# Physical Constraints to Open Access

*Also in this issue • Nuclear Plant Maintenance • Membrane Technologies • Hydronic Heat Pumps*

ELECTRIC POWER RESEARCH INSTITUTE

EPRI JOURNAL

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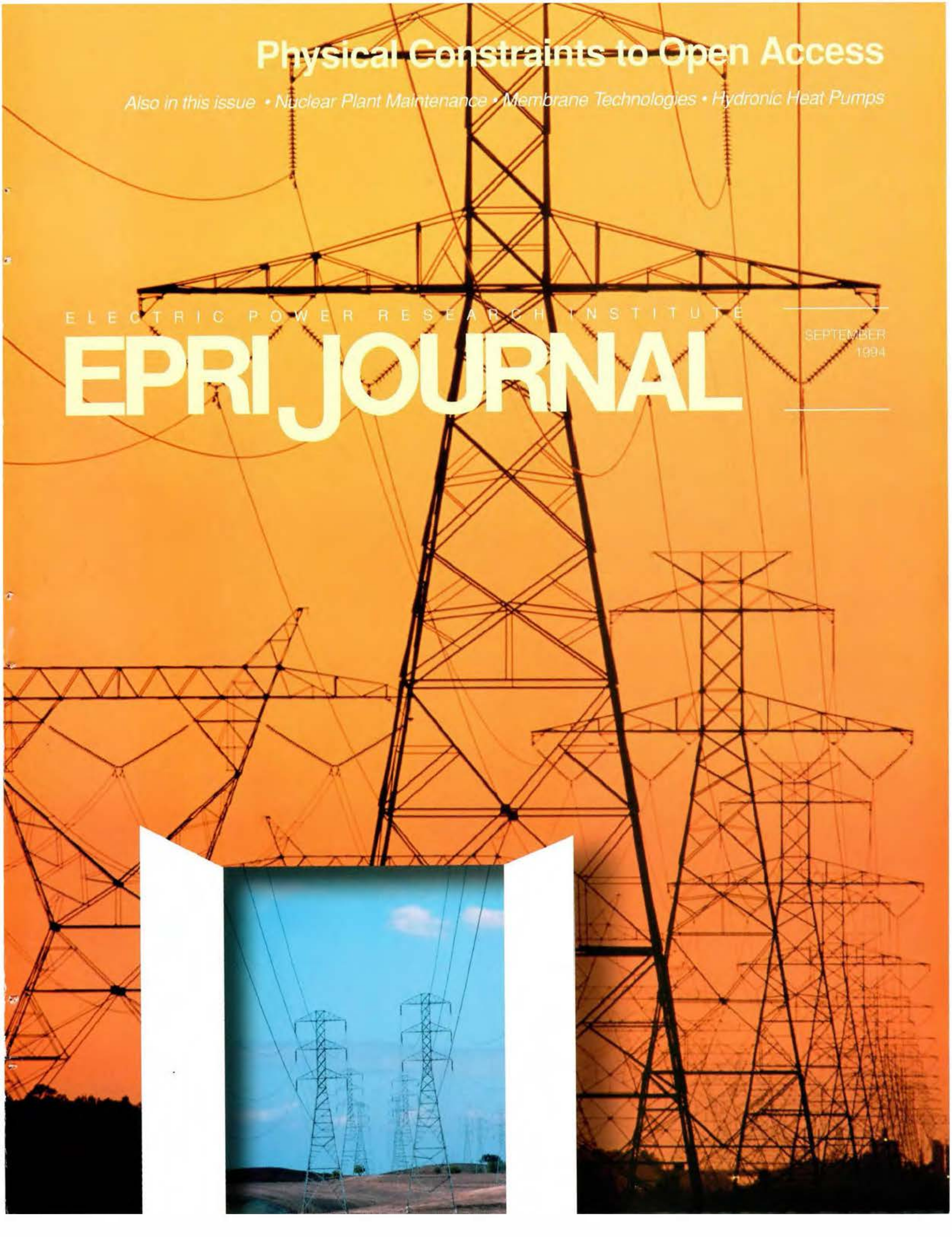

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Cover: Federal regulations are opening the doors wide for third-party access to utility transmission lines. But can existing power delivery systems handle the additional traffic?

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## COVER STORY



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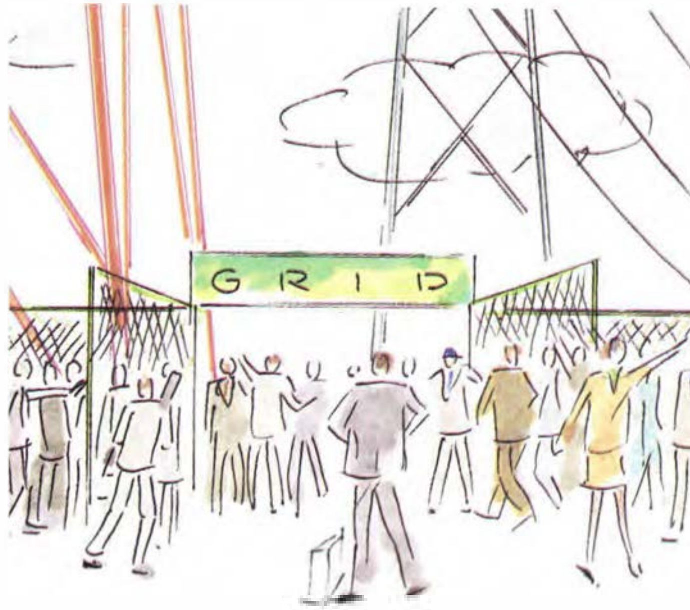


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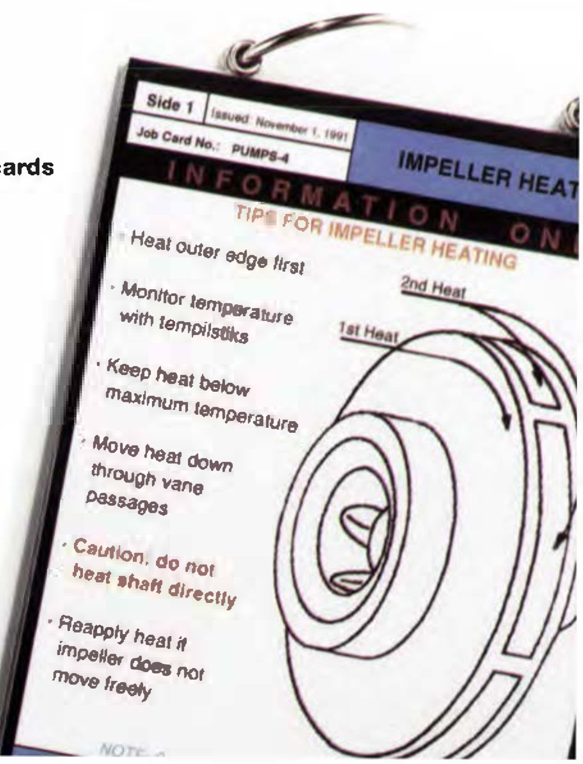
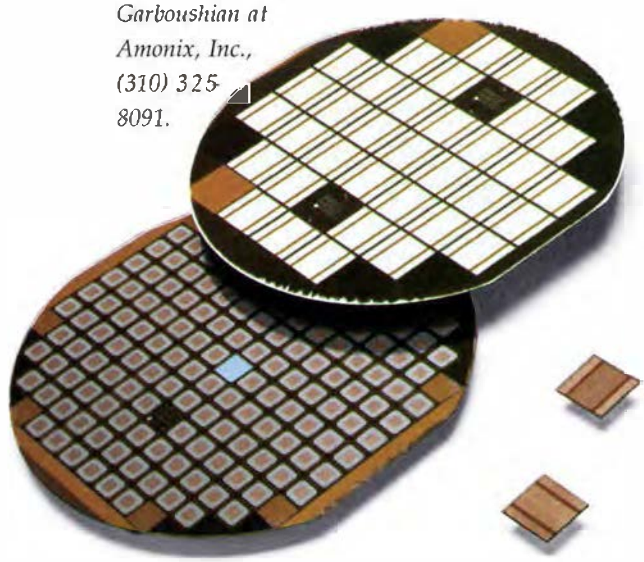



**24 Job cards**

EPRI-sponsored products won a record number of R&D 100 Awards this year. The awards are bestowed by *R&D Magazine*, which assembles a panel of scientific experts for its annual competition. The experts select 100 new products from around the world that they consider to be the year's most technologically significant. Past winners include the video recorder and the fax machine.

## High-Performance Silicon Solar Cell

This advanced photovoltaic cell holds the world's record for efficiency in a silicon-based cell—26%. The cell is appropriate both for concentrator applications, which employ either mirrors or lenses to increase the intensity of the light directed onto the cells, and for smaller, 1-sun applications, in which individual cells absorb sunlight directly. Utilities are expected to be the principal users of this new technology. However, the 1-sun applications—for example, in satellites and mobile power supplies—may help create additional business opportunities.
*For more information, contact Frank Goodman, (415) 855-2872. To order, call Dick Swanson at SunPower Corporation, (408) 991-0908, or Vahan Garboushian at Amonix, Inc., (310) 325-8091.*




## Soft Trencher

Installing underground transmission and distribution cables is safer with EPRI's new Soft Trencher. The trencher uses supersonic air jets to break up soil without harming existing gas, water, phone, or power lines. The machine excavates dirt continuously; as the air jets loosen the soil, a high-power vacuum system removes it, along with rocks as big as 7 inches in diameter and sticks up to 18 inches long. For a better view, the operator can stand alongside the machine, operating it from a tethered remote-control panel. The Soft Trencher can dig trenches up to 10 feet deep and 6 feet wide.
*For more information, contact Tom Rodenbaugh, (415) 855-2306.*

## Low-$NO_x$ Cell Burner

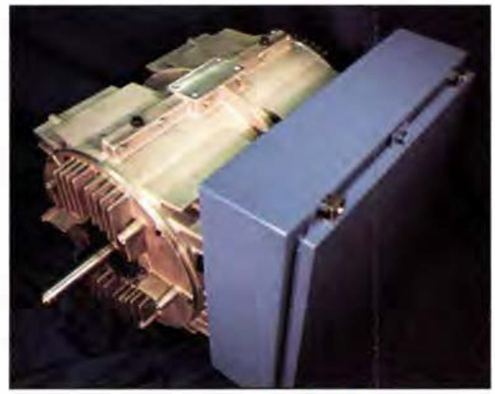
Now utilities with coal-fired cell burners have a reliable and cost-effective option for reducing emissions of nitrogen oxides. Specially developed for retrofitting, the low-$NO_x$ cell burner cuts $NO_x$ emissions by more than 50%. The technology is designed to plug directly into existing cell burners, so it is relatively easy to install and requires no additional openings. Among other benefits, it reduces boiler operating problems, does not increase carbon monoxide emissions, and does not degrade combustion efficiency. Since its introduction early in 1993, the low-$NO_x$ cell burner has been installed on about 1200 MW of capacity.

*For more information, contact David Eskinazi, (202) 293-7515. To order, call Jane Piepho at Babcock & Wilcox Company, (216) 860-6246.*

## Battery-Monitoring System

Emergency power will become more reliable with EPRI's new system for monitoring large banks of lead-acid batteries. Whether the batteries are used as backup power for computers or for protection and control equipment on the utility grid, this system offers reduced maintenance hours, improved power availability, and increased battery life (averaging 25% for a typical installation). Recording data from sensors strapped to individual battery cells, the personal computer–based system plots trends in each cell's performance and provides detailed information on parameters—such as the state of charge, current-path integrity, and liquid levels—that are not covered by other available monitoring systems.

*For more information, contact Ben Damsky, (415) 855-2385.*



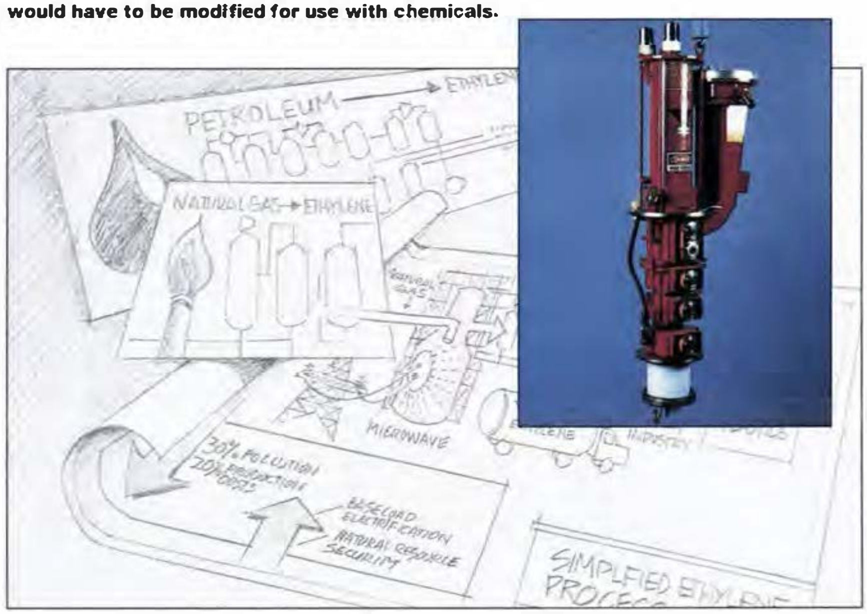
## Single-Phase Motor

At 40 horsepower, this is the world's largest single-phase motor. It's also the most efficient (more than 94%). Designed primarily for rural applications, such as irrigation and other farming and business activities, the motor employs "writtenpole" technology, which makes possible its efficient, synchronous design and allows a starting current that is less than one-third that of a conventional motor of similar size. One critical advantage is that the motor can be powered with the single-phase electricity service generally offered in rural areas; conventional motors larger than 15 horsepower typically require three-phase service. The new motor can also ride through power interruptions of up to 15 seconds at full load.

*For more information, contact Ben Banerjee, (415) 855-7925. To order, call Dick Morash at Precise Power Corporation, (813) 746-3515.*

# Microwave Technology for the Chemical Industry

**This microwave production tube, used for industrial-sized applications, would have to be modified for use with chemicals.**




EPRI researchers are investigating the potential for using industrial-scale microwave technology to trigger chemical reactions. Typically, chemical companies use thermal systems fired by oil or natural gas to generate the heat required for many chemical reactions. But microwave systems could offer a number of advantages over the conventional thermal systems, the researchers say. The potential advantages include the ability to use lower-cost raw materials, a significant reduction in useless chemical by-products, lower capital costs, and energy savings.

Critical to all of these advantages is the ability to direct and control microwave energy at the molecular level. Such fine control enables the reacting chemicals to be heated to a uniform temperature. By contrast, conventional thermal systems heat molecules rather randomly: some of the molecules in the reactor bed reach the appropriate temperature, many others become too hot, and still others do not get hot enough. Molecules that do not reach the appropriate temperature either generate unwanted chemical by-products or do not react at all.

Preliminary laboratory experiments conducted by the EPRI researchers indicate that microwaves could be used to produce ethylene from natural gas. A building block for many chemical compounds, ethylene goes into products like antifreeze, polyester, polyethylene, polystyrene, and synthetic rubber. With conventional thermal systems, it is cost-prohibitive to produce ethylene from natural gas. Instead, chemical companies make ethylene from ethane or naphtha. Since natural gas is cheaper and far more abundant than either ethane or naphtha, it is very attractive as a raw material for ethylene production.

Because microwave technology enables chemical reactions to occur at lower overall temperatures than those of conventional systems, the technology not only saves energy but also may lower capital costs. The higher temperatures of conventional thermal processes typically require the use of complex heat exchange equipment. By comparison, a microwave system would require only a microwave generator, a controller, and a relatively simple reactor. The researchers say that the potential chemical-related applications for microwave technology are numerous, including the production of pharmaceuticals and the removal of nitrogen oxides and carbon dioxide from power plant flue gas. EPRI is collaborating with the National Science Foundation on an in-depth exploration of the science of microwave use with chemicals. This work will help more clearly define the type and breadth of possible applications.

"There's a big potential market out there," says Ammi Amarnath, EPRI's manager for research on this topic. "In the future, every chemical company may have a microwave system."

■ *For more information, contact Ammi Amarnath, (415) 855-2548.*

# Clothes That Deflect Magnetic Fields

Although questions still remain about whether magnetic fields cause certain health effects, EPRI-funded researchers are exploring the feasibility of developing flexible materials that could be made into gloves, masks, aprons, and other clothing that would shield utility workers from such fields.

Under contract to EPRI, researchers at SRI International are currently testing a variety of materials for possible use in such protective clothing. According to Ron Pelrine, a senior research engineer with SRI, a rubbery polymer is the most likely candidate for the base material. Particles that have magnetic properties and are about a thousand times smaller than a speck of dust would be built into the polymer. When exposed to magnetic fields, the material would become magnetized in such a way as to deflect the fields in its vicinity.

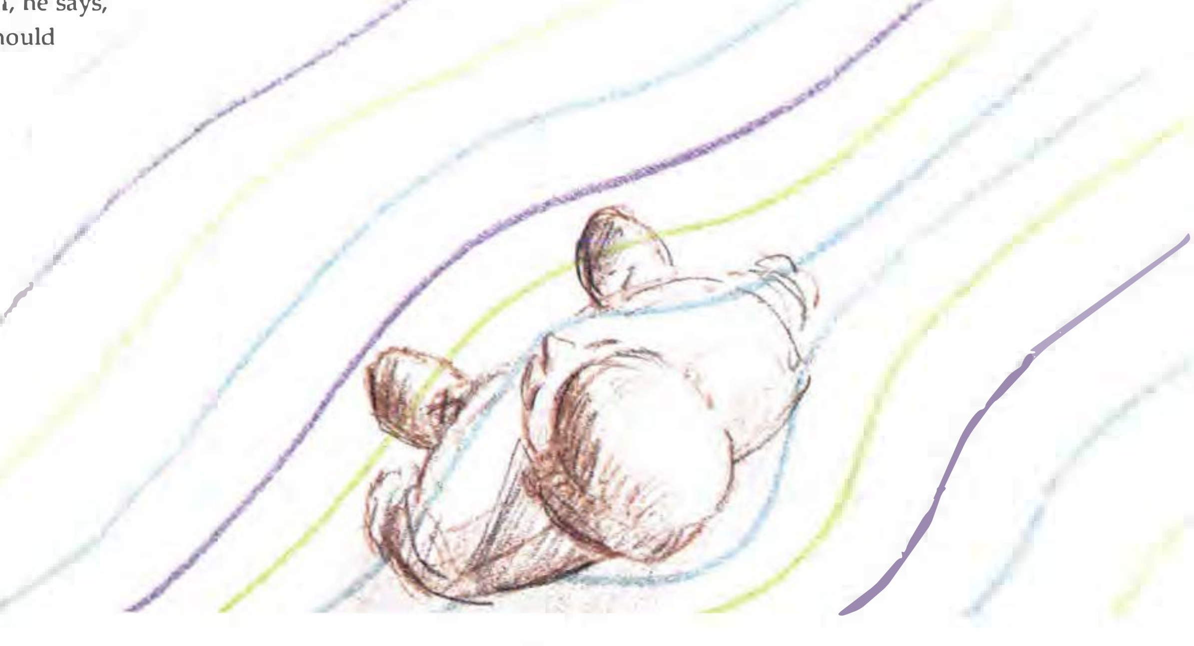
The shielding concept being investigated by the SRI researchers evolved from similar techniques that have been used for years to protect computer disk drives, compasses, and scientific and military equipment from possible damage by the magnetic fields radiated by strong magnets and electromagnets. "There are key differences between such fields and those generated by electricity-driven equipment," Pelrine notes. "For example, the fields emitted by magnets are much stronger, and they are static, whereas the fields emitted by utility equipment are oscillating." Still, he says, the same shielding principle should be effective in deflecting both kinds of fields.

Shielding for computers and other equipment has involved the use of nonflexible metal shields, which are not practical for moving objects like hands and bodies. By embedding the magnetic materials into a more flexible material, the SRI researchers believe that they can effectively deflect magnetic fields while leaving workers the full range of motion they need to accomplish their tasks. Although further research will determine precisely what kind of magnetic material the particles would be made from, potential candidates include metals and nonmetal ferrites.

According to Pelrine, preliminary calculations on the properties of the materials being considered for use are promising. This summer the researchers are conducting proof-of-principle laboratory experiments to determine whether their approach can work. If successful, they will move on to materials development, which would be completed by the end of 1996.

Aside from protective clothing for workers, the SRI researchers aim to develop coatings that could be painted or sprayed on utility equipment to minimize the escape of magnetic fields. Pelrine says that such coatings would have the same magnetic field deflection capabilities and would not interfere with equipment operation. "This study is part of a broader effort designed to apply state-of-the-art polymer technology to meet current utility needs," says Bruce Bernstein, EPRI's manager for the research.

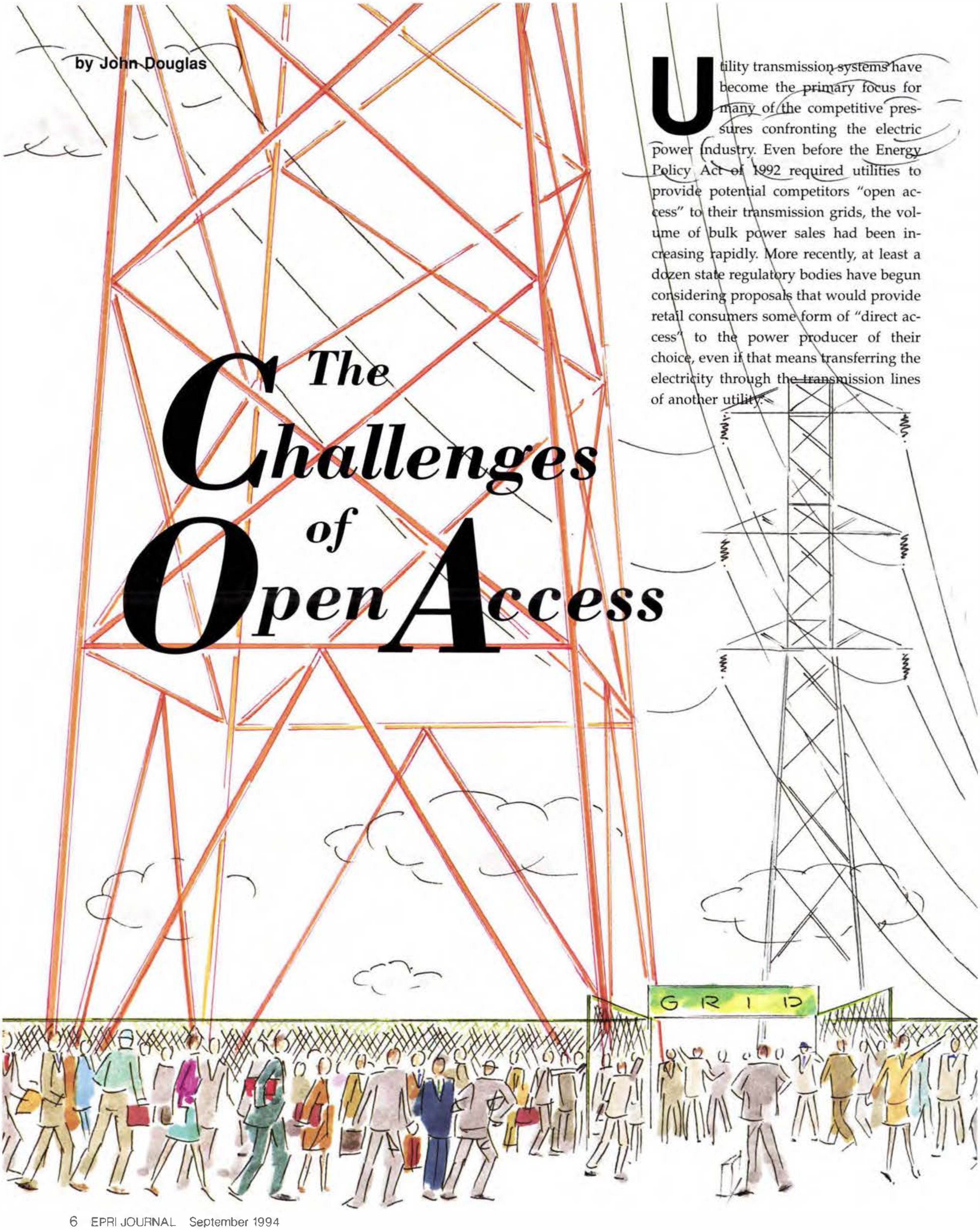
■ *For more information, contact Bruce Bernstein, (202) 293-7511.*



by John Douglas

# The Challenges of Open Access

Utility transmission systems have become the primary focus for many of the competitive pressures confronting the electric power industry. Even before the Energy Policy Act of 1992 required utilities to provide potential competitors "open access" to their transmission grids, the volume of bulk power sales had been increasing rapidly. More recently, at least a dozen state regulatory bodies have begun considering proposals that would provide retail consumers some form of "direct access" to the power producer of their choice, even if that means transferring the electricity through the transmission lines of another utility.



