it moves through complex aquatic systems, how it is taken up by crops, and how it accumulates in fish." Ongoing EPRI research is addressing such uncertainties.

Regardless of the uncertainties, however, the information produced by EPRI's comprehensive study provides a solid starting point for putting the health risks of power plant emissions into perspective. "With the publication of our synthesis report, the EPA and the research community have access to all the raw data resulting from our study as well as our detailed methodology and assumptions," says Ian Torrens. "Naturally they will conduct their own analyses and draw their own conclusions. But at least we know that we have provided them and the industry with the best possible data on which to base future analyses and decisions." ■

Background information for this article was provided by Leonard Levin, Janice Yager, and Abraham Silvers of the Strategic Development Group's Environment & Health Business Unit and by Ian Torrens of the Generation Group's Environmental Control Business Unit.

EPRI Awards for Technical Leadership

EPRI'S LATEST AWARDS FOR STAFF ACHIEVEMENT HIGHLIGHT ADVANCES IN SCIENCE AND TECHNOLOGY THAT ARE OF PARTICULAR VALUE AND IMPORTANCE TO THE INSTITUTE'S MEMBERS.

Each year, EPRI recognizes outstanding staff achievements in furthering the Institute's ability to deliver strategic value to its members. As EPRI President Richard Balzhiser emphasized at the 1994 awards dinner, held on December 4 in Palo Alto, "The Institute and its members are operating in an increasingly competitive era. If we—and the industry—are to thrive in the challenging years ahead, it will be crucial to maintain our commitment to excellence and encourage outstanding achievements by our employees."

This year's Awards of Excellence honored a wealth of initiatives to increase the Institute's value to its customers, with particular focus on promoting closer relationships with members and on improving the efficiency and effectiveness of its operations. The awards given specifically for technical leadership, which are profiled in the following pages, highlight important recent advances in science and technology expected to have very positive impacts. In presenting these awards, Fritz Kalhammer, EPRI's vice president for strategic R&D, commented on the Institute's unique position as a strategic asset and source of advanced technology for the industry: "EPRI's members are operating in an environment where competitive advantage is increasingly dependent on the ability to apply technology effectively—an environment where both threats and opportunities are increasing daily. There is every reason to believe that EPRI's technical leadership—the excellence in technical knowledge and judgment of our staff members, their creativity in getting the best minds and organizations to work with EPRI, and their dedication to achieving results of high value to our members—is more important than ever before. It is heartening to see that technical leadership is alive and well at EPRI, and it is most satisfying to recognize these men and women, whose contributions over the past year are particularly emblematic of this essential EPRI tradition."

Peter Millett, Larry Nelson, Chris Wood *Water Chemistry Guidelines*

Corrosion in reactor coolant systems remains a major issue for nuclear utilities, even though the loss of electricity generation from corrosion problems has decreased in recent years. Considerable progress has been made in developing improved materials for replacement components, but the main option for minimizing corrosion in operating nuclear power plants is improvement in the chemical properties of the cooling water that surrounds vulnerable areas. The recipients of this award developed an innovative concept for plant-specific optimization of water chemistry.

EPRI's new water chemistry guidelines replace the rigid, across-the-board specifications used previously, substituting a series of cost-effective options based on evaluations of individual plants. The initial concept was developed by the EPRI team members, who assembled groups of utility specialists and nuclear industry experts to review and endorse the resulting guidelines. First-of-a-kind software programs were also developed to help utilities implement this new approach to water chemistry control.

These guidelines have already been adopted by more than 80% of the EPRI members that operate nuclear plants, and they are also being used by the majority of nuclear utilities worldwide. Individual utilities have reported multimillion-dollar benefits from applying the guidelines.

Wood
Nelson
Millett

Banerjee

Ben Banerjee *Written-Pole Motor*

Conventional single-phase motors require a high starting current, frequently have insufficient starting torque, are limited in horsepower, and have had poor reliability. Ben Banerjee solved these problems by managing the development of the Written-Pole Motor (WPM), which is the first single-phase design in the 10–100-horsepower range that has a low starting current and high efficiency. For this work, Banerjee has received not only the EPRI award but also his second consecutive R&D 100 Award.

The novel concept underlying the WPM is the use of a single magnetic pole on the stator to "write" multiple, temporary poles on magnetic material covering the surface of the rotor. This design reduces the starting current to less than one-third of that required by a conventional single-phase motor. As a result, the WPM is more reliable and is capable of frequent restarts. Such characteristics are expected to make the motor uniquely suited for rural applications—such as irrigation pumps—which are frequently served by long, single-phase power lines.

A program to test a prototype WPM is under way, and Banerjee negotiated a license agreement with the product's developer, Precise Power Corporation, that will provide royalties to EPRI from future WPM sales. Meanwhile, the basic concept is being modified to create motors that will have high ride-through capability during power interruptions.

Rob Moser, David Owens *Clear-Liquor Scrubbing Process*

Flue gas desulfurization, or scrubbing, usually involves the use of a limestone slurry to react with the sulfur dioxide formed during combustion in a fossil power plant. Rob Moser and David Owens discovered a way to use a sludge bed reactor and organic acid additives in a clear liquor to reduce sulfur emissions, allowing the design of more-compact, lower-cost, and lower-maintenance scrubbers.

This innovative process was developed by taking ideas from several existing techniques, such as dual-alkali scrubbing, and synthesizing them for use in power plant desulfurization. The process has the potential to accomplish 95% SO_2 removal at a 20% capital cost savings and a 10% lower revenue requirement than for conventional scrubbing. This could translate into a 1–2% cost-of-power reduction for utilities that use flue gas desulfurization.

Two patent applications have been filed for the clear-liquor scrubbing process, and two of the largest manufacturers of scrubbing equipment have expressed interest in helping commercialize the concept. Demonstration of the process at a utility site is expected within a few years.

Owens
Moser

Cheng
Ozer
Yang
Yagnik

Rosa Yang, Odelli Ozer, Suresh Yagnik, Bo Cheng *Fuel Degradation Guidelines*

Severe fuel rod degradation has recently caused plant contamination and capacity factor loss at boiling water reactor power plants in the United States and abroad. In response, this EPRI team initiated a comprehensive R&D program to investigate the degradation phenomenon and to provide guidance for mitigating the problem. The result has been the issuance of operational guidelines that have saved a number of utilities from similar plant contamination and forced outages.

The nature of the fuel rod failure is complex and unique, involving the development of cracks up to 100 inches long in the rod cladding, followed by significant fuel loss. When the phenomenon first occurred in Europe, the EPRI team obtained field data from overseas utilities and became convinced that a generic problem existed, despite considerable skepticism in the industry. They put together an aggressive campaign to initiate research, which included simulating the degradation mechanism by irradiating highly instrumented fuel rods in a test reactor. This experiment was crucial in identifying the root cause of the problem.

Since the guidelines have been used, no further midcycle outages due to fuel degradation have occurred and the capacity factor loss has been reduced. A computer program is being prepared to model the degradation phenomenon and provide utilities with a predictive capability for preventing severe fuel degradation.

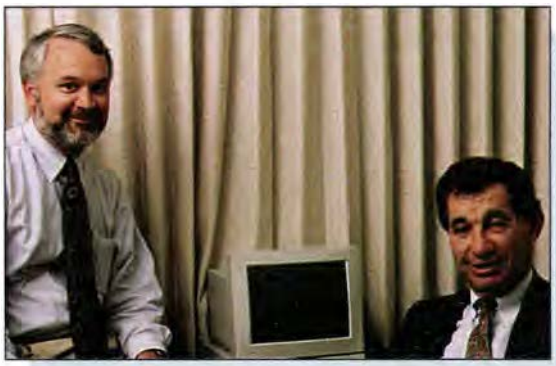
John Kesselring *Electronic Thermostats*

Although electric resistance heaters are often the lowest-first-cost choice for heating new residences, older line-voltage thermostats sometimes create wide temperature swings that reduce comfort and waste energy. John Kesselring attacked this problem by guiding the development of new electronic thermostats that provide better temperature control while being low enough in cost to compete in the zoned-electric-heating market.

To date, three successful products have been delivered, one of which has had sales of more than 350,000 units in just over a year. EPRI-sponsored research to quantify the benefits of the new thermostats revealed that they offer average energy savings of 8–12%. As a result, they are now being sold directly to several EPRI member utilities for use in their demand-side management programs.

These "smart" thermostats were developed in response to a request for proposals written by Kesselring and based on background work identifying the need to improve line-voltage thermostats to protect the electric-heating market. One of the thermostats received the 1993 Pennsylvania Governor's Award for Energy Efficiency.

Kesselring



Pitelka

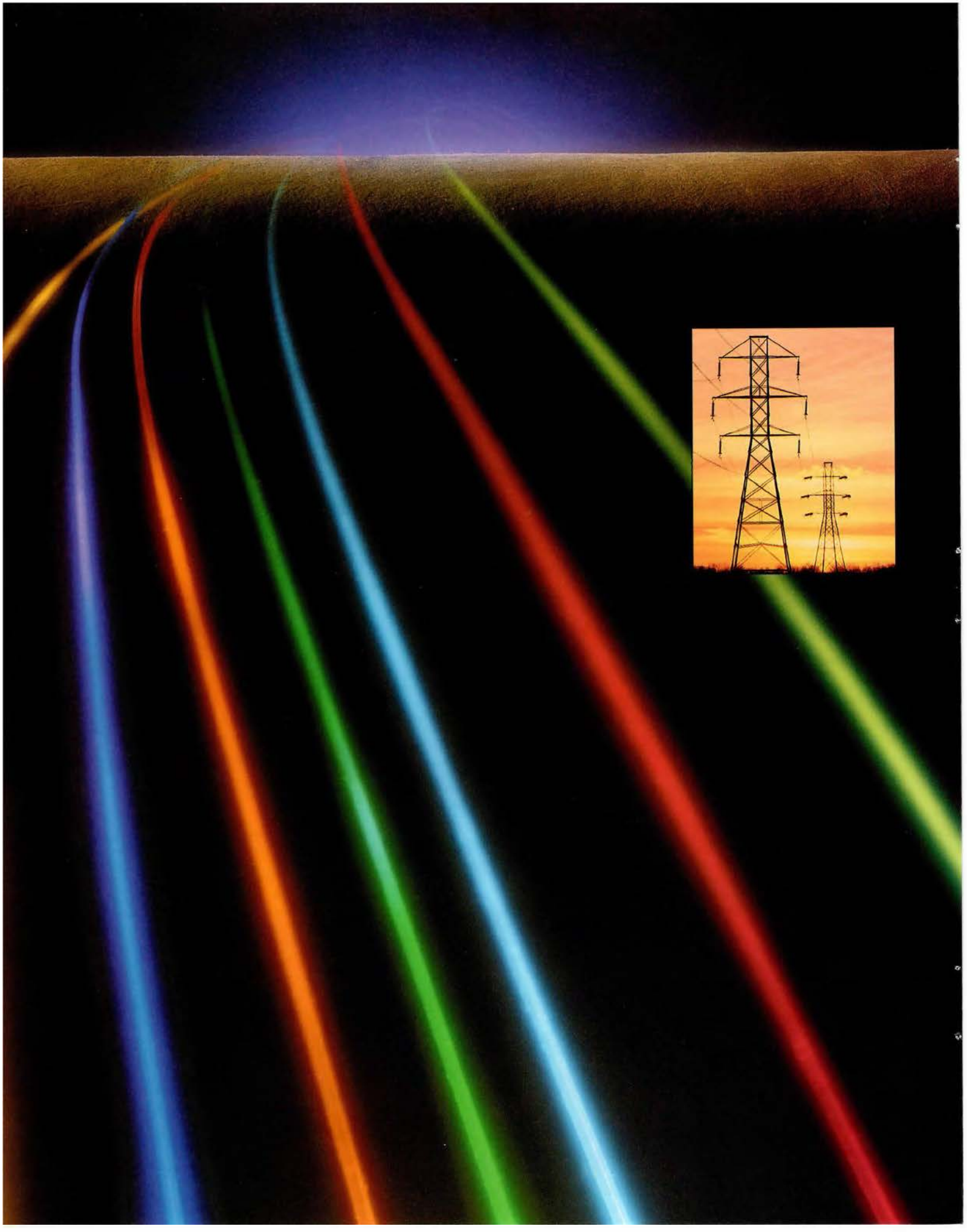
Alper.

Sy Alpert, Louis Pitelka *Halophyte Research*

Halophytes are a diverse group of salt-tolerant plants that have promise for sequestering atmospheric carbon dioxide, removing heavy metals from power plant wastewater, and expanding food production in desert areas. Sy Alpert and Louis Pitelka led exploratory research on these plants that has quantified their potential in each of the important areas of interest and has led to the first utility applications.

The original research, at the University of Arizona, was aimed at stemming desertification and understanding the botanical mechanisms of salt tolerance. During a tour of the university laboratories, Alpert recognized the potential for applications in the utility industry and initiated work with Pitelka, who managed experiments to test these ideas at a research farm in Baja California. A key finding of this work was that halophytes could absorb 90–95% of the saline content of power plant discharges, resulting in significant savings in the cost of treating and disposing of wastewater.

The usefulness of the work has been recognized by the Salt River Project through its participation in the research and by Arizona Public Service Company through its collaboration in a project using halophytes to treat cooling tower blowdown and runoff water containing toxic metals. Future work may include bioremediation for a variety of contamination problems, including the removal of selenium from irrigation water.



GRABBING A LANE ON THE INFORMATION SUPERHIGHWAY

by Peter Jaret

THE STORY IN BRIEF Players from the telecommunications, cable, and even entertainment industries are scrambling for position as the possibilities for a nationwide electronic communications network come more sharply into focus. The information superhighway, as this network has been termed, would allow connections and two-way information exchange between virtually all the households and businesses in the country. Tying into such a system would open up a number of new services for electric utilities, from providing electronic meter reading, billing, and payment to offering customers increased control over their own energy use patterns. But EPRI believes that utilities should consider a more aggressive involvement in the information revolution, adding fiber-optic cable to their already far-reaching power delivery infrastructure and partnering with other investors to take an ownership role in the systems now being developed. The results of a new EPRI study provide an in-depth analysis of the business opportunities and risks associated with different levels of involvement in the National Information Infrastructure and provide an analytical framework utilities can use in planning their own strategies.

Forty years ago, the completion of the nation's interstate highway system transformed daily life and commerce in the United States, offering unprecedented mobility and speeding the movement of goods across the country. Today, the construction of a radically different sort of highway is under way—an information superhighway that, like the interstate highway system, promises to profoundly alter the way we live and work.

The revolution wrought by new forms of communication and information storage is hardly new, of course. The real difference now is that a myriad of computer and communications technologies are coming together—linked by high-capacity coaxial cable, fiber optics, and wireless transmission systems—to create a vast information infrastructure. This network of networks, as it has been called, will link homes, commercial centers, and industries across the nation with voice, data, and video telecommunications. "What we're seeing is a marriage of electricity and information, brought about by sweeping technological, regulatory, and competitive changes," says Marina Mann, EPRI's director for advanced information technology.

Largely because of regulatory constraints, the electric power industry has tended to take a backseat to more-visible players like the telecommunications and cable television companies in the high-stakes struggle to determine who will control the resulting network. No longer. Today, utilities are beginning to move aggressively to contribute their assets to the development of the National Information Infrastructure (NII), as the superhighway is officially called—and to exploit their own competitive opportunities.

In response, EPRI recently assembled a team of experts on information infrastructure technologies, financial and business issues, and public and regulatory policy to assess the business opportunities and risks for electric utilities vis-à-vis the emerging information infrastructure. "Electric power utilities have the potential to become significant players, offering not only commercial energy information services but non-energy value-added services and even telecommunications services in local markets,"

says Mann, who directed the intensive five-month effort. With sponsorship from both the Edison Electric Institute and the U.S. Department of Energy, the study identified a variety of new markets and new competitive opportunities available to utilities. The EPRI team also explored potential strategic alliances of utilities with other utilities as well as with cable television companies, telecommunications companies, and others.

According to Mann, the window of opportunity for developing a strategic plan may be narrow. "The changing markets for communications and information will play out over the next decade or more, but the pivotal business alliances and regulatory policies that will determine the competitive environment for both the telecommunications and power industries are likely to be forged in the next few years. Certainly within the next three years the most important alliances will be formed and the regulatory framework set," she predicts.

What role will utilities play? What are the competitive risks and opportunities? How can utilities position themselves now to secure a fast lane on the information superhighway?

Electric utilities as key players

A year ago, in a speech before the Academy of Television Arts and Sciences, Vice President Al Gore underscored the importance of electric utilities when he announced the administration's willingness to support regulatory changes that will spur competition and speed the development of the NII. "To take one example of what competition means," Gore said, "cable companies, long-distance companies, and electric utilities must be free to offer two-way communications and local telephone service."

