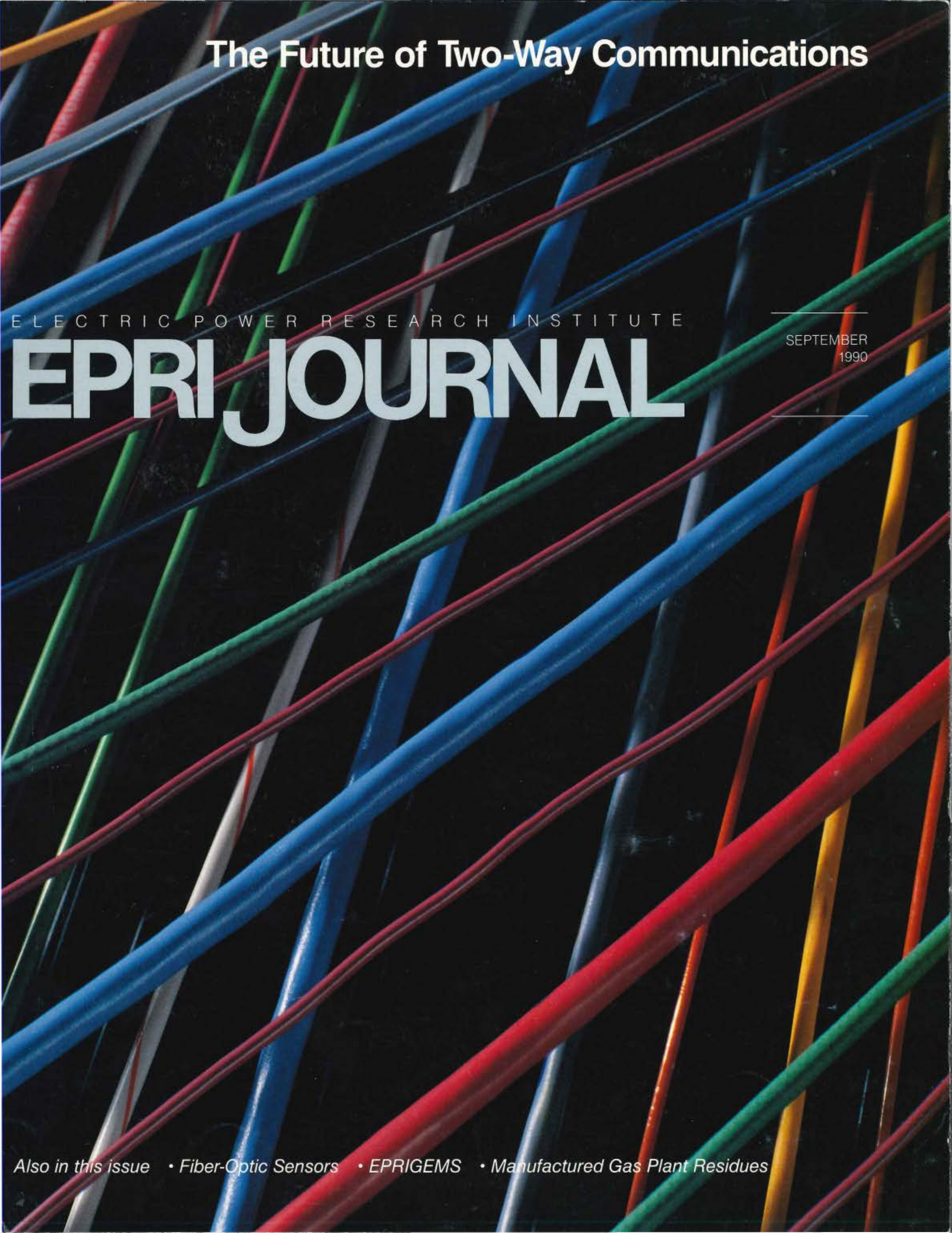

The Future of Two-Way Communications

ELECTRIC POWER RESEARCH INSTITUTE

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Also in this issue • Fiber-Optic Sensors • EPRIGEMS • Manufactured Gas Plant Residues

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Cover: Communications networks that allow transmission of signals both to and from individual customers promise new flexibility, cost-effectiveness, and capability in electric power service.

EDITORIAL

Strategic Implications for Customer Communications

Communication has always played an important role in electric utility system operation. Dispatchers talk with each other to coordinate system operations, and numerous automatic communication links connect relays and protection equipment to control centers. But today a combination of new technology and new emphasis on diversified services is prompting some utilities to set up additional communications systems—including two-way links with individual customers.

Although the demonstration systems now being put in place generally emphasize a few specific functions, such as automatic meter reading and load management, over the long term such utility-customer communications networks have strategic implications that reach far beyond their initial applications. Foremost among these is the ability to offer customers more choices in how they use electricity. Choice is the watchword of modern business—26 flavors of ice cream, 40 shades of lipstick, half a dozen pension plan options—but so far there is only one way to charge for electricity use. Two-way communication can create a new marketplace for electric power by enabling utilities to offer customers a menu of rate options, potentially including real-time price signals.

Beyond providing increased flexibility in marketing electricity, improved communication with the customer will enable utilities to offer a variety of other services. At this point we are limited only by our imagination as to what services might be feasible and appropriate. For example, a utility someday might be able to turn a family's lights on and off during vacation to provide an additional degree of security to their home. Such new services are likely to play an increasing role in the business strategies of utilities, enabling them to make enhanced use of existing assets and to thrive in a period of increased competition. The availability of an expanded utility communications network may also encourage utilities to form new kinds of business alliances with companies in other industries. Installation of state-of-the-art communications systems, however, may well exacerbate some long-standing problems in the utility industry. New communications standards will be needed, for instance, to ensure that utilities can use equipment from different vendors to best advantage, and new safeguards may be needed to ensure consumer privacy.

EPRI's decade-long work in communications can help our member utilities take the greatest advantage of these new opportunities while successfully facing the challenges they present. EPRI has taken the lead, for example, in testing a number of communications systems and in formulating communications standards tailored to utility needs. The Institute is also developing new analytical tools that can help utilities determine the impact of expanded communications capabilities on their overall business plans. The expansion of such cooperative efforts will be vital if the strategic benefits of new communications technology are to be realized throughout the utility industry.

FSYoung

Frank S. Young, Director
Electrical Systems Division

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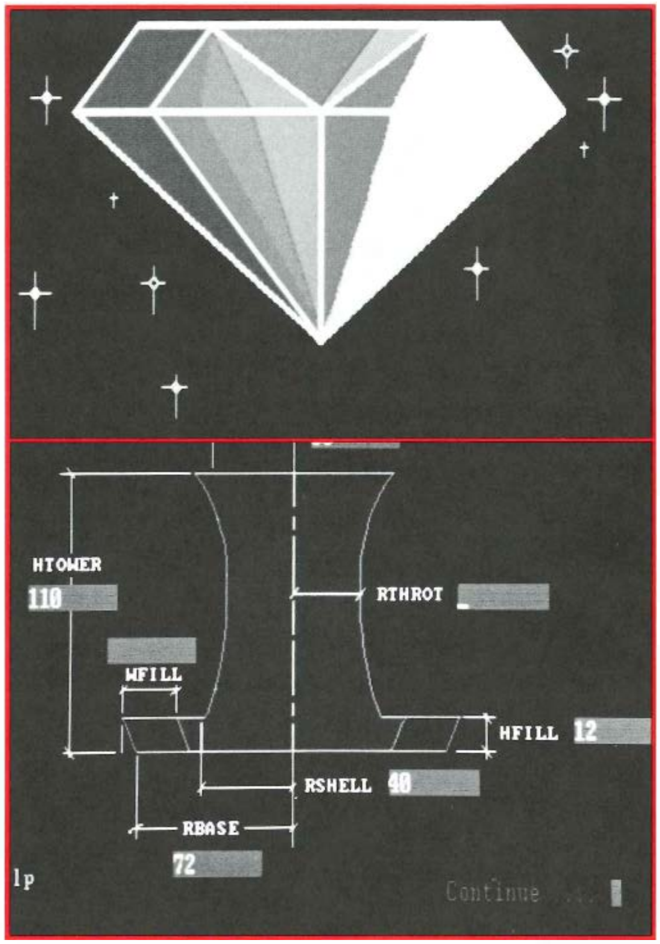

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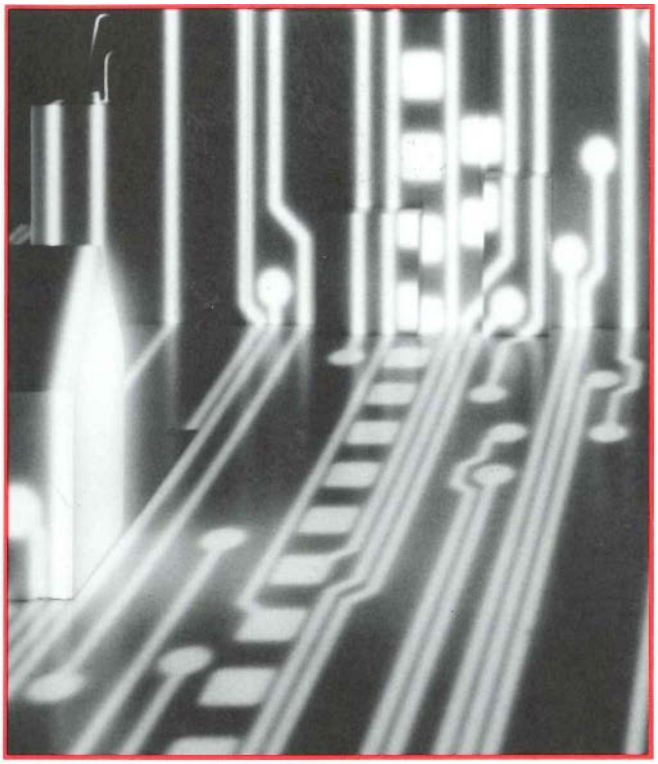

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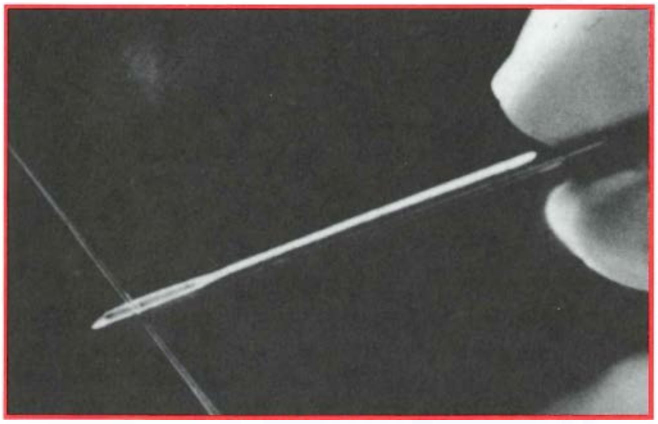

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Direct two-way communications links with individual customers will allow utilities to enhance standard services and offer new ones that increase consumer choice.

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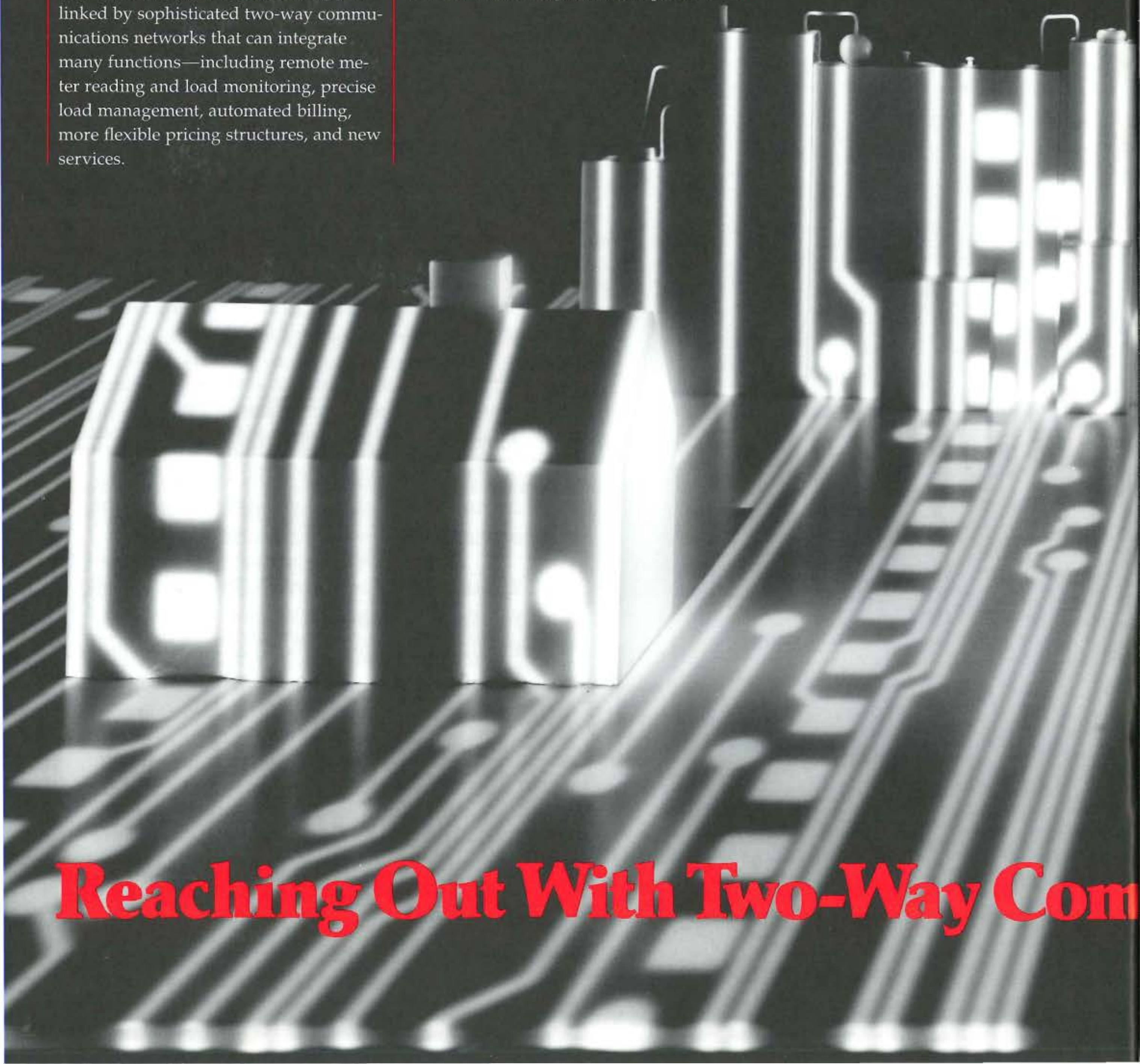
EPRIGEMS software modules bypass the intermediate stage of presenting information, instead delivering actual problem-solving capability through a user's personal computer.

The way electric utilities communicate with their customers is changing dramatically as a result of ongoing technological developments and rapidly shifting business conditions. Traditionally, utility-customer communication has been focused on a few individual applications—meter reading and billing for total energy use alone, occasional customer service calls, and some one-way electronic signaling for load control. In the future, utility offices and customers will increasingly be linked by sophisticated two-way communications networks that can integrate many functions—including remote meter reading and load monitoring, precise load management, automated billing, more flexible pricing structures, and new services.

"[Utility] requirements for information and communications services are likely to balloon in the 1990s," according to Fereidoon (Perry) Sioshansi and Spencer Carlisle of Southern California Edison and Paul Baran, chairman of the board of Metricom, writing in *Telecommunications Policy* (February 1990).* "To compete effectively in an increasingly competitive market, [utilities] have to begin to behave like competitive enterprises in marketing and pricing their services. Practices like market segmentation, product differentiation, and real-time pricing require considerable new capabilities in information collection and analysis, and in real-time, two-way communications with customers."

Some experts believe that's just beginning to scratch the surface of possibilities. A recent EPRI survey found that utilities want to use improved communi-



Reaching Out With Two-Way Com

cations to enhance three broad types of customer interface functions: demand-side management, pricing structures, and customer service.