The mandated wheeling of power across a utility's transmission system for wholesale or retail transactions that the utility might not otherwise be involved in raises a host of critical questions: What is the true cost of providing unbundled transmission services? How much additional power can be transferred within the physical constraints of existing power systems? And what can be done to increase this transfer capacity while minimizing capital expenditures?

The answers to these questions are being sought in research by EPRI's Power System Operations business unit, whose director, Mark Wilhelm, says: "For many decades, utilities have viewed themselves as companies that produce and sell power. Transmission lines happened to go between the generators and the load. In the newly evolving view, however, utilities are more likely to see themselves as *carriers* of power. Transmission systems then become a strategic asset, operated as a major corporate profit center. Our task is to provide the tools utilities need to take full advantage of the opportunities ahead."

## Transmission costing

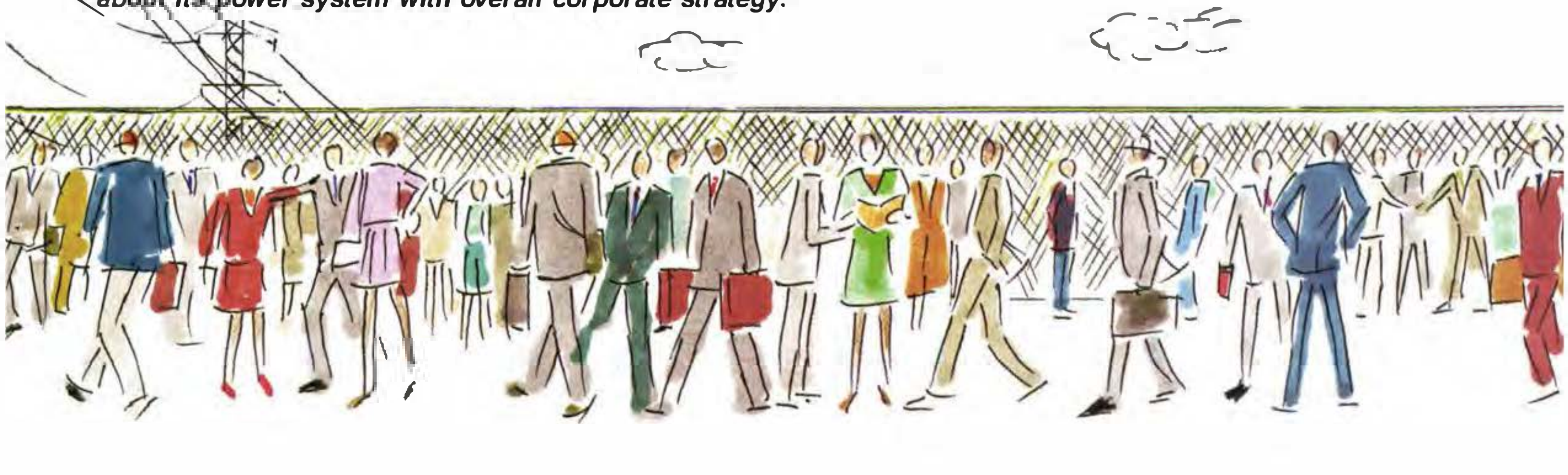
Traditionally, the cost of transmitting electricity from one point to another was simply rolled into the other costs of providing power to a customer. Transmission systems were viewed as a fully integrated part of a power system, and little effort was made to analyze the various factors that could affect the cost of providing transmission access as a separate service. For purposes of conducting wholesale transactions, prices were generally based on cost recovery for a utility's transmission grid considered as a whole—the "postage stamp method" of setting rates, so called because it made little distinction between short and long power transmission distances.

The limitations of such rates were already becoming evident before the advent of open access. As the volume of bulk power sales increased, so did the amount of electricity that flowed over transmission lines outside the "contract path" between buyer and seller. Such spillover meant that other utilities were providing transmission services without a way to receive adequate compensation. Open access has accelerated the unbundling of these services and greatly increased the need for a better understanding of the costs involved.

Following the Energy Policy Act's mandate for open access, the Federal Energy Regulatory Commission (FERC) adopted a major new pricing policy for transmission services. Under this policy, "an open access tariff . . . should offer third parties access on the same or comparable basis, and under the same or comparable terms and conditions, as the transmission provider's uses of its system." In other words, a utility cannot make access to its grid more costly or more difficult for its competitors than for itself.

Implementing this policy will require utilities to find better ways of accounting for their transmission costs—including the cost of grid expansion or upgrading and the cost of changing grid operations to make it possible for a transaction to take place. In response, EPRI is developing a comprehensive framework for analyzing transmission services and evaluating their

***THE STORY IN BRIEF** As utilities provide open access to their transmission grids under new federal regulations, the volume of bulk power transactions is expected to rise sharply—putting a strain on already heavily loaded delivery systems. Can everybody ride a grid that was designed to be operated in a simpler business environment? New EPRI software and analysis methods can help utilities cope with the practical problems that open access brings, such as accurately calculating the costs of providing transmission services to third parties and operating power systems closer to their inherent technical limits. A variety of power system analysis programs are already available for planning purposes, and on-line versions for use by operations personnel are beginning to enter utility demonstration. In addition, new resource scheduling and generation control software can help utilities reduce the total cost of electricity production by up to 3%. A decision framework has also been prepared that a utility can use to integrate technical information about its power system with overall corporate strategy.*



costs. This costing methodology is scheduled for completion in 1995 and will include proposals for computer software to help utilities apply the analytical framework.

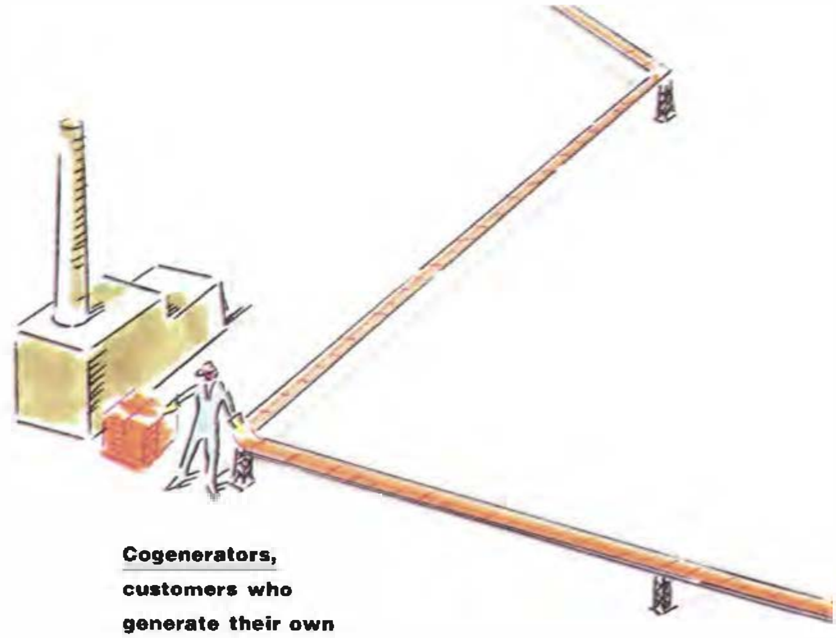
The economic basis for estimating costs by means of this framework is the recognition that transmission is a limited resource. Unlike additional power plants—which, in theory, could always be built in more-remote locations—new transmission lines often may be virtually impossible to site. Also, transmission facilities remain firmly under the control of established utilities and so far are well protected against the encroachment of independent power entrepreneurs. In the words of FERC Commissioner William Massey, "The monopoly power of the industry is in the wires, not the generators."

Against this background, the new costing framework seeks to identify and evaluate not only basic charges like maintenance costs, interest on capital expenditures, and energy losses but all the factors that contribute to the cost of providing specific transmission services, such as load following, frequency control, reserve capacity, and voltage regulation. And, because transmission facilities are limited, particular attention is being paid to the calculation of opportunity costs—that is, costs associated with having to forgo certain transactions because of congestion caused by other power transfers already under way.

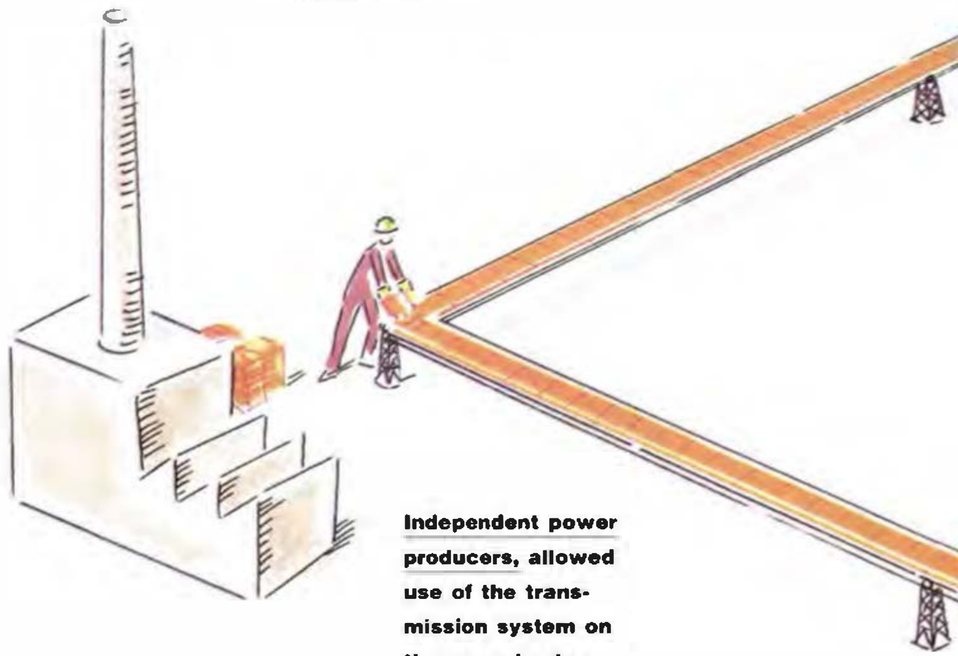
How these costs will eventually be translated into price goes beyond the scope of this methodology and depends on both unresolved regulatory issues and a growing wholesale power market (described in the June 1994 *EPRI Journal*). By using the costing framework, however, a utility will be in a better position to justify its rates to regulators and to profit from expanding market opportunities.

## Impact on system security

Increased wheeling will have a substantial impact on efforts to maintain the integrity of transmission systems. Already, some parts of the highly interconnected North American power grid are becoming congested. To maintain the security of this



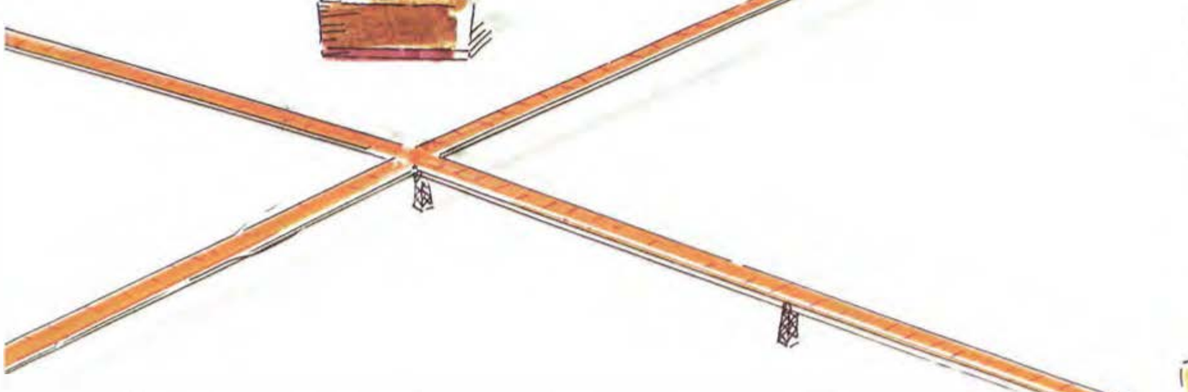
**Cogenerators, customers who generate their own power on-site, can either sell some of this power through the transmission grid when prices are high or buy utility power when prices are low.**

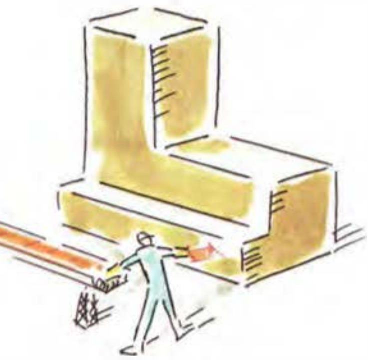


**Independent power producers, allowed use of the transmission system on the same basis as the utility who owns it, will exert increasing market pressure on utilities to decrease their costs.**

**Utility control centers** operate the transmission system, coordinating the increasingly complicated flow of power and maintaining system stability.

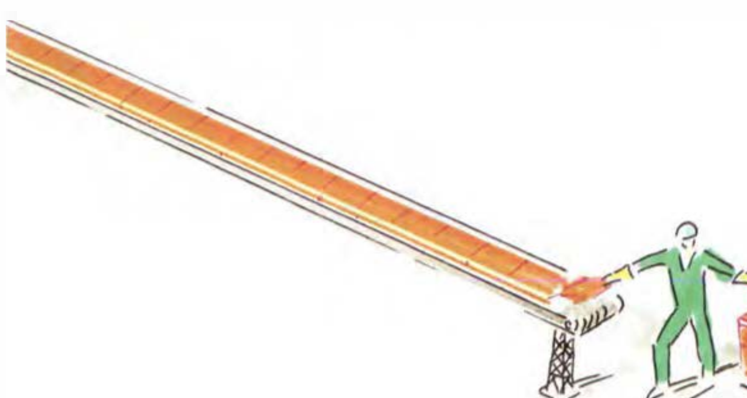
**Customers** will have more opportunity to shop around for power. Large industrial and commercial customers are already beginning to be able to choose their own electricity supplier, and residential customers may eventually have the same opportunity.





**OPEN ACCESS: THE PLAYERS** The regulatory requirement that utilities provide open access to their transmission grids is expected to increase both the volume of power transactions and the number of active participants.

**Power traders** will play a larger role in negotiating wholesale electricity transactions and futures contracts.



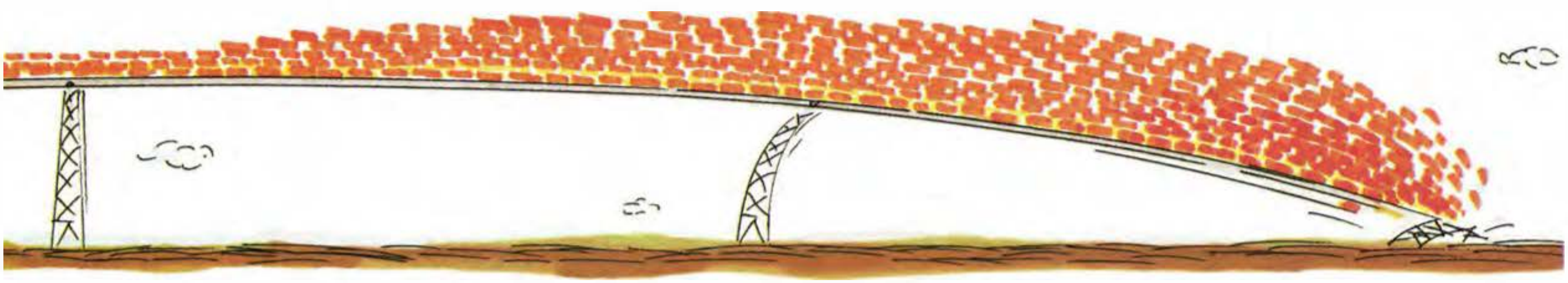
**Utility power plants,** which have typically been the only available sources of power for their service area, must now compete with other generators to sell electricity to customers.

## OPERATING LIMITS

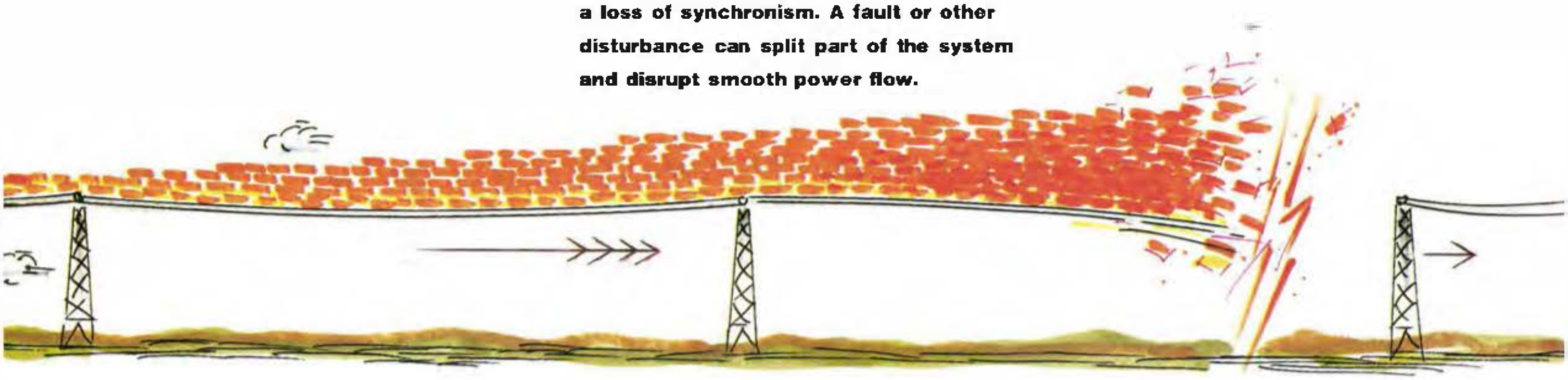
**The amount of power a transmission system can handle is constrained by three types of physical limits.**

**Thermal limits are encountered when a system is so heavily loaded that transmission lines literally begin to sag from overheating, just as a conveyor belt droops under the weight of an excessive load of packages.**

**Voltage stability limits can be a problem when there is not enough reactive power on the line to sustain voltage support, particularly near a major load area. If there is insufficient support, the voltage can collapse altogether, bringing down the system.**



**Power stability limits involve excessive loading that can cause generators or loads on the same grid to experience a loss of synchronism. A fault or other disturbance can split part of the system and disrupt smooth power flow.**



system, control center personnel need more-sophisticated modeling tools to help them understand the system's physical constraints and to help them handle an increased number of bulk power transactions within those constraints.

Generally speaking, there are three kinds of constraints that must be considered. Thermal limits are the easiest to understand: trying to push too much current through transmission equipment will make it overheat. During the events leading to the 1977 blackout in New York City, for example, thermal expansion of overloaded transmission lines running into the city made them droop into trees underneath, causing breakers to open and thus worsen the evolving power failure.

Voltage must also be kept within acceptable limits. Maintaining the proper voltage throughout a power system requires supplying enough reactive power to sustain the magnetic fields needed to transmit and use alternating current. Such power—measured in volt-amperes reactive (VAR)—cannot be carried very far along transmission lines. Thus voltage support on long lines often requires the addition of reactive power at intermediate points. Also, in the event of a disturbance, voltages may decline beyond a point of no return, leading to systemwide collapse.

Finally, the rotation of all the generators connected to a power system must remain synchronized. When a fault or other disturbance occurs on a transmission system, it may cause some generators to accelerate and others to decelerate—tending to throw them out of synchronization. In order to provide reliable service, a power system must have enough resilience to recover from such an event on its own, because transient events occur too quickly for human intervention. Recovery is more likely if a system is not too heavily loaded, so the third set of constraints involves the limitations placed on the amount of power transmitted in order to ensure system stability in the face of transients or longer-term system oscillations.

For many years, EPRI has conducted pioneering research on how to maintain power system reliability. The result is a family of software products that have become widely accepted for use by system planners and operators. As utility needs change in response to the greater number and complexity of bulk power transactions, existing products are being enhanced and new ones added. This software development work is being closely coordinated with research on the new power electronic controllers that form the basis of FACTS (flexible ac transmission system) technology. These controllers, which use solid-state thyristors to quickly control power flow, can increase the capacity of particular transmission lines by as much as 50%, while reducing stability problems throughout a transmission grid because of their virtually instantaneous reaction time.

## Power system planning

Determining whether a transmission system can handle increased bulk power flows requires first that planners conduct a detailed security analysis of the system as a whole. The capability to perform such studies is provided by EPRI's Power System Analysis Package (PSAPAC), which currently contains nine related computer programs that share common data files. In particular, PSAPAC can be used to identify possible bottlenecks on a transmission grid for various levels of wheeling transactions. The package can also show what locations on the grid may need additional VAR support and can identify what further controls are required to maintain system stability.

Each major type of system constraint that could be affected by wheeling is modeled by one or more of the PSAPAC programs, which can be used either independently or in conjunction with each other. The thermal limits of a large-scale power system (up to 12,000 buses), for example, can be calculated using the package's Interactive Power Flow (IPFLOW) program. This program also provides the modeling base for steady-state voltage and power flow analysis. The Voltage Stability (VSTAB) program can tell planners how close a system is to voltage collapse and what the mechanism of collapse would be in response to particular disturbances.

Two PSAPAC programs devoted to analyzing system stability limits have proved particularly important in utility studies involving the proposed addition of FACTS controllers. The Extended Transient–Midterm Stability Program (ETMSP) provides a detailed, time-dependent simulation of fast (within seconds) response to disturbances in systems having up to 2000 generators, while the Small-Signal Stability Program (SSSP) can be used to analyze the subsynchronous oscillations that sometimes arise among generators in very large, interconnected power systems. One or both of these computer codes have been used by the New York Power Authority, Ontario Hydro, Minnesota Power, Southern Company Services, the Tennessee Valley Authority, and the Western Area Power Administration to evaluate the potential benefits of installing various FACTS controllers.

Another package of computer programs, called VBTRA (Value-Based Transmission Resource Analysis), provides a power system planning framework for determining, among other things, the least-cost combination of generation and transmission facilities. Two VBTRA programs are currently available, and several enhancements are scheduled for release in 1995. By using VBTRA, utility planners can calculate how power system performance would change with alternative operating policies or transmission configurations. In turn, this information enables the planners to evaluate the impact of various wheeling contracts on power system reliability. For example, a utility could use VBTRA to determine the relative costs and benefits of building a new power plant or reinforcing its transmission system to meet rising demand or to take advantage of wheeling opportunities.

Finally, planners need to know the maximum simultaneous power transfer capability of interconnected power systems. Most utilities now determine the physical limits of a transmission system only for individual wheeling transactions. To determine the capability for simultaneous transactions between just two or three areas, it may be necessary to run many reliability simulations. EPRI's new Transfer Capability Program (TRACE), scheduled

## Monitoring System Security

EPRI is developing an integrated set of on-line system security analysis tools that will help improve system utilization and lower operating costs.

**SES (Security Enhancement System)** rapidly assesses the potential effects of a large number of selected outages on operating conditions and recommends least-cost corrective actions to be taken if any of them occur (available now).

**VSA (Voltage Stability Assessment)** indicates whether voltage collapse will occur after a disturbance and recommends actions to avoid collapse and restore system voltages to acceptable levels (prototype available 1995).

**DSA (Dynamic Security Analysis)** uses a screening method based on the transient energy function to identify and rank potentially severe contingencies, whose effect on system stability is then analyzed in detail by means of simulation techniques (available 1996).

## Scheduling and Real-Time Control

### RSGC

The Resource Scheduling and Generation Control (RSGC) software package, now being developed, will help utilities minimize power system operating costs through improved unit scheduling, load-frequency control, and dynamic dispatch of generation. Five programs—initially to be released as individual products—will be included in the integrated software package, which is scheduled for delivery in 1998.