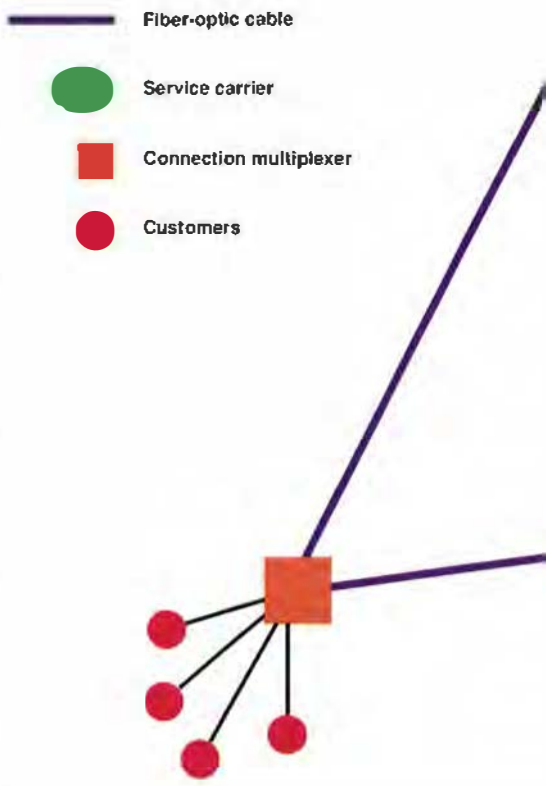
To many in the information and telecommunications industries, the possibility that electric companies will be key players may have come as a surprise. But in fact, EPRI and other industry groups have been working closely with the Cross-Industry Working Team, the White House National Economic Council, and the U.S. Council on Competitiveness to address our country's competitive issues and to provide the technical support necessary to ensure that electric utilities are not precluded from new market opportunities.

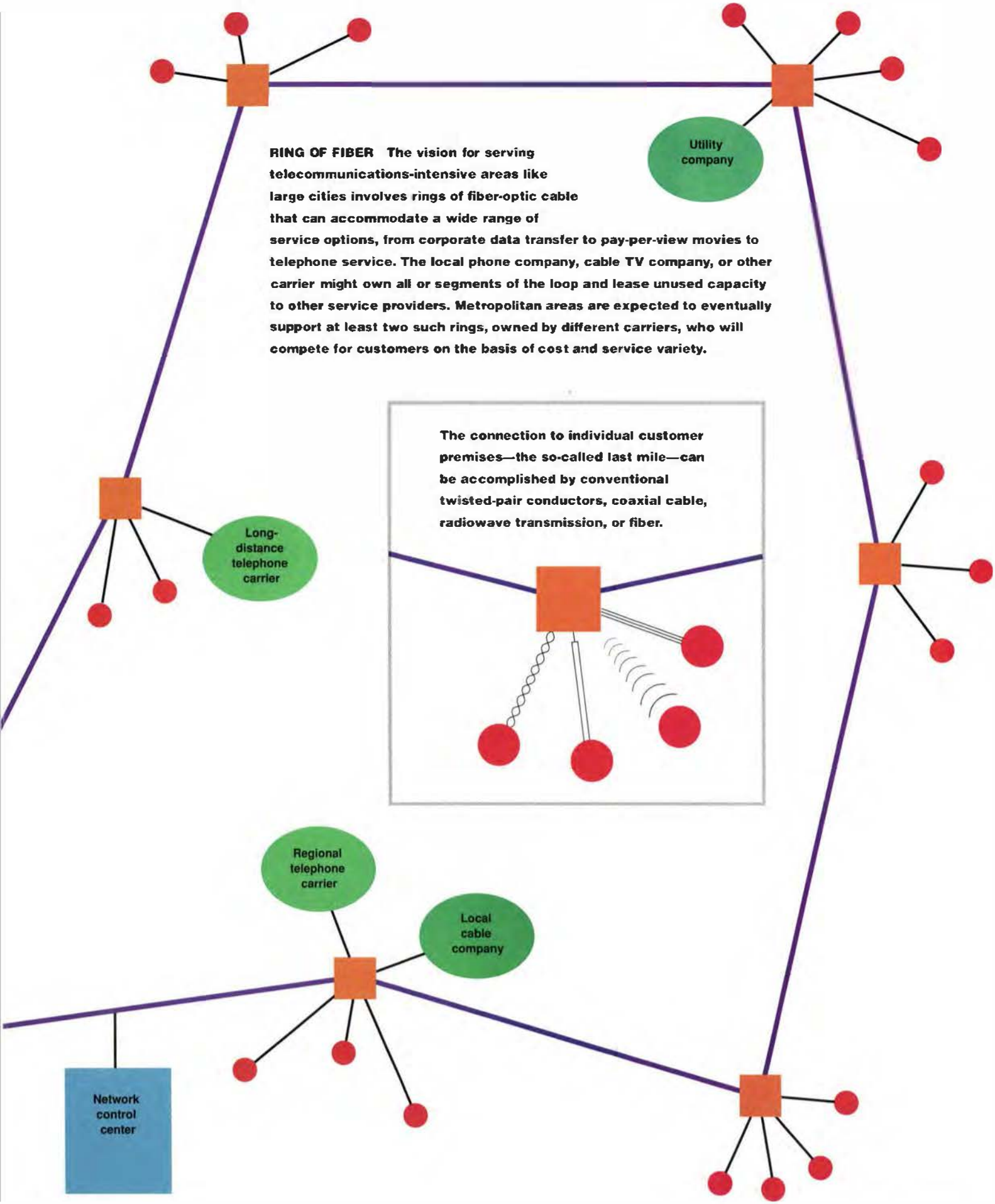
With good reason. "Utilities already have a very strong position in both information and communications, as well as significant assets in terms of rights-of-way, customer-billing systems, and a reputation for reliability," says EPRI's Ron Skelton, who managed the NII assessment study. Electric companies provide service to over 94 million residences; 12 million commercial establishments; and over 500,000 industrial establishments, including 82,000 public schools and 80,000 hospitals and health care facilities. The electric utility industry as a whole is the second-largest owner and user of telecommunications facilities in the country. It spends an estimated $2 billion to $5 billion a year to develop and maintain these facilities. "This is a large sum," adds Skelton, "but since it is a very small percentage of the revenues of the utility industry, it is usual for utilities to treat such investments as operational expenses rather than as a strategic necessity. The study we have just completed suggests that information technology and telecommunications strategy should both influence and support the utilities' strategic business objectives."

Moreover, a growing number of utilities already maintain significant fiber-optic networks. Although no firm numbers exist, estimates suggest that power companies nationwide have laid some 10,000 miles of fiber-optic cable. In a recent article in *Forbes*, Euel Wade, senior vice president at Southern Company Services, called fiber-optic links to customers "the bread and butter [for utilities] to remain competitive." The reason is simple. A 40-strand cable can carry 1.3 million phone conversations or 1920 TV channels simultaneously. Unlike traditional copper phone lines, fiber-optic cables are not affected by electric fields from transmission and distribution systems. Advanced transmission and distribution technologies and information networks are already enabling utilities to move electrons more intelligently.

In fact, of all the major players in the information and telecommunications field, utilities may have the most compelling economic incentive to assume the significant risks of building customer links to the information superhighway. Of the significant players, utilities have the largest plant investment—roughly $6000 per customer, compared with $1200 for local telephone companies and only $800 per line for cable companies. If utilities can reduce load demand through the use of supply-side efficiencies and demand-side management programs based on two-way energy information systems (EISs)—and thus defer the construction of new capacity—the savings could help significantly in offsetting the cost of providing customers with fiber-optic links to the information highway. A recent study by the Southern Company and DRI/McGraw-Hill estimates that accelerating the availability of such systems to allow customers to more closely manage their energy consumption and costs could save customers $78 billion over the next 15 years.

A landmark pilot program being sponsored by Entergy offers an example. Called PowerView, the program uses a real-time, fiber-optic network to provide interactive, two-way communications and price signaling between the host utility and partici-





RING OF FIBER The vision for serving telecommunications-intensive areas like large cities involves rings of fiber-optic cable that can accommodate a wide range of service options, from corporate data transfer to pay-per-view movies to telephone service. The local phone company, cable TV company, or other carrier might own all or segments of the loop and lease unused capacity to other service providers. Metropolitan areas are expected to eventually support at least two such rings, owned by different carriers, who will compete for customers on the basis of cost and service variety.

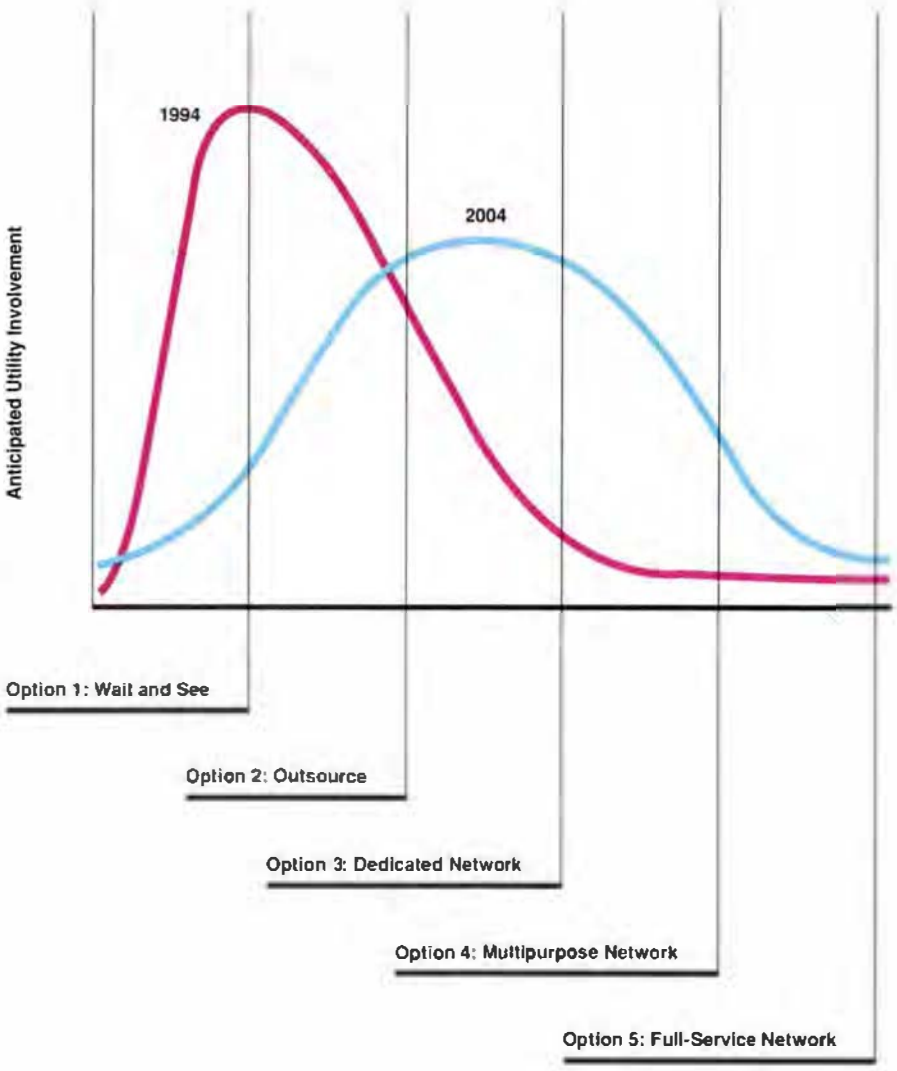
The connection to individual customer premises—the so-called last mile—can be accomplished by conventional twisted-pair conductors, coaxial cable, radiowave transmission, or fiber.

pating customers. The system is currently being deployed in 50 homes in a residential subdivision in Little Rock, Arkansas. By investing $585 to install fiber-optic cable, according to a recent *New York Times* analysis, the company will save an estimated 1.5 kW per house. To supply the same 1.5 kW with new capacity, Entergy would have had to spend $1257 per house. In short, the ability to defer or avoid the cost of building new capacity serves as a powerful economic incentive to install cost-effective demand-side management systems via the evolving information infrastructure.

Deferring new capacity is just the beginning. Advanced information and telecommunications systems will enable utilities to control costs, improve power quality, and even reduce environmental impacts through a variety of innovative initiatives. The installation of electronic sensors and automated control systems linked together along T&D lines, for instance, will provide unprecedented control over the delivery of electric power.

On the customer side of the meter, EISs made possible by two-way communications will enable electric utilities to offer a wide array of new services. In addition to the cost-savings potential of real-time pricing, two-way communications networks will allow for detailed itemized billing (complete with an accounting of consumption by individual appliances or machines), instantaneous remote meter reading, home security systems, and even remote turn-on/turn-off services. "Large customers already expect to be able to manage energy," says EPRI's Marina Mann. "Soon residential customers will expect the same."

UTILITY INVESTMENT PROFILE **While most utilities are currently taking a wait-and-see position on investment in information technology, EPRI believes the industry will become more aggressively involved over the next decade as competition pressures companies to deliver greater value and differentiate their services. EPRI's recent study provides guidance on five investment options.**



At the heart of the issue is competitive position. The evolving information infrastructure is rewriting the rules of competition, creating new links to customers and new means to deliver products and services. "If the utility industry does not move quickly to secure its connections to its customers, other service providers certainly will," warns Mann. Independent EIS providers, for instance, could move in, stepping between power producers and their customers. "And," as Mann emphasizes, "the bottom line of any competitive strategy is simple: Never let anyone come between you and your customer."

Lessons from the telcos

The lessons of the recent past can serve as a useful guide as utilities evaluate the impact of rapidly changing regulations and new business opportunities along the emerging information infrastructure. In 1984, the breakup of the Bell telecommunications system created risks and opportunities similar in many ways to those unfolding today. Who prospered? Who lost market share? "The experience of the telcos should serve as a wake-up call to the utility industry," says Mann. "After the breakup of Bell, the companies that were best positioned in the new markets were those that moved quickly to modernize plants and equipment, to reduce costs, to develop new business ventures through unregulated subsidiaries, and to shape regulatory change in order to ensure open competition."

The first step, according to EPRI's study of risks and opportunities, is for utilities to set in place internal information systems

that will enable them to know as much as possible about their own operations, especially their costs. "That means modernizing plants with advanced digital information systems and installing smart substations that will enable utilities to establish the cost of a kilowatthour at any point in time," Mann explains. "With their own internal information systems in place, utilities will be able to respond by establishing costs and access charges when new entrants in the marketplace begin to demand access to existing T&D lines. The same information will be essential for competitive power brokering."

Many advanced information systems specifically tailored for internal utility operations are already available. EPRI's Utility Communications Architecture, for instance, provides communications protocols and standards that allow once disparate software systems to talk a common language, enabling electric utilities to exchange information more freely. Meanwhile, the EPRINET information network currently gives 7000 users easy access to industry-specific news, e-mail, special-interest bulletin boards, and a library of technical reports and information. At a recent workshop focused on NII issues, EPRI and the Department of Energy agreed to link EPRINET with DOE's ES-Net to improve public access to both EPRI and DOE information. The Institute is also working with several of its members to use EPRINET to create innovative customer energy information systems.

On the supply side, EPRI has designed technologies for fault location and reporting, staggered service restoration, automatic meter reading, and remote service connection and disconnection. On the demand side, EPRI-funded research has played a leading role in developing applications for real-time pricing, direct load management, demand-side management services, power brokering, and improved customer services. A demonstration system for automated real-time pricing installed in New York City's Marriott Marquis hotel, for example, promises to save $200,000 in energy costs the first year, with savings then escalating by 5% a year. Also, a prototype of the Nonintrusive Appliance Load Monitoring System, or NIALMS, has been successfully field-tested. The system will replace conventional load survey systems and provide crucial customer information to utilities.

Eventually, advanced home automation systems will use the information superhighway, providing a powerful tool for sophisticated demand-side management programs. By way of a home automation communications network, for instance, an in-home energy management controller could receive electricity rate information that would then allow residential customers to program appliances to take advantage of the lowest-cost electricity. To facilitate the development of such services, the Electronic Industries Association recently released an interim communications protocol, called Consumer Electronics Bus, or CEBus, which creates a single standard for home automation technology development. Manufacturers have already begun to announce the development of components and products that use CEBus.

Over the past decade, EPRI played a leading role in developing the Smart House, which combines innovative designs for communications protocols and home automation technologies. During the recent workshop on the NII with DOE and the National Economic Council, EPRI discussed the possibility of creating a Smart Town to demonstrate and test the communitywide advantages of intelligent energy and information management, as well as a Smart Grid to create a vision and blueprint for the evolution of the energy system and the information superhighway. According to Skelton, EPRI will take the lead in developing these concepts in 1995.