An important strategy for utilities facing capacity constraints or rapid load growth is demand-side management. Such management not only takes the form of load control but may also in-

nunications

THE STORY IN BRIEF

A combination of new technology and heightened interest in relationships with ratepayers is prompting utilities to consider setting up two-way communications links with individual customers. In addition to enhancing utility capabilities for responding to service problems, these connections make possible such functions as automatic meter reading, implementation of flexible pricing strategies, electronic billing and payment services, and even nontraditional services—home security monitoring and electronic mail systems, for example. While the development of two-way networks is still in its infancy, a number of utility pilot programs are under way with manufacturers of specialized equipment employing a variety of communications media. EPRI is currently focusing on the development of industrywide communications standards that will provide utilities with flexibility and confidence in selecting equipment and integrating new technologies with existing systems.

volve remote reading of customer end-use data and power quality parameters. Load profiling based on these data can help utilities better anticipate and manage power delivery.

A second function is to facilitate pricing strategies that reflect more than just total energy consumption. These strategies include time-of-use rates, peak-demand charges, and communication of real-time price signals to the customer. Such an approach gives consumers more choice in energy management activities than simply accepting the previous "command and control" approach. For example, an industrial customer might decide to wait until the electricity price fell below a certain level before initiating some energy-intensive, time-independent process, such as melting materials in an electric furnace.

Finally, utilities see two-way communication with the customer as a way to improve standard services and to offer new ones. Meter reading and service connection could be done remotely. Outages would be reported automatically. And new services, such as home security or even electronic mail, could be added as desired, once a communications network was in place. For example, a customer could use a utility-provided menu to arrange for lights to be turned on and off when the family was away on vacation. The utility could also receive an emergency signal from an alarm system. Eventually, a utility's two-way communications system could even be used by homeowners to pay all types of bills via their banks or credit cards.

Creating a network that can provide all these functions presents a considerable challenge. At the customer end, a new generation of "smart" meters and other devices, such as load switches and sensors, will be needed. Such meters—built around integrated circuit chips that have the power of a small personal computer—are just coming on the market. They are expected to eventually replace the familiar spinning-disk meters, but they now cost several times as much and, because of their sheer number, will represent a major capital expense.

A second requirement is communications media to link the smart meters with a utility data-gathering center. In the past, most utility efforts to communicate with customers have focused on sending out one-way signals for load control. This process could easily be accomplished by using a single medium—such as a powerful, centralized radio transmitter. But two-way communication requires a far more complex link. Again because of progress in electronic technology, a new generation of systems is under development to provide this link. Most of these systems use more than one medium—for example, combining radio with power line carrier (PLC) or telephone. In the long run, fiber optics offers such huge data capacity that utility communications could easily be handled simultaneously with telephone and even two-way TV service.

Finally, within the utility itself, customer interface functions must be integrated with other communications systems. Real-time load data, for example, may need to be routed immediately to a control center. Automated meter readings could be transmitted to corporate customer billing, where, by prearranged authorization, the customer's account would be debited and the utility's account credited instantaneously. In addition, a hybrid radio-PLC network set up to reach intelligent meters might also be used to implement such distribution automation functions as feeder switching and voltage control. Communications standards are now being established to help make such system integration easier.

Dom Geraghty, director of EPRI's Office of Corporate and Strategic Planning, emphasizes the importance of taking a long-term, strategic view of the changes now taking place: "The industry is beginning to see utility-customer communication as part of an overall business strategy. Technological change is creating opportunities to integrate many functions that were formerly being introduced piecemeal. The challenge will be to figure out which of several technologies works best for a given situation and to ensure that different utility communications systems can be used together."

Experience with distribution automation

Communications is the key to any distribution automation program, and a communications network is less expensive to install if it stops short of the customer interface. For this reason, early demonstrations of distribution automation emphasized functions at substations and along feeder lines, with only limited customer-side involvement. Such automated distribution functions promised to give the earliest payback generally for the investment in automation.

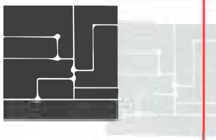
EPRI helped pioneer early attempts to automate the distribution network by developing guidelines utilities could use to determine the costs and benefits of various automation functions. Researchers identified 150 distribution and load-control functions potentially suited to automation and then selected 40 that were expected to prove immediately attractive to utilities. Many of these are distribution system control functions—including feeder switching, integrated volt/VAR control, and several system protection functions—which involve mainly substation and line equipment. Others—such as remote metering, load control, and remote turn-on and turn-off—involve customers directly.

To help utilities assess the benefits of these various functions and gain first-hand experience with the technologies involved, EPRI is currently sponsoring two full-scale demonstrations of automated distribution systems. Both systems can isolate and locate faults, regulate voltage, and control VAR flow. A General Electric system at Texas Utilities is monitoring a single substation and

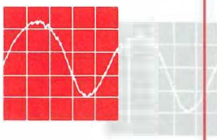
Functions of Two-Way Communication

The ability to establish two-way communication links to remote locations will enable utilities to implement many new functions related to their distribution networks. In a recent EPRI survey, utilities identified several dozen such functions as potentially important. Some of these functions, such as substation monitoring, pertain primarily to system operation. Others, such as those listed here, benefit customers more directly.

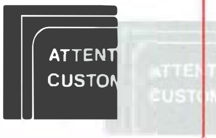
Detection of customer outage The extent of a blackout could be determined immediately, without having to rely on customer complaints or reports from field crews.



Faster service restoration After power interruption due to a fault on the distribution system, service could be restored more quickly by remotely analyzing line loading and performing automatic feeder reconfiguration, which would be facilitated by two-way communication with remote switches.

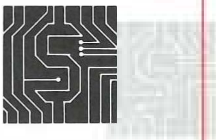


Power quality Voltage deviations and other power quality problems could be detected and remedial actions taken, such as addition of more capacitance to affected circuits. Flickering of lights and misoperation of customer equipment would be minimized.

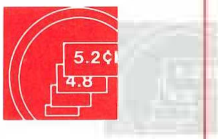


Customer service information exchange Customers could receive messages from their utility, such as "Service representative has been dispatched to analyze voltage problem."

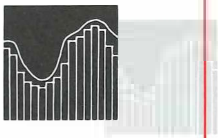
Automated meter reading Integration of "smart" electronic meters could eliminate the need for manual meter reading. First applications have involved commercial and industrial customers and residences in areas where access is difficult or dangerous.



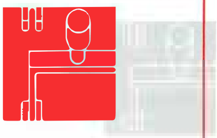
Electronic billing and payment Information gathered from the communications network could be processed automatically, and two-way links would make it possible for billing and customer payment to be done electronically.



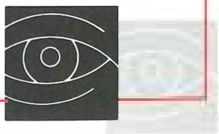
New pricing strategies Customers would be offered more choice through pricing signals downloaded from the utility to a smart meter. The utility, in turn, could track energy usage relative to new pricing strategies by conducting instantaneous load surveys.



Load curtailment In return for lower rates, selected loads on customer premises could be turned on and off remotely, with two-way communication providing verification of load reduction. Load curtailment with two-way communication is expected to focus initially on commercial and industrial customers.



Remote service turn-on/turn-off Remote connection changes mean faster and more convenient service for customers moving into or out of a home or apartment, since no utility service representative would have to be dispatched.



Nontraditional services Utilities that want to diversify their business could offer new services, such as security monitoring of homes and offices.

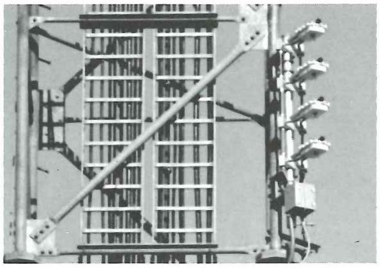
Demonstrating the Connection

One of many demonstrations of two-way, utility-customer communications systems is being conducted in the Valencia district of Los Angeles County by Southern California Edison, using equipment from Metricom, Inc. Called NetComm, this system employs a power line carrier to link several "smart" meters on customer premises to a small radio mounted nearby. The radio signals are eventually received by a central facility for processing. Most other current demonstrations also involve multiple communications media configured into a hybrid system.

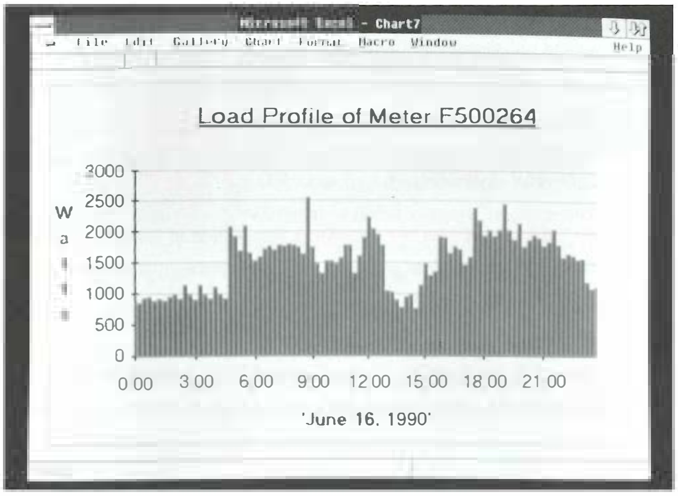
Smart meter and packet radio

Meter installed at residence

Radio receiver at utility control center

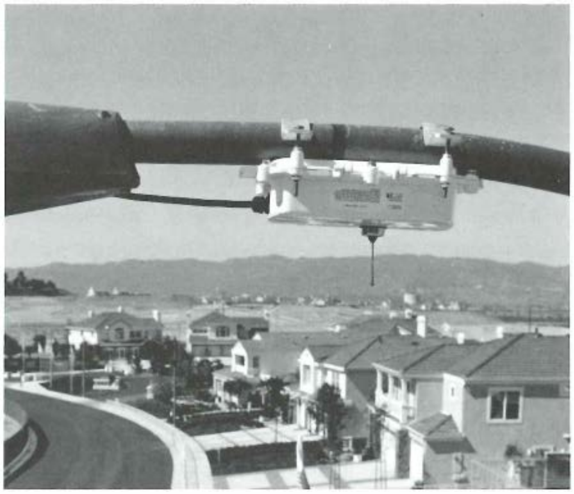


Load data as viewed by utility



Installation of radio on light pole

Radio mounted for operation



Meters undergoing durability testing

three feeders. A Westinghouse system at Carolina Power & Light will integrate operations at three substations and their feeders, plus control some customer loads and read meters.

The Westinghouse system, called Emetcon and now acquired by ABB Power T&D Co., is probably the most widely used of the present generation of distribution automation systems, providing two-way communication to 60,000 points nationwide. It uses a dedicated phone line or microwave channel for communication between central station computers and substation equipment, and a PLC for communication between the substation and customer sites.

In many instances, only a small change in present-day conditions is needed for two-way communication to be readily cost-justified, even with the use of more expensive media, such as phone lines. Northeast Utilities, for example, worked with its regional telephone company to install a remote meter-reading system at hard-to-read locations, such as high-crime areas. (The utility reports that its human meter readers have the highest injury rate of any employee group.) In this system, the phone company installs a subscriber line access controller (SLAC) at its central office, which can send and receive signals from a customer's meter without interfering in any way with regular telephone service.

"Utility experience with distribution automation up to this point has shown that many power network control functions are already cost-effective," says Wade Malcolm, a project manager in the Electrical Systems Division, on loan to EPRI from Philadelphia Electric. "So far, however, customer interface functions have been economically feasible only to a limited extent. On a national basis, one-way load-control signals, for example, now reach about 4 million customer sites—out of 90 million total. But two-way communication is still in its infancy."

The next generation

New technology may improve the economics of both two-way communication with the customer and distribution automation. A new generation of communications systems, now under test at several utilities, *begins* with a two-way link between utility and customer and then adds network control functions. These systems are characterized by hybrid communications networks combining various media in a way that takes advantage of the strengths of each.

The largest demonstration of one of these new systems is under way at Southern California Edison (SCE), using equipment developed by Metricom, a young Silicon Valley company. The communications network, which SCE calls NetComm, uses a series of UHF radios mounted on utility poles to send signals from a neighborhood to a central control office, and a power line carrier to link each radio to the smart meters on nearby houses. The advantage of this hybrid arrangement is that it limits the power line link to carrying only small amounts of data over a very short distance.

The radios, in turn, pass information from one to another in short digital bursts, called packets. One of several advantages of such "packet switching" is that information delivered is guaranteed to be error-free. Also, no individual radio transmitter is required to have a very long broadcasting range; rather a transmitter can rely on other transmitters to pass a message along until it eventually reaches the central office. The particular route a given message will take is not specified ahead of time. Instead, the routing is controlled by a complex, proprietary algorithm embedded in the logic circuits of the radios. Each meter has a unique electronic "address" that is included in the data packets sent to it.

SCE's demonstration includes 1000 smart meters and 220 packet radios in the Valencia district of Los Angeles County. The hilly terrain of the Valencia area provides a good test for NetComm, since previous radio-based communications systems have had difficulty reaching into areas surrounded by hills. SCE is also testing the system in its Ventura and Monrovia districts. Each Metricom meter is fully electronic, with no moving parts like the spinning disks of traditional meters.

In addition to measuring kilowatt-hours, the meters can keep a record of reactive energy consumption (kilovar-hours), peak power demand, number of outages, and outage duration. If SCE needs information about power quality and usage in a particular area, it can use NetComm to poll meters about their present voltage, power factor, and kVA readings, and can retrieve voltage and power profiles for extended periods. If the customer wishes to take advantage of rate benefits, individual loads in a house can be controlled through power line signals sent by NetComm to addressable control devices at customer premises.

"We picked the hardest thing to do first," says Spencer Carlisle, SCE's project manager for the NetComm system. "We believed the specialized communication systems being installed for distribution automation at the top level might not have the capacity to reach the millions of customers required for remote metering and load control. We wanted to start at the bottom, with every customer, and work our way up. Once you have a communication system like that in place, you can add other functions just by installing some more radios. In addition to metering and power quality measures, one of our top priorities is to monitor automatic reclosers on isolated rural lines to reduce outages."

Another demonstration of the Metricom system, involving 1500 customers, is under way at Boston Edison (BE), under the name ServiceNet. There, the system will be tested in very different circumstances than at SCE: more precipitation, greater temperature variation, lots of foliage that could interfere with radio signals, and—most important—communications congestion. Many of Greater Boston's commercial television and radio transmission towers are near the test area.

BE is also eager to see how well ServiceNet will work on its large underground distribution network. This network is set up in a grid formation where all secondaries are linked to each other. The significant increases in noise and, in theory, the capability of each radio to communicate with each meter could result in significant communications congestion. The company has more than 4900 miles of underground cable in the four-square-mile downtown area alone —with manholes and vaults that flood at high tide.

To further complicate the downtown situation, BE does not have rights-of-way to building roofs, and the majority of streetlights are owned by third parties. Historical districts have strict regulations about changing the appearance of the areas. All of these factors call for innovative designs that will meet environmental as well as corporate requirements. State-of-the-art techniques in antennas and power line carriers are becoming the norm here.

A competing product line with a different type of radio network has been developed by another young Silicon Valley firm, Domestic Automation Co. (DAC). Called CellNet, this system also sends signals from smart meters to neighborhood radios via power line carrier; however, all the field radios in a region then communicate directly with a single base station rather than relaying messages from one to another, as in the Metricom system. When the central station interrogates the field radios, the answers are synchronized, with each remote unit assigned a particular time slot in which to respond—a scheme called time division multiplexing.

The first demonstration of CellNet is being conducted by Pacific Gas and Electric (PG&E) in San Rafael, California. Tests so far have concentrated on relocating three prototype radios in various geographic areas to test their ability to communicate with a central station. By late this year, DAC intends to install a network at PG&E that can communicate with 100–200 points, including meters, system monitoring devices, and remote equipment switches. PG&E is also evaluating several other communications systems, including Metricom's.

A third approach to customer communications is being taken by Itron of Spokane, Washington. This packet-switched network is designed to be medium-independent, with data "packetization" taking place in the smart meter before initial transmission over whatever combination of media best fits a given situation. The system is also characterized by providing preset routes through the network for information with various priorities. Itron expects to demonstrate its new two-way communications system at a utility next year.

Fiber optics—the ultimate link?

Over the long term, a fundamentally different technology—fiber optics—is expected to play an increasingly important role in telecommunications. With data transmission rates at least 10,000 times greater than those now available on radio-based networks or voice-grade phone lines, a fiber-optic cable can supply a whole spectrum of communications services. Although fiber optics is used routinely for long-distance communications service, it remains a relatively expensive medium with inherent technical drawbacks: fiber cables are hard and expensive to splice, and optical signals must be converted to electronic ones at both ends of a cable today.