**RSC (Resource Scheduling and Commitment)** is an on-line program that uses advanced optimization methods to prepare a least-cost plan for scheduling diverse resources and transactions (available 1995).

**STLF (Short-Term Load Forecast)** provides load predictions for use by other RSGC programs (available 1995).

**CCPC (Coordinated Control Center/Power Plant Controls)** uses increased data flow between control centers and plant computers to improve both system and plant operating objectives (available 1995).

**CDD (Constrained Dynamic Dispatch)** provides real-time dispatch of diverse energy resources to meet system demand under specific unit constraints (available 1997).

**LFC (Load-Frequency Control)** automatically controls generating units to meet scheduled system frequency and minimum production cost (available 1997).


for commercial release in early 1995, will make it possible to evaluate the maximum simultaneous power transfer capability of several interconnected power systems. This program represents a major departure from traditional system analysis tools in that it uses an optimization method that quickly identifies critical contingencies (such as loss of a generator or power line) that could affect a system's thermal loading during simultaneous transactions. Using TRACE, planners will be able to calculate the capability of a transmission network to handle concurrent wheeling transactions and will be able to identify the best ways to move power among neighboring utilities.

"Open access has made us accelerate our security analysis work for system planners," says Neal Balu, who has managed development for much of this software. "Already, many utilities are finding their transmission systems pushed uncomfortably close to physical limits, and others can expect to face this issue in the near future. EPRI's work on power system planning has produced software tools that our members can use to keep ahead of the game and maintain system security while increasing bulk power transfers."

## Toward on-line analysis

In addition to affecting power system planning, open access and increased wheeling will also require changes in the way systems are operated. Utility dispatchers may have to operate a system closer to its physical limits because of external wheeling transactions, while trying to reduce their own operating costs through more-efficient dispatch of generation and transmission resources. Meeting these divergent needs will require the development of operations support tools that use real-time information. Such tools can enable dispatchers to schedule wholesale transfers on an hour-by-hour basis and can help in optimizing the use of power system resources. Better resource use may enable a utility to reduce operating costs by up to 3%—which translates into billions of dollars in annual savings for the utility industry as a whole.

As in the case of planning software, on-line operations support programs generally correspond to the three types of physical constraints that apply to power systems. One program, dealing with thermal limitations, is already commercially available—the Security Enhancement System (SES). This program continuously monitors the condition of a power system and calculates how the condition would change following specific contingencies, such as the loss of a major transmission line or generator. Corrective actions for individual contingencies are then recommended on a least-cost basis. Because SES uses real-time system data, it can better anticipate abnormal conditions and can propose control adjustments that will reduce costs while maintaining system integrity. Wisconsin Electric Power Company was the initial host utility for the demonstration of SES, which now includes several features proposed by the company's dispatchers. SES is currently being used by 15 EPRI member utilities.

The on-line Voltage Stability Assessment (VSA) program, which can help utilities operate their power systems at higher load levels without risking voltage collapse, is under development. A prototype version of the program is expected to be ready in 1995. The planning tool VSTAB will be used as a starting point for creating VSA, which will use real-time data to continuously monitor and analyze the voltage stability status of large transmission grids. Through such calculations, VSA will show which power transfers can be handled within the limits of voltage stability. If a voltage collapse should begin to evolve, VSA will be able to identify timely mitigation measures, such as load curtailment or emergency VAR support.

Perhaps the most daunting task facing operations software developers is to create the Dynamic Security Analysis (DSA) package—software capable of analyzing system stability limits quickly enough to be used on-line. While the planning process may take months of analysis, DSA must be able to perform system analyses in about 20 minutes. Until recently, real-time operation was not considered possible, but advances in both computer hardware and computational techniques have made the development of DSA feasible. In particular, DSA will use artificial intelligence techniques to select contingencies that are relevant to a power system in its present state and then to identify those contingencies that would be most likely to cause system instability.

Having an on-line security analysis capability could save many utilities millions of dollars a year, since they would be able to prevent the onset of instabilities often associated with heavily loaded transmission lines. During a thunderstorm, for example, a dispatcher could check to see whether an outage on a line likely to be affected would render the system unstable. By performing the necessary calculations in a few minutes with actual system data, DSA could prescribe control actions to prevent a cascading outage. A preliminary demonstration using only a simplified, partially functional prototype of DSA is resulting in savings of $1.4 million over a three-year period for the host utility. DSA is expected to be ready for delivery to EPRI members in 1996.

"Traditionally, the planning function has been quite separate from power system operations, but now they're moving closer together," says Gerry Cauley, who is managing development of the new, on-line system analysis software. "Being able to use real-time data and advanced computing techniques can make a dispatcher faster on his feet, in the sense of anticipating and correcting problems before they get out of control and evaluating the possible system impacts of transaction opportunities as they arise."

## Scheduling and control

Complementing EPRI's work on real-time security analysis is research on advanced resource scheduling and generation control: security analysis tells a dispatcher which power system configurations and bulk power transactions are safe; scheduling and control analysis indicates which are advantageous. EPRI's research in the latter area aims at producing an integrated set of on-line control system software that can minimize total electricity production cost by comparing the marginal costs of all resources available to a utility—including

## Planning for Security and Reliability

### PSAPAC

The Power System Analysis Package (PSAPAC) contains nine computer programs that share common data files and provide complementary capabilities to allow planners to study the static and dynamic characteristics of their power systems.

**DYNRED (Dynamic Reduction)** identifies groups of generators and other synchronous equipment that can be reduced to simple equivalents for analytical purposes.

**LOADSYN (Load Synthesis)** models a network's loads and prepares the data for further analysis.

**IPFLOW (Interactive Power Flow)** conducts steady-state analysis of voltage and power flow for various loads, contingencies, and generation dispatches.

**TLIM (Transmission Limitation)** calculates the real power flows and transfer limits of a system under various circumstances.

**DIRECT** conducts stability analysis based on the evaluation of system transient energy—supplementing more detailed, time-domain analysis methods.

**LTSP (Long-Term Stability Program)** is a time-domain program for simulating the long-term dynamics of a large power system after a disturbance.

**VSTAB (Voltage Stability)** tells how close a system is to voltage instability.

**ETMSP (Extended Transient–Midterm Stability Program)** is a time-domain simulation program for transient and midterm stability analysis of large systems.

### VBTRA

The Value-Based Transmission Resource Analysis (VBTRA) package consists of two programs that evaluate the performance of a transmission grid under various conditions, such as wheeling.

**TRELSS (Transmission Reliability Evaluation for Large-Scale Systems)** uses a systematic contingency selection process to assess bulk system reliability for grids with up to 2500 buses.

**CREAM (Composite Reliability Assessment by Monte Carlo)** uses a random contingency selection process to assess bulk system reliability, providing composite reliability indexes at the system and bus levels.

**SSSP (Small-Signal Stability Program)** consists of two subprograms—MASS (Multi-Area Small-Signal Stability) and PEALS (Program for Eigenvalue Analysis of Large Systems)—that analyze local plant mode oscillations and interarea oscillations in interconnected power systems.

internal generation, wheeling transactions, demand-side management, purchases from other utilities or from nonutility generators, and energy storage. The programs in the Resource Scheduling and Generation Control (RSGC) package would also necessarily take into account physical system limitations, as computed by the security analysis software just described.

Five software programs are being developed for RSGC; they will be delivered as individual products from 1995 to 1997 and as an integrated package in 1998. By using these programs, a utility will be able to obtain better load predictions, prepare a least-cost plan for scheduling diverse types of resources to meet the projected load, and automatically control generating units on the basis of this schedule. Current control technologies are no longer adequate for dealing with the increasingly complex operations of highly interconnected systems; the RSGC package will help significantly reduce both fuel costs and other operating costs.

A critical component of this advanced scheduling and control system is better communication between control centers and power plants. The enhanced, two-way flow of data will enable a dispatcher to send unit commitment schedules to a plant manager and receive, in turn, real-time information on incremental unit heat rates, ramp rates, emissions, and dynamic response characteristics. Simulations and field tests of the new communications system have shown that a 4% cost reduction is possible in a fossil-fired power plant just through improved control based on the use of real-time incremental heat rate data. The first demonstration of the coordinated communications system is currently being set up at Wisconsin Power & Light Company.

In related work, a communications protocol has been developed to support data exchange between control centers. This Inter–Control Center Communications Protocol (ICCP) complies with the Utility Communications Architecture (UCA), which is designed to standardize data exchange throughout the electric power industry. The use of ICCP is expected to reduce the cost of communications be-

tween power system control centers and lead to closer coordination of their activities. Demonstrations of ICCP are being set up at the Western Area Power Administration, Ohio Edison Company, and the Electric Reliability Council of Texas.

"The adoption of ICCP is fundamental to other changes taking place in utility energy management systems," according to EPRI's Ali Vojdani. "The need for better data exchange between control centers has been recognized for more than a decade, and we've received very strong industry support for our efforts to bring it about."

**PREPARING FOR THE FUTURE The increase in bulk power transactions brought about by open access presents utilities with three kinds of technical challenges. New planning and control software will be needed to maintain system stability and prepare for a more heavily loaded system. New transmission system hardware, including innovative power semiconductor controllers, can help expand system capacity in the most cost-effective way. And new analytical tools will enable utilities to identify financial opportunities inherent in open access and incorporate them into an overall business strategy.**

## Strategic asset management

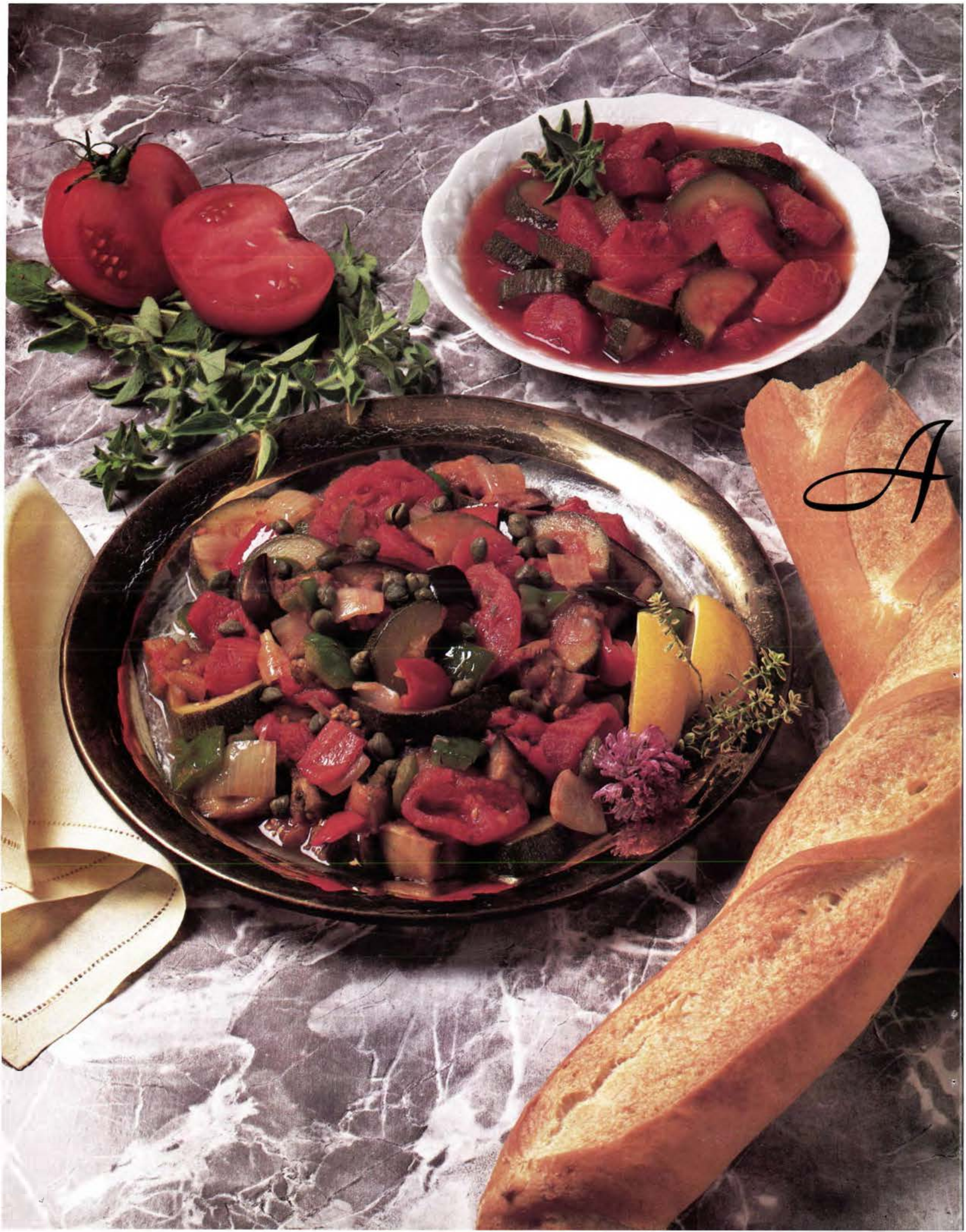
At some point, of course, utility executives have to integrate the technical information produced by power system analyses with overall corporate goals. From this perspective, transmission lines and spinning reserve are strategic assets whose value can be increased through careful deployment—for example, through participation in more wheeling transactions. At the same time, the risks inherent in every operational decision, from line loading to fuel purchases, have to be judiciously considered and managed. Meeting these diverse demands is the goal of a new decision framework, called Strategic Asset Management (SAM), being developed by the Utility Resource Planning and Management business unit.

"The critical juncture between technical feasibility and corporate strategy can be approached from either direction," notes Charlie Clark, who heads the business unit. "A utility may have a particular wholesale marketing tactic in mind and may need to see whether its power system can support the transactions involved, or the utility may start with an assessment of system strengths and weaknesses and then conduct a business analysis to find out how these can be used to best advantage."

These alternative approaches are exemplified by activities under way at two EPRI member utilities. By using SAM, the first utility found that it had a promising opportunity to make wholesale power transactions if it diverted capital investment from generation to transmission. Now it plans to use PSAPAC and VBTRA to identify the parts of the power system that need reinforcement and to determine the cost. The second utility conducted a thorough technical analysis of its power system first and is now using SAM to define a business strategy that will maximize the value of the system in its present form.

"The importance of existing transmission assets is rising rapidly—in a recent survey, state regulatory commissioners estimated that the perceived value of surplus transmission capacity will roughly double over the next five years," says Karl Stahlkopf, vice president for power delivery. "Our goal is to provide utilities with the technologies and insights they need to realize this potential, by analyzing both the inherent physical constraints and the emerging business opportunities associated with transmission assets. Forward-looking utilities are already using these tools to prosper in the newly competitive marketplace." ■

Background information for this article was provided by Mark Wilhelm, Neal Balu, Gerry Cauley, Ali Vojdani, and Charlie Clark, Power Delivery Group.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**THE STORY IN BRIEF** Used in special applications for over a decade, membrane filtration and separation systems offer an electrotechnology solution to the increasing pressure on much of the food-processing industry to reduce its use of fresh water and its discharge of wastewater for treatment. EPRI collaborated with utilities and the food-processing industry in California to equip a semitrailer with state-of-the-art membrane test equipment, and the trailer has been visiting food plants to conduct demonstrations and assessments of what membrane separation systems can do. Utilities in other states have since joined the project as a way to help introduce their food processor customers to the new technology.

by Taylor Moore

# Separable Feast

## *Membrane Applications in Food Processing*

From the vineyards of the Napa Valley, through the square-mile orchards and vegetable fields of the Sacramento and San Joaquin Valleys, south to the sunbaked expanse of the Imperial Valley, California's $70 billion agriculture industry provides 10% of all the food consumed in America and 10–15% of the country's food exports. The industry depends fundamentally on the constant availability and use of a substantial portion of the Golden State's most valuable natural resource—water. Many farms measure their water requirement for irrigation in the millions of acre-feet per day. And many of the more than 8000 food-processing plants that prepare and package California's crops consume millions of gallons of water a day to wash, cook, and send foods on their way to America's store shelves and dining tables.

Particularly in California—where competing demands for its use have made water one of the state's most politically contentious and economically significant public issues—the agriculture and food industries are under growing pressure not only to reduce water consumption but to substantially decrease the discharge of process effluent into public water treatment systems. Many cities and counties, straining to provide for expanding populations, are raising the fees for industrial wastewater discharge even faster than water rates themselves are rising.

Evaporation ponds, the traditional alternative to discharge, are already costly to build and operate and are becoming more so. Ponds constructed today must have double liners and leachate collection and monitoring systems. Given these and other challenges to productivity (including tighter restrictions on the use of pesticides and herbicides and on air emissions) and given the ready availability of many food imports whose production is not subject to such restrictions, how to remain competitive as a major domestic and global supplier is becoming a serious question for California's food producers.

The problems of water use and wastewater quality, however, are only somewhat less acute in other states with generally larger and more-reliable water sup-

Tri-Valley Growers

plies. One of the biggest manufacturing sectors in the United States, food processing is inherently a local and regional industry that is well established in every state. Yet food processors everywhere know that, with current water management practices, they are operating on borrowed time. They will eventually have to recycle and reuse an even greater portion of their process water and treat in place any effluent to meet municipal water quality standards.

Permeable-membrane filtration and separation technologies have great potential to help meet the food-processing industry's water consumption and water treatment challenges. The technologies include microfiltration, ultrafiltration, nanofiltration, and reverse osmosis (in descending order of the size of the particles that can permeate the various types of membranes employed). Their use is already growing at double-digit rates in the chemical industry, where pressures similar to those facing food producers have led to the installation of many membrane systems, primarily as a pretreatment or finishing step or in conjunction with other purification methods, such as deionization.

The recent emergence of advanced ceramic and metallic membranes (polymeric membranes are most commonly used) and the availability of improved equipment designs that offer higher flow rates and lower treatment costs are helping to in-

**A SMORGASBORD OF FRUITS AND VEGETABLES** **Since the fall of 1992, the membrane separation demonstration trailer has been on a nearly nonstop road trip, making six-to-eight-week visits at nine California food-processing plants and, most recently, traveling to plants in Pennsylvania and New Jersey. The California operations evaluated for possible application of membrane systems were olive canning, raisin drying, bean soaking, green pea freezing, fruit cocktail canning, tomato processing and canning, carrot processing, fruit freezing, and processing of kelp into food algins. Researchers have found membrane separation systems to be particularly promising for the state's large tomato industry.**

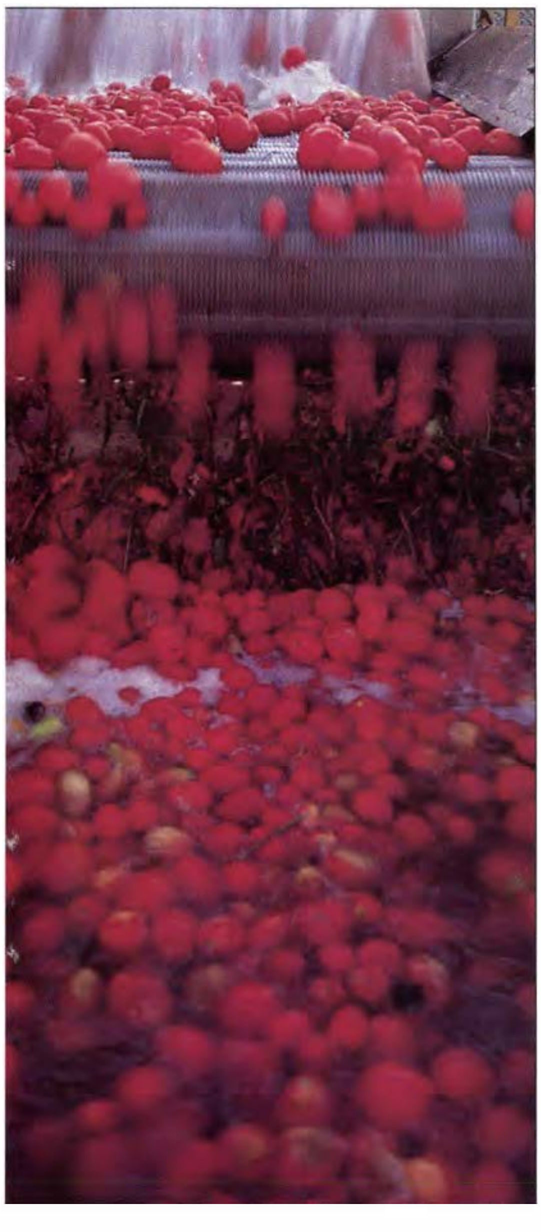
Del Monte Corporation; Tri-Valley Growers

**MEMBRANE DEMONSTRATION TRAILER PROJECT SPONSORS**

**Food processors**
California League of Food Processors (CLFP)
National Food Processors Association (NFPA)
CLFP/NFPA Industry Advisory Technical Committee

**Research organizations**
DOE, Battelle Pacific Northwest Laboratories
EPRI

**Utilities**
Pacific Gas and Electric Company
Pennsylvania Power & Light Company
Public Service Electric and Gas Company
San Diego Gas & Electric Company
Southern California Edison Company



crease the appeal of membrane separation. As a result, its use is spreading beyond the small-scale, specialty applications in which it is well established to more-common, high-volume operations like those of most food processors.

For the last two years, EPRI has been working with California food processors, three of the state's major utilities, U.S. Department of Energy researchers, food processor trade groups, and agricultural and food scientists from the University of California at Davis to demonstrate the application of membrane separation technologies for treating various process water streams in food plants to reduce effluent, conserve water and energy, and recover useful by-products. A 48-by-8-foot semitrailer equipped with membrane test units and data acquisition and analysis gear has been on a nearly nonstop road trip since October 1992. It has made six-to-eight-week visits at nine California food-processing plants whose operations span a wide range: olive canning, raisin drying, bean soaking, green pea freezing, fruit cocktail canning, tomato processing and canning, carrot processing, fruit freezing, and processing of kelp into algins used in food products. Besides promoting awareness of membrane technologies and introducing food processors to their use, the project personnel have conducted technical and economic evaluations of new applications of commercially proven membrane technologies in the recovery and recycling of process water.

## Electrotechnology for wastewater

Membrane separation has been used commercially for as long as 15 years to concentrate whey in the dairy industry, to clarify juices and other beverages, to reclaim salable products like sugars and corn syrup from waste streams, and to desalinate modest quantities of seawater. But the latest membrane technologies, with their improved flow rates and performance, are expanding the spectrum of economically viable applications, principally in the chemical, water treatment, and food-processing industries.

Membrane processes offer several advantages over conventional evaporation and distillation processes, including lower energy use, greater reliability, smaller floor space requirements, lower capital cost, better control of microbes and organic matter in process effluent, and improved product quality. Unlike other


separation and fractionation methods used in food processing, notably vaporization and freeze concentration, membrane processes do not change the phase of selected components.

Although perhaps not widely recognized as an electrotechnology, membrane systems use electric-powered pumps to maintain system pressures and flows (but use no energy to heat or vaporize liquid). Membrane systems designed to recover thermal energy from process water may use only about 10% of the energy typically used in evaporation processes. When used in applications that reclaim and recycle process water drawn from wells, the technology also saves energy through reduced pumping requirements for intake. Membrane systems are one of several industrial electrotechnology applications EPRI has been pursuing since 1980 on behalf of its electric utility members and their customers.

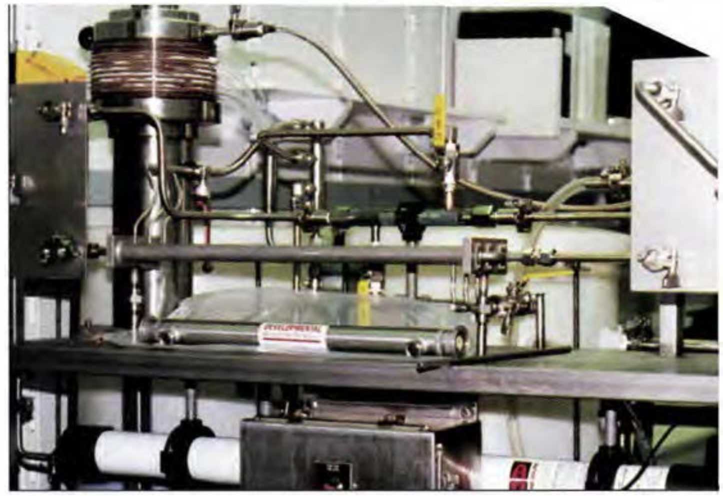
The membrane demonstration trailer resulted from a collaboration of diverse interested parties two years ago when EPRI, DOE's Battelle Pacific Northwest Laboratories, Pacific Gas and Electric Company (PG&E), San Diego Gas & Electric Company, and Southern California Edison Company (SCE) teamed up with the California League of Food Processors (CLFP), the National Food Processors Association (NFPA), and the CLFP/NFPA Industry Advisory Technical Committee. "Working with our partners, we saw an opportunity to demonstrate new water management technologies that can help food processors remain efficient and competitive while meeting new challenges and regulatory requirements," says Ammi Amarnath, manager for process industries in EPRI's Customer Systems Group.