But exploiting advanced information technologies is only part of a successful strategy for getting involved in the coming information infrastructure. Equally important, the experience of the telcos suggests, is working closely with regulatory agencies to clear the way for unimpeded competition in areas of strategic interest. For now, significant regulatory uncertainties remain. Some utilities are currently prohibited from entering the telecommunications business by the Public Utility Holding Company Act (PUHCA) or by state regulatory bodies, for example. And for utilities that opt to move into telecommunications services, regulators are likely to implement measures to protect electric ratepayers from footing the costs for commercial ventures and to provide competitors with nondiscriminatory access to the utilities' network assets.

Southern Company Services, a strong believer in the potential of communications infrastructure investments to enhance national productivity, job creation, and personal income levels, pointed out in a 1994 report the importance of allowing U.S. utilities to take full advantage of competitive opportunities in an increasingly global information economy: "Other countries have recognized the opportunities and are moving aggressively to capture the benefits of increasing electric utility participation in communications and cable TV services. In England, the Netherlands, Finland, Germany, Denmark, and Japan, for example, electric utilities already utilize their communications networks to offer telephone and/or cable TV services. Public policies in these nations encourage electric utilities to participate in these markets in a variety of ways, from leasing out excess communications network capacities to full participation in cable and TV telephony markets."

Industry observers believe that many of the current regulatory barriers in this country are likely to be lowered or eliminated entirely in the coming years, putting electric utilities in a stronger position to compete directly in the field of communications and information delivery. Anticipating such changes, Mann emphasizes how important it is for utilities to frame the regulatory issues and educate regulatory authorities now about the role of telecommunications in their business, while they are planning their own strategies. "Otherwise, regulatory delays and obstacles could derail even the best-thought-out strategy," she cautions.

Assessing the options

With so many uncertainties, how can individual utilities set a wise strategic course along the information superhighway? To provide a road map of risks and potential benefits, EPRI's intensive five-month study

of business opportunities assessed five strategic options. They range from a wait and see approach—in which utilities make only incremental investments in current telecommunications systems while waiting to see if other options become more clear—to constructing a full-service network that provides not only a complete range of energy information systems but also local telephone, cable TV, and value-added services.

Although ongoing changes in both the telecommunications and power industries make the first option tempting, EPRI's Ron Skelton warns that it poses significant risks. Alliances and investments made by competitors and EIS suppliers could lure customers away and leave utilities in a race to catch up, he explains.

A wiser strategic choice for many utilities may be the second option, leasing network facilities from independent providers such as telecommunications or cable TV companies. Such a strategy offers the advantages of flexibility and the ability to take advantage of competition among suppliers. But there are drawbacks and risks here, as well. For example, local telephone company service often does not meet utility needs for continuous and fully reliable communications. Moreover, a utility that relies primarily on public networks could in effect be preparing a road map for potential EIS competitors.

The third option, building a dedicated network, ensures that telecommunications and information systems remain under utility control and are closely integrated with all internal systems. But the capital investment required is significant. A dedicated network with a backbone of fiber-optic cable to the substation level, with broadband or narrowband electronics as necessary and coaxial cable or wireless connections to the customer's premises, is likely to require a capital investment of $500 to $700 per customer location in a metropolitan or suburban area. Rural installations could cost twice as much.

Establishing a multipurpose network, the fourth option, would allow utilities to leverage their own information and customer service networks in order to provide telecommunications services to other businesses in their service areas. Indeed, because direct utility use requires only about 5–10% of fiber-optic capacity, some utilities are already selling the excess capacity on their networks. The obvious benefit, of course, is the creation of new sources of revenue and profit provided by diversification.

Although there is some competitive risk in the telecommunications marketplace, the EPRI study concluded that utilities can offset the risk by upgrading a dedicated network only as deals are made with large-capacity users. The single most important consideration, perhaps, is that managing a multipurpose network will require a broader range of skills in planning, engineering, and marketing than most utilities now possess. Regulation will also prove an important issue. Utilities that invest in a network designed to be leased for commercial telecommunications services are likely to be scrutinized more closely by regulators than are those that build a dedicated network for their own internal use. Indeed, multipurpose networks will almost certainly require a separate subsidiary for at least some commercial services.

The fifth and final option, developing a full-service network, would use a fiber-optic and coaxial cable network to provide a full range of services—including two-way voice, data, and video communications and advanced interactive cable television services like video-on-demand. This option has even greater potential for diversification, with commensurate potential for profit as well as a higher level of competitive risk. But utilities can reduce the risk by offering full-service networks only in selected portions of their service areas and extending the networks as competitive conditions dictate. Like a multiuse network, a full-service network is likely to require considerable attention to marketing and strategic planning.

How far, how fast?

"How far a given utility decides to travel along the superhighway will depend on many factors, from capital position to existing markets," says Ron Skelton. In reality, few utilities are likely to have the resources or expertise to develop full-service networks immediately. Instead, most may opt to phase in new markets and technologies—beginning with the development of a dedicated network, for instance, and exploiting competitive opportunities to lease capacity, partner with others, and provide services to customers as the market evolves.

The first priority is likely to be providing energy information systems to large users of power. From there, the network can be extended to communities where market needs, competition, and regulation make new services, such as remote meter reading or real-time pricing, economically attractive. "Wireless communications could be used initially to provide connections for narrowband telecommunications and energy information systems, for example," explains Skelton. "Later, those could be replaced by wired connections as the customer base and the services offered expand." Whatever form phased implementation takes, it is likely to reduce economic risk and ensure the flexibility to adapt to improved hardware and software as they become available.

Another strategy to reduce risk and improve competitive advantage is the formation of strategic partnerships that exploit the strengths of a variety of players in the field. In some instances, utilities may join forces with other utilities to carve out larger geographic areas for service or to increase their deal-making leverage. Partnerships may also bring utilities together with local telecommunications companies. "While utilities have tremendous assets in terms of rights-of-way and customer-billing systems, as well as a tremendous reputation with customers, they typically have less experience in marketing," says Marina Mann. "A telco brings to the table strong marketing and network skills, as well as solid financial and strategic planning experience. Strategic partnerships that are designed to make the best use of a utility's existing rights-of-way, service fleet, fiber investment, and strong customer image for reliability can offer both parties tremendous opportunities and lowered risks."

Partnerships with telecommunications or cable TV companies could also give utilities a strategic way to complete what Mann calls the last mile—the link between large-

Road Map for the Information Superhighway

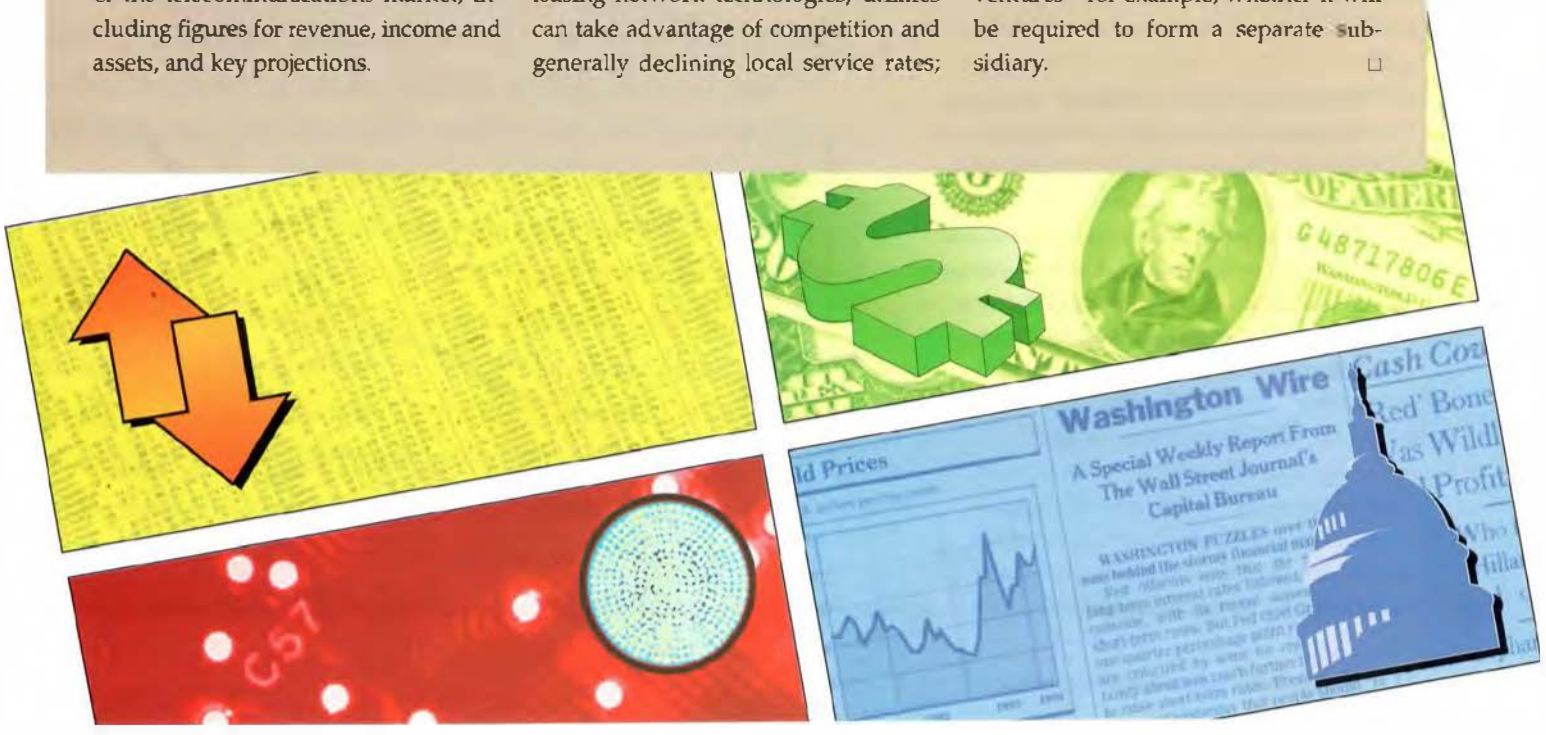
More than just a report, EPRI's *Business Opportunities and Risks for Electric Utilities in the National Information Infrastructure* (TR-104539) is intended to serve as a detailed road map to help utilities plan their own information and telecommunications strategies. "Individual utilities must assess their specific opportunities and define their options in both financial and intangible terms," says EPRI's Ron Skelton. With that in mind, EPRI's team of experts analyzed strategic issues from four key industry perspectives: market risks and opportunities, emerging technologies, financial considerations, and public policy issues.

Market risks and opportunities As the National Information Infrastructure evolves, utilities are confronting enormous opportunities and risks. The report evaluates the opportunities both for internal applications of utility networks and for potential profit-making external uses, such as leasing out unused capacity or offering competitive telecommunications services. The report analyzes the competitive position of utilities in relation to other major players, such as telephone and cable companies. Of special interest is a detailed overview of the major segments of the telecommunications market, including figures for revenue, income and assets, and key projections.

Emerging technologies Fiber optics has emerged as the leading technology for the information infrastructure. But wireless and satellite communications systems will also play a significant part. As the report notes, there are currently more technologies than the marketplace knows what to do with, suggesting that many opportunities exist to define new services for both internal and external purposes. The report details a wide range of technological options available to utilities and other competitors on the information superhighway—from modulation and channel-sharing techniques to satellite networks. For each technology, specific opportunities for electric utilities are reviewed. The report also includes a table listing applicable network technologies that utilities may choose to employ in the future.

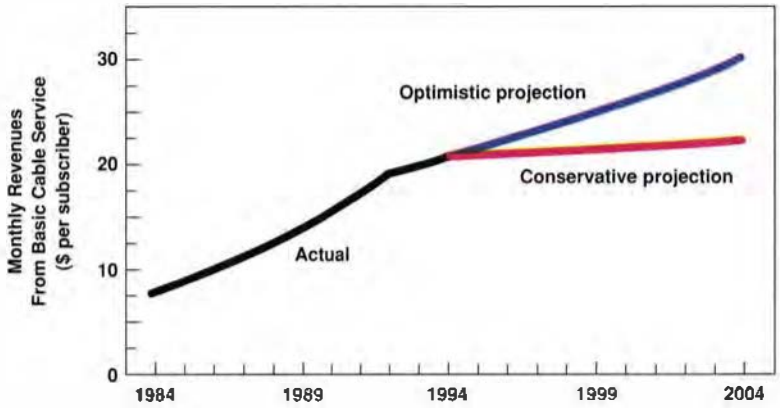
Financial considerations Because telecommunications networks are capital-intensive, financing will be a major factor in setting strategies. In analyzing each of five possible options—from the cautious wait-and-see approach to the aggressive strategy of developing a full-service network—the report details specific costs and financing considerations. For instance, by adopting the option of leasing network technologies, utilities can take advantage of competition and generally declining local service rates; however, the unpredictability of market rates for telecommunications services will also make the long-term costs of that option difficult to quantify. To further guide utilities, the report reviews a variety of risk mitigation strategies, including partnering and phasing in network capabilities and expanded service regions over time.

Public policy issues Despite sweeping regulatory changes, utilities still must balance their societal mission with any profit-making ventures in the telecommunications field. The report points out that universal-service goals—including the extension of information services to schools, hospitals, and public institutions—may enable utilities to fund networks in part from public or universal-service funds. But utilities must also take into account current and potential regulatory constraints in the electricity and telecommunications industries. As a guide, the report reviews in detail the 1993 revisions in the Public Utility Holding Company Act and anticipates future trends. It concludes that barriers will continue to be removed but that regulatory issues are still likely to affect the way in which an electric utility may structure its telecommunications ventures—for example, whether it will be required to form a separate subsidiary. □

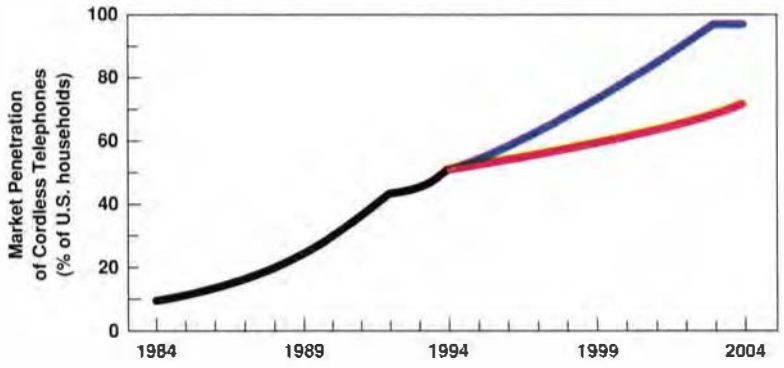


OPPORTUNITIES FOR MARKET EXPANSION As development of the information superhighway expands the ability to interact directly with consumers, markets for information services are expected to grow steadily. Utilities with extensive optical fiber assets could become involved in a number of these telecommunications markets, either by leasing some of their fiber capacity to other companies or by forming subsidiaries to actually provide service. In addition to the existing market segments shown below, there is growing potential in such emerging areas as video conferencing, on-line computer services, e-mail communications systems, and remote monitoring and security systems.

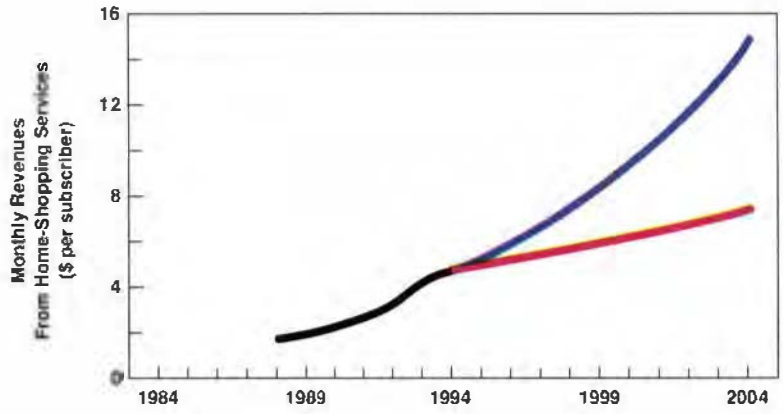
CABLE TV SERVICE Although the cable industry is facing increased regulation and rate limits for basic television service, new services such as digital music channels, telephone dial tone, and data transmission could still mean revenue growth. Some cable companies may offer utilities equity positions in exchange for help in upgrading their systems.



WIRELESS TELEPHONE SERVICES Cellular and other cordless telephone services continue to grow at the expense of conventional hardwired technology. The development of low-cost communications services that use microwave frequencies and very small cells would significantly improve the versatility and convenience of personal telecommunications.