With further technological and economic advances expected, most communications planners foresee the day when homes are routinely connected to a fiber-optic network that will meet all their communications needs, including telephone, cable TV, and utility services. This possibility raises a profound question: who will own and install the fiber-optic cable? At one time, the answer would have been simple: the telephone company, of course. With deregulation of the Bell system, however, potential competitors—including some electric utilities—are finding that proprietary fiber-optic networks built to meet their own specific communications needs can have additional benefits for their customers.

Consider the case of Public Service Co. of Oklahoma, which has looped the Tulsa area with 110 miles of fiber-optic cable in two concentric rings. In addition to using this network for its own communications needs, the company is providing high-volume data transfer service to some 30 commercial customers. Such point-to-point service (versus switched, multipoint service) qualifies the electric utility as a private carrier (versus common carrier) and so exempts it from state licensing requirements.

"We are substituting our service for that of the telephone company for specific business applications," says Will Stratton, senior vice president of finance. "We've received a very enthusiastic response from our commercial customers. The network provides them higher bandwidth, greater security, personal service, and zero errors."

Houston Lighting & Power (HL&P) also markets the use of its fiber-optic network, but it avoids direct competition with the local telephone company. "Our main interest in the network is that it can handle the vast majority of our own telecommunications needs—at about one-half the total cost and with better reliability and more control over facilities than using leased service," says Mike Shea, supervising engineer in HL&P's telecommunications department. "We lease fiber cable pairs to third parties that have a local franchise to serve large business customers. We are not in competition with the phone company to provide a service directly to their customers."

Choosing a Medium

A wide variety of media are being used, at least experimentally, to link electric utilities with their customers. The characteristics of these media vary widely in such two-way communications systems, and two or more media may be used together in any particular system. While rapid technological improvements may change the relative advantages of various media substantially, most experts agree that the huge message-carrying capacity of fiber optics will eventually enable this medium to dominate the field.

Medium	Typical Data Rates (bits per second)	Relative Cost	State of Development	Advantages	Drawbacks	Other Issues
Fiber-Optic Cable	1.5 million–200 million	High	Trials	Virtually unlimited data rates. High immunity to interference.	Regulatory issues unresolved. Limitations on branching fiber-optic signals.	Fiber costs decreasing. Work continues on low-cost splicing.
Standard Phone Lines	110–20,000 (analog) 9600–1.5 million (digital)	Medium (analog) High (digital)	Established (analog) Trials (digital)	High system reliability. Infrastructure in place.	Telephone tariff uncertainties. Nonstandard utility connections to telephone equipment.	Utility must rely on third party for system performance and maintenance. There is steady movement toward digital systems.
UHF/VHF Radio	1200–40,000	Low	Trials	Easily expandable. Low operating cost.	Limited frequency availability.	Harsh radio environment due to frequency congestion in some areas. Terrain-dependent operation.
Long-Haul Power Line Carrier	60–300	Medium to high	Established	Infrastructure in place. Utility has complete control, and acceptance is high.	Circuit-conditioning equipment needed. Interference is high.	Inability to communicate when power is out. Reliability remains unproven.
Short-Haul Power Line Carrier	300–10,000	Low	Established	Logical component of hybrid system. Minimal circuit conditioning required.	Limited range. Interference is high.	Interference with customer equipment unresolved. Backup power required for operation during outages.
Coaxial Cable	1 million–15 million	Medium to high	Trials	Substantial infrastructure in place.	Two-way cable communication is costly and technically difficult.	Third-party ownership. Tariffs uncertain. Reliability may be low.
Satellite	1200–1.5 million	Medium to high	Trials	Good for geographically dispersed customers. Easily expandable.	Cost of two-way earth station is still high, and size of "dish" is still large.	Very small aperture terminals (VSATs)—small dishes—are under development. Reliability may be affected by weather.

EPRI project manager Wade Malcolm sees a complex mix of technologies and business arrangements evolving: "First we'll see upgrading of the present telephone system by introduction of an all-digital network. This will smooth the way for replacement of wires with optical cables, which are also digital but have much higher data rates. The big question is how fast the transition will come and who will install the fiber optics. I expect to see more strategic alliances between telephone companies and electric utilities. For example, telephone companies are already making trial installations of fiber to the home and might in the future have an electric utility provide some services, such as meter reading and energy management."

The search for standards

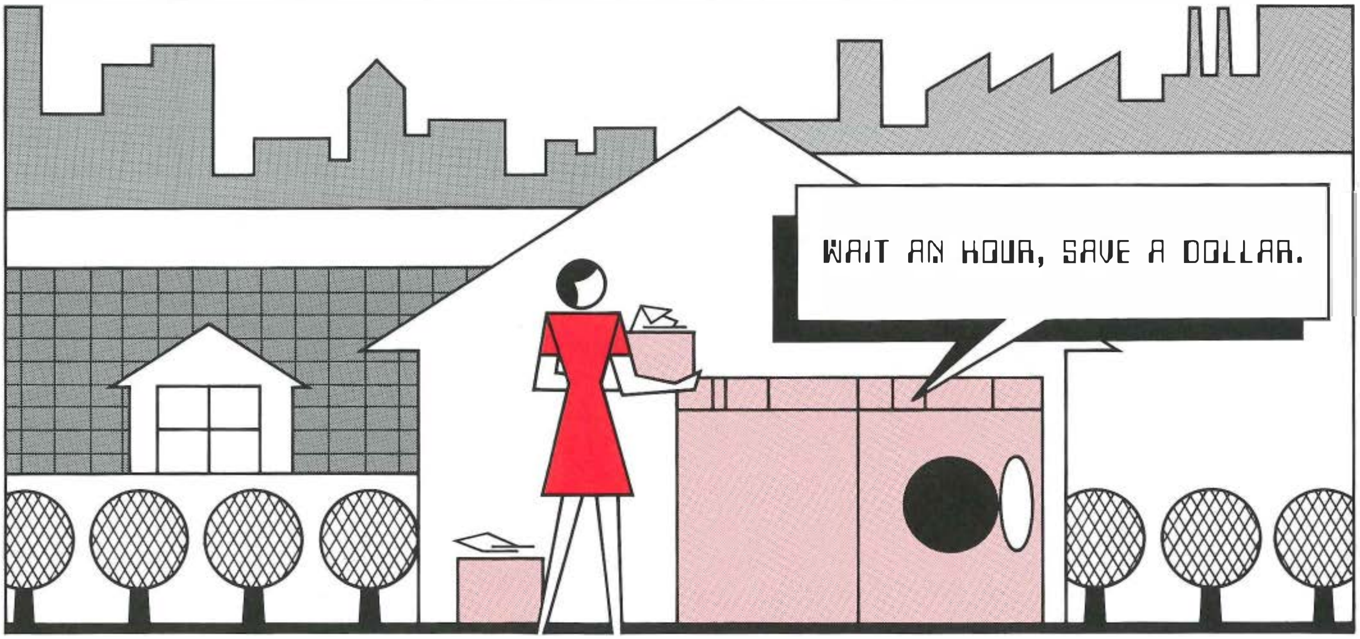
Although advanced communications technologies are opening new opportunities for utilities, they are also exacerbating some old problems. Foremost among these is incompatibility of equipment from different vendors. What happens, for example, when a utility wants to use one vendor's communications system in an urban area and another vendor's system in a rural area? With most of the systems now being introduced, a utility's only option would be to set up two independent communications systems. Another problem with incompatibility is that a utility could not obtain equipment for a particular system from a second source, which means that a communications system could be "orphaned" if the original vendor went out of business.

A major step in the solution of this problem would be to have communications equipment from different vendors pass information in a standard way. Such communications standards are called protocols, which consist of specifications for coding messages so that they can be exchanged between two systems. Major telecommunications and computer users groups have taken the lead in developing protocols that will enable systems from different manufacturers to pass information back and forth. Specifically, a model has been developed—the Open Systems Interconnection (OSI) reference model—that breaks down the process of communication into seven layers, each of which has its own set of protocols.

EPRI is completing an evolutionary initiative to develop an OSI-based set of protocols that meets the specific needs of utilities. Called the Utility Communications Architecture (UCA), these standards will establish an integrated system of interconnectivity and data communication that will allow exchange of information between any communications systems within a utility and also facilitate data exchange between utilities or with external agencies. The UCA Version 1.0 specification, along with a compila-

A Matter of Choice

The advent of two-way communications will mean a wider spectrum of choice in how customers use electricity, with time-of-use rates likely to become much more common for industrial, commercial, and residential customers. Pricing signals could be conveyed in a variety of ways, including specific messages to enable individual consumers to choose when to use appliances and equipment.



tion of selected standards and guidelines and a user's guide, was released in August. The specifications were developed with the assistance of PG&E and HL&P as host utilities.

A second integrated utility industry communications effort—DAIS, or Database Access Integration Services—is seeking to facilitate utility access to information residing in different kinds of data systems. Northern States Power is the host utility for DAIS. EPRI-sponsored projects to demonstrate technologies based on UCA and DAIS standards are expected to begin in 1991.

"The utility industry represents an extremely large market for communications equipment—large enough that we should have a say with regard to what the suppliers make available," says Bill Boston, president and chief operating officer of Wisconsin Electric Power and chairman of EPRI's Integrated Communications Advisory Committee. "The industry needs UCA to determine how data communications will be handled over the next 10–15 years. Utilities have to be proactive in setting standards."

One subset of UCA protocols can be used specifically for utility-customer communication, and Robert Iveson, matrix manager of EPRI's Integrated Utility Communications effort, says these standards "will help utilities take advantage of whatever new technologies are offered. It's important to remember that this is still a very young, rapidly evolving field."

Wade Malcolm, project manager for both UCA and DAIS, adds: "It's been estimated that half the cost of automation comes in trying to integrate the various systems involved. By adopting standards early on, the utility industry will be better able to ensure that future equipment will meet its diverse needs. The fact that some 45 utilities have been active supporters of the development of UCA shows how seriously they consider the need for communications standards."

EPRI's Customer Systems Division is also developing a utility gateway (UG) that can act as an interface between various communications media, smart meters, and intelligent appliances on a customer's premises, while providing UCA compatibility for the utility interface. This project is under way, with Honeywell as the prime contractor.

The initial field demonstration of a UG prototype is scheduled to begin in January 1991 in an electronically sophisticated house in Atlanta based on the Smart House concept. Such residential applications will be particularly important, since the internal communications devices used in various prototypes of intelligent homes are also incompatible. The Smart House concept, backed by the National Association of Home Builders, uses a proprietary communications system. In contrast, the CEBus concept for intelligent homes, backed by the Electronics Industry Association, uses an open communications standard based on OSI. The purpose of UG is to enable such customer systems to be integrated into a utility-customer communications network based on UCA.

"EPRI's goal is to fund research that can help utilities use a variety of communications technologies as they become available, while also providing a path to a more standardized future," says Larry Carmichael, project manager in the Customer Systems Division. "We wish to enable utilities to employ any new technologies related to communications systems and customer service applications. I expect that these applications will initially focus on the needs of relatively large industrial and commercial customers, then eventually develop in the residential market as technologies mature."

Enabling technologies

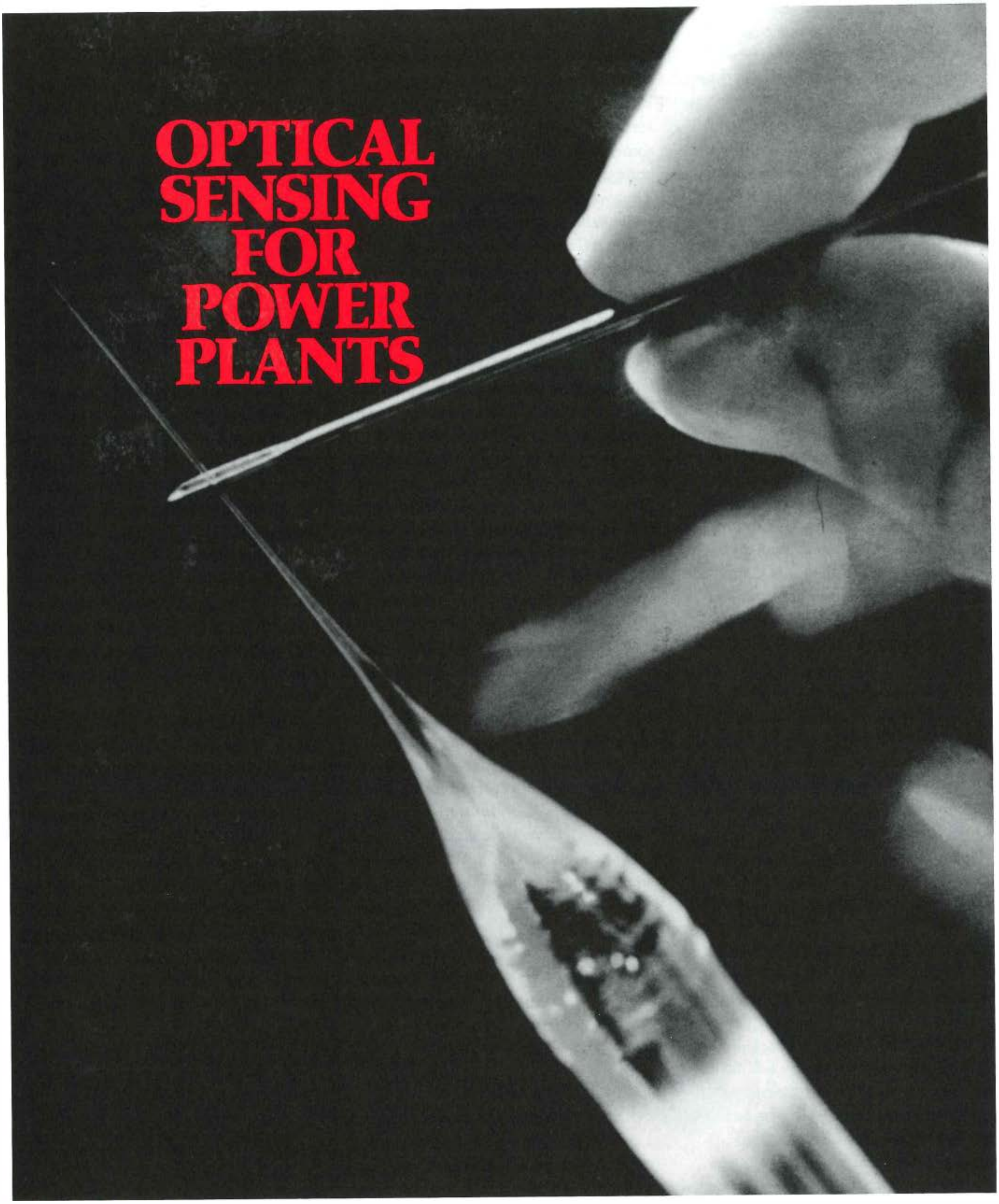
Seen from a broader perspective, advances in communications represent just one of several new technologies that are prompting utilities to look beyond their traditional markets in order to expand business opportunities and make the most of their existing assets.

"Communications is an *enabling* technology that can change the economic underpinnings of electric power production and delivery in ways that could fundamentally alter utility business strategy and organization," says Hung-po Chao, senior scientific adviser in EPRI's Utility Planning Methods Center. "EPRI can help utilities evaluate enabling technologies like a new communications network in terms of their business strategy, with a long-term view toward future opportunities."

Two-way, real-time communication with the customer is not only valuable but necessary for utilities looking toward the future, Chao says. "The utility business is becoming increasingly market-driven, causing utilities to place more emphasis on meeting customer needs. Two-way communication will be a critical element of that utility response. And once a utility has set up such a two-way network, we want to help them evaluate additional ways they can use it to improve the productivity of their assets as a whole."

Dom Geraghty emphasizes EPRI's obligation to support its members through both the economic and technological revolutions now taking place in communications: "EPRI is developing a capability in this rapidly changing area on our members' behalf. The electric power industry is perhaps the largest user of real-time data, and EPRI can provide information that enables utilities to take advantage of new communications technologies for better service to their customers and in support of their overall business objectives." ■

This article was written by John Douglas, science writer. Technical background information was provided by Dom Geraghty, Office of Corporate and Strategic Planning; Frank Young, Robert Iveson, and Wade Malcolm, Electrical Systems Division; and Larry Carmichael, Customer Systems Division.