PG&E and SCE were particularly pleased to be involved in demonstrating and promoting a new technology application with great potential across what is for each utility a significant category of industrial customer. "The food-processing industry represents a key customer market segment for PG&E, and we identified a need to help the food processors stay competitive in California by meeting the energy and environmental challenges they face," says Del Evans, a former PG&E senior product manager who now heads the utility's San Francisco Marketing Department. "The test trailer will help show them how they can meet those challenges. The results at all the plants the trailer has visited are very encouraging, and a couple of those plants are considering or planning the eventual full-scale implementation of membrane technologies."

The Del Monte Food Research Center built and outfitted the membrane demonstration trailer, which is owned and operated by the California Institute of Food and Agricultural Research (CIFAR) at UC Davis. The trailer contains a laboratory-scale membrane test unit, high-pressure and low-pressure test units, stainless steel piping and mounts, and laboratory and computer equipment. Inlets for hot and cold water, deionized water, and compressed-air distribution systems can be readily connected to outlets at a host site.

"We're excited to have this mobile unit, which is supported by the utility companies and the food industry in California, available to actually go to food-processing

**A FOOD-PROCESSING LABORATORY ON WHEELS** The 48-by-8-foot membrane demonstration trailer is outfitted with a laboratory-scale test unit, high-pressure and low-pressure test units, stainless steel fittings and pipes, and computers and other analytical gear. The test units can handle a wide variety of membrane types and materials in evaluating the potential of membrane separation to meet specific process flow requirements at host sites. Built by the Del Monte Food Research Center, the trailer is owned and operated by the California Institute of Food and Agricultural Research at UC Davis.




plants to demonstrate this new technology for reducing water use and wastewater discharge for treatment," says Sharon Shoemaker, executive director of CIFAR.

The test units are designed to accommodate a variety of membrane types, designs, and materials, depending on the requirements of a particular host's process flows, which are sampled and analyzed as part of the site demonstration. Amarnath says that the trailer is equipped with more than 40 types of membranes, from practically every supplier.

During each site visit, CIFAR personnel sample and analyze the process flows of greatest interest to the plant management, conduct separation and filtration tests, and produce a computer-assisted technical recommendation for the optimal combination and configuration of membrane systems and other processes to address the plant's specific needs. The key factors for analysis are biological oxygen demand (BOD) associated with organic matter; total suspended solids (TSS); total dissolved solids; and such characteristics as pH, viscosity, and salt and sugar content.

## On the road

Highlights of the plant visits made by the demonstration trailer over the past two years illustrate the range of potential applications and the impact that membrane technologies could have. The highlights are drawn from material prepared by CIFAR staff for a forthcoming EPRI report.

The first host for the California membrane road show—an Oberti Olives Company canning plant in Madera—estimates that membrane separation technologies could cut its water use by 85% and save it $24 million over the next 10 years in avoided costs for retrofitting effluent disposal ponds. Olive curing requires as much as 10,000 gallons of water per ton of olives processed, and the effluent contains high levels of organic materials, acids, oils, minerals, and salts.

Oberti, a Tri-Valley Growers subsidiary and a PG&E customer, was already looking for an alternative to evaporation processes for removing soluble solids like salts from the process water when it signed on to host the mobile demonstration trailer. During pilot-scale trials that lasted eight weeks, the project personnel evaluated membrane treatment of five process water streams: well water, flotation brine, oil mill slurry, yeast broth, and biotower water.

The feasibility of treating well and biotower water through reverse osmosis was found to depend largely on the success of pretreatments to soften the water. For the yeast broth and flotation brine, ultrafiltration was found to be feasible and relatively trouble-free, although microfiltration of the flotation brine yielded higher, more-stable fluxes. Microfiltration of the thick oil mill slurry turned out to be a problem for the available pumps.

Filtration of the brine using full-scale membrane systems would permit the Oberti plant to recycle the salt, eliminating the need for disposal. Recycling could cut the size requirements for evaporation ponds from 160 to 24 acres and reduce the need for processing chemicals. Oberti Olives Company officials say that they are planning to install a pilot-scale membrane filtration system by the end of this year to better evaluate the potential for a full-size, commercial system.

At the Dole Packaged Foods raisin-drying plant at Kerman (near Fresno), mountains of sun-dried and tunnel-dried raisins are washed to remove surface debris. The washwater absorbs a substantial amount of sugars from the raisins before being discharged to evaporation ponds. Dole wanted to examine the feasibility of recovering a sugar concentrate from the washwater for use as a distillation feedstock.

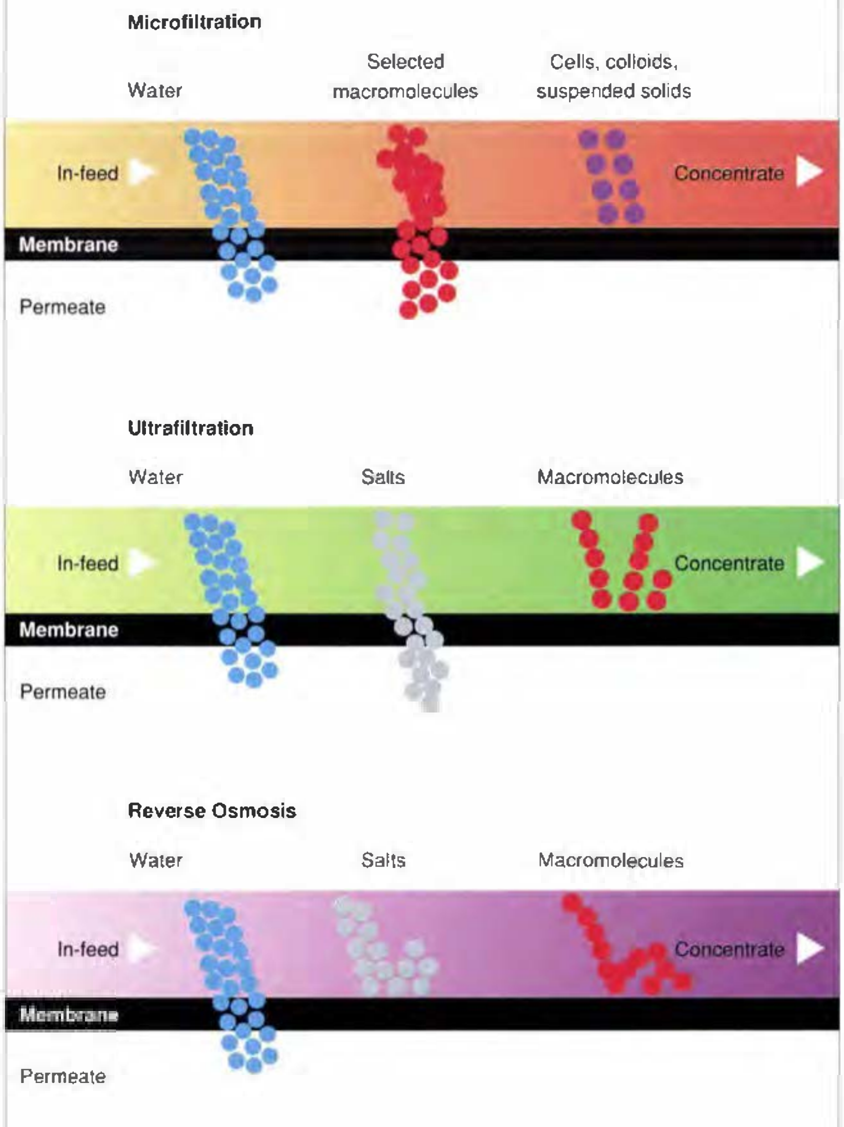
At the Kerman plant, the project personnel identified four water discharge streams whose flow rate and sugar content resulted in a total sugar discharge equivalent to 587 kilograms per hour. The researchers first removed the organic impurities from samples of the water to produce a clean, dilute sugar solution, using microfiltration and ultrafiltration with equal success. They then successfully applied reverse osmosis and nanofiltration to concentrate the permeate of the earlier trials. As a distillation feedstock, the sugar water required only density separation and sand filtration prior to concentration, and the product quality was judged acceptable by the prospective users. The fruit extract is said to be similar in composition to grape juice.

The researchers' preliminary feasibility analysis of a washwater treatment system with sugar concentrate recovery indicated a rapid payback. Dole says that it intends to pursue membrane technology for treatment of the raisin washwater. The company plans to install a pilot-scale ultrafiltration unit operating in tandem with a reverse osmosis unit in order to produce a sufficient quantity of extract to make a better determination of its market value. Dole engineers are also exploring issues related to scale-up of the membrane technology.

## Fruit cocktail, anyone?

Del Monte Foods Plant 3 in San Jose cans fruit cocktail using peaches, pears, grapes, cherries, and pineapples. Since San Jose charges some of the highest freshwater and wastewater rates in California, the plant must maintain high standards of water management in order to contain production costs.

**SEPARATE REALITY: BASIC PRINCIPLES** **Membrane separation technologies include microfiltration, ultrafiltration, and reverse osmosis (in descending order of the size of the particles able to permeate the various types of membranes used). Particles too large to pass through are retained in the concentrate. Polymeric membranes have most commonly been used, but advanced ceramic and metallic membranes have recently become available. Coupled with higher-capacity and more-economical treatment systems, these advanced membranes are expanding the range of cost-effective applications to include high-volume operations, such as various types of food processing.**



Membrane trials at the plant were focused not on the reduction of effluent strength but on specific membrane applications requested by the Del Monte Research Center and the plant management. These included cleaning cooling-tower water, recovering by-products from can-filler overflow, and clarifying off-grade fruit juice concentrate.

The researchers identified nanofiltration, rather than microfiltration, as the likely optimal choice for removing the dissolved solids in cooling-water droplets that leave dark spots on the product cans. A nanofiltration system would be easier to clean, would require less chemicals, and could be sized to meet other soft-water requirements. A combined ultrafiltration and nanofiltration system, it was found, could be used to treat several process water streams and recover sugar concentrate that could be used to supplement can-filler syrup. Overall, the benefits of a by-product recovery system appeared to exceed the cost. And such a system could perhaps be even more cost-effective with improvements in water management that would allow the use of a smaller membrane area.

The researchers identified excellent potential for several membrane applications in the tomato industry as a result of the trailer's visit to the Hunt-Wesson tomato plant in Fullerton. Two applications were developed to the pilot implementation stage, and exploratory work on two others was sufficiently successful to justify in-depth, follow-on investigations, the researchers reported. Other potential applications for membrane separation in tomato processing, such as in peeling operations, were identified but not evaluated. The researchers concluded that, given the magnitude of California's tomato industry, the potential economic benefits and energy savings of membrane filtration justify committing the mobile demonstration unit to that industry for the entire season next year.

Because Hunt-Wesson had successfully implemented several effluent reduction measures (including solids coagulation and peeler solids recovery for tomato paste) at the Fullerton plant before the membrane application evaluation, the tomato transport flumes were found to be the leading contributors to effluent strength.

A two-stage microfiltration process was used to treat the flume water. The first stage concentrated the suspended solids, leaving dissolved solids in the permeate. These were concentrated in the second microfiltration stage. The demonstration established the feasibility of this approach and identified suitable membranes. Budget estimates were developed, and the economics of several alternatives were evaluated.

At the Norcal Crosetti plant in Salinas, the peeling and washing of carrots for freezing transfers large quantities of organic matter to the process water, which increases the effluent's BOD and TSS. Large volumes of fresh water are required for chilling and washing.

The plant's annual expenditure for wastewater disposal—about a quarter of a million dollars—is a major concern for management, so the membrane application evaluation focused on reducing effluent strength and BOD levels, which increase disposal charges. Analysis revealed that while nearly two-thirds of the process water flow is from cooling and defrosting operations, about 75% of the BOD comes from peeling and washing operations, which account for only about 9% of the flow. The study also indicated that the plant discharges daily about 5000 pounds of sugars, worth about $1000 as animal feed.

The researchers conducted membrane trials to concentrate the suspended solids in the process water by nanofiltration and reverse osmosis. And they studied the use of microfiltration to control the chiller water's microbial content. The microfiltration trials produced low fluxes, which would make a system for effluent reduction difficult to justify, but a nanofiltration system preceded by a mechanical suspended-solids separator was considered more economically viable.

The researchers noted that, to be cost-effective, membrane systems should generally be part of an overall water management strategy. Measures that do not involve membrane filtration could cut water consumption at the Norcal Crosetti plant to about one-fourth of its present level, yielding related reductions in the use of energy and chemicals.

## A matter of time

Although not all of the California food processors visited by the demonstration trailer turned out to be immediate candidates for membrane applications, the researchers noted that the rates for fresh-water supply and wastewater treatment will almost certainly head upward in the future, while the cost of membrane separation systems will continue to decline as better-performing and longer-lasting membranes become available. These trends point toward a continuing convergence of cost and necessity that can only mean an expanding market for membrane systems.

On the basis of the results of the demonstration trailer's initial trials with California processors, Ed Yates, senior vice president of the CLFP, estimates that as many as 1800 of the state's food-processing plants could use membrane filtration systems for economical wastewater treatment. If only one-third of these plants actually implemented such systems, he adds, the potential savings would be about 300 million gallons of water per day. "Our industry is always looking for ways to survive and become more competitive, and as these technologies become increasingly economical, they are going to be deployed, no question about it," says Yates.

This summer, the demonstration trailer has made brief side trips to Pennsylvania and New Jersey, showing food processors there what membrane systems have to offer. In Pennsylvania, the trailer conducted a demonstration at the American Home Foods Company's Chef Boyardee pasta plant. "We believe membrane separation is very useful for process water recovery not just in California but everywhere, and we believe the technology will find its way into applications all across the country," says EPRI's Amarnath. ■

Background information for this article was provided by Ammi Amarnath, Customer Systems Group.

by Taylor Moore

# Handy Help for Maintenance Workers

THE STORY IN BRIEF Lightweight, low-cost, color-coded job cards packed with technical reference information and geared to specific types of maintenance tasks offer a proven way to increase maintenance and troubleshooting efficiency in nuclear as well as other types of power plants. Developed in conjunction with EPRI's counterpart in Japan, job card sets have been pilot-tested at two operating U.S. nuclear plants and are also being evaluated by Japanese utilities. In addition to their potential for utility customization, job cards could become a new line of EPRI information product that is used directly by the people who inspect and repair equipment in utility power plants.

Nuclear Energy Institute

Despite four consecutive years of declining costs per megawatthour for nuclear plant operations and maintenance, the costs for nonfuel components of O&M continue in an upward trend. Labor can account for up to 80% of a plant's annual nonfuel O&M costs. Utilities that operate nuclear plants must be constantly vigilant simply to contain O&M expenses, particularly those for maintenance, while sustaining high plant productivity in the face of constant regulatory pressure.

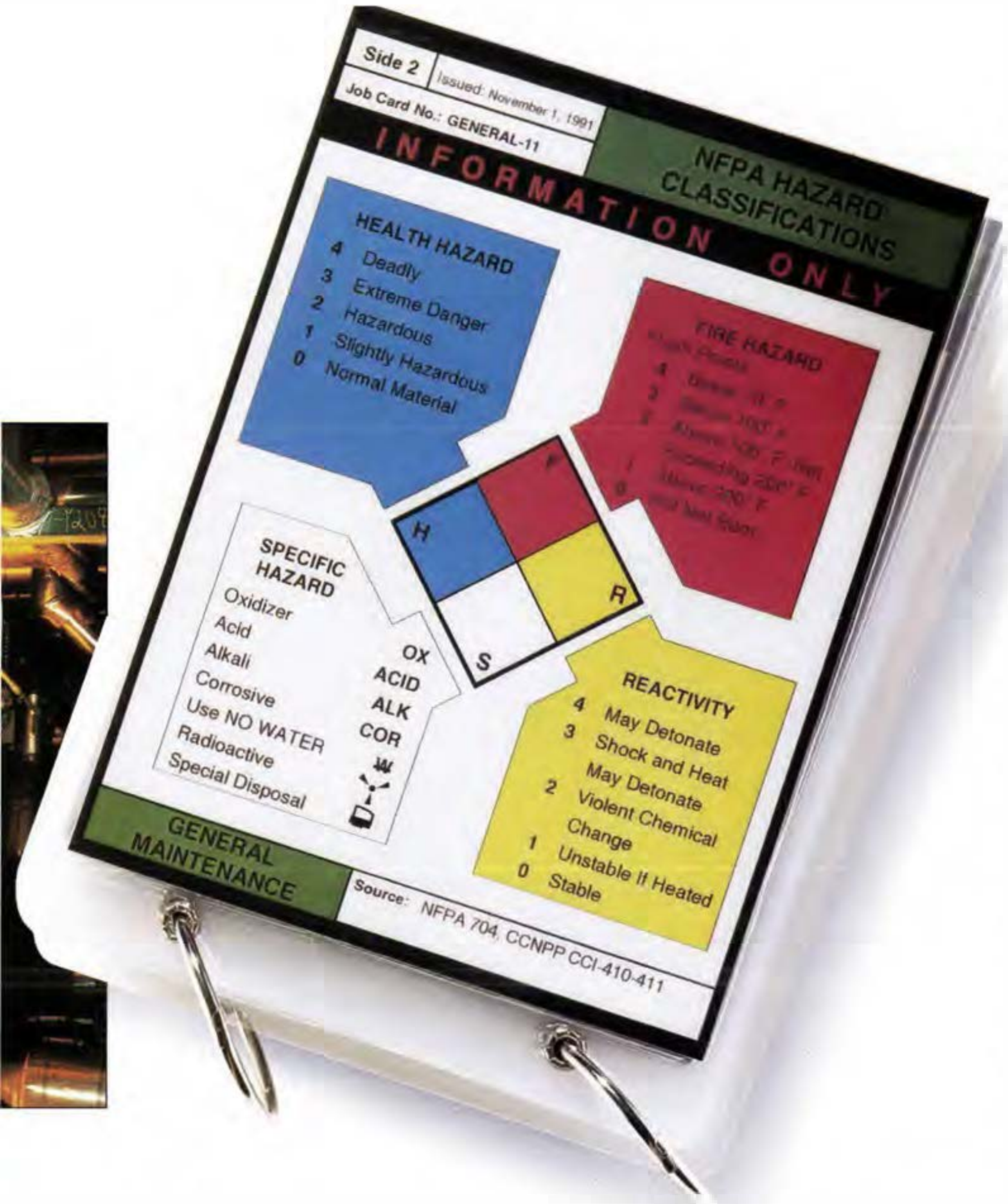
The total cost for maintenance is the sum of many things, not the least of which are the costs stemming from the inefficient use of highly skilled (and highly paid) craft labor in various routine maintenance tasks and from errors made as the result of a worker's lack of the proper technical reference information. As with many maintenance costs, reducing these can translate into a lower bottom-line cost of generation.

Reducing maintenance costs in order to improve plant productivity can involve measures that range from the leading edge of technology—a robotic sludgelancer, for example—to simple, low-tech tools. An example of the latter is job cards, a maintenance aid that grew out of human performance technology research jointly sponsored by EPRI and Japan's Central Research Institute of Electric Power Industry (CRIEPI).

As the result of their successful pilot development at two operating U.S. nuclear power plants, job cards are poised to become a significant new line of low-cost EPRI products for power plants. They could eventually be used by mechanics and other personnel in a wide range of maintenance applications. Generic sets of lightweight job cards are expected to be developed for numerous types of maintenance work by EPRI's Nuclear Maintenance Applications Center (NMAC). In addition, guidelines to help utilities produce their own customized card sets are being published. And in Japan, utilities are evaluating a set of job cards produced in Japanese under the project.

## Result of human performance study

According to Joe Yasutake, a manager in EPRI's Nuclear Power Group, job cards were developed as a result of a joint EPRI-CRIEPI study of ways to reduce error in the performance of mechanical maintenance tasks at nuclear plants. "Among several interventions suggested in surveys and analyses of maintenance workers and




their jobs was a set of task-specific information cards that technicians of all experience levels could readily access and understand," explains Yasutake.

The resulting cards are color coded by category and contain a mix of text, graphic, and tabular information identified as helpful by workers in earlier studies. The cards are intended to reduce the need to interrupt a task in order to consult a coworker or a handbook for information. Job card information is useful during such tasks as inspection, disassembly, reassembly, and postmaintenance tests. The information includes key conversions and formulas, task reminders, and troubleshooting aids. Research managers stress that job cards are intended to supplement—not replace—the detailed procedures documents typically issued for every maintenance job.

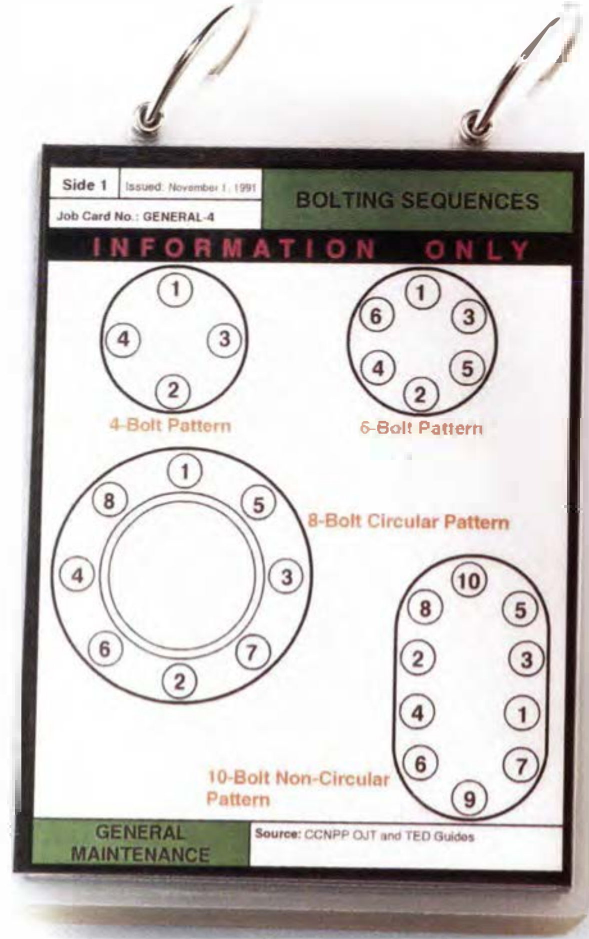
The card sets developed and tested at utility plants to date have been limited to nine categories. Their emphasis is on pumps and major valves, although many other types of equipment could be candidates for job card development. The categories are general maintenance, system information, alignment, rigging, pump maintenance, troubleshooting, valve maintenance, documents, and V-belts and sheaves. One job card, for example, provides torque wrench extension conversion formulas and a wrench diagram.

Job cards are part of a larger category of performance aids that present on-the-job reference material in various forms and media. The job card concept was previously applied in both the military and nuclear power settings. Since the mid-1980s, however, there have been major changes in maintenance practices at U.S. nuclear plants, including the replacement of generic maintenance procedures with specific ones containing detailed information and graphics for many of a plant's major pieces of equipment. As a supplement to these materials, today's job cards are aimed at providing maintenance workers with general information that will save them time in troubleshooting.