HOME-SHOPPING SERVICES Shopping channels typically pay the telecommunications provider—usually a cable company—a small per-subscriber fee plus 3–5% of the gross merchandise revenues. The home-shopping market is expected to show substantial growth, especially if video catalog sales or other innovative services are introduced.



scale fiber-optic networks, which can be strung along existing rights-of-way, and customers' homes. "It's that last mile that represents the most significant cost in providing a multipurpose or full-service network," says Mann. "And since cable TV companies already reach nearly 70% of all homes, and phone companies nearly 90%, alliances between utilities and such firms may have significant strategic advantages."

In one scenario, a utility might opt to collaborate with cable operators in its service area to develop a multipurpose or full-service network. Upgrading an existing cable installation is estimated to cost about $300 less per customer location than putting in a whole new system. Such a collaboration would enable cable operators to upgrade their capabilities and realize the economies of a network spanning an entire metropolitan area; for utilities, collaboration would open up new synergies in marketing, field service, and billing.

Taking the lead

Several such alliances have already been formed. Houston Lighting & Power, for instance, has purchased a local cable TV company. Pacific Gas and Electric has signed agreements with Microsoft, the giant software developer, and TCI, the nation's largest cable TV company, in an effort to take the lead in developing energy information systems and making them available across a wide service area.

This past November, a federal deadline for companies intending to bid on licenses for a new generation of wireless personal communications services touched off a frenzy of announcements about new—and sometimes startling—alliances between major players in the communications, entertainment, and information industries. In one of the most highly publicized examples, Hollywood's largest talent agency joined forces with three major telecommunications companies on the East and West Coasts in a venture designed to offer entertainment services that will operate via phone and be viewed on small TV sets.

Meanwhile, a growing number of utilities are moving more quietly to secure their place on the information superhighway. In most cases, that has meant adding fiber-optic lines to their systems, typically using existing rights-of-way. In recent years, Public Service Company of Oklahoma has created a 110-mile fiber-optic loop around the Tulsa area, which it is currently using both to meet its own communications needs and to provide high-volume data transfer service to some 30 commercial customers.

Adopting a similar strategy, Baltimore Gas and Electric has installed 230 miles of fiber-optic cable inside existing ground wires to connect its corporate offices to 30 of its main power sites and offices. Because BG&E uses only a fraction of the carrying capacity of the fiber-optic lines, the utility has been able to lease the unused capacity to others, including a major long-distance carrier.

SCANA Corporation has moved even more aggressively, forming a telecommunications subsidiary that has installed more than 1600 miles of fiber-optic cable on overhead power lines owned by its sister subsidiary, South Carolina Electric & Gas. An additional 600 miles are planned. Meanwhile, the Southern Company is setting up a new subsidiary, Southern Communications Services, to operate a unified wireless communications network to serve its five operating companies. The combined voice and data network will be used for emergency communications between managers and Southern crews in different states during storm emergency situations. The company also plans to sell excess capacity on the network in order to offset the capital cost and to gain economies of scale.

Even smaller players have found a lane on the information superhighway. Consider the Kentucky town of Glasgow (population 13,000). In 1988, the town's municipal utility, the Electric Plant Board (EPB), began to wire homes with cable. The aim was not only to read meters remotely and exchange data with customers but to go head-to-head with the area's monopoly cable company, according to William Ray, EPB's general manager. To date, the muni has lured away some 30% of the cable business. It is now looking at providing competitive telephone service.

Fiber optics are not the only link in the growing information infrastructure, of course. EPRI's report on business opportunities and risks evaluates more than a dozen telecommunications technologies that are likely to play a significant role on the information superhighway, including wireless telecommunications, point-to-point microwave circuits, and geostationary and low earth-orbiting satellites.

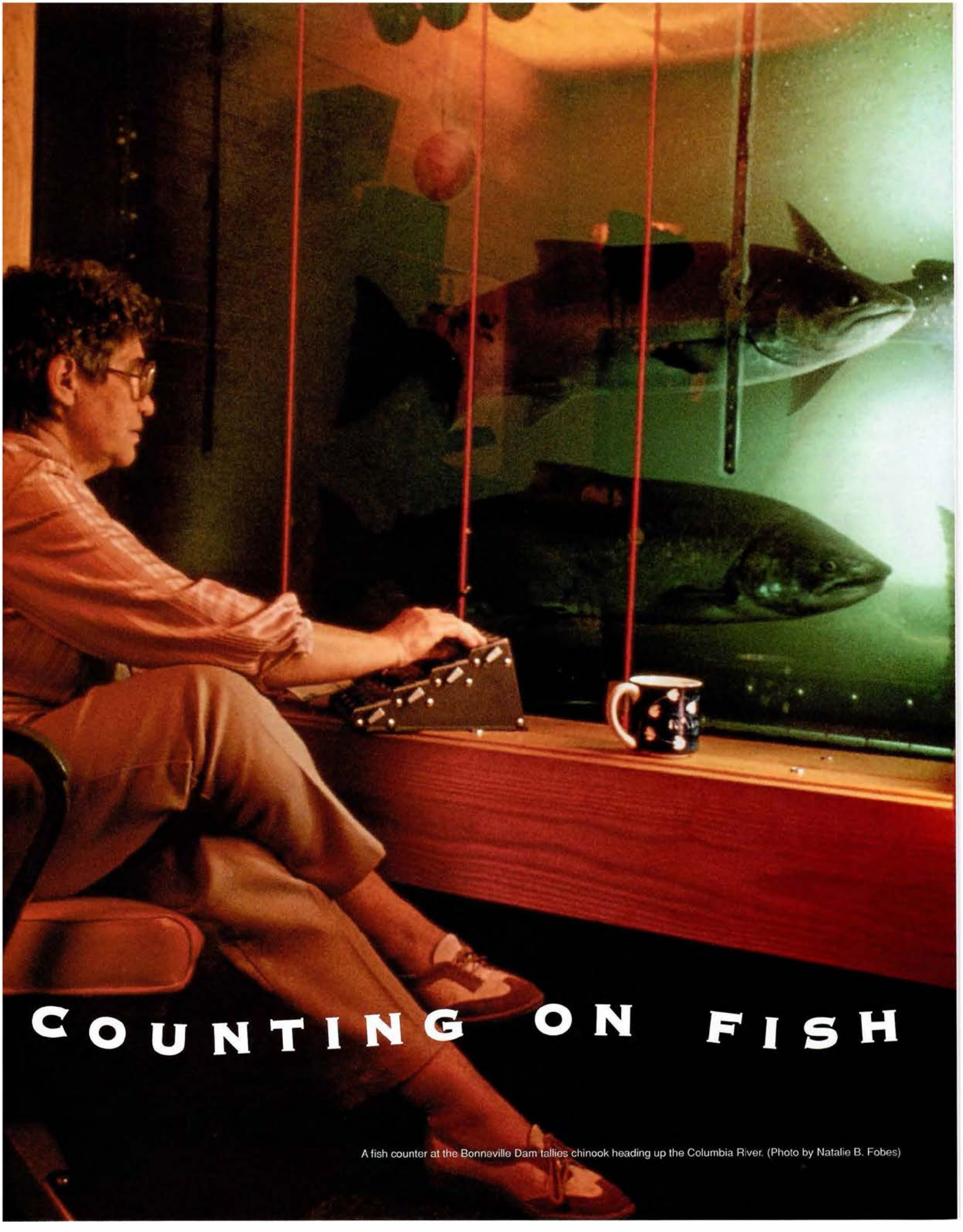
The power of information

As recent alliances make clear, the traditional boundaries between electricity providers, telecommunications companies, cable TV operators, and even interactive entertainment companies are quickly fading as information becomes the principal commodity, whether in the form of telecommunications, cost-saving energy information systems, entertainment, e-mail, or access to the world's libraries through a growing number of databases.

In that context, the National Information Infrastructure is simply the latest step in an economic and social transformation that began almost 75 years ago. As management guru Peter Drucker has pointed out, competitive advantage in the early part of the twentieth century depended principally on obtaining cheap energy—whether in the form of oil and coal or through innovations, like the assembly line, that made more productive use of human energy. Since then, chiefly as a result of technological change, competitive advantage has come to depend on the acquisition and application of information, Drucker notes.

For the better part of the century, electric utilities have been at the forefront of that revolution, providing the power for progress—not only by supplying reliable electricity but also by fostering innovative technologies that have extended what electricity can do. Today, as the United States and other industrialized nations begin to link up myriad communications networks and information technologies in a vast electronic superhighway, utilities once again are positioned to play a central role in tapping the transformative power of electricity. ■

Background information for this article was provided by Marina Mann and Ron Skellon of the Strategic Development Group.



COUNTING ON FISH

A fish counter at the Bonneville Dam tallies chinook heading up the Columbia River. (Photo by Natalie B. Fobes)

When many of the great U.S. dams went up during the Depression and after World War II, they brought jobs, flood control, and cheap power that turned sleepy regional economies into bustling urban centers practically overnight. Observers from a wide range of interest groups hailed the veritable torrent of "clean" power.

Those days are gone. Hydropower is drawing criticism from an ever larger group of observers. The key issue is fish. Over the decades since the country's major dams were established, fish populations have declined dramatically. Anadromous fish, which migrate to the ocean and later return upriver to spawn, have been the hardest hit. Recent years have witnessed declining numbers for all salmon species in the Pacific Northwest. In 1985 coho salmon on the Snake River became extinct, and in 1991 the Snake River sockeye was labeled endangered under the Endangered Species Act. Atlantic salmon fare no better.

Even dam detesters admit that hydropower isn't the only culprit. Overfishing, irrigation, cattle grazing, forestry operations, and poor ocean conditions are all believed to have contributed to the decline of anadromous fish species. Nevertheless, utilities across the country are being called on to step up their fish protection efforts. And the movement has some powerful forces behind it. The governors of Idaho, Washington, Oregon, and California have banded together to pressure the Clinton administration to ensure the efficient and fair administration of the Endangered Species Act. Going one step further, Bruce Babbitt, U.S. interior secretary, told members of Trout Unlimited last fall that he would "love to be the first secretary of interior in history to tear down a really large dam."

"There's no doubt, fish protection is the biggest issue in hydro relicensing right now," says Dick Hunt, a hydro relicensing consultant and former director of the Federal Energy Regulatory Commission (FERC) Office of Hydropower Licensing. Within the past few years, state and private fishery groups have gained a significant say in the licensing renewal process. Many utilities that do not have fish protection systems at their hydro plants must now conduct extensive fish mortality studies to determine whether there is a problem requiring attention. And others that do have such systems in place must conduct studies to prove that the systems offer a satisfactory degree of protection.

As of late last year, only 43 of the 157 relicensing applications filed with FERC for 1993—a record year for hydro relicensing—had been approved. The rest of the plants are operating under temporary permits that must be renewed annually. "The fish protection issue is the biggest holdup," Hunt explains. "Some of these licenses may not be issued until the year 2000." Meanwhile, a steady flow of license renewal applications continues. Between 1996 and 2010, more than 20,000 MW of hydropower will require relicensing, Hunt says.

The challenge of fish protection

Hydropower currently provides about 10% of the electricity consumed annually in the United States. On a regional level, however, the balance of power resources can be drastically different, with hydropower providing the bulk of the electricity consumed in some states. For instance, the northwestern region, including Idaho, Montana, Ore-

THE STORY IN BRIEF The number of salmon migrating up U.S. rivers has declined significantly in recent years, bringing hydro plants under increased scrutiny. Indeed, fish protection has become the biggest issue in hydro plant relicensing, and utilities across the country are under pressure to step up their fish protection efforts. Currently, much of the regulatory emphasis is focused on downstream passage technologies.

PROTECTION

BY LESLIE LAMARRE

EPRI's laboratory and field tests have identified the most promising of these technologies. However, the effectiveness of each approach varies according to the site and the fish species and life stage.

gon, and Washington, gets 75% of its energy from dams in a typical year. With salmon regarded by many as intrinsic to the culture of that area, utilities with hydro plants there are struggling to achieve the delicate balance between power and fish.

"Are we worried?" asks Stephen Brown, hydro engineering supervisor for Grant County Public Utility District, whose capacity is made up almost entirely of hydropower on the Columbia River in Washington. "Sure we are." Last August, the U.S. Fish and Wildlife Service and the mid-Columbia Joint Fisheries Parties (a group of national and state fishery agencies and local indigenous groups) suggested to FERC that two dams owned and operated by Grant County PUD be removed to allow the safe passage of fish migrating downstream. With power resources totaling some 2000 MW, these dams represent 95% of the utility's capacity. The power they produce goes to consumers in Washington, Oregon, and Idaho. The cost of replacing this capacity could exceed $1 billion.

Grant County PUD has researched site-specific technologies to effectively divert salmon around the turbines and guide them safely downstream. So far, the mechanisms tested have shown a 70% effectiveness rate, which means that about 30% of the fish are still passing through the turbines. Brown points out that many of the fish that do pass through the turbines of a hydro plant manage to survive (the estimates of fish survival rates have ranged from 50% to 96%). "Still," he says, "70% diversion is just not good enough."

Indeed, utilities searching for downstream fish passage technologies are aiming for diversion effectiveness rates of at least 90%. This is particularly important on rivers that support a series of large dams, since cumulatively the dams can take a heavy toll. At this writing, Grant County PUD is developing a new bypass system that it plans to test in the spring, when the salmon begin their downstream migration.

Other utilities across the country have also invested years of study and significant resources in their search for effective fish protection systems. In addition to upstream and downstream fish passage technologies, strategies include ensuring an appropriate water release below a dam, controlling water level fluctuation, and altering water temperature and oxygen content. The industry's earliest research focused on upstream passage—namely, the development of fish ladder systems, which are now widely accepted by regulators. More recently, however, the bulk of regulatory attention has focused on improving downstream fish passage. In response, researchers have investigated and developed a wide array of protective technologies—ranging from physical barriers, such as nets and screens, to behavioral devices, such as startling sounds and flashing lights.

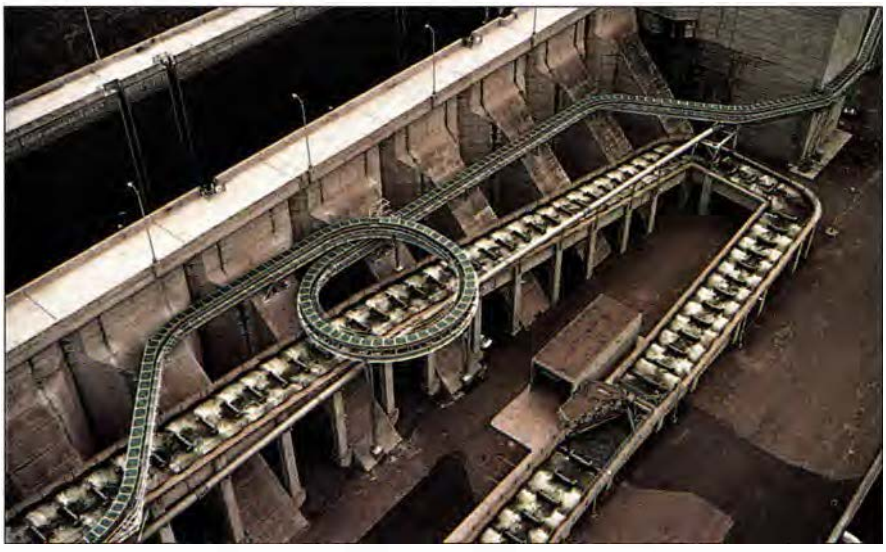
"The problem is not a lack of options; there are plenty of mechanisms available," notes Charles Sullivan, manager of EPRI's research on fish protection. "The difficulty is identifying the right solution for a particular species and site." Indeed, a downstream passage technology that works phenomenally well at one hydro plant may perform dismally at another. As Sullivan notes, the techniques are not only site-specific but species- and life-stage-specific as well.

Lights and sound

A case in point is strobe lights. In the late 1980s, a multiyear EPRI-sponsored study at Metropolitan Edison Company's York Haven hydro plant on the Susquehanna River found the use of strobe lights to be an effective, low-cost method of diverting juvenile American shad around turbine intakes. Ninety-four percent of the migrating shad were effectively repelled to a bypass, which delivered them safely downstream. Metropolitan Edison estimates that the implementation of this technology would save at least $4.8 million, the cost of upgrading its trash rack system. In contrast, BC Hydro tried the strobe light technique with coho salmon at its Puntledge hydro plant without success, even though hatchery-reared coho avoided strobe lights in laboratory studies.