OPTICAL
SENSING
FOR
POWER
PLANTS

Since their development in the mid-1960s, optical fibers have sparked a revolution in telecommunications because they can carry vast amounts of information over great distances with signal quality superior to that of conventional copper wire. Some proponents of the technology maintain that widespread penetration of fiber-optic data and video networks into homes and businesses will soon be transforming the way we live and work.

But another, less heralded fiber-optic revolution has been brewing over the past several years that may transform the way electric utilities monitor the health of power systems. EPRI-sponsored researchers have been exploiting the unique properties of optical fibers for use not just as data highways but as sensors capable of detecting and measuring a host of power system parameters, from temperature, pressure, and strain to chemical species and electric and magnetic fields. In fact, most physical properties can be sensed with optical systems.

An optical fiber is a strand of clear silica or other material about the diameter of a light fishing line. This core is surrounded by a coating with a lower refractive index. The fiber provides a channel for pulses of light—the light rays strike the interface between the core and the coating at an angle and are reflected back into the core with virtually no loss. Signal purity and data capacity have made the telecommunications industry enamored of optical fiber, but researchers aiming to use fibers as diagnostic tools are more interested in the fibers' sensitivity, which the telecommunications industry has minimized with protective shielding and opaque coatings. External influences such as heat will affect the properties of the fiber and alter the characteristics of the light traveling inside, changing its intensity, wavelength, or phase. These changes can be measured, interpreted, and displayed by instruments at the receiving end of the fiber.

Optical fiber can be used to make point

THE STORY IN BRIEF

Sensing instruments based on fiber-optic materials offer an exciting new approach for monitoring the health of utility systems. Because they are extremely thin, flexible, and immune to electromagnetic and radio-frequency interference, optical fibers make ideal transmitters of data monitored from plant components, which are often difficult to access. But besides transmitting light pulses, these thin strands of silica also behave as highly accurate sensors themselves, picking up data both at the fiber tip and continuously along the fiber length—with no moving parts. Optical sensors not only can improve on measurement of such standard parameters as temperature and pressure but also have the potential to perform monitoring functions beyond the capabilities of conventional sensors, including chemistry analysis and direct strain measurement. The ultimate vision would have optical sensors embedded in key plant components during manufacture and fiber-connected to a central processor for real-time monitoring of the entire plant.

measurements, where just the end of the fiber is used to sense a variable, or to make distributed measurements, where the entire length of a fiber serves as the sensor. In the latter type of system, a light signal is sent down the fiber to be influenced by its surroundings; then the return signal is used to determine the magnitude of a variable—a hot spot in a pipe, for example—as well as its location. Sensitivity can be altered by applying coatings that respond to specific variables or by changing the properties of the fiber itself through the addition of dopants during manufacture.

In addition to sensitivity, optical fiber has a number of other desirable attributes. Since it carries pulses of light instead of electric current, it is nonconductive and immune to electromagnetic and radio-frequency interference. It has no moving parts and requires no electrical connections. And owing to its small diameter and flexibility, the fiber can be snaked through tight spaces or wrapped around pipes or other structures, allowing access into otherwise inaccessible areas.

A quantum leap

With roots in the aerospace and biomedical industries, optical sensing is a rapidly developing technology that offers potentially great benefits to the electric power industry. Optical sensors may allow utilities to acquire detailed diagnostic data that are impossible or impractical to obtain with existing instrumentation. The technology also presents challenges, however. Although many fiber-optic sensors are now commercially available, their ability to withstand harsh environments is limited; hence researchers are trying to develop systems that are sensitive enough to take accurate measurements yet rugged enough to operate in the face of high temperatures, corrosive chemicals, and radiation.

EPRI's Office of Exploratory Research, the arm of the Institute involved with high-payoff, high-risk technologies, is overseeing a half-dozen optical-sensing R&D projects managed through the Generation and Storage Division and the Nuclear Power Division. Some of the projects involve fundamental research aimed at better understanding and improving the properties of optical fiber; others have already yielded technologies that are approaching commercial readiness. EPRI project managers are also looking far ahead at potential applications in the power systems of the future.

"Optical sensors will allow us to measure many parameters that we can't measure with existing sensors," says Walt Esselman, a veteran EPRI staff member who serves as a consultant to the Office of Exploratory Research. "This technology marks a quantum leap forward in instrumentation and control," adds Joe Weiss, a project manager in the Nuclear Plant Operations and Maintenance Program who, with Esselman, has spearheaded the Institute's optical-sensing projects. "Optical-sensing technology is not just an incremental improvement over what we have today; it will provide us with a whole new way of looking at things."

Weiss tempers enthusiasm with caution, however. "The field of fiber-optic communications is fairly mature, but optical-sensing technology is not. Right now we're working at the front end of basic research on fiber-optic sensors that will work in utility environments. Much of the research is focused on materials; we're experimenting with different types of coatings, different fiber formulations, and other fiber materials, such as sapphire, that may be more rugged than standard silica fiber."

Some utility applications of optical sensors won't be in place for several more years, especially those intended for high-temperature or high-radiation environments. But there are sensors available now that can be put to use under milder conditions and that possess some remarkable attributes. Small size is one. Weiss displays a miniature pressure transducer designed to work at the tip of an optical fiber. Measuring a sixteenth of an inch on a side, the sensor could easily fit under a thumbnail—or within tight confines that wouldn't admit a far-bulkier conventional transducer. The sensor contains a tiny diaphragm; light reflects off the diaphragm back to a receiver that measures its displacement with exquisite accuracy—to within a wavelength.

The promise of optical sensing has attracted the interest of utility people who have tracked the technology's progress in other industries or have learned about it through EPRI reports or workshops. Emile Hyman, principal investigator for research and development at Public Service Electric & Gas, serves as a utility adviser on EPRI's optical-sensing work. "Utilities have many unmet sensing needs that may be met with optical sensors," he says. "There may not be a lot of utility-grade products available off the shelf right now, but it's not exactly a fledgling technology. There is a great deal of information and hardware from the telecommunications field and a huge body of work describing demonstrations of principles at universities."

Part of the challenge in developing the technology for the power industry involves getting optoelectronics researchers and representatives from optical fiber manufacturers together to discuss requirements and capabilities. With support from EPRI project managers, Hyman is forming an organization to stimulate the development of optical sensors for utility applications. The organization, the Optical Sensing Manufacturers/Utility Group, or OPSM/UG, will bring together representatives from utilities and optical fiber manufacturers to identify utility sensing needs that could be met with the new technology. "I think optical sensing provides an opportunity for utilities to take a proactive role in guiding an emerging technology toward meeting utility needs," says Hyman.

The development of optical-sensing technology dovetails with the power industry trend toward on-line diagnostic plant monitoring using advanced electronic sensors, microprocessors, and computers. Continuous monitoring of power equipment can help signal the onset of failures as well as improve plant performance and reduce maintenance costs.

John Maulbetsch, an executive scientist in EPRI's Office of Exploratory Research, envisions a future in which entire power systems are webbed with fiber-optic cables, serving as both sensors and data highways. "The idea of having fibers spread around generating plants and the transmission-distribution system could have significant implications," he says. "It would allow us to continuously monitor conditions throughout the power plant or throughout the network—providing real-time information on voltage, current, electric and magnetic field strength, temperature, and pressure everywhere on the power system. If we could process all that information at an intelligent control system, we'd have instantaneous knowledge of what the power flows were, or where in the system there were limitations, and could take corrective action before problems arose. If we could assume the instantaneous, real-time availability of any information at any level of detail, from any place in the system, think of the design and operating flexibility that would give us."

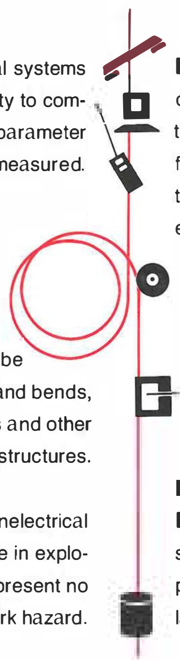
Temperature measurement

While such a vision isn't going to be realized overnight, EPRI research is helping to accelerate the penetration of fiber-optic sensors into the power plant. One project in the Generation and Storage Division has cosponsored the development of a distributed fiber-optic temperature sensor that is ready for commercialization. Developed at Battelle with funding from EPRI and Consolidated Edison, the sensor is intended for use in detecting hot spots in high-voltage environments—for example, bus connections and generator windings—to provide early warning of overheating.

The system overcomes the limitations of conventional temperature sensors, such as thermocouples or resistance temperature detectors. Because these conventional sensors take point measurements, a large number are required to monitor a given region, explains project manager Jan Stein. "The distributed fiber-optic sensor, on the other hand, measures temperature along the entire length of the fiber." The sensor uses optical radar techniques to detect hot spots with a spatial resolution down to 2 centimeters. Such a system would be well suited for detecting hot spots on pipes, for example, because the flexible fiber could be laid alongside or wrapped around the pipe for its entire

Attributes of Optical Sensors

Light-based sensing systems have a number of fundamental characteristics that make them unique candidates for diagnostic instrumentation in electric power systems.



Nonintrusive Many optical systems can operate in close proximity to components without affecting the parameter being measured.

Immunity to interference Fiber-optic sensors are not affected by electromagnetic and radio-frequency interference, which makes them well-suited to electronically noisy power plant environments.

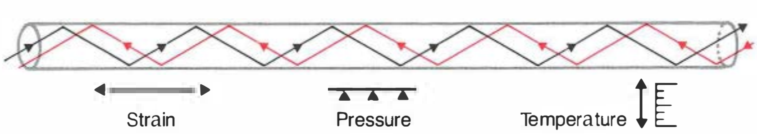
Small size Optical sensors may be used in place of bulkier conventional instruments, affording access to hard-to-reach areas, such as remote locations inside machinery.

Flexibility Optical fiber can be snaked around corners and bends, or wound around pipes and other structures.

Distributed sensing capability Because its entire length can serve as the sensor, an optical fiber can pinpoint locations better than even a large number of point sensors.

Explosion-proof Nonelectrical optical sensors are safe to use in explosive environments, as they present no spark hazard.

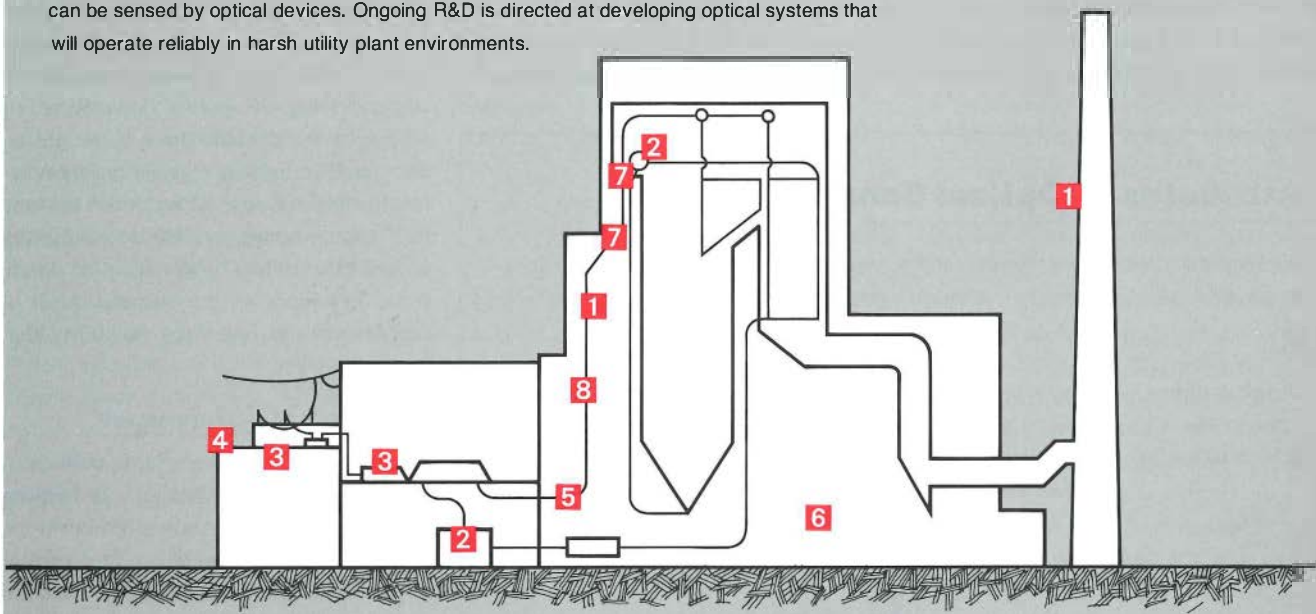
MEASURING WITH LIGHT



Pulses of light traveling through an optical fiber are influenced by external variables, which change the light's intensity, wavelength, or phase. These changes can be measured, interpreted, and displayed by instruments when the light is reflected along the fiber. Fiber-optic sensors can take point measurements, with the fiber serving as a light conduit from a sensing device mounted at the fiber's tip, or distributed measurements, with the fiber itself serving as a sensor along its entire length. A single fiber may even be used to sense multiple parameters—such as temperature, pressure, and strain—at different points along its length.

Optical Sensors in the Power System

A broad spectrum of power system parameters—some of them difficult or impossible to measure by means of conventional instrumentation—can be sensed by optical devices. Ongoing R&D is directed at developing optical systems that will operate reliably in harsh utility plant environments.



1 Temperature Distributed fiber-optic temperature sensors provide better spatial resolution than traditional point sensors and could find application in steam piping, boilers, generator windings, and numerous other plant components to provide on-line diagnostic data and early warning of overheating.

2 Process chemistry Using optical sensors to take continuous on-line chemical measurements of feedwater and other coolants could help utilities control corrosion and improve plant operation. Knowing the pH of water at operating temperatures, for example, would remove a key uncertainty that now hinders corrosion control.

3 Electric fields Fiber-optic electric field sensors are small enough to be installed inside high-voltage components, where they could provide diagnostic information and detect changes in the field, which may indicate equipment degradation.

4 Voltage and current Existing current transformer sensors are very large and expensive. Fiber-optic voltage and current sensors would be much smaller and less costly.

5 Leak detection Several types of optical systems can be used to detect small leaks before they lead to more serious problems. Distributed temperature sensors could detect a leak-caused hot spot on a pipe and identify its location; other types of leaks could be identified by chemical sensors, while laser systems could scan compartments for steam or moisture escaping from a leak.

6 Personnel monitoring Fiber-optic sensors could be incorporated into clothing or protective suits to detect and measure radiation and other parameters, such as temperature and the presence of hazardous chemicals. A radiation-sensitive fiber could be laid along a person's limbs to ensure that all extremities are properly monitored for exposure.

7 Pressure Existing pressure sensors require periodic surveillance and calibration. Fiber-optic pressure sensors, which use light to precisely measure the displacement of a tiny diaphragm, may not require recalibration and are much smaller than existing systems.

8 Strain On-line measurement of strain on high-pressure or high-temperature components by means of optical sensors would make it easier to assess remaining component life.

length. Another possible application would be measuring the sag of transmission lines as they heat up.

EPRI is working with Illinois Power to test a similar fiber-optic distributed temperature sensor in the exhaust stack of the utility's Hennepin power station, which has one unit using clean coal technology and one unit using conventional technology. "We're interested in how well the damp, cooler gas from the clean coal unit mixes with dry, hotter gas from the conventional unit," says Dave Stopek, supervisor of research and development at Illinois Power. The utility had already installed thermocouples in the stack to measure the stack gas temperature and provide early warning of any potential problem. It recently installed the fiber-optic sensor, wrapping the fiber around a duct that spans the diameter of the stack. The test, which will be conducted this fall, will allow researchers to benchmark the performance of the fiber-optic sensor in the harsh stack environment and compare it with that of the industry-standard thermocouples.

"The stack temperature is within the temperature range of the optical fiber, so this is an excellent opportunity to compare a fiber-optic temperature sensor with thermocouples," says Stopek. "It's possible that this demonstration will be helpful in transferring this technology to other hostile-environment applications."

Smart structures

Optical measurements performed on-line could make it possible to directly monitor stress and strain of plant components. "Right now we measure temperature with thermocouples at discrete points and use the data as input to a stress calculation and then a temperature- and time-dependent strain calculation," explains Steve Gehl, a program manager in EPRI's Fossil Plant Performance Program. "If we could directly measure strain at real operating temperatures, it would be much easier to determine the life expectancy of critical components such as headers and steam piping, which are difficult and expensive to replace, require long lead times, and pose a serious hazard in the event of catastrophic failure."