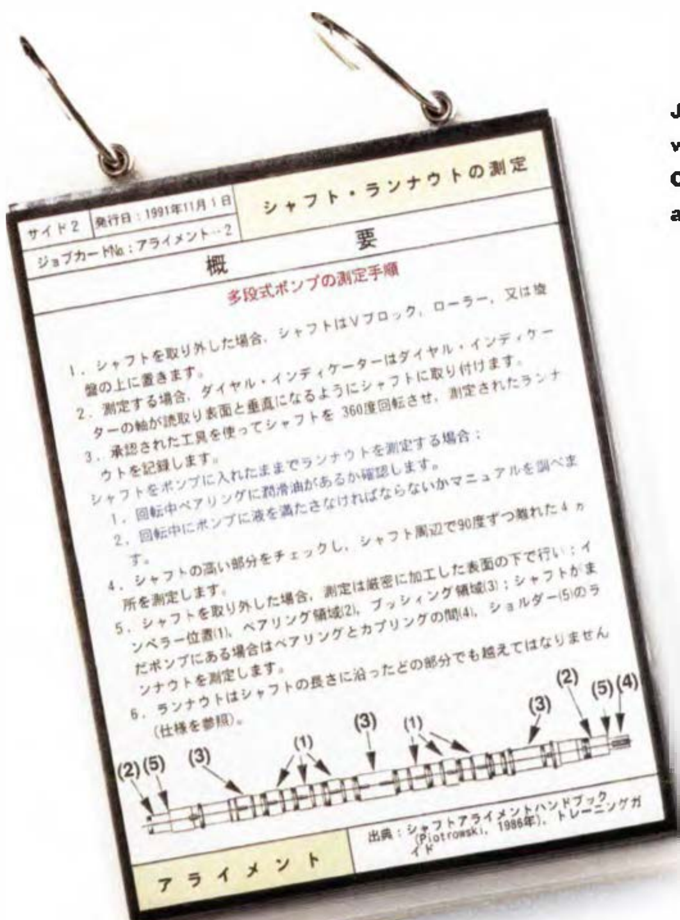
Job cards are intended to help improve the operations interface between the plant engineers who design systems and the maintenance personnel who do the hands-on work but may have limited knowledge of engineering principles. The project researchers noted that the performance of error-free maintenance requires more than mechanical aptitude; it also entails cognitive skills for understanding equipment-system interactions, choosing effective troubleshooting strategies, and making repair-or-replace decisions. In the past, technologies for enhancing cognitive skills in the nuclear power industry have focused more on the engineering disciplines than on maintenance.

Discussions with experts during the EPRI-CRIEPI study of maintenance tasks revealed many examples of how maintenance productivity could benefit from an improved, engineering-based cognitive understanding of equipment operation. Especially beneficial would be a deeper knowledge of system operation, a greater familiarity with engineering principles and terminology, and the development of an analytical framework for performing detailed inspections, interpreting information in vendor manuals, and troubleshooting complex systems when engineers are not present at the job site. Job cards are designed to become one of the tools for facilitating the exchange of knowledge between engineers and maintenance personnel without the overhead cost of cross-skills training.

As a tool that provides actual on-the-job assistance to craft workers, job cards are a new twist in EPRI's product offerings. "Most of the products of EPRI research related to nuclear power plants are used by engineers and plant operators," notes Lew Hanes, who manages EPRI projects in human performance improvement technolo-


**TECH DATA AT A GLANCE** The job cards developed and tested to date contain a mix of text, graphic, and tabular information identified as helpful in previous studies of maintenance work. Marked "Information Only," the cards are intended to supplement—not replace—detailed maintenance procedures documents. This year, EPRI member nuclear utilities will be provided with wire-bound booklets containing about 35 job cards generic to the industry.




**JAPANESE JOB CARDS** A set of generic job cards in Japanese was produced under the project, cosponsored with Japan's Central Research Institute of Electric Power Industry. The cards are being evaluated by Japanese utilities for possible use.

gies. "But job cards are something that carries the EPRI logo and are placed directly in the hands of the people who inspect and repair the equipment in the plant."

## Development and field testing

The initial sets of job cards were developed with the extensive cooperation and assistance of the training and mechanical maintenance departments at Baltimore Gas and Electric Company's Calvert Cliffs nuclear plant and Pacific Gas and Electric Company's Diablo Canyon nuclear plant. A customized set of cards was developed for each plant on the basis of input from personnel regarding topics, content, and layout. The cards were then field-tested by mechanics and training personnel at each plant during a nine-month trial.

There were 65 laminated, 5-by-7-inch, two-sided cards in each test set. The cards, made from heavy-duty paper, were packaged in three-hole notebooks and two-ring looseleaf binders. They may be used individually or combined in groups of the user's choosing. In the field tests, the users were encouraged to remove cards for individual use and to combine cards from different categories as they planned, performed, and checked jobs or studied between jobs.

The overall reaction to the job cards at both plants was very favorable. The test users affirmed the cards' potential for reducing maintenance errors and increasing efficiency. They gave the cards high marks for technical content and for durability. They indicated that they would recommend job cards to other maintenance personnel as well as to training and engineering personnel. The field tests also provided a number of insights for future job card development.

EPRI's contractor, Anacapa Sciences, developed the job cards for Calvert Cliffs and Diablo Canyon personnel in parallel efforts that followed the same procedure: plant requirements were specified; user requirements were identified; format, content, and organization were decided on; and, finally, production methods were selected. At each plant, the sponsor for the job cards effort was the supervisor of mechanical maintenance training.

**Calvert Cliffs**

**TESTED ON THE JOB** **Prototype sets of job cards were field-tested for nine months at Baltimore Gas and Electric's Calvert Cliffs nuclear plant in Maryland and at Pacific Gas and Electric's Diablo Canyon nuclear plant in California. The general reaction of test users at both plants was favorable and affirmed the cards' potential for reducing costs and increasing maintenance efficiency. At Calvert Cliffs, all nine categories of the cards were used frequently and were found to significantly reduce the time workers spent looking up technical information for routine maintenance jobs.**

It was decided early on that job card development would focus on pumps and valves because of their importance to the operation of all plants and their frequent need for overhaul. The researchers reported that satisfying all the user requirements identified in interviews with maintenance personnel proved a particular challenge because of the large number of constraints imposed. Ultimately, six user requirements were identified as essential and were applied in developing the job cards. The requirements were that the cards be rugged, portable, easy to read, task specific, procedure compliant, and colored for coding and visibility.

The plant personnel at Calvert Cliffs and Diablo Canyon were given detailed surveys to evaluate their reactions to and use of the job cards. At Calvert Cliffs, the response was particularly favorable in all survey categories. Workers reported that the cards were durable and easy to use and that all nine categories of cards were frequently used. Many indicated that the readily accessible information resulted in significant reductions in lookup time alone. One example was the time saved in preparing to move heavy equipment: a job card provided the relevant weight data, eliminating the need for workers to consult another reference. Personnel also cited the benefits of reduced errors and rework time, reduced radiation exposure through more-efficient task execution, and fewer instances of equipment damage.

The maintenance staff at Calvert Cliffs developed several job cards in addition to those originally produced for the field tests. The plant estimates that the use of job cards by 50 maintenance personnel over a seven-year period would be worth $700,000 in time savings alone, even after accounting for the cost of producing and replacing the cards.

"The EPRI job cards have proved bene-

## CATEGORIES AND TOPICS

The initial set of EPRI job cards, consisting of about 35 cards in seven categories, will be available this year. It will include cards on the topics listed here.

**General Maintenance**
- Micrometer measurement
- Vernier caliper measurement
- Torquing conversions
- Bolting sequences
- Flange data (two cards)
- Flange gasket installation

**Alignment**
- Alignment definitions
- Types of misalignment

**Rigging**
- Prerigging requirements
- Rigging inspection
- Sling load calculation
- Figure-eight knot for safety harness

**Pump Maintenance**
- Pump engineering terms
- Pump calculation reminders
- Preliminary pump disassembly steps
- Impeller heating
- Bearing inspection
- Examples of bearing failures
- Bearing removal and installation
- Identifying causes of seal leakage
- Packing inspection

**Troubleshooting**
- Valve troubleshooting: excessive noise
- Valve troubleshooting: leaking
- Valve troubleshooting: failure to operate smoothly

**Valve Maintenance**
- Gasket crush
- Calculation reminders
- Packing valves with graphite packing (top loaded)
- Chesterton valve packing data

**V-Belts and Sheaves**
- V-belt installation
- V-belt drive troubleshooting
- Sheave inspection
- Sheave alignment

ficial in on-the-job training as well as in the field at Calvert Cliffs," says Wally Price, supervisor of the plant's mechanical maintenance training unit. "They are accessible, easily used, accurate reference cards filled with otherwise hard-to-locate everyday information. They are not procedurally conflicting but information enhancing. Many of the job cards contain generic information that could be used in mechanical applications in nuclear power, fossil power, or any other such field."

### A role for generic job cards?

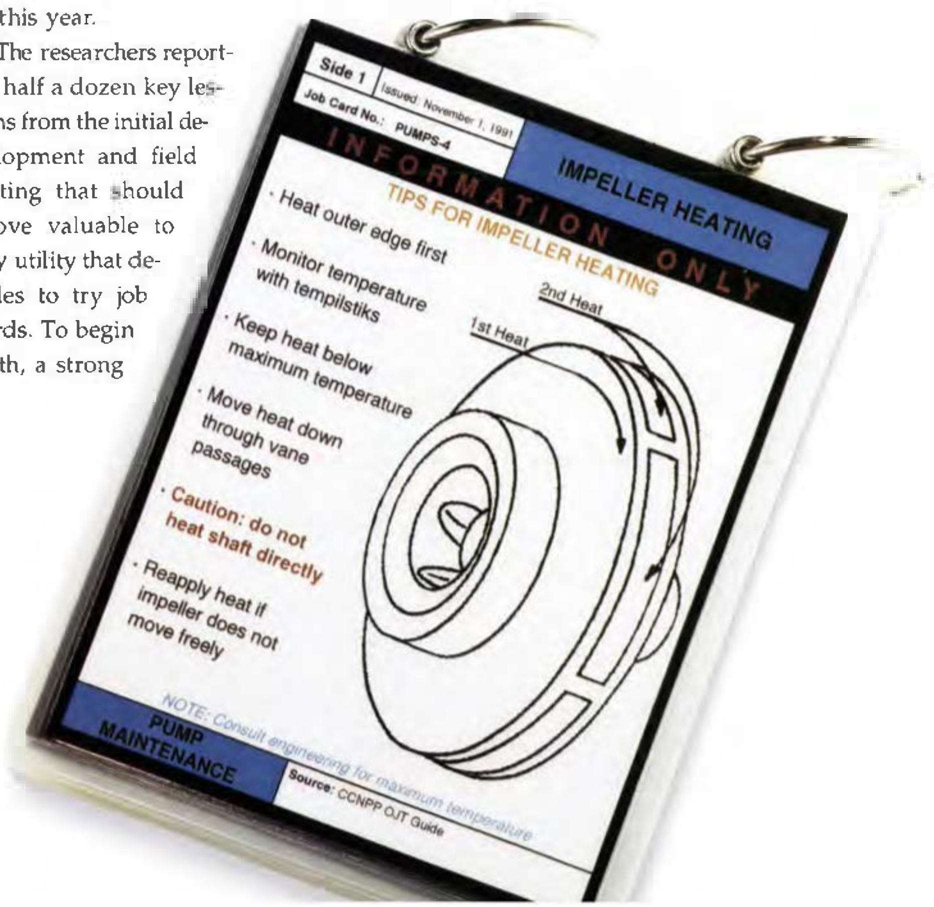
An important issue highlighted by the field tests is how applicable the job cards are to other plants. The survey results indicated that about half the cards are applicable with no modifications, 35% need minor modifications, and 10% are relevant only to an individual plant. The researchers concluded that a set of generic job cards might be useful across much of the nuclear generation sector.

NMAC is exploring this issue further and plans to begin development of a generic set of job cards for distribution to EPRI member utilities. A guidelines document describing how to develop information for utility-customized job cards is planned for publication later this year.

The researchers reported half a dozen key lessons from the initial development and field testing that should prove valuable to any utility that decides to try job cards. To begin with, a strong advocate is needed to introduce job cards into a plant. This champion for the cards should have high credibility and frequent access to first-line maintenance supervisors. To ensure greatest use of the cards, they must be kept near the mechanics' work area for continuous visibility. Specific methods of card use should not be predetermined; personnel should be free to decide for themselves how best to use the cards. Flexibility in terms of card packaging and sizing is also important. The cards should be able to be produced in different sizes, depending on their intended application. Some—such as those indicating hand signals for rigging—might be wall-sized, while others should be wallet-sized to be handy for carrying around.

A multilevel strategy for distributing the cards is necessary, with different sets for different types of workers. Senior staff may require or use only a subset of the cards that an apprentice would find helpful. Finally, EPRI research has shown that job cards can be viewed as both a maintenance aid and a training aid. Their use will ultimately be based on individual plant needs. ■

Background information for this article was provided by Lew Hanes and Joe Yasutake, Nuclear Power Group.



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*Technical sources for Journal feature articles*

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**The Challenges of Open Access** (page 6) was written by science writer John Douglas with technical information provided by members of EPRI's Power Delivery Group.

**Mark Wilhelm**, director, power system operations, came to EPRI in 1992 from Siemens, where he had worked since 1979. His responsibilities there ranged from power system transient analysis and network simulation to the design, marketing, and installation of industrial static VAR systems. He managed Siemens's Power Systems Projects organization from 1988 to 1992. Wilhelm holds BS degrees in electrical engineering and computer science from the University of Wisconsin and a master of engineering degree from Rensselaer Polytechnic Institute.

**Gerry Cauley**, target manager for power system planning and operations, joined the Institute in 1991, initially focusing on research strategies and technologies for power system control centers. Previously he had been with General Physics Corporation for 10 years, eventually managing the firm's training services for power system operations. Cauley also served with the Army Corps of Engineers as a construction engineer and as a supervisor at a power generation training center. He holds a BS in electrical engineering from the U.S. Military Academy at West Point as well as an MS in nuclear engineering from the University of Maryland and an MBA from Loyola College.

**Neal Balu** has been at EPRI since 1979, managing a broad spectrum of system planning and operations research and serving as program manager from 1988 through 1993. Earlier he spent seven years with Southern Company Services and four years on the faculty of the Indian Institute of Technology in Bombay. Balu received an MSc degree from the University of Saskatchewan, an MS from Louisiana State University, and a PhD from the University of Alabama, all in electrical engineering. He also holds an MBA from Santa Clara University. ■

**A Separable Feast: Membrane Applications in Food Processing** (page 16) was written by Taylor Moore, Journal senior feature writer, with assistance from **Ammi Amarnath**, manager for process industries in EPRI's Customer Systems Group. Amarnath joined the Institute in 1988 after three years with Metito International of Houston, Texas, where he was involved in the design of membrane-based purification systems, and four years as a technical supervisor of process equipment engineering and fabrication at K-Sons Ltd. in India. He received an MS in chemical engineering from the University of California at Santa Barbara and an MBA from the University of Houston. ■

**Handy Help for Maintenance Workers** (page 24) was written by Taylor Moore, Journal senior feature writer, with information from two managers of human performance improvement technologies in EPRI's Nuclear Power Group.

**Lewis Hanes** joined EPRI this year after a 20-year career as a research manager at Westinghouse Electric Corporation's Science & Technology Center in Pennsylvania. Hanes received a BS in agronomy and MS and PhD degrees in human factors from Ohio State University.

**Joe Yasutake** joined EPRI in 1990 following 3 years with Lockheed Missiles & Space Company, where he was manager of integrated logistics support for the Milstar defense program. Before that, he spent 17 years as a technical advisor to the training systems division of the Air Force Human Resources Laboratory and, still earlier, 10 years with the Air Force Systems Command. Yasutake received a BS in psychology from the University of Illinois, an MA in industrial psychology from New York University, and a PhD in industrial psychology from Ohio State University. ■

*Electricity on Maui*

## Sweet Power May Stay Green

Sugarcane fields and the root nodules of a legume that may replace bagasse as a

Hawaii's sugar industry not only has been an important source of income for the state but has also provided a valuable feedstock for power production. About 10% of the electricity consumed on the islands is produced from bagasse—the fibrous waste of sugarcane stalks—with the remainder produced from fuel oil. But this scenario is expected to change. The worldwide cane sugar market has shrunk in recent years, and Hawaii is having a hard time competing against other sugar-producing countries.

As islanders brace themselves for the economic impact of the sugar industry's rapid decline, EPRI and other groups are focused on finding a power resource to replace bagasse. Through one project initiated in May, researchers with the Pacific International Center for High-Technology Research (PICHTR) are exploring the feasibility of retrofitting an 8-MW bagasse plant near Lahaina, Maui, to accept an alternative biomass feedstock.

According to Jane Turnbull, EPRI's representative on the project team, PICHTR is considering the use of fast-growing biomass grasses as well as fast-growing tree species like eucalyptus and leuceana. One advantage leuceana offers is that, like other legumes, its root nodules contain nitrogen-fixing bacteria—bacteria that absorb nitrogen from the atmosphere and convert it into a fertilizer, further stimulating tree growth. PICHTR is also exploring the possibility of using effluent from the island's sewage plants to fertilize and irrigate the biomass crops.

"Unlike most other biomass projects we've undertaken, this project has much of the infrastructure for planting and harvesting already in place," says Turnbull. Rather than being interspersed in smaller fields with traditional farm crops, the biomass would simply replace the 6000 acres of sugarcane that currently supply the Lahaina plant. Transportation of the biomass to the plant would not be a significant issue, since the fields surround the plant.

The plant currently employs conventional boilers to make steam that runs through a turbine to generate power. But the electricity production is less than 20% efficient. The technologies being considered for the retrofit include not only more-efficient steam turbines but also gas turbines and fuel cells. The resulting electricity would be sold to Maui Electric (a subsidiary of Hawaiian Electric Company), which buys the power produced by the existing plant.

Also being explored in the study is the socioeconomic impact—in terms of jobs and economic return to the community—of both the retrofit biomass plant and the feedstock production. Although an 8-MW plant is tiny compared with baseload power plants in the mainland United States, Maui's entire power demand totals only 160 MW. And a successful retrofit of the Lahaina plant could encourage a similar conversion of other bagasse plants.

Amfac/JMB Hawaii Inc., which owns the 6000-acre site, is part of the local team contributing 50% of the study's cost. EPRI and the U.S. Department of Energy are committed to sharing the remainder of the financial burden. The feasibility study is expected to be completed by the end of the year.

■ *For more information, contact Jane Turnbull, (415) 855-2407.*

*PWR Radiation Reduction*

## First Full-System Decontamination Planned

Consolidated Edison Company of New York and EPRI have undertaken a project that will culminate in the nuclear power industry's first full-system decontamination of a utility-owned pressurized water reactor. Over the years, utilities have practiced partial-system decontamination of their nuclear plants in order to comply with federal regulations, reduce workers' radiation exposures, and cut operation and maintenance costs. But as Chris Wood, EPRI's manager for the project, explains, full-system decontamination is much more effective.

"A full-system decontamination will allow a greater reduction in radiation exposures than can be achieved by decontaminating individual parts of a plant separately," Wood says. In a full-system decontamination, the reactor's coolant pumps circulate a chemical decontamination solution throughout the system. Not only does the use of the reactor pumps make it possible to decontaminate sections of a system that would not otherwise be reached, but the pumps generate a swifter rate of water flow than smaller pumps can achieve.

Wood notes that lower radiation levels result in lower daily exposures for maintenance workers, which means that fewer workers are needed to complete a given job, a factor that significantly reduces maintenance costs and improves productivity. The full-system decontamination of Consolidated Edison's Indian Point Unit 2 PWR in Buchanan, New York, is expected to save 3500 man-rems over five operating cycles. Equipment is currently being assembled for the process. The full-system decontamination is scheduled to be performed at the plant's next refueling outage, in 1995.

"One important aspect of this project is the transfer of information to the rest of the industry," says Wood. Officials at Consolidated Edison report that industrywide participation could reduce radiation exposures by an order of magnitude and save an estimated $1 billion.

Several EPRI member utilities participating in the project will receive detailed information as it becomes available. This information is expected to help reduce the time and cost involved in their own decontamination processes. Empire State Electric Energy Research Corporation is also participating in the project.

■ *For more information, contact Chris Wood, (415) 855-2379.*

*Electric Vehicles*

## Project Aims to Improve Battery-Powered Buses

Battery-powered shuttle buses in operation across the country today number fewer than 40. Yet shuttle bus transportation—which involves low speeds, short distances, and frequent stops—is an ideal application for electric vehicle technology. However, the existing battery-powered shuttle bus technology has deficiencies that work against its wider use. EPRI researchers have initiated a project aimed at overcoming these deficiencies.

The existing technology's main drawbacks are its high cost, the heavy weight of the battery systems, and the severe impact that heating and cooling of the passenger compartment can have on vehicle range. Even without heating or cooling, the battery-powered shuttle buses currently available will typically run for only about half a day on one charge. And the only way to extend a vehicle's daily range is to exchange its battery pack.

"This is an unsatisfactory long-term solution," says Phil Symons, EPRI's manager for the project. Symons notes that the deficiencies of today's battery-powered buses have limited their use to areas with mild climates. Very few existing models have air conditioning systems; when such systems are available, they typically run on separate fossil-fuel-burning engines.

Three EPRI member utilities—Duke Power, Pennsylvania Power & Light, and Duquesne Light—are participating in the project. The utilities are in the process of purchasing four battery-powered buses that will be specially equipped with data acquisition systems. Each bus will become part of a regular fleet operated by a local transit company and will be used on an established urban route.

Over a two-year period, the researchers will test at least two space-conditioning systems in each vehicle, with careful attention to performance at various ambient temperatures. The utilities involved will follow specified protocols for battery charging and discharging and for collecting and reporting data. Drivers will be specially trained and will be asked to follow a protocol for acceleration, coasting, and stopping.

The researchers will analyze the resulting data to identify ways to improve battery systems, charging and discharging methods, and thermal management systems.

■ *For more information, contact Phil Symons, (415) 855-2797.*

## Improving Plume Dispersion Models

Field results are expected to be available this fall, with modeling results to follow next spring, from a study of plume rise and building downwash from combustion turbine power plants. The study, cosponsored by six utilities and EPRI in a tailored collaboration project, will provide improved algorithms for air quality dispersion models used in the regulatory permitting of power plants.

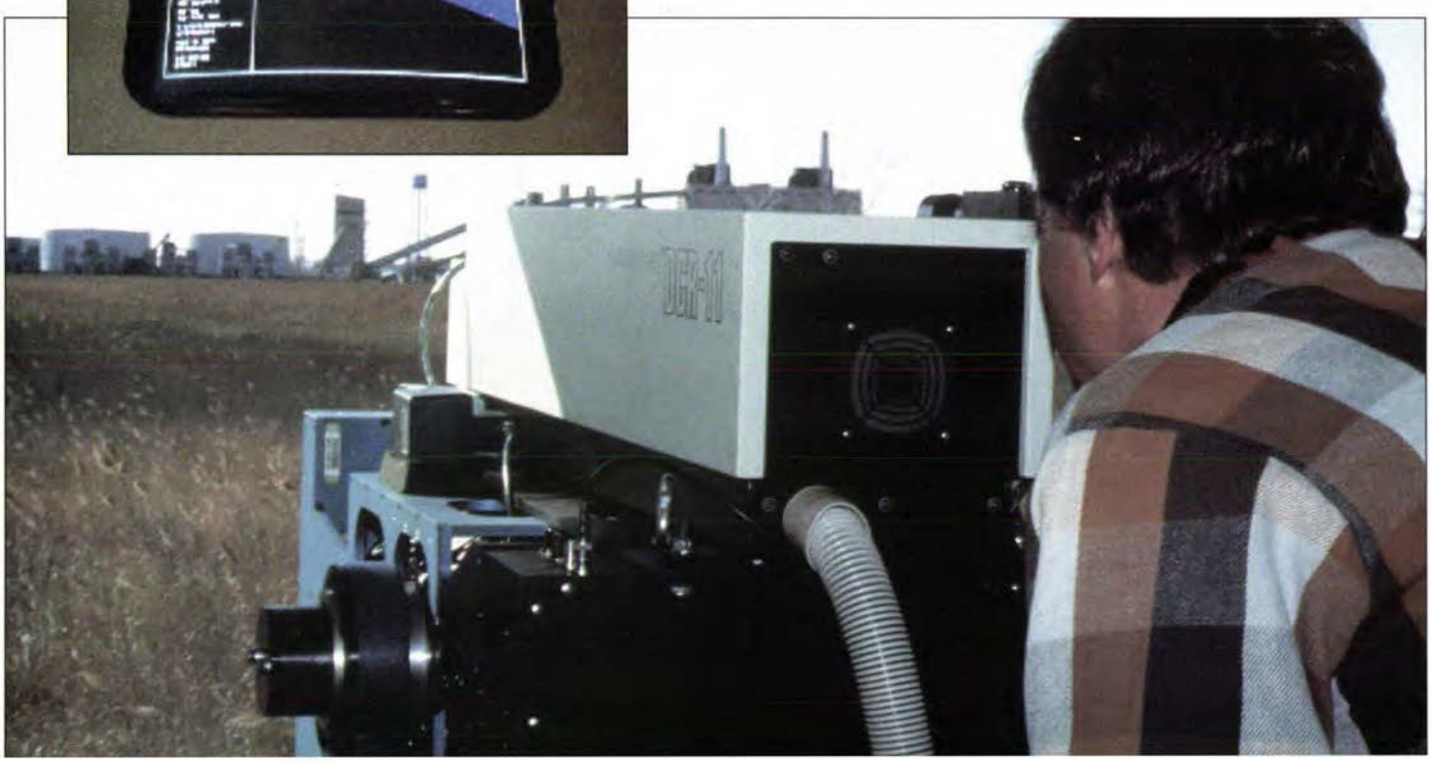
Plume dispersion models currently being used by the U.S. Environmental Protection Agency were developed from observations of steam boilers and may not realistically represent the behavior of plumes from combustion turbines, which have much higher exhaust-gas exit velocities and temperatures. In simple-cycle operation, combustion turbines are used by utilities mainly for generating electricity during periods of peak demand.