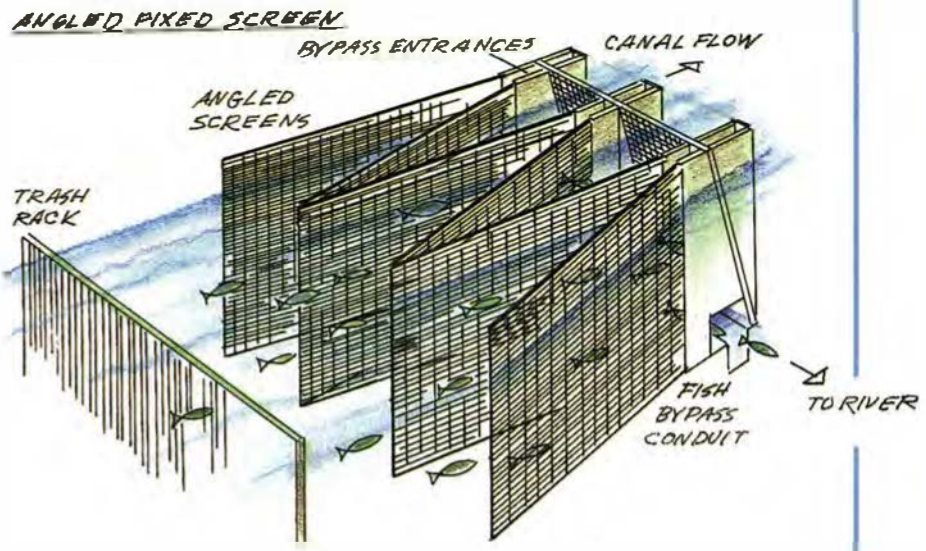
Edward Taft, a biologist with Alden Research Laboratory and a principal investigator for a number of EPRI studies on fish protection, notes that water clarity plays a significant role in the effectiveness of the strobe light approach. Other factors that can influence response include the strobe's flash rate, the time of day, the water velocity, and the life stage of the fish. For example, while juvenile American shad have

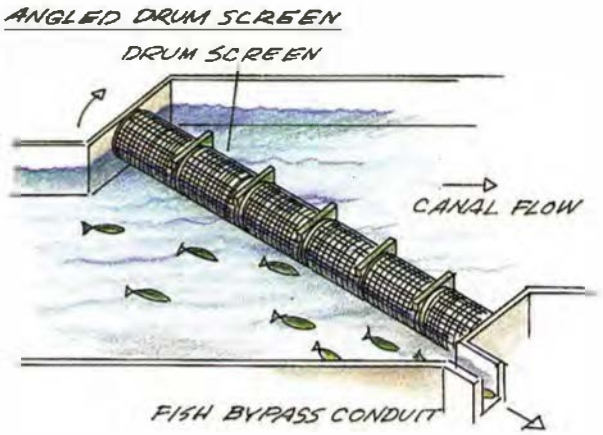
CHUTES AND LADDERS **This installation at the U.S. Army Corps of Engineers' Little Goose Dam on the lower Snake River in eastern Washington shows both upstream and downstream fish passage technologies. The fish ladder on the lower level allows adult salmon to migrate upstream, while the bypass above it carries juveniles to a safe point downstream of the turbines. The loop helps slow the water flow to prevent fish injuries. A screen covers the top of the flume to protect the juveniles from predators like seagulls.**



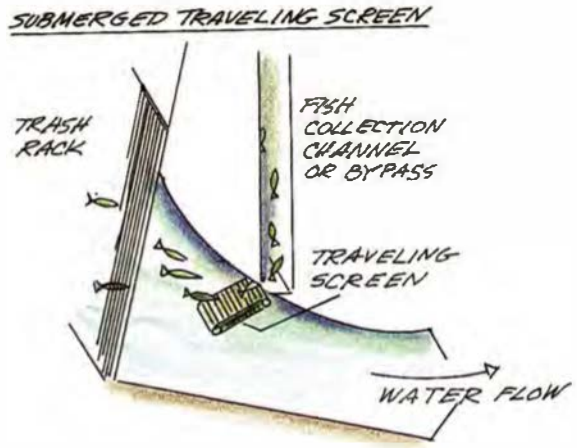
SCREENING FOR SAFETY

Angled fixed screens and angled drum screens—so named because they are installed diagonally to the water flow—have gained wide regulatory acceptance as effective downstream fish passage technologies. In each system, fish are guided into a bypass conduit that routes them around the hydro turbines to a point in the river below the dam. Drum screens, which rotate slowly to prevent debris accumulation, are the better option for sites with high debris loads.





Although generally regarded as less effective than angled fixed and angled drum screens, submerged traveling screens are perhaps the best available technology for larger sites. This screen hangs from the ceiling of the water intake structure into the upper part of the water column, where fish tend to swim. Like a conveyor belt, the screen moves continuously, guiding fish either into a bypass system or into a collection channel for delivery by barge downstream.



THE MAD RUSH Sockeye salmon in British Columbia hurry upstream to their spawning grounds. Sockeye populations in the northwestern United States are nowhere near as plentiful; the Snake River sockeye was listed as endangered in 1991. (Photo by Jeff Foott)

shown a strong avoidance of strobe lights, adults of the same species have shown little or no response. Researchers also point out that hatchery fish and wild fish of the same species have responded differently.

In an EPRI-sponsored research project, investigators are conducting field tests to determine the responses of different fish species to strobe lights. "The key is to find one system that will work well with a wide variety of fish species," says Jack Mattice of EPRI, a biologist involved in the Institute's fish protection research. "What might prove to be most successful is a combination of sound and light. Some fish might be repelled by sound and others by strobe lights."

Researchers have recorded and analyzed fish sounds to determine the frequencies, durations, and amplitudes to which fish respond. Sounds tested have ranged from the recorded cries of predatory mammals like dolphins and killer whales to startling noises produced by special underwater transducers developed by the U.S. Navy. Steelhead trout, chinook salmon, and a variety of fish in the herring family have all responded well. Mattice notes that further research must be done before such behavioral systems are accepted by regulators and are ready for widespread application.

Best bets

Of the technologies currently in use, Sullivan says, angled fixed screens and angled drum screens have gained the most acceptance from fishery agencies in the Pacific Northwest. And because the salmon migration issue has made this region the country's most aggressive in terms of fish protection, this acceptance has influenced similar agencies in other regions. Fixed screens and drum screens are low-velocity screening systems, through which water typically flows at a velocity of 0.5 foot (0.15 m) per second or less. In contrast to earlier screening systems, which were set perpendicular to the water flow, these screens are installed at an angle to the flow. This orientation has significantly increased fish survival rates, which frequently top 96%.

Used successfully in the Pacific Northwest, many angled fixed screens are made of wedge wire, a series of evenly spaced 2-mm-wide steel bars that taper—from front to back—like wedges. Some utilities that employ these screens have arranged them in a zigzag pattern spanning the width of the canal leading to the powerhouse. Water passes through the screens to the turbines, while fish are guided along the length of the screening and routed to a bypass system that delivers them around the turbines. Most angled fixed screen systems have mechanically driven brushes for debris removal.

Considered the best technology for protecting fish at sites with high debris loads, angled drum screens function in a similar manner. Named for their cylindrical shape, these screens are installed horizontally, sometimes in an angled arrangement similar to that of angled fixed screens. Rather than employing brushes for debris removal, drum screens simply rotate to prevent debris from accumulating in the first place. The rotation occurs at a slow rate that is probably imperceptible to fish.

One drawback of low-velocity screening systems is that they can cause the migrating fish to slow down to such an extent that they become vulnerable to predators. And, as Sullivan puts it, "these predators can figure out where lunch is very fast." The predators may linger in the shadows of the low-velocity screening systems, awaiting their opportunity for an easy meal. This problem has surfaced on the Columbia River, where squawfish gobble up 6–8-inch salmon smolts as they head downstream. Another common problem of vulnerability to predators can crop up at the outfall below a dam, where fish emerge from the bypass system.

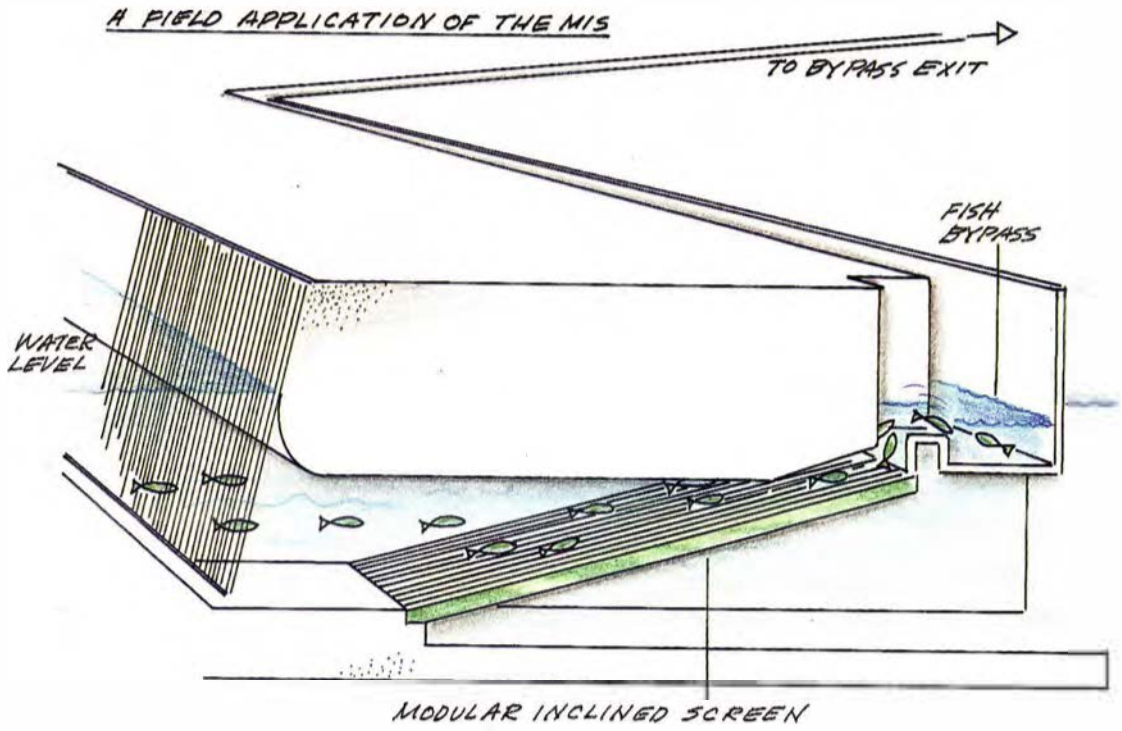
At very large dams, for which angled fixed screens and angled drum screens are not practical options, submerged traveling screens have been employed. This technology has been installed at most—and is planned for the remainder—of the large dams on the Columbia and lower Snake Rivers. A submerged traveling screen hangs from the ceiling of the water intake structure into the upper portion of the water column—the area where migrating salmon have been observed most frequently. The screen is set at an angle to the flow, diverting fish from the turbine intake and into a gatewell, where they either enter a bypass that carries them below the dam or are collected for transport by barge.

High-velocity screens

High-velocity screening systems, with water velocities ranging from 5 to 10 feet (1.5 to 3 m) per second, are also beginning to gain acceptance from regulatory groups.

EPRI'S MODULAR INCLINED SCREEN

EPRI has developed a new high-velocity screening system called the modular inclined screen (MIS). Like low-velocity screening systems, such as angled fixed and angled drum screens, the MIS diverts fish into a bypass around hydro turbines. The modular nature of the MIS allows it to be used—singly or in series—at any type of water intake; thus it is a potential solution for many different sites. Currently in transition from the laboratory to commercial use, the MIS has proved 99% effective in protecting most of the species of fish tested. EPRI has applied for a patent on the technology.



EPRI researchers test a model of the MIS.

The MIS is made from wedge wire, typically a series of 2-mm-wide steel bars that taper like wedges to minimize debris accumulation.

The primary advantage of high-velocity systems is their small size (they require only 10–20% of the screen area of low-velocity systems), which helps reduce their cost to about half that of low-velocity systems. Also, because the water is flowing more swiftly, passing fish are not as vulnerable to predators as they can be in low-velocity screening systems.

High-velocity screens are typically installed on an incline, with a pivot supporting the center (as in a seesaw). The fish are guided over the screen and into a bypass system. Accumulated debris can be washed away by simply pivoting the screen so that the debris is forced toward the downstream side. One high-velocity screen that EPRI has successfully demonstrated was designed by George Eicher, a former utility biologist. Called the Eicher screen, this system is made from wedge wire and is designed for installation inside a penstock. EPRI-sponsored studies over the past decade have contributed to the refinement of the Eicher screen. Efficiencies for fish diversion now typically surpass 99%. BC Hydro has employed the Eicher screen with great success, saving $4.4 million over the cost of a low-velocity screening system. Regulatory agencies in Canada and the United States have accepted the technology for certain hydro plants.

In the meantime, EPRI has developed its own high-velocity screening system, called the modular inclined screen (MIS). Also made of wedge wire, the MIS is not designed for installation directly inside a penstock. It is square, rather than elliptical, and a series of the screens can be installed virtually anywhere upstream of a penstock. The screen's modularity enables it to be used at any type of water intake. Improvements to the system's hydraulics have provided a more uniform flow over the entire screen surface than with other screens, such as the Eicher. This modification reduces the likelihood of fish injuries due to screen contact. EPRI has applied for a patent on the technology.

"The intent was to develop a standardized design that can eliminate the need for site-specific hydraulic model studies and biological evaluations," says Sullivan. "The modular nature of the MIS means that it can be used with a wide variety of water intakes. Several of the screens can be installed at a single intake to provide fish protection for any amount of flow."

So far, the MIS has proved 99% effective in protecting most species of fish. "The agencies are very excited about the data we have," says Taft, who helped develop the screen under EPRI sponsorship. "But they'd like to see how it performs in a real-life application." Next fall, the MIS will undergo a field demonstration outside Albany, New York, timed to occur during the seasonal run of blueback herring on the Hudson River. This demonstration will help move the technology from the laboratory to commercial development.

Turbine tactics

In the meantime, experts continue to explore new angles on fish protection. In fact, the U.S. Department of Energy, utilities, the National Hydropower Association (NHA), and EPRI are investigating the possibility of redesigning hydro plant turbines to make them more environmentally friendly and fish-safe. "For the bigger plants especially, it is possible that approaches other than fish diversion systems may prove more cost-effective," Sullivan explains.

Last fall, DOE—on behalf of the utilities, NHA, and EPRI—asked bidders to submit their ideas for new turbine designs that would combine state-of-the-art approaches for avoiding adverse impacts. Responses are expected in the spring. Meanwhile, no one is offering any hints as to how a turbine might be changed to become more fish-friendly. "DOE does not want to influence the bidders in any way," Sullivan says. With the intention of aiding DOE in selecting the best design, EPRI is planning to initiate a project that will take a detailed look at the scientific mechanisms of fish mortality; the project will draw on work conducted by the U.S. Army Corps of Engineers.

For decades, the scientific community has known about many of the fundamental mechanisms for injury during turbine passage, says Sullivan. They are vapor bubble collapse (cavitation), generated by rapid pressure changes near the turbine blades; shear and turbulence, which create a washing-machine-like environment; grinding, which occurs when fish get trapped between two pieces of machinery; abrasion, caused when fish bump up against rough surfaces; gas bubble disease, in which fish experience a phenomenon similar to the bends as the result of dissolved gases (for example, an abundance of nitrogen in spillway areas); and stress, associated with passage through dark, turbulent regions.

What researchers don't know at this stage is which of these mechanisms cause the bulk of fish injuries and mortality. They also do not know whether other, undiscovered mechanisms may play a role. The hope is that, as researchers find answers to these questions, new clues will emerge to guide designers in their development of fish-friendly turbines. For the most part, EPRI will rely on data already gathered by the U.S. Army Corps of Engineers over the past several decades. The Institute may also conduct supplemental testing to provide further insight.

Sullivan believes that a careful analysis of these data will provide valuable guidance not just for turbine redesign but for fish protection in general. "This new information, combined with the state-of-the-art fish protection measures that are already becoming available, will offer utilities the best approaches to fish protection they have ever had," he says. "Fish protection at hydro plants is a difficult and serious issue. But personally, I believe that it's not going to come down to a question of fish or power. I think most people recognize it's important to have both, and I believe that balance is attainable." ■

Background information for this article was provided by Charles Sullivan of the Generation Group's Renewables, Storage & Hydro Business Unit and Jack Mattice of the Strategic Development Group's Environment & Health Business Unit.

CONTRIBUTORS

Technical sources for Journal feature articles

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Assessing the Risks of Utility Hazardous Air Pollutants (page 6) was written by Leslie Lamarre, *Journal* senior feature writer, with technical information from two EPRI staff members.