Gehl is intrigued by the possibility of embedding fiber-optic sensors in plant components—an idea spun off from the aerospace industry, which has been working to develop "smart" structures for aircraft. This effort involves embedding optical sensors in aircraft components to continually monitor the aircraft's status. Plants of the future may have components with sensors embedded during manufacture, says Gehl, but in the nearer term it's more likely that optical sensors would be applied to components already in service.

The chief impediment to realizing the vision of smart structures in power plants is the temperature limitation of existing silica fibers. In addition to tolerating high temperatures, the sensors will be required to stand up to repeated heating and cooling cycles. Fibers made from sapphire may be able to tolerate much higher temperatures than those made from silica, but they are much more expensive. The temperature tolerance of the coating used is also of concern, notes Gehl. "Thermal cycling can change the properties of coatings before it affects the fiber core. So we need coatings, as well as fibers, that can withstand higher temperatures and thermal cycling."

Optical dipsticks

Another area where conventional instrumentation falls short and where fiber optics may play an important role is the measurement of chemical parameters. EPRI's Nuclear Power Division is working to develop a fiber-optic sensor to perform continuous, on-line measurements of pH in hot water, such as that flowing through the secondary loop of a pressurized water reactor. This capability is desirable—and not just in the case of nuclear power plants—because the pH of water is a key variable in controlling corrosion. But measuring pH has proved impossible because conventional instruments cannot tolerate the water's 300°C temperature. The current practice, therefore, requires taking a sample of the hot water and cooling it to near room temperature, where it's acceptable to the instruments. This raises another problem: the pH changes as the water cools, so calculations must be made to determine what the pH was when the water was hot. Unless the concentrations of the constituent chemical species present in the water are carefully factored into these calculations, the result may be inaccurate.

Project manager Tom Passell turned to fiber optics after efforts to extend the temperature range of conventional instruments failed to produce a system that could operate for long periods under field conditions. Passell says a visit to the laboratory of the late Tomas Hirschfeld, a pioneer in optical sensing at the Lawrence Livermore National Laboratory, stimulated his interest in using fiber optics for chemical measurement. "Hirschfeld used fibers to measure a whole realm of variables," says Passell. "Pressure, the concentrations of plutonium and uranium in solutions, the amount of nitric oxide given off as high explosive deteriorates—he'd have up to two dozen kilometer-length fibers laid out for measuring chemical samples throughout the entire lab and carry the data back to a central location where he did his work. The power of this technology to measure such a wide range of variables inspired me to try to use fiber optics to measure pH."

Passell contracted with Livermore to develop a fiber-optic pH measurement system consisting of a fiber tipped with an organic dye known to fluoresce as a function of pH. This dye-coated tip would be immersed like an optical dipstick in the water to be sampled, sending a fluorescent signal back up the fiber to a receiver for interpretation and display. "Thus the sensitive instruments needed to process the spectroscopic information can be located in a protected environment," explains Passell. "They can be improved as technology advances without disruption at the point of measurement."

The project has already been successful at measuring pH at lower water temperatures, according to Passell; the continuing challenge is to extend the life span of both the coating and the fiber. While 300°C water will dissolve silica, the coating itself serves to shield the fiber from the water. The approach is to develop a coating that can survive a suitable length of time—a year or 18 months, the interval between refueling shutdowns.

If 300°C operation isn't achieved any time soon, such a system would prove useful even when operated at lower water temperatures, in the range of 150–180°C, according to Passell. "A nuclear reactor steam loop contains water at all temperatures between approximately 40°C and 320°C," he explains. "Some parts of the loop exposed to water at 150 180°C are the locale of an important pipe-wall-thinning effect known as erosion-corrosion. So even if we develop a sensor that operates no higher than that range, we'll have done something of value."

Nuclear plant application of fiber-optic sensors is now limited by the tolerance of fibers to radiation. In the relatively low-rad environment in which Passell's pH sensor would operate, radiation shouldn't pose much of a problem, he says. But prolonged exposure to large doses of radiation will cause the fiber core to fog up and lose its desirable optical properties. This fogging can be reversed, however, by thermal-annealing or photobleaching techniques, which involve heating the fiber or shooting a high-energy laser pulse through it. "These processes can be used to clear the fiber and make it effectively as good as new," says Joe Weiss, "but the processes can be repeated only x number of times before the fiber gives out, and right now we don't know what that x value is." EPRI-sponsored research at Ohio State University is evaluating the annealing properties of optical fibers as well as ways to harden fibers to increase their radiation tolerance.

Light pipes

Not all optical-sensing applications use the fiber itself as the sensor. Jan Stein is managing a project for EPRI's Office of Exploratory Research in which Brown University researchers are developing a fiber-optic sensor to measure electric fields. Unlike the distributed temperature measurement system, this sensor is a tiny device mounted at the fiber tip. The system's small size will allow it to be installed inside machines such as generators and transformers, where it would pick up changes in the electric field that may be indicative of off-normal operation.

In addition, EPRI's Electrical Systems Division is developing fiber-optic point sensors to measure current and voltage on distribution systems. "The existing sensors are heavy and cumbersome," says project manager Joe Porter. "We're trying to replace them with fiber-optic sensors that are lighter, smaller, and ultimately less expensive. If we're successful, we will be able to utilize a lot more sensors, which will be very useful for automation—it will allow us to measure at more points so we will better know the conditions on the system and what types of actions to take." The project's two independent contractors are studying feasibility, preliminary design, and costing.

Some optical-sensing systems exploit the properties of light to make noncontact measurements that are nonintrusive or are impossible to obtain any other way. In most of these systems, fiber-optic cables serve as pipes to deliver light to the scene of the measurement. For example, materials that fluoresce or phosphoresce as a function of temperature can be applied to a surface and an optical fiber used to illuminate the material. The resulting emitted signal is collected by another fiber and passed to an instrument for analysis. This technique can be used to take remote measurements that require bridging a gap that can't be crossed with a cable.

An EPRI project performed with Ontario Hydro provides a case in point. Researchers applied a thermographic phosphor material in stripes on a generator rotor, then snaked an optical fiber through the stator to illuminate the phosphor stripes on the spinning rotor and obtain temperature readings. In another project, the Generation and Storage Division is exploring this approach to measure temperature on the fireside of boiler walls.

Optical techniques can also sense airborne chemical species and can be used to spot leaks or to measure gases and particles in the exhaust plumes rising from power plant stacks. EPRI's John Hosler is managing a project to develop an optical system to detect borated-water leaks in the containments of pressurized water reactors. Once leaked, borated water will evaporate—leaving behind concentrated boric acid, which can corrode carbon steel components. The leaks of concern are very small, less than a tenth of a gallon per minute, and often escape detection by conventional methods.

"When we started looking at the problem, we thought of using a distributed fiber-optic temperature sensor that would detect a temperature change when hot water touched it," Hosler says. The main drawback of this approach, he explains, was that the fiber wouldn't provide a basis for evaluating the leak. In addition, the susceptibility of optical fiber to radiation made it unsuited to the task. Hosler is now working with an aerospace contractor to adapt optical absorption and holographic techniques developed to perform remote detection of hydrogen leaks from rocket engines. The scheme essentially involves scanning the area of interest with a wide-angle laser beam that can pick up leaks invisible to the naked eye.

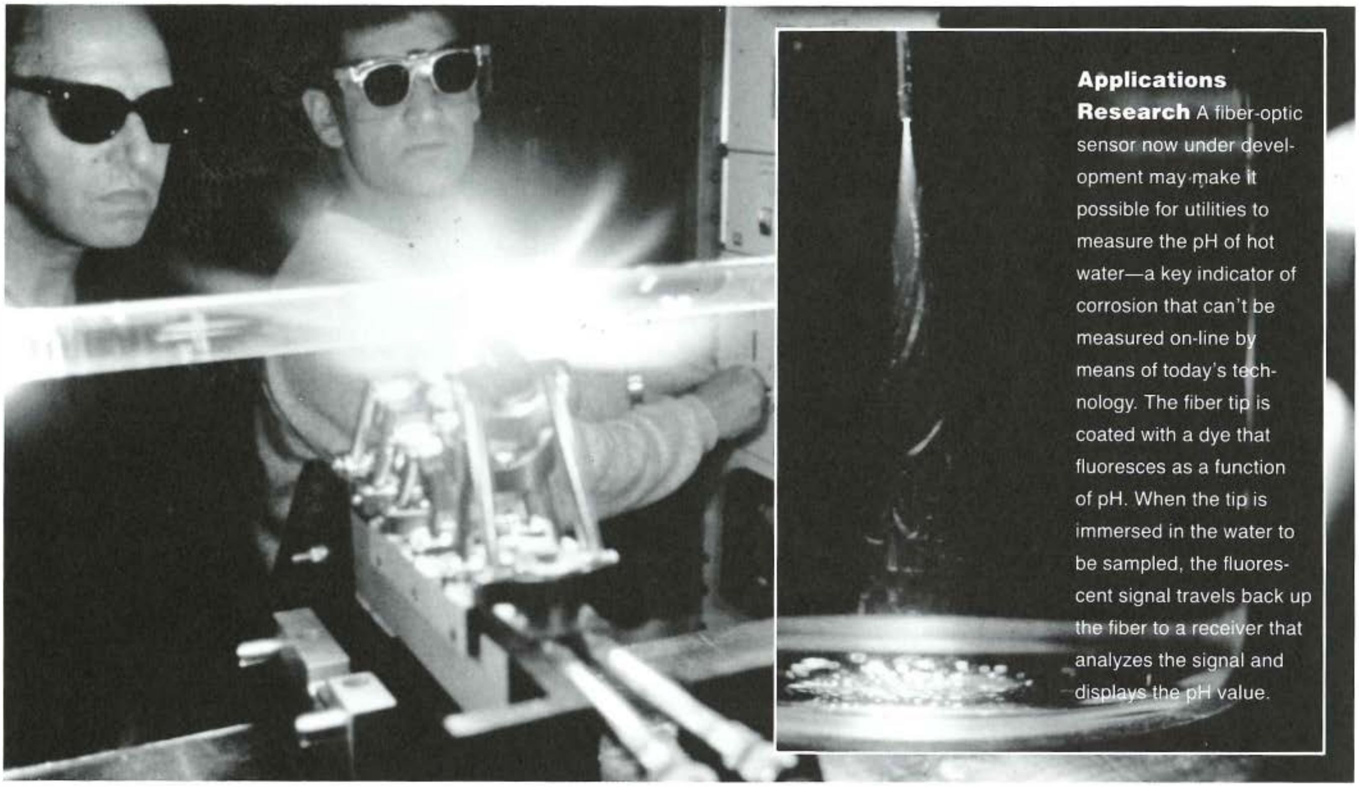
A bright future

EPRI project managers are looking ahead to new projects that will develop optical sensors to meet sensing needs that can't

Research Lights the Way

Research is proceeding on both materials properties of optical fibers and new applications for optical sensing. While there are many optical sensors currently available, they generally aren't suited for use in utility environments.

Materials Research EPRI-sponsored researchers are working to better understand the limitations of fiber-optic technology and to improve the sensing properties of the fibers and increase their tolerance to harsh conditions. Researchers at Brown University (shown here) are working with specialized dopants and novel fabrication techniques to develop specialized fibers for sensing applications.



Applications Research A fiber-optic sensor now under development may make it possible for utilities to measure the pH of hot water—a key indicator of corrosion that can't be measured on-line by means of today's technology. The fiber tip is coated with a dye that fluoresces as a function of pH. When the tip is immersed in the water to be sampled, the fluorescent signal travels back up the fiber to a receiver that analyzes the signal and displays the pH value.

be met with today's instruments. Jan Stein, for example, thinks it should be possible to develop an optical system that uses interferometric techniques to perform noncontact torque measurement. Such a system would allow utilities to directly measure the output of motor-driven equipment. Tom Passell, now working on the optical pH sensor, has ideas for a fiber-optic strain gage that would measure the creep in structures from crevice corrosion. Fiber-optic sensors could even be incorporated into the clothing of plant technicians, according to Joe Weiss, giving the workers a more accurate assessment of the environmental conditions, including temperature, radiation, and the presence of caustic chemicals.

"The range of possibilities seems almost endless," says Emile Hyman of Public Service Electric & Gas, which held a seminar last year in which utility personnel identified more than 50 applications for optical sensing. PSE&G has since put together a companywide optical-sensing task force and held several workshops; it is now actively exploring five optical-sensing applications.

Says EPRI's Tom Passell, "This technology presents an inspiring set of opportunities for the utility industry—opportunities that are limited only by the level of our research effort." ■

Further reading

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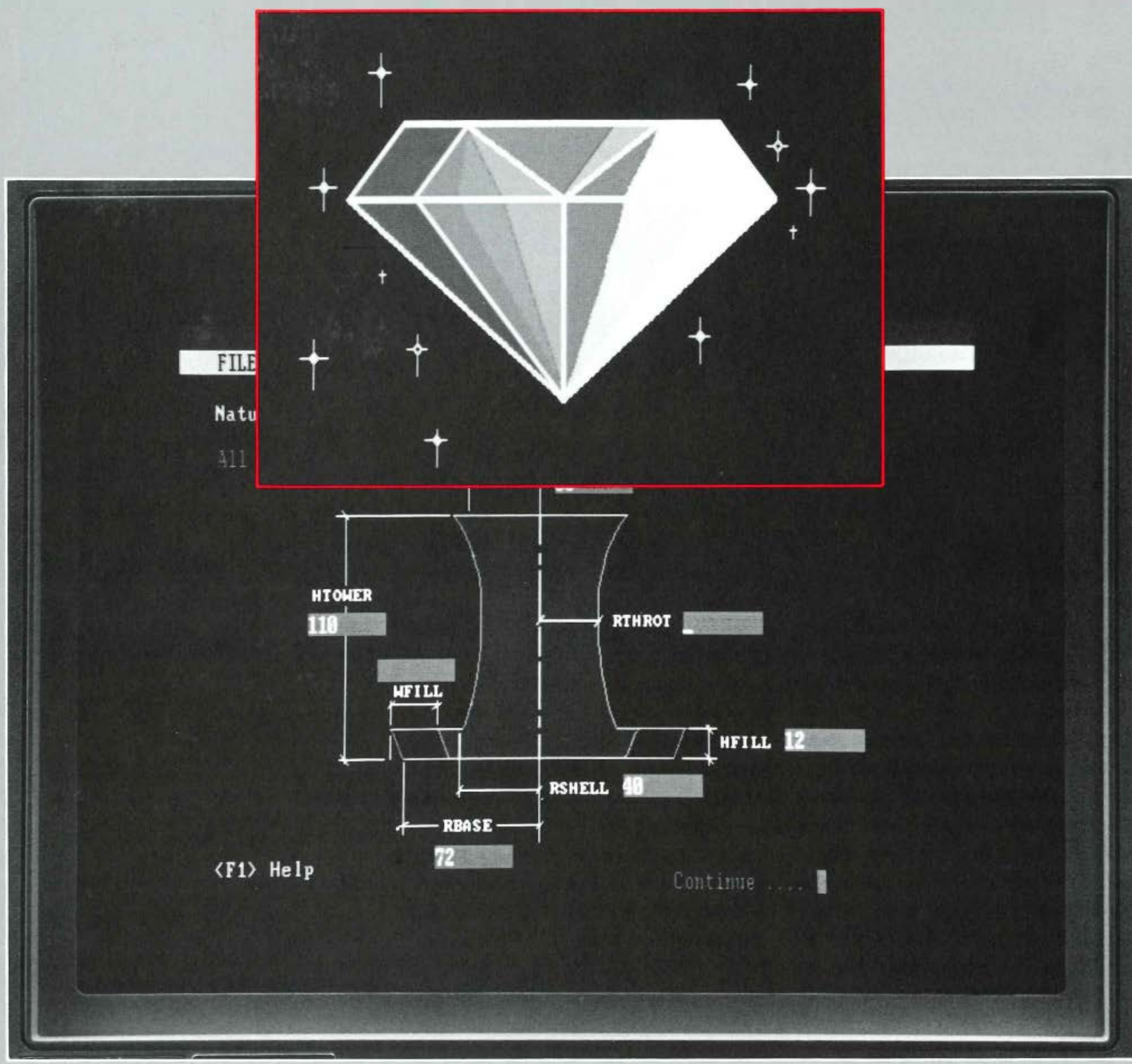
This article was written by David Boutacoff. Background information was provided by Walt Esselman and John Maulbetsch, Office of Exploratory Research; Joe Weiss, Tom Passell, and John Hosler, Nuclear Power Division; Jan Stein and Steve Gehl, Generation and Storage Division; and Joe Porter, Electrical Systems Division.