"It's important from a scientific and regulatory standpoint to look at combustion turbines as a separate category," says Rich Dunk of Jersey Central Power & Light Company, which hosted the project's field measurement phase at its Sayreville station in February. Remote and in situ measurements of the plant's emission plume and of meteorological conditions were made by teams from ENSR Consulting and Engineering, the National Center for Atmospheric Research, and SRI International. Sigma Research Corporation is integrating the field data with wind tunnel modeling data provided by the EPA. Results from the project's computer model development and testing phase will be presented in the spring of 1995 at the next EPA triennial modeling conference.

The EPA and the Electricity Supply Association of Australia have cooperated with the project by providing wind tunnel modeling at EPA facilities and at Monash University in Australia. "Wind tunnel modeling provides a flexible and cost-effective technique for introducing an element of control into atmospheric experiments," explains William Snyder, director of the EPA's fluid modeling laboratory. "While we have confidence in our own modeling abilities and those of our Australian colleagues, this project's field measurements provide a 'ground truth' opportunity that is lacking in many previous studies."

■ *For more information, contact Chuck Hakkarinen, (415) 855-2592.*

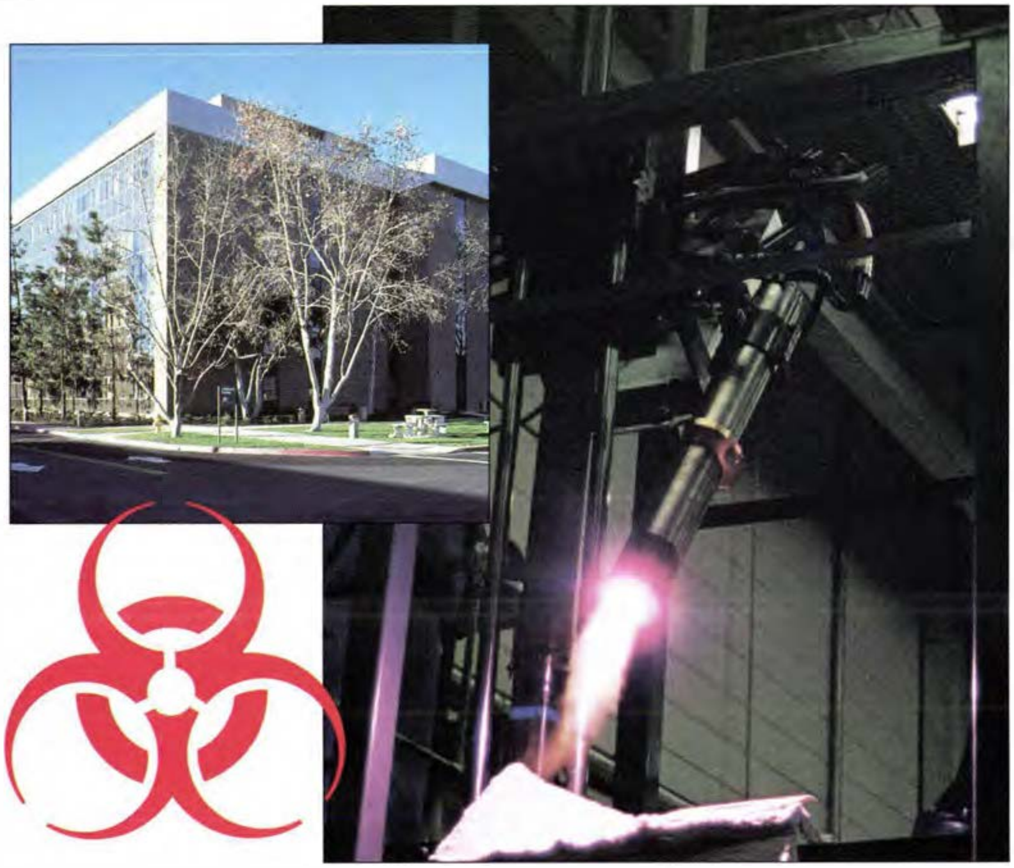
**Real-time display of LIDAR response**



**Sighting a LIDAR system to measure plume dispersion at Sayreville Unit 4**

Jim Kerm, JCP&L

## Plasma Pyrolysis System for Medical Waste Planned for San Diego



The country's first commercial plasma pyrolysis system for processing medical waste is planned for a Kaiser Permanente medical center in the San Diego area and could be operating as early as next year. EPRI is helping to offset a portion of the system's capital cost as part of its support of several new electrotechnologies for waste disposal in the health care industry.

Hospitals traditionally have incinerated their medical waste on-site. But tightening air quality regulations are forcing the closure of many on-site incinerators. Most hospitals that have lost the use of their incinerators must rely on contractors for off-site disposal, which not only is more costly but also raises concerns about liability should problems occur after the waste leaves the hospital.

In the plasma pyrolysis process, an electric arc is created that heats gases to 12,000°F—to an ionized, or plasma, state. The plasma, in turn, heats the waste-processing chamber to about 3000°F. During pyrolysis, or heating in a low-oxygen environment, the organic waste is converted into stable gases like hydrogen, carbon monoxide, and nitrogen. What's left is a molten mass that cools to become a slag of glass beads. The slag is disinfected and can be recycled for use as an aggregate substitute in roadbed material or concrete.

Plasma pyrolysis reduces the volume of infectious waste (so-called red bag waste) by more than 90% and its weight by 80%. In principle, the process is capable of handling all types of medical wastes except those that are radioactive. Hot gases released in the pyrolysis process can be used for other purposes, such as generating hot water for use in the hospital. The resulting stack emissions are like those from combustion processes and include particulates, nitrogen oxides, and trace metals. However, the quantities of these emissions are significantly lower than in incineration; trace organic emissions, such as dioxins and furans, are near zero.

Disadvantages of the plasma pyrolysis process include its currently high capital cost and the significant throughput rates required for economical operation. These factors make the technology appropriate only for large hospitals and regional treatment facilities. In supporting the Kaiser Permanente project, EPRI hopes to help make other health care facilities familiar with the technology, the capital cost of which should come down as use grows. The system planned at Kaiser, to be supplied by Plasma Energy Applied Technology, Inc., could be under construction this year and operating by 1995.

■ *For more information, contact Myron Jones, (415) 855-2993.*

*Exploratory Research*

# Fundamental Studies of Particle-Turbulence Interaction

*by John Maulbetsch, Strategic Development Group*

From convection in hot coffee to gusts of wind, turbulence can be found in liquids and gases all around us. Swirls and eddies, and zephyrs and tornadoes, are manifestations of turbulent fluid flow, in which energy of motion is transferred from large-scale, more or less coherent bulk movements to smaller-scale, more chaotic motions and eventually to the microscopic fluctuations associated with viscosity.

In turbulent fluids, convection processes promote the transport and mixing of entrained particles, combustion gases, and other fluid elements, as well as the transfer of thermal energy. As a result, many engineered systems, such as coal combustors, engine cylinders, precipitators, and aerosol reactors, are designed to encourage turbulent flow. Turbulent, particle-laden flows can also occur inadvertently because of contaminants—for example, sand, dust, or water droplets in gas turbine passages. And similar natural processes are involved in the weather, in pollutant transport, and in heat and chemical exchanges in the oceans and the atmosphere. Because an understanding of turbulent, particle-laden flow is instrumental for improving the performance of a variety of power plant systems, enhancing equipment designs, and accurately modeling various natural processes, EPRI supports fundamental exploratory research in this area.

### Turbulent flow structures

Scientists have attempted to model turbulence for more than 100 years, but it has proved difficult to characterize, even for a fluid without particles. Until recently, models focused on average fluid behavior and on scaling factors, neglecting the seemingly random motion characteristic of turbulence. Although successful in many ways, these bulk-fluid approaches were unable to fully describe the nature of turbulence. In the past 25 years, however, researchers—while both helping in the discovery of chaos and applying its theoretical underpinnings—have found that some turbulent motions are quite organized. Features that are characteristic of a particular flow occur repeatedly, dominating the turbulent fluctuations. Through detailed examination of these flow features, researchers have characterized some important structures.

One structure commonly encountered in turbulent flow is meandering, long-lasting streams or streaks of low-speed fluid that are parallel and proximate to a channel wall or other surface. These streaks are little affected by wall roughness, pressure gradient, and other flow conditions. At times, however, portions of the streaks appear to lift away from the wall, oscillate, and roll up into patchy bursts of intense activity, as in the roiling often seen in rivers and streams. Research suggests that much fluid mixing and heat transfer occurs within these bursts.

Another structure characteristic of turbulent flow is whirlpool-like vortices of spinning fluid. Spectacular large-scale vortex structures have been observed when two fluids traveling at different rates meet and interact, as well as when a fluid flows around an obstruction. Smaller-scale vortices have been observed accompanying low-speed streaks. Although some vortices can be persistent, most are short-lived compared with the slow, meandering streaks. However, because of their high local velocities and in-

**ABSTRACT** *Because turbulent fluid flow facilitates mixing, transport, and heat exchange, turbulence is encouraged in many utility applications—for example, in combustors, electrostatic precipitators, and reactors. Turbulent flow is also associated with many oceanic and atmospheric processes. Although the recent discovery of an underlying organization in turbulent fluids has led to a considerably better understanding of this flow regime, the complex interactions between turbulence and entrained particles—interactions that play a key role in transport and mixing processes—have not yet been fully elucidated. Several EPRI exploratory research projects seek to enhance our understanding and control of particle-turbulence interactions. Findings from these projects may lead to improvements in the performance of various power plant systems, to advanced pollution control methods, and to more-accurate modeling of many significant natural processes.*

tense stirring action, vortices also play a key role in fluid mixing and heat transfer.

### Particles in turbulent flow

Turbulence structures control much fluid transport and mixing and thus strongly influence the distribution and motion of fluid-borne particles. Typically, the actions of these structures segregate particles (except when the structures change more rapidly than the particles can move around in the fluid). For example, denser-than-fluid particles are generally flung out of vortices, becoming concentrated in relatively stagnant, nonrotating regions of flow, such as the slow streaks that develop near walls. Even if overall particle loading is low, turbulence-induced particle segregation can cause relatively high local particle concentrations, which in turn may change flow behavior.

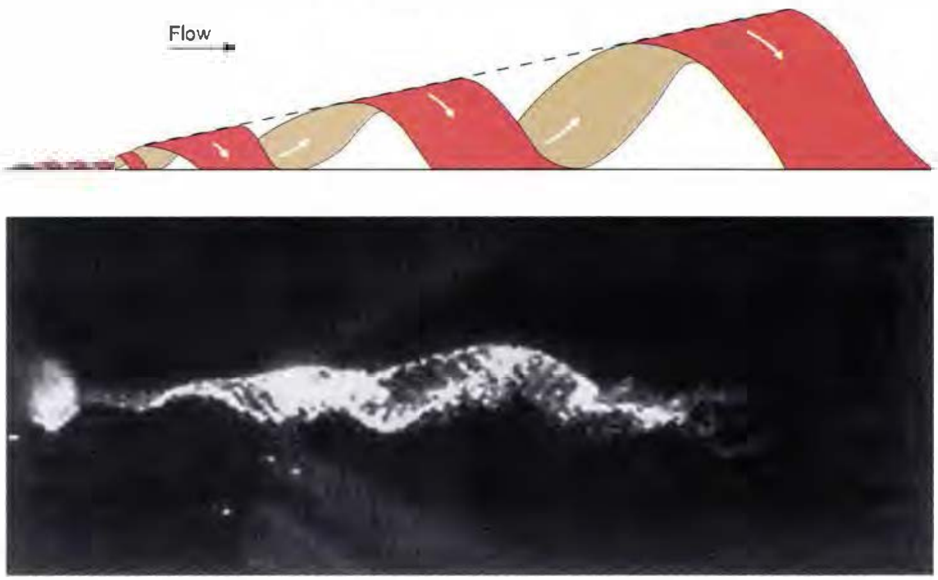
Because the effects of turbulence structures and fluid-borne particles on fluid flow are interdependent and highly nonlinear, analysis is difficult. As a result, the fundamental relations for this flow regime remain poorly understood. However, the control of particle-turbulence interactions offers potential for optimizing fluid mixing and heat exchange in combustion and other utility processes. Another possible benefit would be the regulation of flow behavior to decrease turbulent friction in pipelines and so reduce pumping costs.

To improve understanding of particle-turbulence interactions in utility applications, EPRI has initiated a number of exploratory research projects. Three laboratory-based studies are exploring fundamental aspects of turbulence for mixtures in which the momentum of the fluid (gas or liquid) component is generally more significant than that of the suspended particles (liquid or solid). Such mixtures are characteristic of combustion, pollution control, and other utility processes. Related projects are addressing the behavior of atmospheric aerosols in turbulent flow and the theoretical modeling of particle-turbulence interactions.

### Pipes and rivers: turbulent flow along a wall

Scientists at the University of California at Santa Barbara (UCSB) are investigating the fundamental relations between turbulence structures and low loadings of polystyrene spheres in shear flows, focusing particularly on the low-speed streak and burst behaviors that develop near flow-parallel boundaries, such as pipe surfaces or riverbanks (RP8034-2). An improved understanding of these phenomena could lead to increased control of particle deposition and reentrainment, reduced fouling in heat exchangers, and enhanced control of particle behavior in electrostatic precipitators.

**Figure 1** Side-view schematic and top-view photograph of a typical funnel-shaped vortex observed in turbulent flow. This recently discovered structure is thought to underlie other turbulence phenomena, such as small streamwise vortices and particle deposition and reentrainment near walls. An increased understanding of funnel vortices could lead to enhanced control of particle-laden flows and thus, for example, to reduced fouling in heat exchangers.

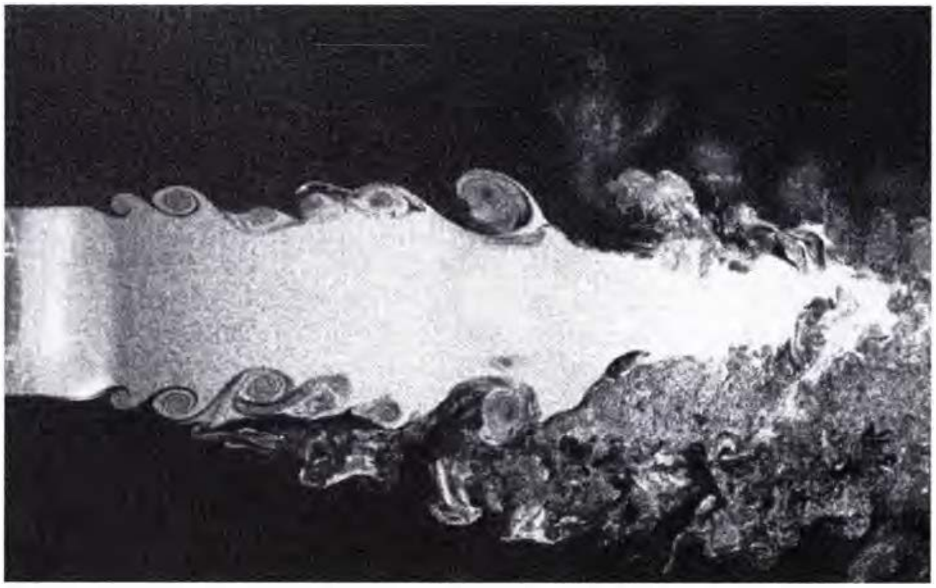



The UCSB researchers are using laser Doppler anemometry, high-speed video, and streak-line photography of oxygen bubbles for the visualization of flow structures; reference bubbles are produced via pulsed electrolysis at wire electrodes installed in the flow channel. This experimental work has helped clarify the interactions of particles and turbulent flow, revealing what may be a fundamental large-scale turbulence structure: streamwise funnel vortices (Figure 1). These vortices, each shaped like an expanding spiral wound around a funnel laid in the direction of flow, originate near a solid boundary and grow toward the air-water (free) interface; the spiraling stream flows considerably faster than the surrounding fluid. Turbulence features described in previous research—such as small quasi-streamwise vortices, low-speed streaks, and bursts—appear to be aspects of this underlying structure.

The UCSB scientists hypothesize that funnel vortices are responsible for most of the particle-turbulence effects occurring near flow boundaries. These vortices appear to be the primary mechanism of particle entrainment and deposition: they both eject particles into the main flow and sweep them toward walls, where deposition is promoted. Particle concentration and velocity are higher within vortices than outside.

Further studies indicate that particle loading in the flow has a relatively small effect on the overall intensity of funnel-vortex-related turbulence, although higher concentrations reduce it somewhat. Particle size and density have a more pronounced effect: small, light particles suppress turbulence while large, heavy ones enhance it. Thus the addition of particles to a fluid may offer a cost-effective way to optimize flow behavior. For example, preliminary results suggest that it might be possible to increase heat transfer rates in film coolers and similar equipment by 20% or more with this approach while keeping particle volume fractions very low.

Figure 2 Unforced smoke-laden jet flow into quiescent air shows the vortex structures rolling up in the mixing fluid downstream of a jet nozzle. By controlling these vortex rings through flow forcing, particles can be concentrated or dispersed. One practical application of such control would be to regulate coal particle distribution, a key factor in reducing pollutant formation during combustion.



## Combustors: turbulence in forced jet flow

To improve combustion control in coal-fired boilers, researchers at Stanford University are studying the forced jet flow of particle-laden fluid into quiescent air (RP8005-2). Although coal combustors have been empirically optimized, environmental regulations requiring reduced emissions of nitrogen oxides necessitate improved understanding and control of the coal-air mixing processes in combustor jets. $NO_x$ production can be minimized if the feed coal particles are starved of oxygen during devolatilization and pyrolysis, although this approach can decrease combustion efficiency.

Coal-air mixing is being simulated in a round jet with annular coflow. In this device an inner stream of air laden with glass particles is surrounded by swirling annular airflow. These flows represent the central fuel feed and the rotating outer airflow that are employed in coal combustors to delay fuel-air mixing and thereby reduce $NO_x$ production. Acoustic speakers mounted on the device provide adjustable axial forcing for each flow to control the smoke-ring-like vortex structures rolling up in the mixing fluid downstream of the jet nozzle (Figure 2). Velocity measurement and particle visualization techniques that are phase-locked to the acoustic forcing are used to study the jet flow.

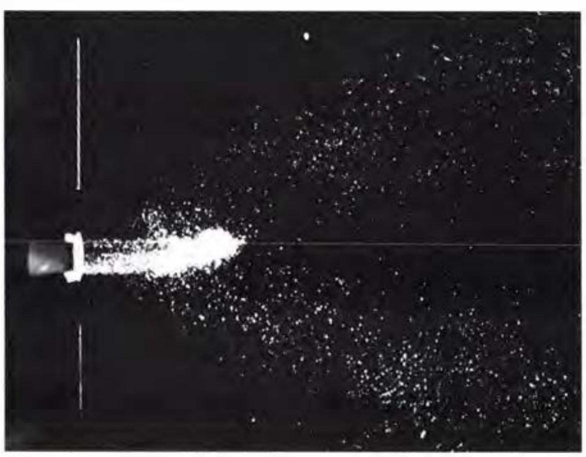


Figure 3 Forced particle-laden flow in a round jet with annular coflow representative of a typical coal combustor. The swirling outer flow initially concentrates the particles in the inner region and then scatters them. In a combustor, flow could be controlled to concentrate pulverized coal and delay fuel-air mixing during devolatilization, thus reducing $NO_x$ formation, and then to scatter the particles, promoting complete combustion.

Experiments indicate that turbulence structures at first develop independently in each flow phase but that the large-scale vortex structure of the outer (air) flow ultimately controls turbulence in the inner (fuel) flow. As a result, axial forcing of the outer flow can strongly affect particle distribution in the inner flow (Figure 3). The effect of core-flow forcing is smaller and is restricted to the inner region. Continued investigation is expected to provide a practical means of controlling fuel-air mixing to improve coal combustion while minimizing $NO_x$ production.

## Turbines: turbulent flow against a solid plate

In recently initiated work, researchers at the University of Minnesota are exploring fundamental particle-turbulence interactions in a forced jet flow impinging against a flat plate (RP8034-1). This effort is intended to support design improvements for turbines, cyclones, and other utility equipment exposed to pressurized, particle-laden flow. For example, the turbines used to expand hot gases downstream of a pressurized coal combustor must be heavily reinforced—at a cost in efficiency—to withstand erosion due to particle impact. An improved understanding of the flow around turbine blades could lead to designs that are more cost-effective.

The Minnesota researchers are using a simple round air jet; glass beads and smoke can be introduced into the flow to simulate the behavior of contaminant particles and to aid in the visualization of turbulence structures. By forcing the jet with acoustic waves, turbulence development can be controlled to produce coherent vortex ring structures.

Turbulence structures and particle trajectories are being examined at a variety of forcing frequencies. Both particle loadings that influence turbulence structure and local concentrations of particles in relation to flow structure are being determined, with particular emphasis on particle impingement locations and rebound characteristics. In addition, heat exchange between the flow and the plate is being studied to determine how moderate particle loading can affect heat transfer by altering flow structure. This research could lead to more-efficient combustors as well as to improved protection of exposed surfaces.

### Other particle-turbulence research

EPRI is also supporting experimental and theoretical exploration of the interactions of entrained particles and turbulence in other environments.

Scientists at the Massachusetts Institute of Technology are investigating the response of ultramicroscopic particles to turbulence in an effort to characterize the transport and deposition of aerosols in a gas stream (RP8000-41). Enhanced understanding in this area could lead to more-effective erosion protection in fluidized-bed combustors, to advanced particle precipitation and filtration techniques, and to improved ways to protect the human respiratory system from airborne pollutants.

And University of Southern California researchers are applying a computational approach to model the general processes of particle and droplet dispersion in unsteady three-dimensional shear flows, such as those found in clouds, sprays, cooling towers, and combustors (RP8006-23). This effort is intended to complement EPRI-funded experimental investigations of particle-turbulence interactions by improving the capability for numerical simulation of fluid flow. The researchers aim to refine existing laws and derive new ones governing the distribution of particles in various flow regimes.