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Ian Torrens, director of the Generation Group's Environmental Control Business Unit, joined EPRI in 1987. Previously he was with the Organization for Economic Cooperation and Development in Paris for 14 years—7 with its International Energy Agency and 7 as head of its Pollution Control Division. He has BS degrees in physics and applied mathematics from Queen's University in Belfast and a PhD in nuclear physics from the University of Cambridge, England. ■

Grabbing a Lane on the Information Superhighway (page 20) was written by science writer Peter Jaret with technical information provided by two members of the Strategic Development Group.

Marina Mann, director of advanced information technology, joined the Institute in 1984 and had overall responsibility for development of the EPRINET information/communications network. She currently represents the interests of EPRI and the electric utility industry in the development of the National Information Infrastructure through participation in a number of government and private-sector organizations. Previously she served as vice president of central systems at Wells Fargo Bank and as vice president of computer systems at the Federal Reserve Bank of San Francisco. Earlier in her career, Mann worked in the international pharmaceutical industry, where she was responsible for scientific, manufacturing, and cost-accounting systems. She is a graduate of the University of New Mexico.

Ron Skelton, senior project leader for network engineering, is involved with the assessment and integration of information technology and telecommunications. Skelton joined EPRI in 1991. In the previous 20 years, he worked for Continental Telecom and for Aetna Life and Casualty, serving as director of information technology planning at each. In addition to having managed the planning, engineering, and implementation of state-of-the-art fiber-optic networks, Skelton pioneered the commercial use of digital microwave and switching systems in the United States. He has managed many projects using both terrestrial and satellite-based systems internationally. He earned a degree in communications engineering in England and is a chartered engineer in the UK. ■

Counting on Fish Protection (page 30) was written by Leslie Lamarre, *Journal* senior feature writer, with background information from two EPRI staff members.

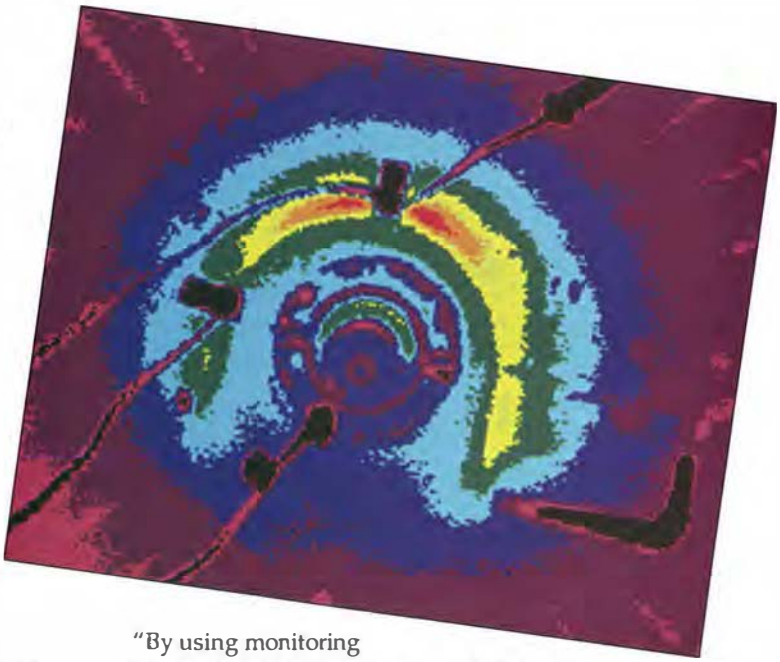
Chuck Sullivan, manager of hydro resources in the Generation Group's Renewables, Storage & Hydro Business Unit, came to EPRI in 1974 after two years as a mechanical engineer with the Reactor Systems Branch of the Nuclear Regulatory Commission. Before that, he was a mechanical engineer with Lawrence Livermore Laboratory for five years. He has BS and MS degrees in mechanical engineering from Arizona State University.

Jack Mattice, a manager with the Strategic Development Group's Environment & Health Business Unit, joined EPRI in 1981. He previously spent nine years on the research staff of the Environmental Sciences Division of Oak Ridge National Laboratory. He has a BS in biology from the State University of New York at Stony Brook and a PhD in invertebrate zoology from Syracuse University. ■

Motor Predictive Maintenance Cuts O&M Costs, Boosts Reliability

Electric motor maintenance at fossil power plants is typically based on vendor-recommended time-in-service intervals rather than actual motor conditions. Such an approach can lead to unnecessary maintenance and may not prevent unexpected motor failures. At PECO Energy Company's Eddystone station, engineers were looking for ways to reduce or eliminate unexpected motor failures when they teamed up with personnel from EPRI's Monitoring & Diagnostic (M&D) Center, which is located at the Philadelphia power plant.

Together, utility and M&D Center personnel explored the use of condition-based monitoring techniques. They subsequently developed a condition-based electric motor predictive maintenance (EMPM) program that uses field-proven monitoring technologies such as infrared thermography, current monitoring, and vibration analysis to assess motor conditions and detect potential problems. PECO Energy then tested electric motors at Eddystone with these technologies and integrated the results and maintenance histories in a computer database. The utility used the test results as the basis for decisions to defer motor maintenance or to make repairs as needed. As a result, PECO Energy reports that it was able to save on maintenance costs for some large motors while avoiding possible unexpected failures in the case of others. The utility estimates that the program will save $1 million over a five-year period.



"By using monitoring technologies at Eddystone, we can eliminate unnecessary time-based maintenance, focus our maintenance efforts on motors that need work, and increase motor reliability," says PECO Energy's John Yacyshyn. Other utilities can expect comparable results by operating EMPM programs like the one at Eddystone. Draft guidelines that can help other utilities set up their own motor monitoring programs are available from EPRI's M&D Center, which can be reached at (215) 595-8872.

■ *For more information, contact Richard Colsher, (215) 595-8870.*

NSP Saves Millions With Lightning Protection Design Workstation

In Northern States Power Company's service territory, many momentary customer outages are caused by lightning, particularly by strikes on or near NSP's 440 miles of unshielded 69-kV lines. To minimize construction costs, overhead shield wires were not included when the lines were built in the 1940s and 1950s—a time when lightning-caused outages were of less concern to customers than they are today. When NSP embarked on a project to reduce lightning-caused outages on these lines, the utility used EPRI resources to optimize the selection of alternatives to line reconstruction, for a one-time avoided-cost savings of as much as $45 million.

To verify company data linking lightning storms and outages, the utility used the Lightning Protection Design Workstation (LPDW) to tap the resources of EPRI's National Lightning Detection Network, which provided statistical records of lightning flash density over several years. Using these data and its own outage data, NSP determined the average annual lightning-caused outage rates for shielded and unshielded 69-kV lines in the Minnesota area and set out to reduce the outages on unshielded lines as part of an overall goal of a 30% reduction in feeder outages.

EPRI's LPDW software provided NSP the design tool it

needed for conducting an efficient evaluation of lightning protection options and for predicting their performance in the utility's service territory. LPDW lets users select tower or pole configuration and material, arrester configuration and rating, ground resistance value, and lightning flash density in calculating the number of lightning-caused outages on a line per year.

NSP used the software to evaluate four options: rebuilding a line with overhead shield wire; retrofitting a line with shield wire and neutral wire; installing one arrester assembly on every pole; and installing three arrester assemblies on every third pole. Ultimately, the utility installed single-arrester assemblies on 358 miles of 69-kV line and made other improvements to another 44 miles of line. A year of monitoring the lines during the lightning season showed that the ratio of lightning challenges to outages improved from 125:1 to 665:1, the degree of improvement predicted by LPDW.

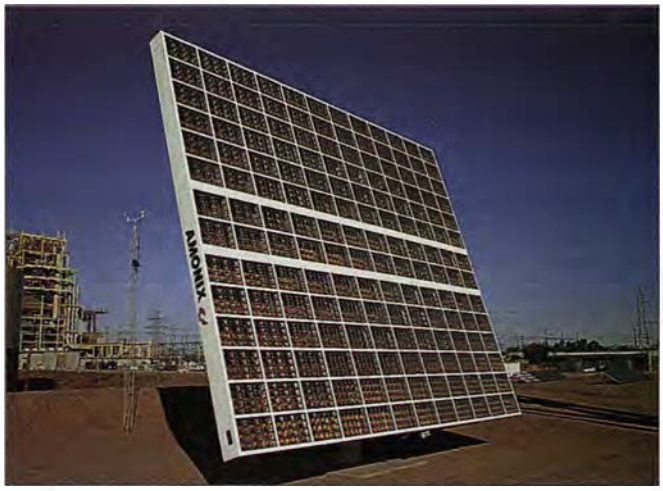
Over 200 users, including 100 utilities, are currently applying LPDW for distribution and subtransmission line design and improvement. An updated release of the software that incorporates both distribution and transmission lightning protection design capability entered beta testing in the second quarter of 1994. LPDW is available to EPRI members through the Electric Power Software Center, (800) 763-3772. Subscriptions to the National Lightning Detection Network are also available but are not necessary for operating LPDW. License agreements for access to the network are available through GeoMet Data Services, (800) 283-4557.

■ *For more information, contact Ralph Bernstein, (415) 855-2023.*

Milestones Reached by High-Concentration Photovoltaic System

Two milestones were reached recently in the progress of EPRI's integrated high-concentration photovoltaic (IHCPV) system to commercial reality. Late last year, the first commercial prototype of a full-size, 20-kW IHCPV array was installed by Amonix, Inc., the system's commercializer, at Arizona Public Service Company's STAR (Solar Test and Research) facility, located at the utility's Ocotillo power plant near Tempe (photo). Also last year, a 2-kW test-bed IHCPV array at Georgia Power Company's Shenandoah Environment and Education Center near Atlanta recorded a net solar energy conversion efficiency greater than 20%, the highest ever for a field-deployed PV array.

Additional demonstrations at utility test sites are planned for this year. In large-volume production, the IHCPV system is expected to be capable of generating electricity at a cost that is competitive with electricity generated by conventional



sources. EPRI and Amonix shared an R&D 100 Award last year for the high-efficiency cells used in the IHCPV system.

■ *For more information, contact Amonix, (310) 325-8091, or EPRI's Ed DeMeo, (415) 855-2159.*

Applied Science and Technology

Small-Punch Testing for Assessing Thick-Section Components

by Vis Viswanathan, Strategic R&D Business Unit

Because of embrittlement phenomena that occur during service, the material toughness of thick-section power plant components like turbine rotors and pressure vessels can decrease over time. As toughness is lost, tolerance to intrinsic and service-induced flaws and cracks is reduced, degradation can accelerate, and, in a worst-case scenario, unforeseen failure can occur through sudden, nearly instantaneous crack propagation.

In the case of turbine rotors, monitoring service-induced embrittlement is essential for ensuring component reliability and plant security. A highly cautious approach is taken because existing toughness assessment techniques rely on indirect calculations. If toughness loss is predicted, a utility may increase inspection frequency and may implement operational modifications like turbine prewarming. These and similar compensatory measures have proved highly effective in safely extending component life, but in many cases they may not be required and may add unnecessarily to utility costs. Faced with increasing competition and the need for tighter control of operating costs, utilities want more-accurate methods of measuring toughness and assessing embrittlement.

Characterizing toughness

The material fracture toughness parameter (K_{Ic}) indicates a material's resistance to fracture, which directly influences the tolerance of a component constructed of that substance to flaws or cracks. K_{Ic} typically varies with temperature: many materials become more brittle—and thus more likely to crack—under colder conditions. The practical consequence is that, as for car engines, warming up power plant components may help prevent damage and maximize useful life.

Standard methods of measuring K_{Ic} require large material samples and generally cannot be applied to operating equipment. For many power plant components, therefore, K_{Ic} has traditionally been determined by using a well-known empirical correlation with a related characteristic—fracture appearance transition temperature (FATT). This temperature is the point at which the fracture behavior of a material under impact changes from a brittle mode (below the FATT) to a tougher, ductile mode (above the FATT).

FATT measurement procedures entail the destructive testing of several bar-shaped Charpy specimens, which is time-consuming and can be impractical for in-service equipment. In practice, FATT predictions for most power plant components are based on highly conservative calculations. Several nondestructive alternatives have recently been developed, such as bulk-chemistry-based compositional correlation and grain-boundary-evaluation-based chemical etching, but these methods are also indirect and introduce considerable conservatism to K_{Ic} estimates. As a result, they do not help to reduce the high utility costs associated with overly cautious assessment procedures.

ABSTRACT *Service-induced material toughness loss can increase the failure potential of turbine rotors and other critical thick-section power plant components. Because conventional test methods for measuring toughness require large samples of component material, they are impractical for in-service equipment. Therefore, indirect toughness estimation techniques are often used. These techniques can be extremely conservative, leading to the adoption of unnecessarily protective operational restrictions or the premature replacement of equipment. EPRI-funded scientists have devised a new, essentially nondestructive test technique with promise for the direct measurement of component material toughness. The approach, based on mechanical punch-and-die testing of miniature specimens, has accurately assessed the toughness of several utility turbine and generator rotors. Current efforts are aimed at refining this small-punch technique and at extending it to the assessment of nuclear component radiation embrittlement.*

Small-punch testing

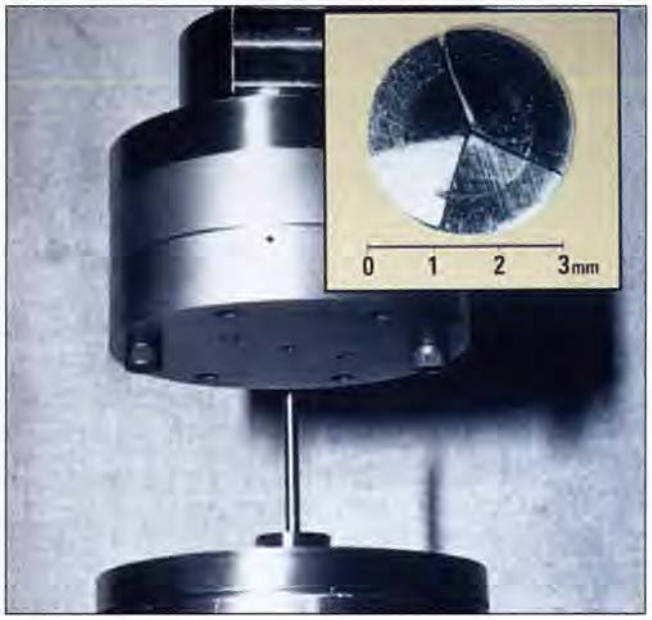
In a long-term R&D program, EPRI is sponsoring efforts by Failure Analysis Associates of Menlo Park, California, to devise a direct, more accurate means of assessing material toughness. The program is focused on small-punch (SP) testing, an essentially nondestructive miniature-specimen technique. This technique was first explored in the early 1980s as a material embrittlement screening tool for nuclear fission and fusion reactor applications, where small sample size is critical.

EPRI work began in 1990 with the development of an SP technique for determining FATT values for the NiCrMoV and CrMoV steels used in turbine rotors and disks (RP1957-10); this approach has been selectively demonstrated at a few fossil power plants. Research now focuses on applying the SP method to estimate K_{Ic} directly from test results (RP2426-38) and extending the method to assess the radiation embrittlement of nuclear reactor pressure vessels (RP8046-3).

As the first step in developing practical SP techniques, EPRI-funded researchers devised specialized punch-and-die equipment and procedures for testing miniature specimens up to 6.35 mm in diameter and 0.5 mm in thickness. About the size of shirt buttons and only a few pieces of paper thick, these disks can be removed from in-service components without compromising structural integrity. Figure 1 shows the punch apparatus and a brittle specimen after testing.

In experimental studies, researchers determined that, for a given material, a series of SP tests conducted at various temperatures provides a fracture energy–temperature curve similar in shape to a Charpy FATT curve. Both curves show that as temperature increases, a transition occurs from low fracture energy, which characterizes brittle behavior, to high fracture energy, which characterizes ductile behavior. On the basis of this similarity, the scientists were able to define an SP brittle-to-ductile transition temperature (T_{sp}) for a material from its SP curve.

Figure 1 In a newly developed nondestructive technique for assessing material toughness, a punch-and-die apparatus is used to test miniature specimens removed from in-service equipment. Shown here with the apparatus is a brittle specimen after testing. Through small-punch testing, utilities can obtain direct, accurate toughness measurements for turbine rotors and other thick-section components and can avoid the costly overconservatism often associated with conventional, indirect assessment methods.



The scientists assessed the correlation of SP transition temperatures with large-sample Charpy FATT values for a range of low-alloy ferritic steels. For this effort, they used samples from several retired CrMoV steel rotors for which FATT values had previously been determined by standard Charpy test procedures. By comparing the T_{sp} results for these samples with the FATT results, the researchers were able to show a direct empirical relation with a correlation coefficient of better than 0.94 (Figure 2).