EPRIGEMS

Medium of Choice for Tech Transfer



Transforming research results into useful products has never been easy. Too often, "technology transfer" has meant issuing voluminous reports or complex computer codes that overburden the targeted professional and intimidate the neophyte. In many areas of electric power research, what is needed is not so much a better vehicle for conveying information but rather a new kind of tool for immediate problem solving, accessible to both the seasoned utility veteran and the struggling novice.

Such a tool is now becoming available for several electric power applications in the form of EPRIGEMS—personal computer software modules that guide the user through the solution of common utility problems. By combining a standardized "look and feel" at the user interface with liberal use of expert systems software technology, EPRIGEMS speed the knowledgeable professional past superfluous information and usher the newcomer gradually into unfamiliar territory.

For utilities, this approach means faster application of new technology with minimal training requirements for personnel. For EPRI, these modules represent a fundamentally new way of delivering value on members' R&D investment by integrating research results into an immediately useful form while actually lowering the cost of software development. Ten EPRIGEMS modules have been released so far, and about 300 copies have been sent to member utilities. Another approximately 40 modules are currently under development.

"The response of the utilities has been enthusiastic," says EPRIGEMS manager David Cain. "This is something they haven't seen before. Here's a tool a person in the field can run on his or her PC and bring state-of-the-art knowledge to bear on a real problem. At the same time, we've developed a way for EPRI project managers to incorporate their results more easily into a high-quality software product—without turning an electric

THE STORY IN BRIEF

Accessibility is the key to successful application of research results—even the most valuable knowledge and expertise are worthless if they remain buried in a stack of reports or a dense mass of extraneous data. Developed as an alternative to conventional technology transfer vehicles, EPRIGEMS software modules bypass the intermediate stage of presenting information and instead deliver actual problem-solving capability through a utility user's personal computer. The modules, which deal with specific technical areas ranging from boiler maintenance to groundwater quality, contain practical know-how mined from EPRI projects and tailored for easy use in an interactive format. Requiring neither computer expertise nor special knowledge in the technology of interest, EPRIGEMS modules make compiled knowledge immediately available for specific problem-solving and decision-making tasks.

power research project into a computer science research project."

Trouble spots in red

Some of the advantages of the EPRIGEMS approach can best be appreciated by considering a couple of examples. The Boiler Maintenance Workstation (BMW) combines three major computational codes developed under previous EPRI projects with a diagnostic expert system. One of the incorporated codes is a database for recording boiler tube failures and repairs; another calculates tube condition from ultrasonic scan data and optimizes tube inspection schedules; the third predicts remaining tube life. The expert system helps the user diagnose basic tube failure mechanisms and prepare a maintenance program to prevent future failures.

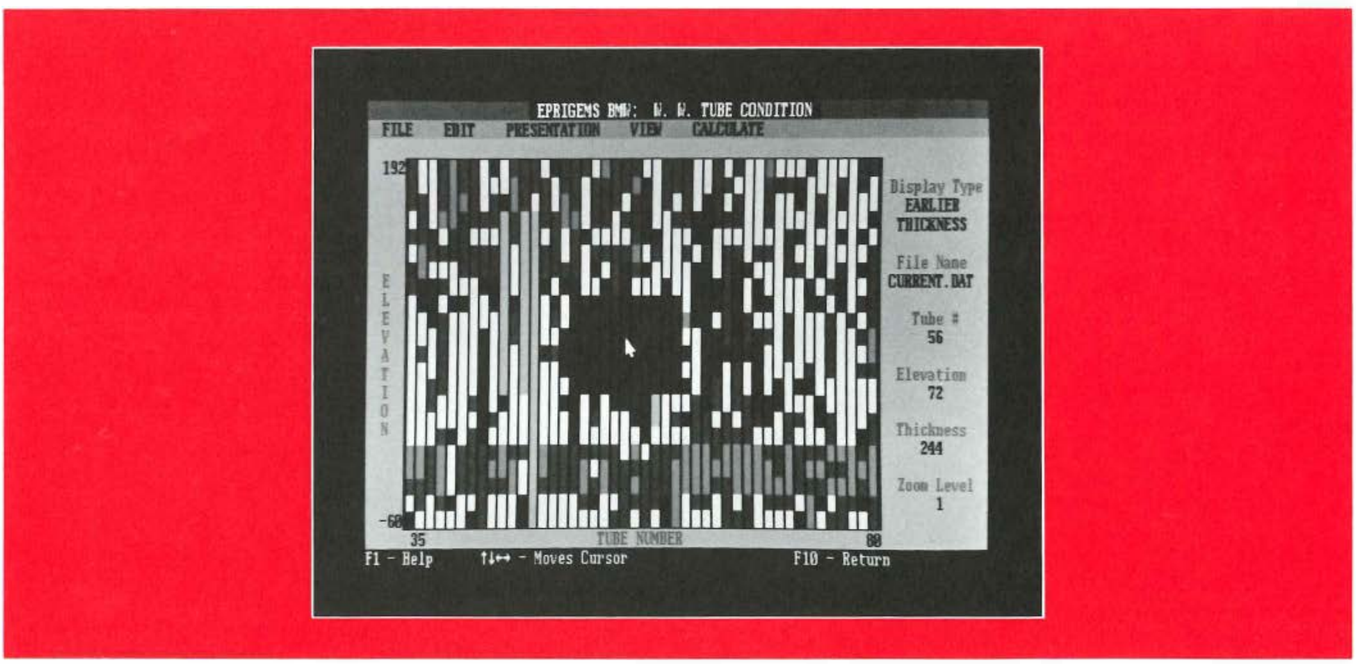
The presentation of BMW results on a user's computer screen is highly intuitive and graphic. Ultrasonic scan data, for instance, can be combined into a color-coded picture of a water-wall interior. Thin regions of individual tubes stand out in bright red against a background mosaic of blues and greens. A user can zoom in on one of the red regions, select an alternative display option from a pull-down menu, and instantly see a simulated three-dimensional view of the area. In this surrealistic landscape, the thinning tube walls appear as a depression with easily measurable dimensions.

"We had similar software with a different user interface before we developed the Boiler Maintenance Workstation, but utility acceptance was disappointing," says Steve Gehl, program manager in the Generation and Storage Division. "Then we added the EPRIGEMS interface and brought together separate but related programs to form BMW. Acceptance of the new product has been high—utilities report that it is easier to use, speeds up analysis, and makes a good training tool."

One of these reports comes from Tom Williams of PSI Energy: "BMW provides *one* source of data, whereas before, boiler tube data were scattered. Before BMW it took us two to three months to do a tube survey. Now we can do it in six to eight days."

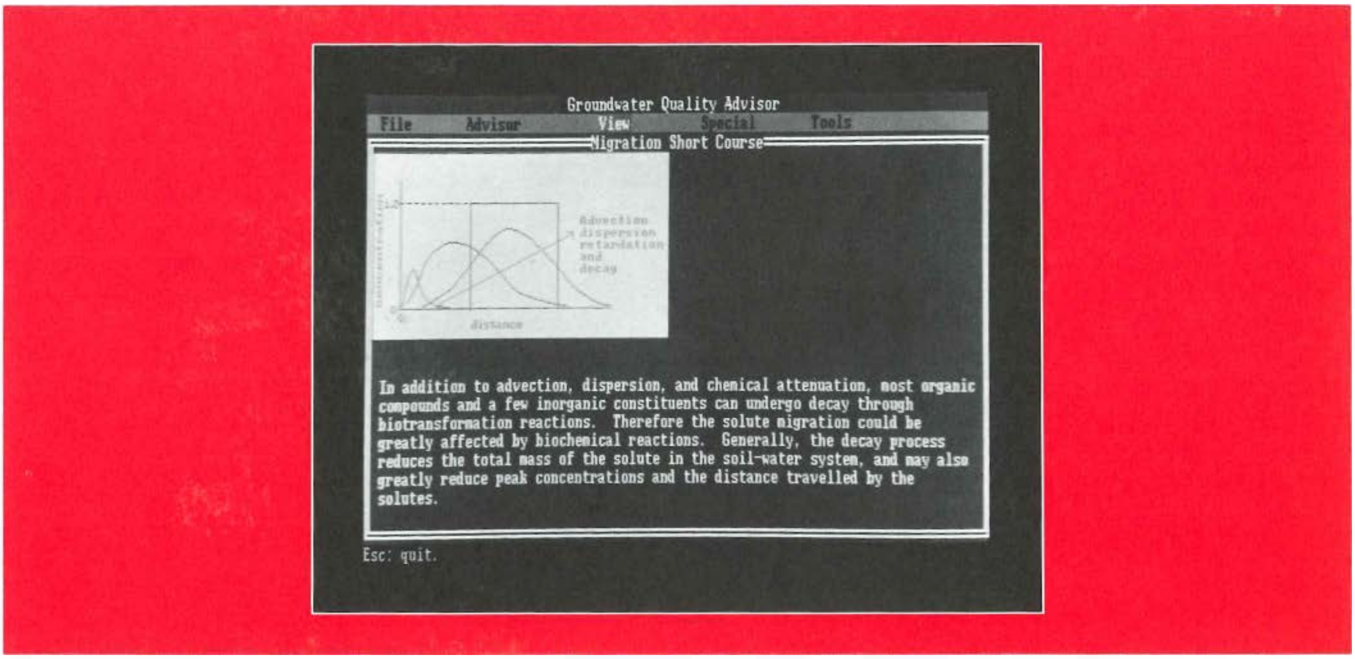
Another EPRIGEMS module, the Cooling Tower Advisor, illustrates some of the benefits this new approach offers to novice or occasional users. Cooling-tower performance is critical to maintaining the efficiency of power plants with closed-cycle cooling systems. A recent study found, however, that for more than 65% of the utility capacity surveyed, the cooling towers were not performing as well as they should. Sometimes the utility engineer charged with improving such performance may not be familiar with the details of cooling-tower performance or be aware of relevant results from EPRI's Cooling Tower Performance Prediction and Improvement project.

Here's how the Cooling Tower Advisor can help: The first screen a user sees is a multicolor diagram showing how a cooling tower is connected to the rest of a power plant. To review cooling-tower function, the user can immediately select a tutorial that emphasizes thermal perfor-



Graphic representation of data can give a quicker feel for the overall situation than tables of numbers can. The Boiler Maintenance Workstation illuminates the erosion patterns of fossil fuel boiler tubes by allowing the user to view an entire water wall or portion thereof, color-differentiated by wear region.

Custom tutorials give nonexperts a quick grasp of the basic factors and dynamics that may have to be considered in order to understand and solve a problem. The Groundwater Quality Advisor includes "short courses" on leachate chemistry, migration, key chemicals of concern, and monitoring methods and equipment. Tutorials are a common feature in EPRIGEMS modules.



mance. The user can even customize this tutorial by selecting a combination of specific topics. A glossary is provided that identifies acronyms and defines common technical terms used to describe cooling towers.

Numerical analyses of cooling-tower thermal performance are provided by two computational codes incorporated into the EPRIGEMS module. These codes —TEFERI and VERA2D—were originally written for mainframe computers, and some users complained about the difficulty of preparing input data. An expert system built into the Cooling Tower Advisor facilitates data input by orchestrating the presentation of input forms and dynamically changing sequence to reflect the user's choices. If some data are missing or obviously incorrect, the expert system informs the user—thus preventing loss of time on a faulty computational exercise.

"I see a lot of advantages to this approach," says Jeffery Hynds, principal research engineer at Public Service Electric & Gas. "When I tried out the Cooling Tower Advisor, I knew next to nothing about the technology, and I consider it a tribute to EPRI that I could use the program. EPRIGEMS will be really great for people coming in new to a subject area. They'll be able to do useful work much faster and spend less time with someone standing over them."

A variety of applications

Not every research project, of course, will lend itself to the creation of an EPRIGEMS module. Specifically, if a project deals with basic technologies or issues that do not immediately relate to utility problems, traditional methods of publication are still probably the best way to disseminate research results. Also, if a project generates a product with clear market potential, the best course of action is to seek direct commercialization as soon as possible.

For numerous applications that involve utility problem solving, however, EPRIGEMS will increasingly become the medium of choice for technology transfer. Judging from modules already released or in preparation, one common application will be to provide a user-friendly "wraparound" for complex analysis codes, such as those in the Cooling Tower Advisor. Such codes typically require elaborate preparation of input files, as well as considerable interpretation of results by the user. An EPRIGEMS module containing the analysis code can take on much of the burden of putting data into the proper format for input and then provide expert systems help for interpreting results. In this way, wraparound functions can help make some underutilized EPRI codes more acceptable to utility users.

Another application is the use of EPRIGEMS to combine a series of related analysis codes into a readily usable workstation format. In addition to providing wraparound functions, the EPRIGEMS workstation can integrate software written in different programming languages and enable several individual codes to exchange files or share a common database.

Semiautomated facilities allow utility engineers to update their workstations as new programs or computational routines come along. The Boiler Maintenance Workstation is an example of this type of application.

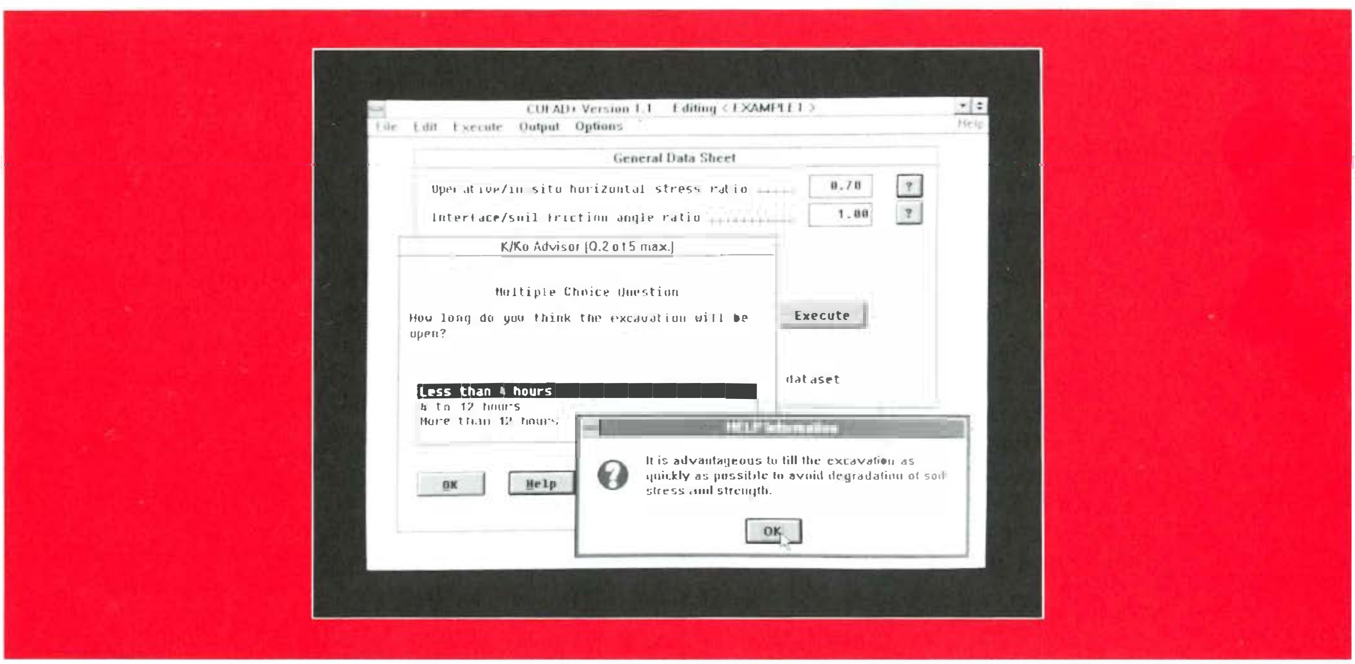
"I believe we're going to see substantially more EPRI codes written for personal computers, thus giving fingertip access to EPRI technology," David Cain predicts. "The power of a mainframe of five years ago may now be sitting on your desk. A typical analysis code might run 10 minutes on a PC, which is theoretically longer than it would take on a mainframe; but by the time you've created and checked your input data, waited for access, and checked the output, the total time required to use the mainframe may actually be longer. What really counts is turnaround time, not speed of execution. Also, because mainframes are shared computing resources, as the power of PCs and workstations increases, it will be more common for them to actually outperform mainframes.