*Residential Heating and Cooling*

# Field-Testing a Hydronic Thermal-Distribution System

*by John Kesselring and Sekhar Kondepudi, Customer Systems Group*

**ABSTRACT** *A 1990 EPRI study showed that heat pump systems using hydronic, or circulating-water, distribution with zoned control could offer several advantages over systems using conventional air distribution. In testing during the 1992–1993 heating and cooling seasons, a prototype hydronic system functioned reliably and compared favorably with a conventional forced-air system in terms of comfort provided. Zoned control with individual fan-coil units proved successful, and the researchers concluded that an improved, commercial hydronic system could further increase comfort and provide significant energy savings. EPRI has initiated discussions to license a commercial developer for the system, and field testing at utility sites will begin soon.*

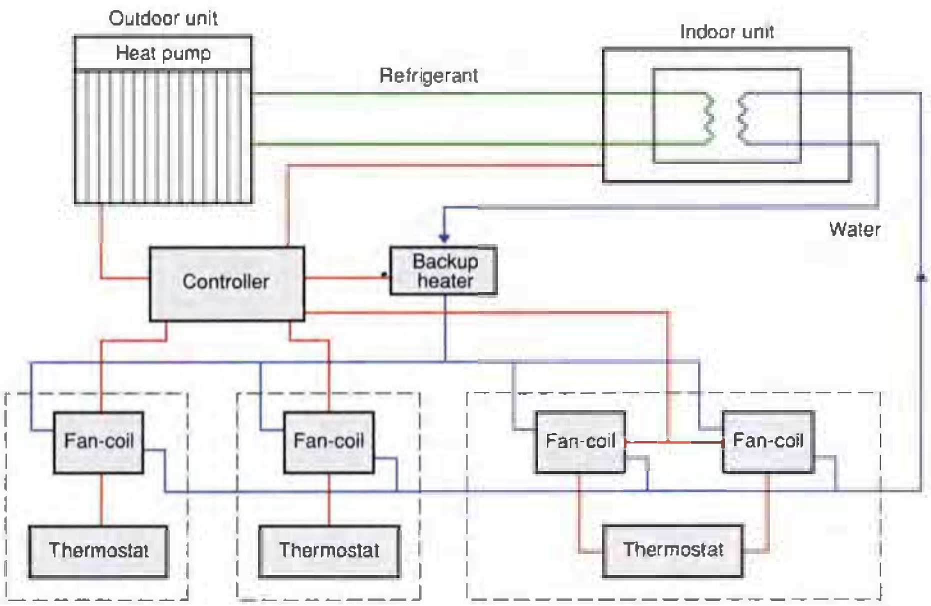
In homes with conventional forced-air, duct-type thermal-distribution systems, it is not uncommon to lose 30% of the thermal output from the central space-conditioning device. Loss mechanisms include duct air leakage into unconditioned spaces, such as attics; thermal conduction from duct surfaces; and infiltration by unconditioned ambient air because of static-pressure variations created by the circulating blower. Single-point thermostatic control leads to additional energy losses, since some areas are conditioned more than they need to be (and more than they would be with independent thermostats). Overall, forced-air distribution systems lose an estimated 2.5–4 quads (2.5–4 × $10^{15}$ Btu) of energy annually—energy worth over $12.5 billion. Peak electric power demand due to duct leakage can be as high as 2 kW per heat pump in hot and humid climates and 1 kW in moderate climates.

The use of hydronic, or circulating-water, thermal-distribution systems, which eliminate potentially leaky air ducts, could help raise the energy efficiency of residential space-conditioning systems. This could have a major favorable impact on electric utilities in both summer (cooling) and winter (heating) seasons. A 1990 EPRI study found that, in addition to offering customers greater energy efficiency than do heat pump systems using conventional air distribution, systems with hydronic distribution could offer a lower first cost, lower heating and cooling costs, and greater comfort. Consequently, under EPRI sponsorship, Tecogen, Inc., developed a prototype multiple-zone hydronic system, which was installed in an unoccupied test house in Gaithersburg, Maryland. At the test house, GEOMET Technologies, Inc., conducted extensive performance testing on the hydronic system during the 1992–1993 heating and cooling seasons and compared the test results with those for an already-installed conventional system.

### System components

A hydronic system similar to the one used in the field testing is shown schematically in Figure 1. As in any heat pump system used

**Figure 1** Heat pump space-conditioning system with hydronic thermal distribution. Such a system, which provides zoned temperature control, was used in EPRI field testing. It features a standard outdoor condensing unit and a compact indoor unit with a refrigerant-to-water heat exchanger. The water is circulated to thermostat-controlled fan-coil units in the space-conditioning zones. Flexible multichannel cable contains both the water passages for thermal distribution (blue) and the electrical wiring used in system control (red).




for space conditioning, the prototype system's 3-ton outdoor unit, equipped with a two-speed compressor and a constant-speed fan, absorbs heat from the ambient in the heating mode and rejects heat to the ambient in the cooling mode. A specially designed indoor unit transfers heat between the refrigerant and the circulating hydronic fluid—water alone (as in the test house) or water with an antifreeze additive. The water is heated in the heating mode and cooled in the air conditioning mode. A circulating pump is used to distribute the heated or chilled water throughout the house.

The indoor unit, built around a refrigerant-to-water heat exchanger, is slightly more complex than units in air distribution systems; but it is not larger, since, in the absence of airflow, less space is needed for heat exchange and no blower is required. Water is circulated to terminal fan-coil units through a single, compact multichannel cable. This flexible, easy-to-install cable also carries control system wiring to 10 fan-coil units throughout the house and to the thermostats used to control individual or clustered terminal units. In most cases, each fan-coil is controlled by its own thermostat; a single thermostat controls the three fan-coils used for the unified living room, kitchen, and dining area.

The indoor unit also contains a microprocessor-based controller to handle all the control functions of the thermal-distribution system. The thermostat for each space-conditioning zone communicates with the controller, which sends signals to switch the appropriate fan-coil units on or off. When the heating load of the house exceeds the heat pump's heating capacity, supplemental heat is supplied by resistance heating elements. (For more on hydronic thermal-distribution systems, see the *EPRI Journal*, March 1993, p. 30.)

## Assessing comfort and energy use

The primary purpose of the testing in the unoccupied house was to determine whether the hydronic heat pump system would function reliably. The tests were also designed to evaluate the comfort levels provided by the system, as well as its energy consumption, system-related air infiltration, and responsiveness to changes in insolation, outdoor temperature, wind speed, and various indoor conditions.

In occupied residences, thermal gains are provided not only by solar radiation, air infiltration, and conduction but also by internal gains from appliances, lighting, hot water production and use, and the occupants themselves. The occupants may also affect energy flow into and out of the house by moving window coverings, which can affect the solar input, or by opening windows, which can increase indoor moisture content in the summer.

In the test house, GEOMET used black-bin heat radiators to simulate thermal inputs from appliance waste heat and from occupants. That allowed the researchers to provide realistic thermal conditions while maintaining experimental control over the simulation of normal occupant activities in the house. The simulation provided a reasonable spatiotemporal array of heat and moisture gains that might be associated with typical occupancy patterns. The project team designed daily living schedules for the simulated occupants—two adults (one working, one at home) and one child—taking into account their activities, their use of appliances, and the corresponding thermal inputs in the various rooms of the house.

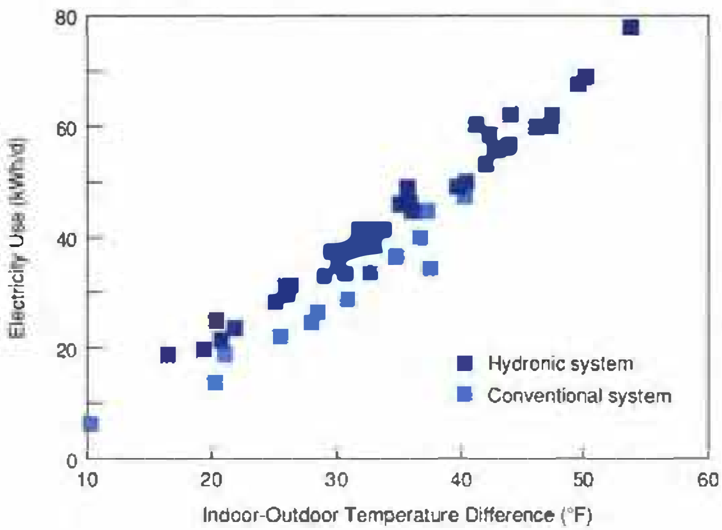
Several indexes have been developed to quantify thermal comfort, which may be defined as a condition of mind corresponding to the experience of satisfaction with the thermal environment. To quantify thermal comfort, GEOMET used two environmental indexes adopted by the International Organization for Standardization—predicted mean vote (PMV) and predicted percentage dissatisfied (PPD).

PMV is an empirical index that takes into account the composite effect of several parameters, including the human body's activity-dependent metabolic rate, the thermal resistance of clothing, relative air velocity, mean radiant temperature, dry-bulb temperature, and water vapor partial pressure. Using an equation that incorporates these parameters, researchers can calculate PMV for a clothed person performing a variety of activities under given environmental conditions. PMV is measured over a seven-point psychophysical scale, ranging from cold (−3) to hot (+3). Using an equation relating PPD to PMV, researchers can estimate the percentage of subjects dissatisfied with a thermal environment (i.e., those for whom the PMV value is −3, −2, +2, or +3).

The instrumentation at the research house provided the data required to make PMV and PPD calculations for both the hydronic and conventional heat pump systems. The data acquisition system scanned more than 100 channels per minute and stored 15-minute summary statistics on several variables, including meteorological parameters, indoor temperature and comfort parameters, hydronic system parameters, energy parameters, and air infiltration rates.

In addition to assessing comfort levels, GEOMET compared subsystem and total energy consumption for the hydronic and conventional heat pump systems, using data gathered on meteorologically similar days. In designing the test program, the researchers took into account differences between the two systems. The hydronic system is a zoned system. Unlike the case with a conventional forced-air system, each fan-coil has a supply and a return; there is no central return. Because different set points can be maintained in different zones of the house, it is best to operate a hydronic system with all internal doors closed. In contrast, it is usually best to operate conventional systems with internal doors open to avoid creating unequal temperature and pressure distributions in the house. The two heat pump systems were operated with various combinations of open and closed doors in order to quantify energy consumption under various operating conditions.

**Figure 2** The total daily electricity use of each heat pump system in the heating mode was correlated with the daily average difference between indoor and outdoor temperatures. The hydronic system consumed more energy largely because the circulating pump operated continuously and the fans in the terminal units were inefficient—two areas to be addressed by improvements in the next-generation design.



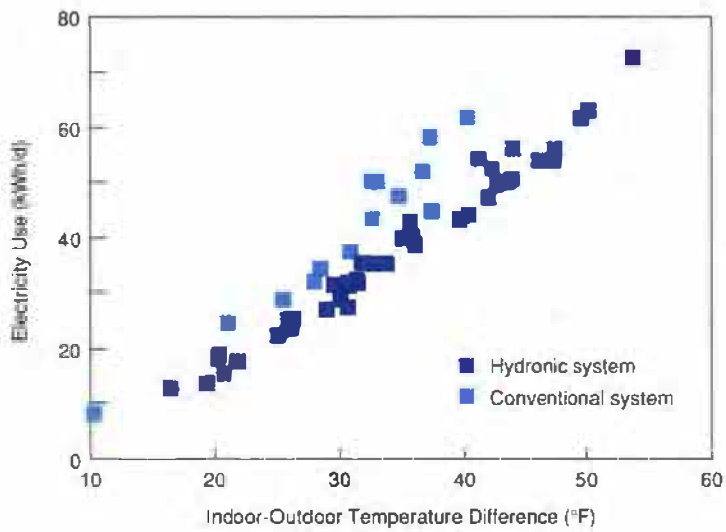




**Figure 3** The data on the heat pump systems' daily electricity use in the heating mode were adjusted to account for various factors. The conventional unit was penalized to reflect the duct-related energy losses that are typical of many houses (but not the test house), and the hydronic system's performance was upgraded to reflect the projected effects of recommended design changes.

## Field test results: comfort

In analyzing comfort conditions, GEOMET assumed that the temperatures maintained inside the house generally indicate the degree of comfort provided under changing outdoor and indoor conditions. The closer the temperatures are to the set point chosen by the occupants, the higher the degree of comfort provided by the system. In addition, in the cooling season, thermal comfort is greatly influenced by the indoor humidity levels maintained by a system. The same comfort level that can be achieved by lowering the temperature can be achieved by lowering the humidity while keeping the temperature at the original set point. Higher indoor humidity levels typically encourage occupants to lower the temperature set point to maintain the desired level of comfort. This increases energy consumption.

The analysis of comfort conditions required the calculation of hourly PMV and PPD values for the primary locations in the house, including the master bedroom and the living room. In the heating season, the conventional and hydronic systems maintained equivalent levels of thermal comfort in the living room, as expected because the thermostat for the conventional system is located in that area. However, the average temperatures for each zone of the house and the average temperatures for the house as a whole were higher during hydronic system operation. As a result, the hydronic system provided slightly better PMV and PPD values in its normal operating mode (internal doors closed) than did the conventional system in its normal operating mode (internal doors open).

In the cooling season, the two systems provided equivalent levels of cooling. However, the hydronic system appeared to provide poorer humidity control. The analysts found that as a result of the fan-coil airflow design, condensate was retained between the fins. That led to an increase in delivered air temperature; in turn, humidity levels rose and fan-coil energy consumption increased. This problem will be eliminated in the next-generation fan-coil design.

**Field test results: energy use**

To compare energy use by the two systems, GEOMET and Tecogen correlated their daily energy consumption with the daily average difference between indoor and outdoor temperatures. Although this correlation relied on simplifying assumptions (e.g., that average temperature differences persisted throughout whole days and that load did not vary from day to day), enough data were collected to secure useful results.

The systems' outdoor units consumed energy at similar levels. It should be noted, however, that the operation of the two systems made no significant difference in the house's air infiltration rate, and that the location of the ductwork in the house minimized any effects of air distribution duct leakage on infiltration. In many U.S. homes, however, as pointed out earlier, duct leakage and air infiltration can account for large energy losses.

When the indoor equipment was taken into account, total energy consumption was higher for the hydronic system, as shown for the heating season in Figure 2. The difference in energy consumption was largely due to a few factors that will be easy to rectify. For instance, the hydronic system's circulating pump operated continuously, regardless of heating or cooling demand, consuming about 6 kWh of electric energy per day. Also, although the system's electronic controller was rather sophisticated, it functioned in addition to the normal heat pump controller. In a more energy-efficient design, only one controller would be used, and water would circulate through the system only when heating or cooling was required in any of the zones. Further, the fans in the fan-coil units were inefficient; fans designed for this specific application would consume less energy. And, as noted above, a redesign would eliminate condensate retention in the heat transfer coil, which increased energy consumption in the summer.

Figure 3 shows the projected energy consumption for a conventional system in a house with a 30% energy loss due to duct effects and for a redesigned hydronic system. Under these circumstances, the redesigned system would consume considerably less energy than the conventional system.

**Moving toward commercialization**

Now that a prototype hydronic system has performed reliably in the field, EPRI is focusing on improving system design to increase energy efficiency. Discussions are under way with a major manufacturer, who has begun to identify and implement the design modifications needed for an improved system. The commercializer will optimize the location of the fan-coil units, will provide water flow control by means of an adjustable pump whose speed can vary with indoor load, and will use two-speed fan-coil units to improve humidity control during the cooling season.

The fan-coil units to be used in the commercial system will be very quiet. The commercializer plans to develop a refrigerant-to-water heat exchanger for the system and to use heat pumps and multichannel hydronic cable purchased from other companies. In addition, the commercializer will join EPRI in conducting a study to identify potential target markets. Meanwhile, EPRI plans to enter into tailored collaboration agreements with utilities who will provide field sites for testing the improved system under a variety of climatic conditions in different geographic locations.

# New Contracts

| *Project* | *Funding/ Duration* | *Contractor/EPRI Project Manager* |
|---|---|---|
| **Customer Systems** | | |
| Ozone Energy Efficiency Project (RP2662-59) | $191,100<br>21 months | Process Applications/ *K. Carns* |
| Electrochemical Ion Exchange (RP2662-73) | $270,900<br>11 months | Electrochemical Design Associates/ *M. Jones* |
| Application of Ultraviolet Germicidal Irradiation for Air Disinfection (RP2662-74) | $75,000<br>9 months | Lighting Research Institute/ *M. Jones* |
| Energy Audits at Wastewater Treatment Plants (RP2662-75) | $59,500<br>3 months | HDR Engineering/ *K. Carns* |
| Oxygen Enrichment in Lime Kilns in Pulp Mills (RP3328-9) | $150,000<br>6 months | BOC Group/ *A. Amarnath* |
| Supermarket Analysis Program (RP3526-5) | $82,600<br>11 months | University of Wisconsin, Madison/ *M. Khattar* |
| Industrial Environmental Project Laboratory Screening of Advanced Oxidation Processes (RP3762-1) | $50,000<br>5 months | Southern Company Services/ *M. Jones* |
| Distribution Automation Demonstration (RP3807-1) | $533,000<br>24 months | Northern States Power Co./ *L. Carmichael* |
| Commercial Cool Storage (RP3819-15) | $173,100<br>49 months | Fleming Group/ *R. Gillman* |
| Residential Space-Heating Load (RP3819-16) | $70,800<br>9 months | Quantum Consulting/ *R. Gillman* |
| EPRI Partnership for Industrial Competitiveness: Plant Surveys for Foundries (RP3829-11) | $73,500<br>8 months | Process Metallurgy International/ *W. Smith* |
| EPRI Partnership for Industrial Competitiveness: Plant Surveys for Forging/Heat Treating (RP3829-12) | $70,000<br>8 months | Process Metallurgy International/ *W. Smith* |
| Method for Estimating Thermal Efficiency of Residential Forced-Air Distribution (RP3841-1) | $105,300<br>9 months | Ecotope/ *S. Kondepudi* |
| Development of a Comprehensive End-Use Emissions Database and Software (RP3886-1) | $328,000<br>15 months | Science Applications International Corp./ *P. Sioshansi* |
| Product Design Workbench: Development and Support (RP4001-18) | $75,000<br>9 months | National Analysts/ *T. Henneberger* |
| **Environment and Vital Issues** | | |
| Risk Assessment and Communication Research (RP2966-12) | $100,000<br>8 months | Harvard Center for Risk Analysis/ *S. Sussman* |
| $CO_2$ Offset Opportunities in Siberian Forests (RP3041-13) | $96,300<br>10 months | EcoAnalysis/ *L. Pitelka* |
| Planning for Coordinated Climate Modeling and Integrated Assessment (RP3267-29) | $234,600<br>20 months | University Corporation for Atmospheric Research/ *C. Hakkarinen* |
| Assessment of Alternative Mechanisms for Reaching Environmental Goals (RP3306-8) | $100,000<br>11 months | University of New Mexico/ *G. Hester* |
| Effects of Extremely Low Frequency Electric and Magnetic Fields on Calcium Spiking in ROS Cells (RP3349-8) | $150,000<br>35 months | University of Kentucky Research Foundation/ *C. Rafferty* |
| Power and Reservoir System Model for Colorado River (RP3369-3) | $436,900<br>14 months | University of Colorado/ *D. McIntosh* |
| Evaluation of Market Mechanisms to Control $NO_x$ (RP3835-2) | $319,600<br>23 months | National Economic Research Associates/ *G. Hester* |
| Bioremediation of PCBs at Electric Power Substations (RP9034-3) | $238,100<br>31 months | Martin Marietta Energy Systems/ *R. Brocksen* |
| Florida Atmospheric Mercury Study (RP9050-3) | $322,300<br>45 months | KBN Engineering & Applied Sciences/ *D. Porcella* |
| Use of CROW Process for Removing Coal Tar From Gas Holder Pits (RP9054-2) | $537,000<br>18 months | Remediation Technologies/ *I. Murarka* |
| Development of Cost-Effective Wetland Clearing and Construction Specifications Based on Functional Impacts (RP9057-1) | $383,300<br>35 months | Earth Systems Associates/ *J. Huckabee* |
| Development of Site-Specific Criteria for Establishing Water-Quality-Based Effluent Limitations (RP9063-1) | $50,000<br>7 months | Eichleay Engineers/ *J. Goodrich-Mahoney* |
| Northeast Air Quality Study: Pennsylvania Sampling Site (RP9072-3) | $86,400<br>4 months | Battelle Columbus Laboratories/ *P. Mueller* |
| **Generation** | | |
| Fabrication, Measurement, and Computer Modeling for Improved Performance and Stability of Amorphous-Silicon-Based Materials and Devices (RP3120-3) | $548,500<br>12 months | Pennsylvania State University/ *T. Peterson* |
| Training Simulator Model for Power Plant Emissions Control (RP3152-22) | $653,900<br>21 months | PowerSafety International/ *R. Fray* |
| Power Plant Performance Instrumentation System (RP3383-2) | $600,000<br>24 months | Potomac Electric Power Co./ *E. Petrill* |
| Intelligent Tutoring System: South Carolina Electric & Gas Company's Cope Station (RP3384-20) | $126,600<br>12 months | Babcock & Wilcox Co./ *R. Fray* |
| North Dakota Wind Resource Assessment Program (RP3404-15) | $160,700<br>34 months | University of North Dakota/ *E. Davis* |
| Biomass Production/Gasification Case Study (RP3407-21) | $199,500<br>9 months | Northern States Power Co./ *E. Hughes* |
| Reburning With Wood: $NO_x$ Control Studies (RP3407-24) | $60,000<br>13 months | Tennessee Valley Authority/ *E. Hughes* |
| Bench-Scale Mercury Sorbent Evaluation (RP3453-5) | $70,000<br>6 months | Acurex Environmental Corp./ *R. Chang* |
| Acoustic Boiler Temperature Monitoring System (RP3459-3) | $231,000<br>4 months | Bogan/ *R. Colsher* |
| Gas Turbine Capacity Enhancement Options (RP3534-3) | $81,600<br>27 months | Fern Engineering/ *H. Schreiber* |
| Value and Impact of Photovoltaics–Demand-Side Management Systems Installed on Commercial and Industrial Buildings (RP3749-1) | $865,700<br>21 months | Ascension Technology/ *J. Bigger* |
| Predictive Emissions Modeling System for Combustion-Turbine-Based Power Plants (RP3768-1) | $288,100<br>15 months | Enter Software/ *G. Quentin* |
| O&M Workstation Development (RP3782-2) | $190,000<br>7 months | Bogan/ *R. Colsher* |
| Active Magnetic Damper for Machinery Vibration Control and Diagnostics (RP3846-1) | $476,400<br>34 months | Mechanical Technology/ *T. McCloskey* |
| Application of Fossil Plant Maintenance Optimization (RP3854-2) | $255,000<br>21 months | ERIN Engineering and Research/ *G. Pflasterer* |