Because the empirical T_{sp}-FATT relation may vary with material, however, researchers are developing a database of test results to progressively increase the accuracy of the correlation for common power plant alloys. To date, well-characterized relations have been determined for the CrMoV, NiCrMoV, and CrMo steels used in high- and intermediate-pressure (HP/IP) and low-pressure (LP) steam turbine components and in pressure vessels.

Practical SP testing has been facilitated by the recent development of small, remotely controlled sampling equipment. For example, the SSam-2™ system devised by Failure Analysis Associates allows sample collection from component locations having less than 8 cm of clearance, sufficient even for sampling the rotor bores of most turbines. About an hour is needed to acquire a sample, which can yield as many as four SP specimens. Figure 3 shows the SSam-2 in operation, removing samples from a turbine disk hub.

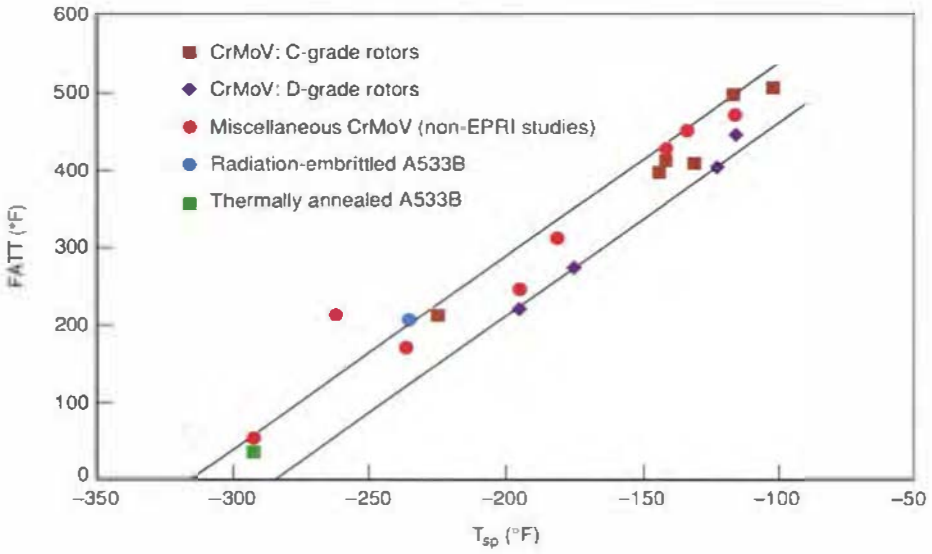
Applications of SP testing for FATT

EPRI researchers have worked with several utilities to demonstrate the SP technology on turbine and generator rotors at a number of fossil and nuclear plants. The results have indicated the overly conservative nature of conventional FATT assessment techniques and, in many cases, have allowed utilities to avoid unnecessary precautionary measures or equipment replacement. Data from these efforts have also been used in building the empirical database needed for general application of the technique.

The first utility application of SP analysis took place in 1990 on a CrMoV HP/IP steam turbine rotor at Centerior Energy Corporation's 256-MW Lake Shore Unit 18. This turbine, installed in 1962, had accumulated approximately 200,000 operating hours. On the basis of conservative calculations, the rotor manufacturer estimated the near-bore FATT to exceed 218°C and recommended prewarming and more-frequent inspection. Because these O&M modifications would compromise cost-effective turbine operation, Centerior wanted a direct evaluation of the rotor material's FATT.

EPRI-funded researchers collaborated with utility engineers to remove small samples from the rotor bore at four locations. SP testing on specimens that were cored from these samples revealed the near-bore FATT to be 77±56°C—lower than the worst-case value (163°C) calculated by an analysis based on bulk chemical composition and significantly lower than the manufac-

Figure 2 Results from EPRI-sponsored and other research on a variety of steels, including radiation-embrittled and thermally annealed types, show a good correlation between fracture appearance transition temperature (FATT), commonly used to characterize material toughness, and the brittle-to-ductile transition temperature (T_{sp}) obtained in miniature-specimen testing. This correlation indicates that small-punch analysis is a highly accurate means of determining component toughness.



turer's estimate.

A second SP study was conducted in 1991 on NiCrMoV LP turbine rotor disks at four 120-MW units operated by the Electricity Trust of South Australia. These disks, put into service between 1967 and 1971, had accumulated approximately 150,000 operating hours. Calculations by the turbine manufacturer indicated that FATT values could be as high as 125°C, a level at which—on the basis of experience at similar units—the majority of disks were considered to be at risk for catastrophic failure. To more accurately assess turbine conditions, the utility desired a direct FATT determination via sample removal and testing.

In the EPRI work, 69 samples were collected from 23 disks from three of the Australian units. (For the fourth unit, large-sample Charpy tests were conducted to develop the aforementioned empirical correlation between T_{sp} and FATT for NiCrMoV steel.) SP analysis revealed a FATT of 9±27°C for 19 of the disks, far lower than the manufacturer's conservative estimates and within the range of acceptable toughness for safe operation. The other four disks—two in each of two units—were found to have FATTs as high as the calculation-based estimates of 125°C.

Additional demonstrations of SP technology for FATT determination have been conducted on turbines or generators at four utility sites. In all instances, a component- and location-specific assessment of material toughness was obtained, thus enabling a more accurate and less conservative evaluation of component integrity than would have been possible using traditional approaches and assumptions regarding material properties. A comprehensive report describing SP fundamentals and utility applications (*Miniature Specimen Test Techniques for Estimating Toughness*, EPRI GS-7526) can be obtained from the EPRI Distribution Center at (510) 934-4212. Additional publications addressing the more recent advances in SP technology are planned.

Ongoing SP research

As a result of EPRI's pioneering efforts, SP testing is gaining recognition in this country and abroad as a valuable technique for measuring the toughness of many thick-section components. To make the SP technology even more useful to utilities, additional research has been initiated in two areas—direct correlation with K_{Ic} and evaluation of radiation embrittlement.

An analytically based interpretation of SP test results for estimating K_{Ic} has been developed in subsequent EPRI-funded work at Failure Analysis Associates. This research, initiated in 1992, has shown that fracture toughness estimates equivalent to conventionally measured values obtained

Figure 3 Compact, remotely controlled tools like the SSam-2 device (left) enable small material samples to be quickly obtained from turbine bores and disks (right) and other equipment in tight spaces, leaving only a smooth, shallow depression that does not compromise component structural integrity.

by destructive testing of large specimens can be made directly from a single SP test on a miniature specimen. SP test results provide estimates of K_{Ic} accurate to within 25% (better than estimates obtained through FATT-K_{Ic} correlations), as well as estimates of uniaxial stress-strain behavior to within 5% of stress. The method has been demonstrated to be applicable to nuclear reactor vessel material (A533B) and several forged steels (including CrMoV and NiCrMoV) used in steam turbines.

Compared with traditional FATT-based methods and other, recently devised indirect techniques, this direct approach for determining K_{Ic} significantly enhances the accuracy of toughness estimation. As a result, more-accurate flaw tolerance assessments are possible for in-service components, enabling a reduction of the excessive conservatism associated with some power plant operations. The technique is beginning to be used for turbine and generator rotors in fossil plants. A final report detailing the test and analysis procedures will be issued in the first quarter of this year.

Radiation embrittlement, like other forms of toughness loss, is typically characterized by a change in FATT and K_{Ic}, and existing evaluation methods are indirect and conservative. In EPRI-sponsored work, Failure Analysis Associates is collaborating with the Westinghouse Science & Technology Center to demonstrate the feasibility of SP testing for irradiated nuclear plant reactor vessel steels. Preliminary results for samples from previously well-characterized material that has been irradiated—and, in some cases, thermally annealed—indicate that SP methods can be applied to these materials and that previously developed T_{SP}-FATT correlations are relevant. As more data are developed and confidence in the technique grows, it will be possible to use SP testing to maximize the information obtained from nuclear reactor surveillance capsule samples. Ultimately, the technique may provide a means for in-service assessment of radiation embrittlement in pressure vessels.

EPRI's comprehensive research program has shown that SP testing provides direct, accurate FATT estimates for in-service and irradiated components, eliminates the excessive conservatism associated with conventional methods, and, for the first time, offers an accurate, nondestructive means of determining the fundamental toughness parameter K_{Ic}. Once it is in widespread use, SP testing is expected to significantly reduce utility O&M costs and improve run-retire decision making for critical plant components.

Air Quality

Tropospheric Ozone Research

by D. Alan Hansen, Environment & Health Business Unit

Title I of the 1990 Clean Air Act Amendments (CAAA) includes an aggressive program to bring the historically resistant urban ozone problem under control. For nonattainment areas—that is, areas that do not meet the National Ambient Air Quality Standard for ozone—it mandates control measures for emissions of nitrogen oxides (NO_x) and volatile organic compounds (VOCs), the photochemical precursors of ozone. The greater an area's noncompliance with the standard, the more stringent the control measures. However, the length of time an area is given to meet the standard also increases with the severity of its noncompliance. An area is considered to be out of compliance if the 1-hour average ozone concentration measured at monitoring stations exceeds 120 ppb four times in three years. Table 1 shows the noncompliance levels and the compliance deadlines.

Title I places a much stronger emphasis on NO_x control than did earlier legislation, whose emphasis on VOC controls has come to be viewed as only partially effective. This new emphasis on NO_x places fossil fuel power plants on center stage because they contribute a significant fraction of the total NO_x emissions nationally.

A unique—and initially viewed as enlightened—feature of the 1990 CAAA is the stipulation that nonattainment areas classified as serious or worse must demonstrate

ABSTRACT *EPRI is dealing with the issue of ozone nonattainment on several fronts, including research on tropospheric ozone. This research consists of a balanced, highly leveraged mixture of field, laboratory, and modeling studies. The goal is to produce data and tools that will help clarify the role of power plant emissions in tropospheric ozone production and fill in key knowledge gaps hindering our ability to respond effectively to the nonattainment problem.*

TABLE 1
Ozone Nonattainment Levels and Deadlines

Area Classification	*Noncompliance Level (ppb)**	*Compliance Deadline*
Marginal	121–137	November 15, 1993
Moderate	138–159	November 15, 1996
Serious	160–179	November 15, 1999
Severe	180–279	November 15, 2005
Extreme	280 and above	November 15, 2010

*An area is out of compliance when its 1-hour average ozone level exceeds 120 ppb four times in three years. The noncompliance level corresponds to the fourth-highest value measured in those three years.

that their proposed emissions controls will attain the standard, "based on photochemical grid modeling or any other analytical method determined by the Administrator . . . to be at least as effective." In practice, all serious and worse nonattainment areas have opted to rely on photochemical grid modeling for such demonstrations. Initially, photochemical grid models (PGMs) were widely considered by the technical community to be the most scientifically credible tools for assessing air quality. Once these modeling efforts were launched, however, users and observers became increasingly aware of the imprudence of relying so heavily on PGMs without adequate data to support their use.

Photochemical grid models

Modern PGMs, the culmination of over 20 years of research and development, numerically represent the meteorological and chemical processes involved in the production of tropospheric ozone in a fixed (Eulerian) reference frame. The atmosphere is divided vertically and horizontally into a grid of boxes between which pollutants and their chemical products are moved by diffusion and transport. Emissions and such meteorological variables as sunlight, wind, and temperature serve as input to the models. PGMs currently are the only tools we have for predicting with a modicum of confidence the air quality that will result from given emissions changes.

PGMs are very complex. They include representations of thermal and photochemical reactions among dozens of species; horizontal and vertical air movements; and deposition on surfaces. Some of the more advanced models also simulate the effects of clouds and aerosol dynamics.

All PGMs rely on complex meteorological and emissions models to provide the inputs necessary for their operation. Each of these models has uncertainty in its formulations and in its inputs: the numerical algorithms are generally approximations of the natural processes; the processes are intrinsically averaged over the volume of a grid cell; undetected errors occur; and many inputs are merely best estimates. These uncertainties can be characterized only through careful evaluation of the models and their components, using observational data, other models, and our best scientific understanding of the relevant processes. If these uncertainties are not characterized, their cumulative effect and the degrees of freedom allowed by the models' complexity can cause the simulations to diverge in unknown ways from the real world.

Although virtually mandating the use of PGMs, the 1990 CAAA did not also mandate the acquisition of more-accurate emissions estimates or the collection of three-dimensional atmospheric data necessary for reliable inputs to the models and for their rigorous evaluation. Nor did the CAAA provide resources to the states should they want to collect these essential pieces of information. Thus many states have been put in the untenable situation of having to rely on PGMs to demonstrate ozone attainment without knowing what confidence they can place in the demonstrations. The implications for the electric utility industry are obvious: costly, overly stringent NO_x emissions controls may be required by the states in order to err on the side of caution.

EPRI's response

EPRI is dealing with the issue of ozone nonattainment on several fronts: advancing technology for controlling NO_x emissions, improving our understanding of the role that power plant NO_x emissions play in the production of tropospheric ozone, and developing innovative risk management tools. The Institute's initial work on ozone actually preceded the 1990 CAAA. Because EPRI conducts its research on tropospheric chemistry and physics in a holistic way, it has had the capability to address the ozone nonattainment issue at a state-of-the-science level. As the issue heated up, EPRI simply focused its research more sharply on the development of information and tools to address it more directly.

The Institute's work on ozone per se began in about 1985 with involvement in the initial planning of the Southern California Air Quality Study (SCAQS). Since then, EPRI has designed a program to attack the problem of tropospheric ozone in a concerted manner in six areas:

- Improving the modeling technology
- Improving the scientific underpinnings of models
- Acquiring data sets for the development, application, and evaluation of models
- Evaluating models
- Developing independent methods for corroborating model inputs and outputs
- Delivering results when and where they will be most effective

As a result, EPRI is involved in a variety of projects, many of them collaborations with other organizations, including tailored collaboration or cofunding with EPRI member utilities. Each project focuses on one or more of the six areas; examples will be described below. (Table 2 shows the studies with both data collection and modeling components in which EPRI has participated or is participating.) The Institute's goals are to identify and reduce the sources of uncertainty in current air quality management models, develop improved models and corroborative methods, and ensure that all these tools are used in the most effective way practically achievable.

Recently EPRI has worked closely with the U.S. Environmental Protection Agency and the National Oceanographic and Atmospheric Administration (NOAA) to form a broad coalition of governmental, industrial, academic, and environmental organizations across our continent called the North

American Research Strategy for Tropospheric Ozone (NARSTO). Designed to continue for a decade, the coalition has among its aims the timely production of useful and scientifically credible assessment tools and guidance for the air quality policy and management communities. Essentially all of EPRI's tropospheric-ozone-related research is now being planned and conducted under the NARSTO umbrella.

TABLE 2
Field Measurement and Modeling Studies

Study	*Dates*
SCAQS (Southern California Air Quality Study)*	1987
EMEFS (Eulerian Model Evaluation and Field Study)*	1988–1990
SJVAQS/AUSPEX (San Joaquin Valley Air Quality Study/Atmospheric Utility Signatures: Predictions and Experiments)*	1990
LMOS (Lake Michigan Ozone Study)	1991
SOS (Southern Oxidants Study)*	1992–
COAST (Coastal Ozone Assessment for Southeast Texas)	1993
NEAQS (Northeast Air Quality Study)*	1994–

*Funded jointly with EPRI member utilities.

Improving modeling technology

EPRI is a key player in two initiatives aimed at providing advanced modeling systems for use by regulators, researchers, and policy analysts: the SJVAQS/AUSPEX Regional Model Adaptation Project, or SARMAP, and the Consortium for Advanced Modeling of Regional Air Quality, or CAMRAQ. Both are collaborative efforts sponsored in partnership with regulatory agencies, electric utilities, and other industrial organizations.

SARMAP has the immediate goal of developing a modeling system that minimizes many of the problems identified with earlier-generation models: oversimplified meteorology, too coarse spatial resolution, and overly gross estimates of emissions strengths and distributions. The SARMAP modeling system—made up of emissions (GEMAP), meteorological (MM5), and air quality (SAQM) subsystems—was used by California in preparing its 1994 state implementation plan for ozone compliance and is undergoing further systematic evaluation and refinement. It may well be the most sophisticated modeling system of its type and should be available soon for general use.

CAMRAQ (the subject of a research update in the October/November 1992 *EPRI Journal*) is an international consortium of governmental and private-sector research organizations dedicated to the collaborative development of a comprehensive modeling system (CMS) for air quality that will be faster, easier to use, more versatile, and more accessible than anything in existence today. The design of the framework for such a CMS is under way. Although the development program is envisioned to last a decade or longer, key elements of the design are planned for implementation later this year or early next year. With this system, it will be possible to examine ozone impacts in the context of virtually all other air-quality-related impacts.

A still-open question in model development in general is whether it is important to simulate the dispersion of power plant plume NO_x realistically in PGMs in order to obtain a reasonable assessment of its influence on downwind ozone production. This question is being addressed in two efforts: a field measurement component in the 1995 Nashville Intensive of SOS and a modeling component in SARMAP.