"Most important, running EPRIGEMS on a PC enables the user to participate in the solution of a problem, rather than just be a bystander. Gone are the days when an engineer submitted runs to the mainframe and then just hoped that the analysis would converge on a solution, while he or she was frozen out of the solution process."

In applications that are not computationally intensive, EPRIGEMS provide a more useful way to present information that would otherwise simply have been published. One or more databases, for example, can be prepared as an EPRIGEMS module, thus enabling an occasional user to easily browse, extract data, produce a graph, or export data for use in an analysis code. Similarly, these modules provide an excellent vehicle for computer-based instruction—integrating text, simulations, interactive graphics, and test cases. Product guides can also be incorporated into EPRIGEMS so that utility personnel can quickly find the items of most interest to them. For example, Cogen-Advisor integrates information on 17 recent EPRI products related to cogeneration and provides a means for identifying EPRI staff with special expertise in cogeneration technical disciplines.

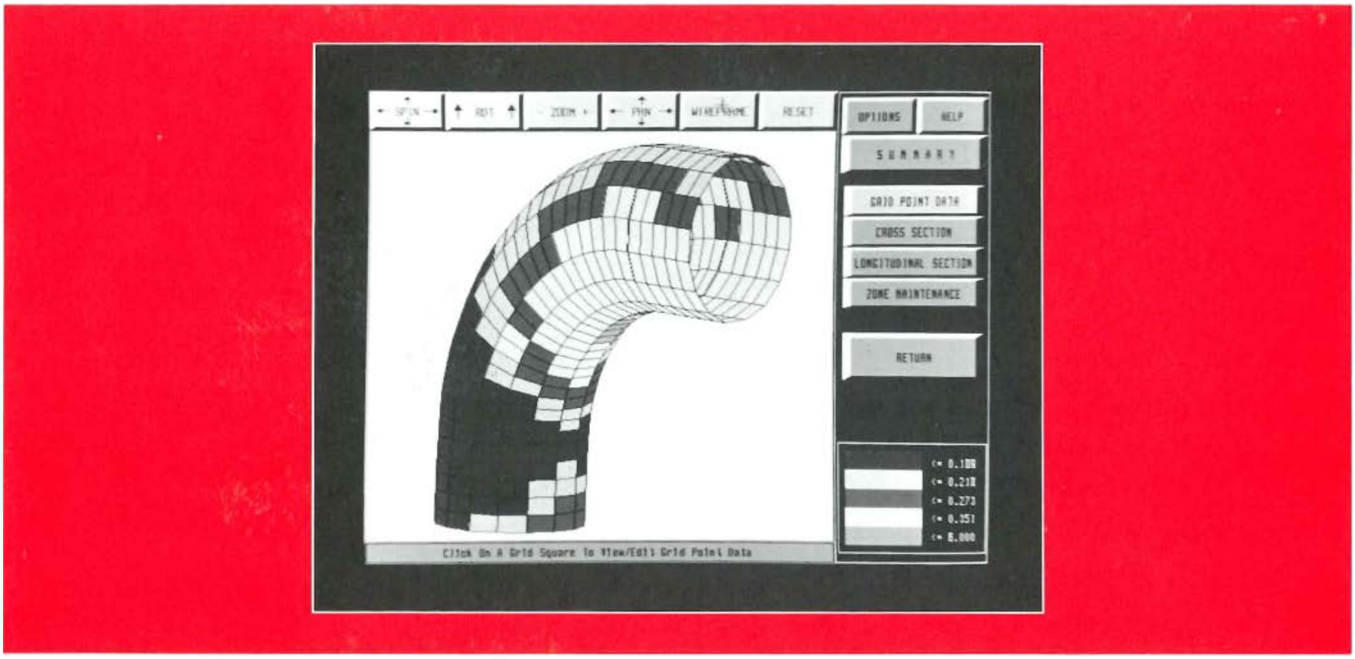
The Groundwater Quality Advisor combines several tutorials—related to such topics as waste chemical properties and the environmental processes that affect dispersion—with analytical models for estimating waste leaching, attenuation, and migration underground. This combination of informational and analytical abilities should be particularly attractive to utilities suddenly faced with a specific environmental problem that requires personnel to learn new details about a complex subject while trying to find solutions.

"We expect to use the Groundwater Quality Advisor both to develop preliminary approaches to site cleanup and to deal with emergency responses," declares Thomas Siedhoff, manager of the Environmental Services Department of Union Electric Co. "In particular, we have a cou-



Artificial intelligence software is built into the CUFAD+ module to help the user zero in quickly on the best design options for transmission tower foundations. The module's specialized expert system is highly user-interactive and can be consulted for clarification and decision-making assistance at any point in the design process.

Advanced computer capabilities are being built into EPRIGEMS modules as they are developed to keep pace with the latest in software innovation. Some of the modules scheduled for release in 1991 will include CAD-based three-dimensional visualization, multimedia integration, and advanced decision analysis techniques.



ple of very old sites where some PCB contamination has occurred. We intend to use the advisor to model migration and to develop a monitoring strategy."

Many utility decisions related to particular pieces of equipment are currently made by following the steps of a complex procedure prescribed in an engineering handbook. EPRIGEMS can greatly simplify this process by guiding the user through the minimum number of steps necessary for a particular case and by circumventing the need to enter the same data at multiple steps. An EPRIGEMS handbook can also provide the user with background information appropriate to the context at any point in a procedure. One example is SRPIPE, a soon-to-be-released module that can guide nuclear plant engineers through a process of evaluating piping snubbers for possible removal.

Many EPRIGEMS include an expert system to help streamline a decision analysis process or simplify the manipulation of a complex logical procedure. Such systems are in a class of software that attempts to capture the reasoning and knowledge of experts in a particular discipline. Their presence in EPRIGEMS enables these modules to be highly interactive, eliciting information from the user in an organized fashion and, in turn, leading the user through a maze of logical rules toward a decision based on judgment as well as facts. The CUFAD+ module, for example, provides expert systems "advisors" that help the user specify the input parameters required by the program. CUFAD+ analyzes the compression and uplift capacity of transmission tower foundations, and the input advisors are designed especially to assist users who may be inexperienced in specifying soil properties to characterize a site.

After examining several EPRIGEMS modules for possible use at Central and Southwest Corp., John Farrell, coordinator of operations analysis, concludes: "I'm convinced this is the way to go. EPRIGEMS can help get EPRI technology transferred more smoothly. People just don't want to read those big manuals."

Building a gem

As the name implies, EPRIGEMS are supposed to represent nuggets of information, extracted from voluminous research results and made available in the form of tools for utility problem solving. Critical to the successful "mining" of these gems from EPRI R&D is a relatively inexpensive and straightforward process that project managers can use for creating EPRIGEMS modules. A small EPRIGEMS staff is available to help provide training, software support, contract development, quality assurance testing, and packaging. In addition, the staff is planning to provide expanded assistance to end users through a telephone hot line and electronic data links in 1991.

The first step of the process is for a manager to decide whether the results of a particular project are a suitable basis for an EPRIGEMS module. Some-

Power Tools for Utility Problems

Boiler Maintenance Workstation (BMW) Designed to help power plant personnel minimize boiler tube failures in order to improve plant availability and reduce maintenance and inspection costs.

CogenAdvisor Developed by the Customer Systems Division to help end users evaluate cogeneration applications and assess the prospects for using high-efficiency electrical alternatives.

Cooling Tower Advisor Presents an overview of cooling towers, assesses thermal performance, and indicates what products are available from the Cooling Tower Performance Prediction and Improvements (CTPPI) project.

CUFAD+ Incorporates a TLWorkstation™ task module, Compression/Uplift Foundation Analysis and Design, and provides an expert system to assist in specifying soil properties. Based on Cornell University's transmission tower foundation research.

Groundwater Quality Advisor Contains information and analytical tools needed to address waste disposal, utilization, and groundwater issues. Incorporates research results from the EPRI Land and Water Quality Studies Program.

IGSCC Advisor An expert system that assesses the residual life of reactor components affected by intergranular stress corrosion cracking and recommends intervals for inspection.

LIFEX A knowledge-based system to analyze nuclear plant equipment to determine potentially active degradation mechanisms that affect expected plant life; a companion to EPRI's materials degradation handbook.

MICPro Designed to predict microbially induced corrosion (MIC) in power plant equipment and to assess the probable effectiveness of candidate mitigation measures.

STARRS Incorporates the mainframe code Secondary-Side Transport and Retention of Radioactive Species, which quantifies the amount and composition of materials released during a steam generator tube rupture.

times this decision will be clear from the outset, and module development can be included in the initial research contract. At other times, the decision will have to wait until early results have been reported. In any case, active development usually begins midway through a project so that the module is ready for use soon after research has been completed.

A variety of programming tools are available to help make module development as easy as possible once the crucial go/no-go decision has been made. In particular, EPRI has developed or prelicensed several "software platforms" for producing modules that conform to EPRIGEMS specifications. These platforms are essentially programming templates, which a contractor can manipulate to produce a customized module without having to do much code writing in basic computer languages. For example, platforms are available for building either simple or complex workstation applications, together with corresponding expert systems.

After an EPRIGEMS module has been created in prototype form, it must be tested and approved for release. Initial, "alpha" testing—designed to reveal any major problems and elicit early feedback—is conducted by a few users, who typically include the project manager and the principal research investigator. "Beta" testing, by carefully selected utility users, ensures that the software will operate as intended under realistic field conditions. An EPRIGEMS user's manual is completed before beta testing, but each module is designed to require only minimal reference to the manual.

"Our goal is to make EPRIGEMS not only easy to use but also easy to create," says David Cain. "Producing commercial-grade software by means of a conventional programming approach can be prohibitively expensive—the cost is typically between one-quarter and one-half million dollars for top-of-the-line PC applications. By obtaining prelicensed software platforms, establishing a stable of software contractors familiar with the EPRIGEMS concept, and recycling as much software as possible, we've been able to lower the cost of building a module to about $100,000. Eventually, I believe we can get it down to about $50,000."

Multifaceted future

In general, the current generation of EPRIGEMS has been designed for use by utility engineers on IBM-compatible personal computers. Efforts are now under way to broaden both the technology base and the potential audience.

Specifically, the EPRIGEMS team is experimenting with tutorial modules designed for use on the Apple Macintosh. Such modules will tend to be issue-oriented and will provide utility personnel with self-guided training. This system will have the ability to mix media—interspersing video clips, for example, with other tutorial aids. The first Mac module, related to SO_2 control, is scheduled for demonstration this fall and first release next year.

Another concept currently undergoing investigation is the "bundled" EPRI workstation—a ready-to-use PC that can run EPRI software right out of the box. Because the price of computer hardware has fallen below the cost of much engineering software, there are increasing advantages in offering the hardware and software together as a unit. This bundling concept would provide a standard hardware platform for utilities that want a highly convenient dedicated computer for running EPRI software, including EPRIGEMS.

Over the long term, David Cain sees further technological developments that will make EPRIGEMS even more flexible. "Computer technology is accelerating so quickly that we have to run like crazy just to keep abreast. About half our R&D money in EPRIGEMS is spent on keeping up with the state of the art. Right now, for example, we're trying to see how EPRIGEMS modules could take advantage of the new Microsoft Windows software for IBM and compatible computers. And within about two years, I expect, IBM-compatible PCs will be able to make the sorts of mixed-media presentations now possible on the Mac. Also, with the rapid development of laser disks, we will have dramatic new capabilities for graphic displays."

Cain is also working with Steve Drenker of EPRI's Generation and Storage Division to develop a master information vehicle for EPRI products. This vehicle would provide integrated access to research results originally prepared in a variety of media, tailored to the needs of specific users. A utility executive, for example, would be shown a brief video presentation of an issue, while an engineer could obtain detailed information on related technology and use the same vehicle to run an analytical code. Laser disks would be used to store the vast number of data required to offer such a wide spectrum of information.

EPRI's president, Richard Balzhiser, was personally involved in initiating the EPRIGEMS project and has followed its development closely. "We were looking for a fundamentally new approach to technology transfer," he says, "one that could really help people work smarter. EPRIGEMS modules are people enhancers that capture years of practical experience and put it at the fingertips of the users. As a tech transfer tool, the EPRIGEMS series is unique in its ability to bypass the intermediate stage of presenting information and to deliver it instead as an actual problem-solving capability." ■

This article was written by John Douglas, science writer. Technical information was provided by David Cain and Tom Wilson, Membership Division.

TECH TRANSFER NEWS

Do PV Arrays Affect Distribution Feeders?

The growing popularity of rooftop photovoltaic (PV) arrays has raised utility concerns over the effects that large numbers of PV generators might have on the distribution system and on the reliability and quality of power going to customers. Passing clouds affect the output of PV units—their output drops when clouds obscure the sun, then rises again as the clouds move on. The utility distribution system has to compensate for these variations in PV output and provide a steady supply of power to customers. As certain areas come to have high concentrations of PV arrays, will the burden on voltage regulators be increased, requiring more frequent maintenance? Will there be other adverse effects on the distribution feeder?

The answer is no, according to a recent EPRI study performed by New England Power Service Co.—provided the PV systems have well-designed power-conditioning equipment.

To evaluate the impact of roof-mounted photovoltaic generators on distribution systems, researchers instrumented a 13.8-kV feeder branch serving 30 PV-equipped homes in Gardner, Massachusetts. They also monitored the feeder at the substation and, between the two instrument sets, were able to determine the impact of PV systems on feeder performance. The researchers used these data to develop and test a model to predict PV generation as affected by the passage of clouds, as well as models to study fast transients and harmonic effects. Using these computer models, the researchers predicted the effect of increasing PV generation capacity on the same 13.8-kV feeder to 3000 kVA, as it might be configured 30 years from now.

The researchers concluded that conventional feeder designs and voltage regulation techniques deal adequately with cloud-induced effects. "PV systems with proper power-conditioning equipment had no adverse effects on either the customer or the distribution system," says EPRI's William Shula, manager of the Electrical Systems Division's Distribution Program.

The research is described in the first volume of a recently released EPRI report, *Photovoltaic Generation Effects on Distribution Feeders* (EL-6754). The forthcoming second and third volumes will summarize analysis methods and present monitoring results. The report provides examples of pitfalls to avoid and analytical techniques to use when designing feeders that serve a high concentration of customer-owned generation equipment. ■ *EPRI Contact: William Shula, (415) 855-2303*

From TICs to METTs

Technical information coordinators (TICs), utility personnel designated to manage the flow of EPRI information in their organizations, recently received a new title that more accurately reflects their expanded duties. Last spring, the TIC Committee decided that the title METT, or manager of EPRI technology transfer, would replace TIC. The committee also changed its name, to the Committee on Management of EPRI Technology Transfer.

The new title, according to EPRI's Ed Beardsworth, manager of membership services, reflects the ongoing evolutionary change in the function of the position—from an earlier focus on information transfer to the much broader task of creating opportunities within the utilities for the strategic application of EPRI technology.

"The METT is critical to EPRI's being able to work in a coordinated and effective manner with each member utility to ensure that maximum value is realized," explains Beardsworth. "In many ways, he or she is an extension of EPRI, ideally situated inside the member organization."

The term METT will be used by EPRI to denote the function generically, though most utilities will have their own job title for the position, depending on other internal considerations.

Beardsworth encourages member-utility personnel to "get to know your METT" and to call him or her for help in getting assistance from EPRI. ■ *EPRI Contact: Ed Beardsworth, (415) 855-2740*

Verifying Product Readiness

How can a utility be sure that a new technology is ready for commercial use? EPRI's Electrical Systems Division has established a procedure whereby its advisory committees review new EPRI-developed products to verify that they are ready to be put to work. The final and key step in this process is obtaining feedback from member utilities that have reviewed the products.

The review committees, which consist of task forces and the division committee, qualify the products according to established guidelines. For example, software products must meet EPRI standards for production-grade software and be fully debugged, and hardware products must be commercially available under full warranty. After a sufficient number of products have been selected by this review process, the product descriptions are sent to member utilities along with a survey questionnaire to solicit feedback on the products' usefulness and applicability.