| Project | Funding/ Duration | Contractor/EPRI Project Manager |
|---|---|---|
| Development of RRING-Life Software Module for Generator Rotor Tooth Top Life Prediction (RP3857-3) | $178,500 7 months | Structural Integrity Associates/*J. Stein* |
| Substation Predictive Maintenance (RP3883-1) | $90,000 7 months | Bogan/*R. Colsher* |
| Effectiveness of Chlorine Dioxide as a Biocide for the Treatment of Zebra Mussels in River Water (RP3894-1) | $217,700 21 months | Illinois Power Co./*J. Tsou* |
| Effectiveness of Chlorine Dioxide as a Biocide for the Treatment of Zebra Mussels in River Water (RP3894-2) | $120,900 12 months | Central Illinois Public Service Co./*J. Tsou* |
| Hot Gas Filter Ash Characterization (RP3910-1) | $690,000 36 months | University of North Dakota/*R. Brown* |
| Fuel Cells for Residential Applications: Technical Feasibility and Market Assessment (RP3934-1) | $240,000 10 months | Polydyne/*D. Rastler* |
| Selective Catalytic Reduction Project at Gulf Power Company's Plant Crist (RP9025-12) | $1,122,000 30 months | Southern Company Services/*J. Stallings* |
| Groundwater Treatment Using Metals Coprecipitation (RP9048-1) | $555,700 22 months | Southern Company Services/*M. McLearn* |
| In Situ Solidification/Stabilization of Arsenic-Contaminated Soil (RP9049-1) | $733,800 22 months | Southern Company Services/*M. McLearn* |
| **Nuclear Power** | | |
| Management Guidelines for Solid Low-Level Waste (RP2414-66) | $51,300 8 months | CENTEC-21/*C. Hornibrook* |
| Technical Repair Guidelines for Rotor Valve Actuators (RP2814-94) | $65,900 9 months | Duke Engineering and Services/*V. Varma* |
| Development of Ion Exchange Models (RP2977-14) | $210,000 43 months | Oklahoma State University/*P. Millett* |
| Commercial Version of RAYTRACE and RAYNEW (RP3148-11) | $140,000 8 months | Karta Technology/*T. Taylor* |
| Measurement of Crevice Chemistry With Raman Spectroscopy (RP3173-6) | $94,000 11 months | Babcock & Wilcox Co./*P. Millett* |
| Environmental Fatigue Rules (RP3321-3) | $79,100 20 months | General Electric Co./*S. Gosselin* |
| Advanced Condensate Demineralizer Resin Cleaning (RP3388-10) | $334,900 11 months | CENTEC-21/*P. Millett* |
| Detection of Localized Cable Damage (RP3427-4) | $197,300 15 months | Ontario Hydro/*J. Carey* |
| Effects of Low-Dose Ionizing Radiation (RP3500-27) | $268,100 19 months | University of California, San Francisco/*L. Sagan* |
| Decontamination for Decommissioning (RP3500-28) | $148,200 15 months | Bradtec/*C. Wood* |
| Hot pH Demonstration at TU Electric (RP3528-5) | $240,600 20 months | Vectra Technologies/*R. Mahini* |
| Mixed-Waste Reduction Demonstration Project (RP3800-22) | $67,500 12 months | Duke Engineering and Services/*C. Hornibrook* |
| Check Valve Maintenance Guide (RP3814-2) | $123,800 13 months | Stone & Webster Engineering Corp./*V. Varma* |
| NMAC Bolted-Joint Applications and Maintenance Guide (RP3814-7) | $65,000 7 months | Aptech Engineering Services/*J. Jenco* |
| Ultrasonic Primary-Coolant-System Flow and Temperature Measurement System (RP3885-1) | $279,500 22 months | MPR Associates/*R. James* |
| Boraflex Research Project (RP3907-1) | $411,200 22 months | Northeast Technology Corp./*R. Lambert* |
| Steam Generator Tubing Corrosion Tests in Sodium Silicate Solutions (RPS514-1) | $74,300 19 months | CIEMAT/*P. Paine* |
| Diagnostic Technology for Antivibration-Bar Gap Spacing and Tube Wall Measurement (RPS530-12) | $107,100 12 months | NUCON Inspection Services/*M. Behravesh* |
| Fuel Cladding Integrity at High Burnups (RPX103-1) | $678,900 30 months | Paul Scherrer Institute/*S. Yagnik* |
| Thermal Conductivity of Oxide Layer on LWR Cladding (RPX103-3) | $500,000 13 months | Institutt for Energiteknikk/*S. Yagnik* |
| Mechanism of Hydrogen Pickup in Zirconium Base Alloys (RPX103-6) | $155,000 24 months | Ontario Hydro/*S. Yagnik* |
| **Power Delivery** | | |
| Power Transformer Expert System (RP2445-4) | $298,600 29 months | Iris Power Engineering/*S. Lindgren* |
| Simulation Program for On-Line Dynamic Security Assessment (RP3103-7) | $1,118,300 28 months | Siemens Energy and Automation/*P. Hirsch* |
| Substation Magnetic Field Management (RP3193-3) | $365,100 12 months | Ohio State University/*R. Lordan* |
| Improved Medium-Voltage-Cable Manufacturing (RP3522-1) | $1,093,800 35 months | Southwire Co./*B. Bernstein* |
| Advanced Concepts in Energy Resource Scheduling and Generation Control: Load-Frequency Control (RP3555-4) | $472,700 21 months | Network Management Technology/*D. Maratukulam* |
| Transient Behavior of Systems Containing FACTS Devices (RP3573-18) | $59,000 17 months | University of Waterloo/*R. Adapa* |
| Integrated Control, Protection, and Data Acquisition (RP3599-2) | $320,900 8 months | ABB Power T&D Co./*J. Melcher* |
| Integrated Control, Protection, and Data Acquisition (RP3599-3) | $497,000 9 months | General Electric Co./*J. Melcher* |
| Laser-Induced-Lightning Research: Discharge of Lightning With Ultrashort Pulses (RP3669-2) | $94,600 17 months | University of New Mexico/*B. Bernstein* |
| Assessment of FACTS Requirements on the Entergy System (RP3789-2) | $99,900 7 months | Entergy Services/*R. Adapa* |
| Integrated Dispatch Information Management System at Wisconsin Power & Light (RP3869-1) | $388,300 13 months | ABB Systems Control Co./*D. Maratukulam* |
| Technologies for Inspecting Transmission Lines (RP3873-1) | $448,700 10 months | Engineering Data Management/*P. Lyons* |
| Evaluation of Gases Generated by Heating and Burning of Cables (RP3927-4) | $518,400 24 months | Underwriters Laboratories/*T. Kendrew* |
| Nuclear Magnetic Resonance Earth Probe for Subsurface Imaging of Buried Cable and Pipe: Feasibility Study (RP3927-5) | $125,200 18 months | Electrascan/*T. Kendrew* |
| ESWorkstations Quality Assurance (RP3928-1) | $98,600 11 months | Reasoning Systems/*C. Wells* |
| ESWorkstation Framework (RP3928-2) | $300,000 9 months | Power Computing Co./*C. Wells* |
| Leak Detection Demonstration Field Tests (RP7910-33) | $72,900 9 months | Vista Research/*J. Shimshock* |
| Transmission Cable End-of-Life Criteria (RP7914-4) | $614,500 44 months | Power Delivery Consultants/*J. Shimshock* |
| **Strategic R&D** | | |
| Environment for Specification and Analysis of Sequential Process Control Systems (RP8014-5) | $288,400 52 months | UniView Systems/*M. Wildberger* |
| Transparent Neural Networks (RP8016-5) | $199,100 23 months | Wayne State University/*M. Wildberger* |
| Na,K-ATPase in Electric and Magnetic Fields (RP8021-4) | $159,900 24 months | Columbia University/*C. Rafferty* |
| Intelligent Fossil Fuel Control Procedures (RP8030-17) | $100,000 28 months | University of Michigan/*M. Perakis* |
| Solar Variability and Potential Influences on the Earth's Climate (RP8035-1) | $348,000 36 months | Mount Wilson Institute/*J. Maulbetsch* |
| Development of a Cyclic Damage Evaluation Method (RP8046-5) | $100,000 19 months | Ishikawajima Harima Heavy Industries Co./*M. Lapides* |
| Synthesis of Lithium Salts (RP8061-1) | $55,000 12 months | Arizona State University/*F. Will* |
| Low-Temperature Solid Oxide Fuel Cells: Electrode Structure and Electrode/Electrolyte Materials (RP8062-6) | $461,100 48 months | University of Utah/*R. Goldstein* |
| Search for New Superconductors Using the Phase Spread Alloy Method (RP8066-2) | $165,000 36 months | University of California, San Diego/*P. Grant* |
| Development of New Creep-Resistant Martensitic Steels (RP9000-27) | $75,000 31 months | Carnegie Mellon University/*R. Viswanathan* |

# 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

**Proceedings: Second International Conference on Power Quality—End-Use Applications and Perspectives, Vols. 1 and 2**
TR-100822-V1, TR-100822-V2 Proceedings (RP2935-1); $200 each volume
Contractor: CK & Associates
EPRI Project Manager: M. Samotyj

**Water-Loop Heat Pump Systems, Vol. 1: Engineering Design Guide (Revision 1)**
TR-101134-V1R1 Final Report (RP2480-13); $30
Contractor: Eley Associates
EPRI Project Manager: M. Khattar

**Hydrogen Emissions From Electric Vehicle Batteries Undergoing Charging in Residential Garages**
TR-103421 Final Report (RP3272-12); $200
Contractor: GEOMET Technologies, Inc.
EPRI Project Manager: G. Purcell

**50 Successful DSM Programs: A Comparative Review of Program Attributes and Data**
TR-103463 Final Report (RP3269-26); $200
Contractor: The Results Center, IRT Environment, Inc.
EPRI Project Managers: P. Hanser, P. Hummel

**Development of a Microwave Clothes Dryer: Interim Report II**
TR-103899 Interim Report (RP3417-1); $200
Contractors: Thermo Energy Corp.; JG Microwave, Inc.
EPRI Project Manager: J. Kesselring

## GENERATION

**Preliminary Comparison of Advanced Control Strategies for Fossil Plant Control Systems Improvements**
TR-103383 Final Report (RP2710-30); $10,000
Contractor: PowerGen Power Technology Centre
EPRI Project Managers: J. Weiss, M. Perakis

**Battery Storage Evaluation Software (BaSES, Version 2.0): User's Manual**
TR-103800 Final Report (RP2123-25); $200
Contractor: Electric Power Consulting, Inc.
EPRI Project Manager: S. Eckroad

**Capital Expenditure Decisions: Obtaining Commitment to Action (Case Study for San Diego Gas & Electric Company)**
TR-103883 Final Report (RP3288-2); $5000
Contractor: Strategic Decisions Group
EPRI Project Managers: M. Blanco, R. Fray, R. Goldberg

**Proceedings: 1993 EPRI/GRI Repowering With Gas Turbines Workshop**
TR-103968 Final Report (RP2915-6); $200
Contractor: Carnot
EPRI Project Manager: H. Schreiber

**Fish Protection/Passage Technologies Evaluated by EPRI and Guidelines for Their Application**
TR-104120 Final Report (RP2694-1); $200
Contractor: Stone & Webster Engineering Corp.
EPRI Project Manager: C. Sullivan

**Biological Evaluation of a Modular Inclined Screen for Protecting Fish at Water Intakes**
TR-104121 Final Report (RP2694-1); $200
Contractor: Stone & Webster Engineering Corp.
EPRI Project Manager: C. Sullivan

**Research Update on Fish Protection Technologies for Water Intakes**
TR-104122 Final Report (RP2694-1); $200
Contractor: Stone & Webster Engineering Corp.
EPRI Project Managers: C. Sullivan, J. Mattice

## NUCLEAR POWER

**Circuit Breaker Maintenance, Vol. 2, Part 3: Medium-Voltage Circuit Breakers—Westinghouse Types DH and DHP**
NP-7410-V2P3 Final Report (RP2814-84); $8500
Contractor: BCP Technical Services
EPRI Project Manager: J. Sharkey

**Deep Draft Vertical Centrifugal Pump Maintenance and Application Guide**
NP-7413 Final Report (RP2814-44); $10,000
Contractor: Hydro Engineering Services Inc.
EPRI Project Manager: K. Barry

**Guide for the Examination of Service Water System Piping**
TR-102063 Application Report (RP2495-9); call (704) 547-6100 for price
EPRI Project Managers: R. Edwards, N. Hirota

**Supplemental Guidance for the Application of EPRI Report NP-5652 on the Utilization of Commercial-Grade Items**
TR-102260 Final Report (RPQ101-43); $200
Contractors: CYGNA Energy Services; Gilbert/Commonwealth, Inc.
EPRI Project Manager: F. Rosch

**Handbook for Electromagnetic Compatibility of Digital Equipment in Power Plants, Vols. 1 and 2**
TR-102400-V1, TR-102400-V2 Final Report (RP3406-3, -7); $25,000 for set
Contractors: Interference Control Technologies, Inc. (Vol. 1); CHAR Services, Inc. (Vol. 2)
EPRI Project Manager: C. Lin

**Understanding Radiation Attenuation Through the Reactor Pressure Vessel Wall**
TR-103435 Final Report (RP2975-6); $1000
Contractor: B&W Nuclear Technologies
EPRI Project Manager: R. Carter

**Critical Flaw Evaluation for PWR Steam Generator Girth Welds**
TR-103557 Final Report (RP2455-25); $5000
Contractor: Structural Integrity Associates, Inc.
EPRI Project Manager: R. Carter

**Temperature Limit Determination for the Inert Dry Storage of Spent Nuclear Fuel**
TR-103949 Final Report (RP3290-3); $200
Contractor: Brookhaven National Laboratory
EPRI Project Manager: R. Lambert

**Susceptibility of Alloys 600 and 690 to Acidified Sulfate and Chloride Environments**
TR-104045 Final Report (RPS407-25, -28); $2000
Contractors: Materials Engineering Associates; Dominion Engineering, Inc.
EPRI Project Manager: P. Paine

## POWER DELIVERY

**Round-Robin Test on CIGRE Water Tree Resistance Evaluation Methods for Extruded Cable Insulation, Vol. 2: Phase 2**
EL-7432-V2 Final Report (RP2957-1); $5000
Contractor: University of Connecticut
EPRI Project Manager: B. Bernstein

**Small Signal Stability Analysis Program, Version 3.1, Vols. 1–5 (Revision 1)**
TR-101850-V1R1 Final Report (RP2447-1, RP1208-11, -12, -13); $5000
TR-101850-V2–V5R1 Final Report; license required
Contractor: Ontario Hydro
EPRI Project Manager: P. Hirsch

**Extended Transient–Midterm Stability Program (ETMSP), Version 3.1, Vols. 1–6 (Revision 1)**
TR-102004-V1R1 Final Report (RP1208-11, -12, -13); $5000
TR-102004-V2–V6R1 Final Report, license required
Contractor: Ontario Hydro
EPRI Project Manager: P. Hirsch

**Dynamic Reduction, Version 1.1, Vols. 1–4 (Revision 1)**
TR-102234-V1–V4R1 Final Report (RP1208-11, -12, -13; RP2447-1); license required
Contractor: Ontario Hydro
EPRI Project Manager: P. Hirsch

**Power System Steady-State Stability Monitor, Vols. 1–4**
TR-103169-V1–V4 Final Report (RP2473-43); $5000 for set
Contractor: SCS Computer Consulting
EPRI Project Manager: R. Adapa

**Water Treeing, Distribution Cable Oxidation, and Diagnostics in XLPE**
TR-103170 Final Report (RP2957-5); $5000
Contractor: University of Connecticut
EPRI Project Manager: B. Bernstein

**Proceedings: Multi-Factor Aging Mechanisms and Models 1992 Workshop**
TR-103172 Proceedings (RP2986-6); $500
Contractor: Moorhead State University
EPRI Project Manager: B. Bernstein

**Evaluation of Trenchless Technology for Installation of Pipe-Type Cable, Phase 1**
TR-103219 Final Report (RP7925-1); $5000
Contractor: Sargent & Lundy
EPRI Project Manager: T. Rodenbaugh

**Power System Dynamic Security Analysis Using Time Domain Techniques, Phase 1: Feasibility Evaluation**
TR-103601 Final Report (RP3103-1); $5000
Contractor: Arizona State University
EPRI Project Manager: G. Cauley

**Active and Reactive Power Modulation of HVDC Transmission Systems**
TR-103604 Final Report (RP1426-4); $5000
Contractor: General Electric Co.
EPRI Project Managers: S. Nilsson, A. Edris

**Long-Term Stability Program, Version 1.0, Vols. 1–3**
TR-103632-V1 Final Report (RP3144-1); $5000
TR-103632-V2–V3 Final Report, license required
Contractor: Ontario Hydro
EPRI Project Manager: P. Hirsch

**Advanced Graphics for Power System Operation**
TR-103633 Final Report (RP4000-13); $5000
Contractor: University of Missouri, Rolla
EPRI Project Manager: R. Adapa

**Application of Quadratic Interior Point Method to Optimal Power Flow**
TR-103635 Final Report (RP3788-1); $5000
Contractor: Howard University
EPRI Project Manager: R. Adapa

**Operating Information Needed to Enhance System Planning**
TR-103638 Final Report (RP2473-66); $5000
Contractor: EPIC Engineering, Inc.
EPRI Project Managers: J. Gralow, R. Adapa

**Flexible AC Transmission Systems (FACTS): Application of Thyristor-Controlled Series Capacitors in New York State**
TR-103641 Final Report (RP3022-15); $5000
Contractors: New York Power Authority; Power Technologies, Inc.; General Electric Co.; Ontario Hydro
EPRI Project Manager: R. Adapa

**Electromagnetic Transients Program (EMTP)**
TR-103642 Final Report (RP2149-90); $5000
Contractor: Electricité de France
EPRI Project Manager: R. Adapa

**Interactive Power Flow, Version 2.1, Vols. 1–3**
TR-103643-V1 Final Report (RP2746-2); $5000
TR-103643-V2–V3 Final Report, license required
Contractor: Ontario Hydro
EPRI Project Manager: P. Hirsch

**Proceedings: Substation Equipment Diagnostics Conference**
TR-103848 Proceedings (RP2747); $200
EPRI Project Manager: J. Porter

**Diagnostics for the Detection and Measurement of Charge Motion in Water Trees in Polymers**
TR-103892 Final Report (RP2957-3); $5000
Contractor: University of Tennessee
EPRI Project Manager: T. Rodenbaugh

**Static VAR Compensation by Energy Flow Routing**
TR-103903 Final Report (RP3155-2); $5000
Contractor: University of Kentucky
EPRI Project Manager: R. Adapa

**Flexible AC Transmission Systems (FACTS): Hardware Feasibility Study of a Minnesota Power 150-MVA, 115-kV Thyristor-Controlled Phase Angle Regulating Transformer**
TR-103904 Final Report (RP3022-2); $5000
Contractors: GE Industrial and Power Systems; Minnesota Power Company
EPRI Project Manager: A. Edris

**EPRI Integrated Protection and Control Demonstration Program**
TR-104087 Final Report (RP1359-16); $5000
Contractor: Electric Research and Management, Inc.
EPRI Project Manager: S. Nilsson

## STRATEGIC R&D

**Proceedings: On-Line Monitoring of Corrosion and Water Chemistry for the Electric Power Utility Industry (EPRI Workshop Held During the 12th International Corrosion Congress)**
TR-103742 Proceedings (RP2426-63); $200
Contractor: Structural Integrity Associates
EPRI Project Manager: B. Syrett

**Thermographic Phosphor Strain Measurements**
TR-103867 Final Report (RP8004-3); $200
Contractor: Oak Ridge National Laboratory
EPRI Project Manager: B. Dooley

**Genetic Optimization of Neural Network Architecture**
TR-104074 Final Report (RP8016-4); $200
Contractor: Honeywell Technology Center
EPRI Project Manager: M. Wildberger

**High-Temperature Corrosion Research in Progress, 1994, Vols. 1 and 2**
TR-104124 Final Report (RP2426-10), Vols. 1 and 2, $200 each volume
Contractor: University of Manchester Institute of Science and Technology
EPRI Project Manager: J. Stringer

**Permanent Magnet Materials: An Assessment of the State of the Art**
TR-104162 Final Report (RP2426-32); $200
Contractor: Daedalus Associates, Inc.
EPRI Project Manager: J. Stringer

# New Computer Software

The Electric Power Software Center (EPSC) provides a single distribution center for computer programs developed by EPRI. The programs are distributed under license to users. EPRI member utilities, in paying their membership fees, prepay all royalties. Nonmember organizations licensing EPRI computer programs are required to pay royalties. For more information about EPSC and licensing arrangements, EPRI member utilities should contact the Electric Power Software Center, Power Computing Co., 1930 Hi Line Drive, Dallas, Texas 75207; (214) 655-8883. Other organizations should contact EPRI's Manager of Licensing, P.O. Box 10412, Palo Alto, California 94303; (415) 855-2866.

**CREAM: Composite Reliability Assessment by Monte Carlo**
Version 1.2 (Sun-UNIX)
Developer: Power Systems Research
EPRI Project Manager: Ali Vojdani

**DYNAMICS**
Version 3.0 (RS6000-AIX; Sun-UNIX)
Developer: Decision Focus Inc.
EPRI Project Manager: Robert Schainker

**EGEAS: Electric Generation Expansion Analysis System**
Version 1.0 (PC-DOS)
Developer: Science Applications International Corp.
EPRI Project Manager: Perry Sioshansi

**EPRI Clean: Environmental End-Use Emissions Database**
Version 7.15 (IBM-MVS; PC-DOS; RS6000-AIX)
Developer: Stone & Webster
EPRI Project Manager: Rambabu Adapa

**MADE-2: Database for the Second Macrodispersion Experiment**
Version 1.0 (PC-DOS)
Developer: Tennessee Valley Authority
EPRI Project Manager: Dave McIntosh

**REEPS: The Residential End-Use Energy Planning System**
Version 2.12 (PC-DOS)
Developer: Regional Economic Research
EPRI Project Manager: Paul Meagher

**TRELSS: Transmission Reliability Evaluation for Large-Scale Systems**
Version 1.2 (Sun-UNIX)
Developer: Southern Company Services, Inc.
EPRI Project Manager: Ali Vojdani

**UFIM: Utility Fuel Inventory Model**
Version 3.11 (PC-DOS)
Developer: Applied Decision Analysis, Inc.
EPRI Project Manager: Charles Clark

# EPRI Events

## OCTOBER

**3–5**
**International Joint Power Generation Conference and Exposition**
Phoenix, Arizona
Contact: Cynthia White, (212) 705-7637

**4–6**
**Pollution Prevention Seminar**
Scottsdale, Arizona
Contact: Pam Turner, (415) 855-2010

**5–7**
**Flexible AC Transmission Systems (FACTS) Conference**
Baltimore, Maryland
Contact: Lori Adams, (415) 855-8763

**12–13**
**Fuel Oil Utilization Workshop**
Tampa, Florida
Contact: Stephanie Drees, (714) 259-9520

**17–18**
**Center for Materials Production (CMP) Economics and Technology Workshop**
Pittsburgh, Pennsylvania
Contact: John Kollar, (412) 268-3496

**17–19**
**Energy-Efficient Office Technology**
New York, New York
Contact: Lori Adams, (415) 855-8763

**19–21**
**13th Conference on Coal Gasification Power Plants**
San Francisco, California
Contact: Linda Nelson, (415) 855-2127

**19–21**
**Fuel Supply Seminar**
Chicago, Illinois
Contact: Susan Bisetti, (415) 855-7919

**24–27**
**Power Quality Applications, 1994**
Amsterdam, Netherlands
Contact: Carrie Koeturius, (510) 525-1205

**28**
**Municipal Wastewater and Energy Conference**
New York, New York
Contact: Keith Carns, (314) 935-8598

**31–November 3**
**Decision Analysis for Utility Planning and Management**
New Orleans, Louisiana
Contact: Katrina Rolfes, (415) 926-9227

## NOVEMBER

**1–3**
**Substation Equipment Diagnostics Conference**
New Orleans, Louisiana
Contact: Kathleen Lyons, (415) 855-2656

**9–10**
**Water Heating Training Seminar**
Dallas, Texas
Contact: Carl Hiller, (415) 855-8950

**10–12**
**3d International Workshop on Rough Sets and Soft Computing**
San Jose, California
Contact: T. Y. Lin, (408) 924-5121

**14**
**Occupational EMF Studies Video Teleconference**
(from Washington, D.C.)
Contact: Sharon Kiley, (510) 838-2654

**14–15**
**Power Transfer Capability Evaluation**
St. Louis, Missouri
Contact: Linda Nelson, (415) 855-2127

**15–17**
**Primary Water Stress Corrosion Cracking in Alloy 600 PWRs**
Tampa, Florida
Contact: Linda Nelson, (415) 855-2127

**15–18**
**Market Research Symposium**
Marina del Rey, California
Contact: Susan Bisetti, (415) 855-7919

**28–December 1**
**Fuel Cell Seminar**
San Diego, California
Contact: John O'Sullivan, (415) 855-2292

## DECEMBER

**5–7**
**12th International Electric Vehicle Symposium**
Anaheim, California
Contact: Pam Turner, (415) 855-2010

## FEBRUARY 1995

**8–9**
**Energy Efficiency and the Global Environment**
Newport Beach, California
Contact: June Appel, (610) 667-2160

## MARCH

**13–16**
**5th NMAC Annual Conference**
Amelia Island, Florida
Contact: Linda Suddreth, (704) 547-6141

**22–24**
**Verification and Validation of Digital Systems**
Nashville, Tennessee
Contact: Linda Nelson, (415) 855-2127

**28–31**
**1995 $SO_2$ Control Symposium**
Miami, Florida
Contact: Pam Turner, (415) 855-2010

## 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: Shelton Ehrlich, (415) 855-2444

**15–19**
**Joint Symposium on Stationary Combustion $NO_x$ Control**
Kansas City, Missouri
Contact: Lori Adams, (415) 855-8763

## JUNE

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

**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

## AUGUST

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

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

## SEPTEMBER

**13–15**
**1995 Heat Rate Improvement Conference**
Dallas, Texas
Contact: Susan Bisetti, (415) 855-7919

## OCTOBER

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

**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

**28–30**
**Predictive Maintenance and Refurbishment**
Orlando, Florida
Contact: Susan Bisetti, (415) 855-7919

# EPRI JOURNAL

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