Improving scientific understanding

In cosponsoring SOS, EPRI is helping to improve the scientific foundation of air quality models. SOS projects are focusing on clarifying the exchange of materials between urban and rural atmospheres; the influence of power plant plumes, vertical mixing, and long-term chemical climatological patterns on ozone episodes; and the role of the atmospheric free radical pool, oxygenated VOCs, biogenic hydrocarbons, soil NO_x, and lightning-induced NO_x in ozone production. All these efforts rely on observations in the natural environment, with interpretation facilitated by modeling.

Some information is best gathered in the laboratory. This is exemplified by the chemical kinetic and mechanistic studies EPRI is cosponsoring with the Empire State Electric Energy Research Corporation at the atmospheric pressure discharge flow facility at Harvard University. This unique facility is being used to study the photochemical oxidation of biogenic and aromatic VOCs, a topic not adequately treated in PGMs.

Collecting data sets

EPRI has been a partner in the collection of, and therefore has ready access to, most of the enhanced field data sets now used for in-depth ozone assessments in connection with model development, evaluation, and application (see Table 2). Collectively, these data sets provide an invaluable resource not only for modeling but also for empirical corroborations of emissions inventories and analyses of the factors controlling ozone episodes.

EPRI has supported this large and diverse group of data collection efforts for several reasons. First, in addition to their value for advancing the modeling and interpretive sciences, the efforts each have had valuable distinctive benefits. For example, in 1994 NEAQS provided crucial information on the structure of the planetary boundary layer to support more-definitive modeling. Second, EPRI believes that PGMs can be applied to a particular geographic domain only after they have been thoroughly evaluated with data from that domain; therefore, it feels that it can best serve its members in affected domains by making sure that the most credible modeling exercises practicable are conducted there. Third, valuable insights into model performance are gained through comparative analysis of results from many domains. Finally, in each effort, EPRI has been able to leverage its investment through collaborative arrangements with other sponsors.

Evaluating models

Several of the studies that have strong data collection components also have substan-

tial resources devoted to model evaluation. For example, SCAQS researchers have evaluated the Caltech Airshed Model and a version of the Urban Airshed Model (UAM-IV); EMEFS researchers, the Regional Acid Deposition Model (RADM) and the Acid Deposition and Oxidant Model; and LMOS researchers, UAM-V. Also, SOS researchers have evaluated or plan to evaluate UAM-IV, UAM-V, RADM, the Regional Ozone Model, and the NOAA Regional Oxidants Model. And COAST data are expected to be used in evaluating UAM-IV and UAM-V. The relatively comprehensive nature of the data sets from these studies should, in principle, support commensurately comprehensive model evaluations, limited only by the time and resources available. Further, EPRI's partners in the Cooperative Regional Model Evaluation, or CReME, project are comparing the performance of UAM-IV, UAM-V, and SAQM against the LMOS data set.

Until there are relatively comprehensive emissions, air quality, and meteorological data for the Northeast, an EPRI-developed method is available for estimating the uncertainty in the currently modeled response of ozone to changes in VOC and NO_x emissions. At present, there is no other basis for estimating this uncertainty. In the EPRI method, a series of scenarios is constructed by using model parameter values that span the parameters' uncertainty ranges. Then the differences in ozone response to the emissions changes in the scenarios are analyzed. This method should provide information essential for near-term emissions control policy decision analyses.

Corroboration methods

In this area of the EPRI program, researchers are developing independent methods of corroborating model inputs and outputs. One example of these methods is the use of factor analysis of observational data to independently check the relative contributions of VOC source types as represented in the emissions inventory. Another example is the use of observational data in empirical models to check the guidance provided by PGMs with respect to VOC versus NO_x controls.

These types of methods are being employed in COAST, NEAQS, SARMAP, and SOS. The effect of using a broad spectrum of analysis and assessment methods is to build confidence in the validity of the policy choices that must be made.

Delivering results

The final area of EPRI's program focuses on effective delivery methods, which differ according to audience and client. The scientific community generally places the highest priority on information dissemination through the peer-reviewed literature. Authors associated with EMEFS, SARMAP, and SOS, for example, have produced dozens of papers and articles, greatly expanding our knowledge of ozone dynamics on regional, local, episodic, and climatological scales.

When the intended audience is the policy or regulatory community, EPRI has found that the best way to ensure timely and serious consideration of the results is to include the community in the planning, oversight, and often even the management of the studies. This has occurred with CReME, NEAQS, SARMAP, and SOS, for example.

EPRI has taken a similar approach with its utility clients by forming partnerships with them on CReME, NEAQS, SARMAP, and SOS. EPRI also uses the more traditional methods of delivering results through reports, presentations, seminars, and workshops.

From the beginning, EPRI has conducted a program of research aimed at clarifying the role of utility emissions in tropospheric physics and chemistry. It has responded rapidly to the ozone issue by focusing its tropospheric research on knowledge gaps that are hindering the development of effective solutions to the ozone nonattainment problem. By leveraging its resources, EPRI has developed a broad tropospheric ozone program that includes data collection, data analysis, model development, and model evaluation. The information and tools emerging from this program have provided and will continue to provide a more useful and reliable capability for managing ozone nonattainment.

New Technical Reports

Requests for copies of reports should be directed to the EPRI Distribution Center, 207 Coggins Drive, P.O. Box 23205, Pleasant Hill, California 94523; (510) 934-4212. There is no charge for reports requested by EPRI member utilities. Reports will be provided to others in the United States for the price listed or, in some cases, under the terms of a license agreement. Those outside the United States should contact the Distribution Center for price information.

CUSTOMER SYSTEMS

Engineering Methods for Estimating the Impacts of Demand-Side Management Programs, Vol. 3: Six Case Studies
TR-100984-V3 Final Report (RP3269-3); $200
Contractors: Architectural Energy Corp.; RCG/Hagler, Bailly, Inc.
EPRI Project Managers: R. Gilman, P. Hummel

Electroosmotic Removal of Nitrates From Soils
TR-102687 Final Report (RP2782-4); $200
EPRI Project Managers: A. Amarnath, O. Zimmerman

Proceedings: 1992 Electric Thermal Storage (ETS) and Thermal Energy Storage (TES) Conference
TR-103729 Proceedings (RP2731-11); $200
Contractors: Policy Research Associates, Inc.; Lockwood & Associates
EPRI Project Manager: J. Kesselring

The Rate Effects of Including Environmental Externalities in Electric Utility Resource Planning
TR-103910 Final Report (RP3084-5); $200
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EPRI Project Managers: P. Sioshansi, V. Niemeyer

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EPRI Project Managers: B. Banerjee, K. Vejtasa

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TR-104265 Proceedings (RP3337-6); $200
Contractor: Barakat & Chamberlin, Inc.
EPRI Project Manager: G. Helfner

Comparing Software Models for Screening and Evaluating DSM Programs
TR-104346 Final Report (RP2982-19); $200
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EPRI Project Manager: P. Sioshansi

Proceedings: Sixth Biennial Marketing Research Symposium
TR-104558 Proceedings (RP2581); $200
Contractor: Synergic Resources Corp.
EPRI Project Managers: M. Evans, T. Henneberger

GENERATION

Causes of FGD Construction Materials Failures, Vol. 3: January 1987–May 1993
GS-6396-V3 Final Report (RP2248-2); $5000
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EPRI Project Manager: P. Radcliffe

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TR-103474 Final Report (RP3456-1); $5000
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EPRI Project Manager: J. Tsou

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EPRI Project Manager: E. Davis

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TR-103940 Final Report (RP3455-1); $10,000
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TR-104152 Final Report (RP2626); $10,000
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EPRI Project Manager: J. Stein

Boiler Feedpump Operation and Maintenance Guidelines, Vols. 1 and 2
TR-104292-V1, TR-104292-V2 Final Report (RP1884-23, -28); $10,000 for set
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EPRI Project Manager: T. McCloskey

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EPRI Project Manager: D. Rastler

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TR-104409 Final Report (RP2422-18); $5000
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EPRI Project Manager: D. Golden

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EPRI Project Manager: R. Rhudy

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EPRI Project Manager: R. Rhudy

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EPRI Project Manager: C. Lin

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EPRI Project Managers: C. Stepp, J. Kessler

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EPRI Project Manager: C. Hornibrook

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TR-104401 Final Report (RP3800-16); $20,000
EPRI Project Manager: C. Hornibrook

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EPRI Project Manager: R. Thomas

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EPRI Project Manager: S. Chapel

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TR-104227-V1–V5 Final Report (RP2675-1); Vol. 1, $200; Vols. 2–5, $5000 for set
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EPRI Project Managers: S. Nilsson, S. Wright

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EPRI Project Manager: R. Kavet

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Contractor: Woodlis Associates
EPRI Project Manager: R. Brocksen

Proceedings: Health Implications of EMF—Neural Effects Workshop
TR-104327 Proceedings (RP2965-99, RP2964-6); $200
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EPRI Project Manager: C. Rafferty

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EPRI Project Manager: J. Stringer

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Contractor: Clay Whitehead Associates
EPRI Project Manager: R. Skelton

New Computer Software

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CAT Workstation™: Clean Air Technology Workstation
Version 2.0 (PC-DOS)
Developer: Sargent & Lundy
EPRI Project Manager: Richard Rhudy

EMWorkstation: EPRI Electric and Magnetic Fields Workstation
Version 2.0 (PC-DOS)
Developer: Enertech Consultants
EPRI Project Manager: Rich Lordan

ETADS/ETADSEZ: EPRI Tower Analysis and Design System
Version 2.3 (PC-OS/2)
Developer: Sverdrup Technology
EPRI Project Manager: Paul Lyons

GATE/CYCLE: Gas Turbine Evaluation Code
Version 4.03 (PC-DOS)
Developer: Enter Software, Inc.
EPRI Project Manager: George Quentin

GENCAT™: Electronic Product Catalog and Benefits Estimator (Generation, Storage, and Environmental Control)
Version 2.0 (PC-DOS)
Developer: Decision Focus Inc.
EPRI Project Manager: Ruseli Owens

IGSCC REPORTS: Intergranular Stress Corrosion Cracking
Version 1.0 (CD-ROM)
Developer: Electric Software Products
EPRI Project Manager: Joe Gilman

Micro-AXCESS: Building Energy Analysis Program
Version 10.2E (PC-DOS)
Developer: James J. Hirsch & Associates
EPRI Project Manager: Karl Johnson

RESICALC: Magnetic Field Modeling Program
Version 2.0 (PC-DOS)
Developer: Enertech Consultants
EPRI Project Manager: Robert Kavet

SW*COR™: Materials Selection, Corrosion Failure Analysis, and Corrosion Countermeasures in Service Water Systems
Version 1.0 (PC-DOS)
Developers: National Institute of Standards and Technology; National Association of Corrosion Engineers
EPRI Project Manager: Barry Syrett

TLWorkstation™: Transmission Line Workstation
Version 2.4 (PC-DOS)
Developer: Power Computing Co.
EPRI Project Manager: Anwar Hirany

UCA/DAIS™: Utility Communications Architecture/Database Access Integration Services
Version 1.0 (CD-ROM)
Developer: Electric Software Products
EPRI Project Manager: William Blair

VISIRISK: Visibility Risk Management Framework
Version R1.1 (PC-DOS)
Developer: Applied Decision Analysis
EPRI Project Manager: Hung-Po Chao

VSTAB: Voltage Stability
Version 2.2 (DEC-ULTRIX; DEC-VMS; RS6000-AIX, Sun-UNIX)
Developer: Ontario Hydro
EPRI Project Manager: Dominic Maratukulam

EPRI Events

MAY

3–5
Continuous Emissions Monitoring Users Group Meeting
Atlanta, Georgia
Contact: Linda Nelson, (415) 855-2127

8–10
13th International Conference on Fluidized-Bed Combustion
Orlando, Florida
Contact: Ellen Petrill, (415) 855-8939

8–11
4th International Conference on Power Quality: Applications and Perspectives—PQA '95
New York, New York
Contact: Lori Adams, (415) 855-8763

8–12
Transmission Line Foundations
Binghamton, New York
Contact: Denise O'Toole, (415) 855-2259

9–11
Energy Storage Benefits Workshop
St. Louis, Missouri
Contact: Denise O'Toole, (415) 855-2259

10–12
Seminar on Resource Planning in a Competitive Environment
Minneapolis, Minnesota
Contact: Lynn Stone, (214) 556-6529

15–19
Joint Symposium on Stationary Combustion NO_x Control
Kansas City, Missouri
Contact: Susan Bisetti, (415) 855-7919

25
Risk Analysis of Surface Water Quality and Thermal Issues
Irving, Texas
Contact: Bob Goldstein, (415) 855-2593

JUNE

1–2
Analysis of Regional Ozone and Visibility Issues in a Risk Framework
Dallas, Texas
Contact: Lynn Stone, (214) 556-6529

6–7
Decision Analysis for Environmental Risk Management
Dallas, Texas
Contact: Bob Goldstein, (415) 855-2593

7–9
3d Joint GRI/EPRI Seminar on Manufactured Gas Plant Issues
Chicago, Illinois
Contact: Ishwar Murarka, (415) 855-2150

12–14
2d International Conference on Arsenic Exposure and Health Effects
San Diego, California
Contact: Janice Yager, (415) 855-2724

13–15
5th EPRI Valve Symposium
Albuquerque, New Mexico
Contact: Susan Otto, (704) 547-6072

19–21
ISA POWID/EPRI Controls and Instrumentation Conference
San Diego, California
Contact: Lori Adams, (415) 855-8763

19–21
Technology Delivery Workshop
San Francisco, California
Contact: Susan Bisetti, (415) 855-7919

22–23
EPRI Partnership for Industrial Competitiveness
San Francisco, California
Contact: Bill Smith, (415) 855-2415

26–27
Integrated Resource Planning: From Regulatory to Business-Driven Strategies
Dallas, Texas
Contact: Lynn Stone, (214) 556-6529

26–27
Pricing in the 1990s: Meeting Challenges and Creating Opportunities in a Competitive Environment
Dallas, Texas
Contact: Lynn Stone, (214) 556-6529

28–30
7th National Demand-Side Management Conference
Dallas, Texas
Contact: Pam Turner, (415) 855-8900

JULY

10–12
Low-Level-Waste Conference
Orlando, Florida
Contact: Linda Nelson, (415) 855-2127

12–14
EPRI/ASME Radwaste Workshop
Orlando, Florida
Contact: Linda Nelson, (415) 855-2127

12–14
Steel Mill Workshop
Chicago, Illinois
Contact: Susan Bisetti, (415) 855-7919

18–22
5th International Conference on Batteries for Utility Energy Storage
San Juan, Puerto Rico
Contact: Kathleen Lyons, (415) 855-2656

AUGUST

10–11
Pricing in the 1990s: Meeting Challenges and Creating Opportunities in a Competitive Environment
Boston, Massachusetts
Contact: Lynn Stone, (214) 556-6529

15–18
Particulate Control/Managing Hazardous Air Pollutants
Toronto, Canada
Contact: Lori Adams, (415) 855-8763

22–23
Tools for Ecological Risk Assessment
Irving, Texas
Contact: Susan Dyroff, (516) 751-4350

29–31
PCB Seminar
Boston, Massachusetts
Contact: Linda Nelson, (415) 855-2127

SEPTEMBER

25–26
Feedwater Heater Technology Seminar
Kansas City, Missouri
Contact: Linda Nelson, (415) 855-2127

27–29
Feedwater Heater Technology Symposium
Kansas City, Missouri
Contact: Linda Nelson, (415) 855-2127

27–29
Forecasting in a More Competitive Environment
New Orleans, Louisiana
Contact: Lori Adams, (415) 855-8763

28
Risk Analysis of Surface Water Quality and Thermal Issues
Palo Alto, California
Contact: Bob Goldstein, (415) 855-2593

OCTOBER

4–6
Biodiversity and Ecosystem Health
Jackson Hole, Wyoming
Contact: Pam Turner, (415) 855-2010

5–6
Decision Analysis for Environmental Risk Management
Palo Alto, California
Contact: Mimi Warfel, (415) 926-9227

10–12
Retail Market Management
Atlanta, Georgia
Contact: Susan Bisetti, (415) 855-7919

18–20
1995 Fuel Supply Seminar
New Orleans, Louisiana
Contact: Susan Bisetti, (415) 855-7919

25–27
Gasification Power Plants Conference
San Francisco, California
Contact: Linda Nelson, (415) 855-2127

NOVEMBER

1–3
Seminar on Resource Planning in a Competitive Environment
Dallas, Texas
Contact: Lynn Stone, (214) 556-6529

6–8
Radiation Field Control Conference
Tampa, Florida
Contact: Lori Adams, (415) 855-8763

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