The procedure gets high marks from Jim Ray, assistant to the director for system planning at Bonneville Power Administration and manager of EPRI technology transfer (METT). "The criteria for product readiness are well thought out," he says. "Readiness means essentially that an EPRI member can use the product with little help from a contractor or EPRI staff. The second part of the process, the survey, provides useful feedback to the task force and division about the needs of member utilities. METTs are uncomfortable about recommending a new product to their utilities if it's not really ready for use: if the implementation is unsuccessful, they face a much tougher battle the next time around. That has happened to too many product champions. The best way to promote technology transfer is through success."

The results of the most recent survey, consisting of utility evaluations of 28 new products, have been tabulated and are available to members. The report on the survey includes member-utility usage status and comments on various products. It gives other utilities confidence to use the product, according to Vasu Tahiliani, the Electrical Systems Division's program manager for technology transfer.

"This procedure helps expedite utility implementation of the products of our research," says Tahiliani. "As a result of the successive reviews by the task forces, division committee, and utilities themselves, these products can be used with confidence." ■ *EPRI Contact: Vasu Tahiliani, (415) 855-2315*

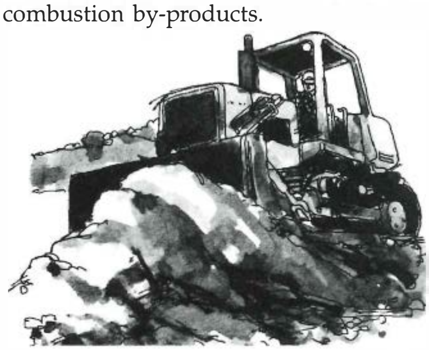
Fly Ash Backfill Cuts Construction Costs

When Delmarva Power set out to build a new cooling tower and associated structures at its Indian River station, the utility became concerned about the cost of constructing the foundation. Soil conditions at the site, including a 6- to 11-foot-thick peat deposit 15 feet below grade, dictated the use of conventional deep-foundation construction. Large-volume backfilling around the pile caps and the driving of piles close to existing structures could have been expensive; moreover, conventional earthen fill material could have caused additional settlement of the foundation because of its weight.

Delmarva planners decided to make use of something they didn't need around the plant to improve on their options: lightweight, flowable fly ash was employed as backfill around the tower pile caps, as well as for part of a compensated foundation for the 108-inch concrete hot water return pipe and concrete cold water discharge flume. Working from two EPRI reports on placement of slurried ash (CS-4419 and CS-6100), the project team developed four different ash/cement mixes tailored to cover the structural requirements of the various applications.

Using flowable fly ash at Indian River helped Delmarva Power avoid driving some foundation piles, reduce backfilling costs, and place the new cooling tower in service ahead of schedule, at a savings of $614,000 in labor, time, and materials. The Indian River project also yielded valuable information that will help other utilities use ash in similar high-volume projects.

Coal-burning power plants use only 20–25% of their coal combustion products, such as coal ash and flue gas desulfurization by-products. But as Delmarva's experience shows, these materials can be substituted for soil in large-volume construction applications, and some coal ash can be substituted for cement in concrete. Although such applications offer opportunities to conserve natural resources and valuable landfill capacity, uncertainties about engineering performance and potential environmental impacts have limited the use of coal combustion by-products.



Through research projects conducted since 1984 by its Waste and Water Management Program, EPRI has been clearing up those uncertainties to support the increased use of fly ash in high-volume applications. The list of potential uses is long, according to EPRI's Dean Golden, a project manager in the Generation and Storage Division: "High-volume uses of fly ash include fills, embankments, backfills, landfill cover, soil amendment, subgrade stabilization, grouting, pavement base courses, slurry walls, and hydraulic fills." ■ *EPRI Contact: Dean Golden, (415) 855-2516*

Environmental and Health Assessment

Toxicological Analysis of MGP Residues

by Larry Goldstein, Environment Division

ABSTRACT *Though some of the chemical constituents of manufactured gas plant residues have been shown to cause cancer in laboratory animals, the risk to human health from these waste mixtures has not been determined. EPRI has begun an ambitious program to establish the toxicity of these residues in test animals. Initial results suggest that the complexity of the problem mirrors the complexity of the residues themselves.*

Although commercial-scale gasification of coal and oil has not been conducted in the United States for over 40 years, complex mixtures of potentially hazardous chemicals in residues formed by these processes continue to contaminate the environment. These residues are found at over 1500 sites in the United States. Many are less than one acre, but others may be as large as 75 acres. Residues may be found in open fields, in dumps, under buildings, or in backyards.

Much of what is known about the ability of chemicals to cause cancer is based on data from the exposure of laboratory animals to individual chemicals. Cancer formation as a result of the pyrolysis product benzo(a)pyrene was established by means of this approach over 50 years ago. Indeed, much of our understanding of cancer induction by chemicals is based on experiments performed with benzo(a)pyrene.

Benzo(a)pyrene is found in residues from coal and oil gasification. It is one of perhaps 10,000 such compounds that have several benzene rings fused together and are referred to collectively as polycyclic aromatic hydrocarbons (PAHs). Not all of these compounds share benzo(a)pyrene's propensity to induce cancer, however. In fact, a comparison of the molecular structure of the other PAHs with that of benzo(a)pyrene suggests that few of the PAHs will cause cancer. The data on individual PAHs indicate that many do not cause cancer, and those that are carcinogenic are usually less potent than benzo(a)pyrene.

In contrast to the extensive database for benzo(a)pyrene, there are few data on cancer induced by manufactured gas plant (MGP) residues. In the absence of data for MGP residues, one can only estimate carcinogenic hazard. The following two approaches represent extremes:

- Determine the total PAH content and assume that each individual PAH has the same effectiveness as benzo(a)pyrene. The potency of the mixture would then be based on the dose-response curve for cancer induction by benzo(a)pyrene alone.
- Assume that all the cancer formation is due solely to the benzo(a)pyrene content and that this potency is unaffected by the other PAHs. In this case, too, the potency is based on the dose-response curve for benzo(a)pyrene alone, but the dose range of interest is orders of magnitude lower than that in the first scenario.

Regulating agencies set limits of exposure based on the levels of the offending agent in the substance of interest. Therefore it is important to establish not only what the offending agent is but also what level of exposure results in acceptable levels of risk.

In considering a potential hazard, it is necessary to determine how much of the offending chemical the host is exposed to, how much gets inside the body, and how it is distributed among organs, tissues, and cells. Regulators tend to emphasize ingestion as the major exposure route. There are many anecdotal reports of people, especially children, breaking off a piece of the residue and chewing it like gum. The extensive database for benzo(a)pyrene includes very few experiments in which dosing was by ingestion. Most workers rely on an ingestion study that was performed almost 25 years ago by Neal and Rigdon and that does not meet currently accepted criteria for application to risk assessment. Among the goals of EPRI's project on the toxicology of MGP residues are the following:

- To generate data on cancer induction by MGP residues in an experimental approach that is appropriate for human risk assessment
- To determine the concentration of PAHs from MGP residues that were formed by different manufacturing processes and that used different feedstocks in their production

- To develop an understanding of the mechanism of cancer induction by these complex mixtures through the evaluation of several biological and biochemical effects associated with cancer formation
- To relate these data to similarly generated data for benzo(a)pyrene alone

Although experimentation has been under way for less than one year, the data support the overall experimental design and provide valuable preliminary information in support of the more complex protocols scheduled to begin soon.

Table 1
CONCENTRATION OF EIGHT CARCINOGENIC PAHS IN THREE MGP RESIDUES

PAH	Relative Potency*	Sample 1 Concentration (ppm)	Sample 2 Concentration (ppm)	Sample 3 Concentration (ppm)
Benz(a)anthracene	0.145	4,890	8,230	2,930
Chrysene	0.0044	5,140	14,700	3,170
Benzo(b)fluoranthene	0.14	2,150	3,390	2,430
Benzo(k)fluoranthene	0.066	2,960	8,390	2,560
Benzo(a)pyrene	1.000	3,870	12,000	2,420
Indol(1,2,3-c,d)pyrene	0.232	ND†	6,690	ND
Dibenz(a,h)anthracene	1.11	ND	4,270	ND
Benzo(g,h,i)perylene	0.022	ND	8,060	ND

*Potency for cancer induction, relative to benzo(a)pyrene. †ND = not detected.

Chemical characterization

MGP residues were collected from three different sites where similar gasification processes had been conducted, and the amounts of 36 organic compounds were determined. Gas chromatography/mass spectroscopy was unsuccessful because the instrument sensitivity was not sufficient and because the residues fouled the instrument. Selective ion-monitoring mass spectrometry (SIM) overcame these difficulties. In a procedure developed specifically for EPRI, the organic compounds were separated into different classes to minimize interference by other compounds and then analyzed by SIM. Each sample was run in triplicate. Reproducibility was ±5%, and the lower limit of sensitivity was about 1 part per million (ppm). Thirty-four of the 36 compounds were detected in the residues. The amounts of eight compounds known to cause cancer in laboratory animals are shown in Table 1. Clearly, the amounts of cancer-causing compounds are different for each site, even though the feedstocks and the manufacturing processes were similar. Of special importance are the amounts of benzo(a)pyrene and dibenz(a,h)anthracene in the sample from Site 2, since these compounds are usually assigned the highest potency for cancer formation.

These tests are the first to compare the amounts of PAHs in different residues in the same laboratory, and they give the first indication that the chemical composition of residues at different sites will be very different. This finding is consistent with data that demonstrate that PAH content varies at different locations and varies in different levels of a vertical core at a given site.

Biological characterization

Human exposure to PAHs may be the result of topical application, inhalation, or ingestion. The most extensive database for cancer effects caused by PAHs is based on topical application. This route is not the preferred one for standard-setting, however, which generally requires a two-year ingestion study. Initial biological studies with MGP residues have therefore emphasized oral routes of exposure.

The study of oral exposure presents two problems: how can a tarry substance be distributed uniformly in a food pellet or meal, and how can the study animals be encouraged to consume food adulterated by MGP residues? The EPRI contractor at Rutgers University, rather than attempting to distribute the residues in solid food, adds them to a liquid diet containing gelatin at temperatures just below boiling. The liquid food is poured into molds and allowed to set. Densitometry scans across the gels show that the distribution of the tars is uniform.

After the animals learned to eat unadulterated food prepared in this manner, they were given the same food containing various amounts of MGP residues. At concentrations above 1%, the animals refused to eat for some days and lost weight. At lower doses, the animals were initially reluctant to eat but eventually resumed eating at normal rates. The weight range of the animals fed MGP residues at the lower dosage levels was the same as that of the animals given the gel diet without MGP residues. A group of animals has been maintained on this diet for 90 days without overt adverse effects. This protocol establishes a value known as the maximally tolerated dose (MTD). In conventional cancer bioassays, the MTD is the upper limit of dose. On the basis of the chemical data (Table 1), the MTD for MGP residues will result in a dose of approximately 15.6 mg of residue per day and a dose of benzo(a)pyrene of 0.037–0.187 mg per day, depending upon the particular sample. For a two-year feeding study, the total dose of benzo(a)pyrene is 27–136 mg. In the work of Neal and Rigdon, a total dose of 27 mg administered over approximately 200 days resulted in a tumor rate of 70%. Researchers are therefore reasonably sure that if the cancer rate in the complex mixture is caused by the benzo(a)pyrene content alone, the group of animals dosed at or near the MTD will have a high incidence of tumors and the group of animals dosed at less than the MTD will have a lower incidence of tumors. In the EPRI protocol for the two-year feeding study, special emphasis will be placed on tumor induction at doses below the MTD in order to establish the shape of the dose-response curve in a dose range that is most useful for standard-setting by regulatory agencies.

The MTD is a measure of the administered dose and does not address the question of the efficiency with which the chemicals of interest reach target tissues within the body. For ingested coal tars, the major sites of tumor formation are the lungs and a part of the stomach. New biochemical procedures make it possible to detect the products of the reaction of PAHs with their chemical target within the cell, DNA. These reaction products are termed DNA adducts. The lower limit for detecting them is one DNA adduct per 10^{10} normal nucleotides.

Using this methodology, the Rutgers team has found DNA adducts in all tissues examined so far. Significantly, the amount of adducted DNA in one target organ, the stomach, is proportional to the amount of MGP residue consumed by the animal. This suggests that the probability of tumor formation is related to the extent of DNA damage detected as adducts. Unanswered is the intriguing question of why only some organs are targets for cancer formation when all seem accessible to cancer-forming PAHs.

Future benefits

Establishing the toxicology of MGP residues is a necessary first step in assessing the risk to humans that these sites pose. Toxicology data indicate that several approaches may be used to estimate the cancer hazard of MGP residues in general: methodologies may be developed to assess the hazard at each site without resorting to expensive and time-consuming bioassays.

There are many benefits for the electric utilities. Regulation of these sites would have a firm scientific basis derived from studies designed specifically to address MGP residues and their complexity. Since remediation costs depend on the nature of the site improvements (such as homes or other buildings), the size of the site, and the extent of the contamination, regulation based on an overly strict standard translates into rapidly escalating costs. Regulation based on an overly permissive standard could endanger human health. Defining the toxic hazard will directly influence the extent of cleanup without compromising human health.

Systems and Equipment Life Extension

Life Estimation Procedures

by R. Viswanathan, Generation and Storage Division

ABSTRACT *Application of life estimation procedures is crucial to the optimization of equipment life and the scheduling of appropriate operation, maintenance, and inspection activities for boiler components that operate at elevated temperatures. EPRI has been in the forefront of developing nondestructive and destructive procedures for life estimation. The primary objective of the EPRI-developed techniques is to reduce uncertainties and associated conservatism in the current procedures.*

Superheater/reheater tubes, headers, and pipes in boilers that operate at elevated temperatures are subject to creep damage. In addition, cyclic operation and load transients can lead to fatigue damage. With the increasing number of older utility boilers that are expected to continue operating reliably, it has become very important to assess the current condition of the critical components. Such assessment is a vital part of scheduling appropriate operation, maintenance, and inspection activities.

Before EPRI conducted its research, component life assessment consisted principally of calculating the expended life on the basis of operating history. These calculations often embodied many conservative assumptions and invariably led to the premature retirement of components. EPRI research during the last few years not only has focused on improving the calculation procedures but also has developed an array of nondestructive and destructive techniques that can assess component condition with increasing accuracy. These techniques have found widespread industry acceptance.

Creep damage in headers and steam pipes

In the past, a lack of appropriate material property data and damage rules was a major source of uncertainty in the calculation of the expended life of components under creep conditions. To remedy this uncertainty, an extensive amount of information on creep rupture, creep fatigue, and toughness has been developed by testing service-exposed headers as well as laboratory-aged sample materials. Test results have shown that the use of data on the creep rupture of standard

ASTM-type specimens tested in air to calculate creep life expenditure in heavy-walled piping may lead to factors of conservatism ranging from 1.5 to 3. EPRI research has also confirmed that the cumulative damage under varying temperature conditions can be expressed as the linear sum of the fractional damage accrued under each of those conditions. This so-called life fraction rule has been found to be less valid, however, when damage occurs under varying stress conditions.

Creep damage in steels often results in observable changes in microstructural features; quantifying them can lead to improved techniques for estimating the creep life consumed. Such changes include the formation and growth of creep cavities at the grain boundaries, and the coarsening of the carbide precipitate particles in the steel. This coarsening shows up as an increase in the intercarbide spacing. EPRI researchers have now established a correlation between the extent of the creep cavitation observable in the microstructure and the creep life expended (CS-5588, Vol. 4). This correlation is applicable to the damage occurring in the heat-affected zones associated with welds. For base metal regions of 1 Cr–¼ Mo steels, a preliminary model that describes creep life consumption in terms of intercarbide spacing has been developed (CS-5588, Vol. 3), and detailed replication procedures for creep cavitation measurement have been established. For carbide spacing measurements, small samples may still have to be removed.

The hardness, tensile strength, and creep rupture strength of low-alloy steels decrease with service exposure in a time- and temperature-dependent manner. It has been shown that hardness, which can be measured in a simple, nondestructive test, is related to strength. Hardness can therefore be used in two different ways to assess creep damage in components: decrease in hardness can be used to estimate the mean operating temperature, and the creep life expenditure can then be estimated using calculational methods; alternatively, hardness can be related to the current rupture strength of the steel and can be used to assess the remaining creep rupture life at the operating stress and temperature. EPRI research has yielded results that can be used in either of the above methods.

The change of hardness in low-alloy steels that occurs as a function of time and temperature has been extensively quantified, so hardness changes can be used to estimate operating temperature (GS-6693). Correlations have also been established between tensile strength (hence hardness) and the Larson-Miller rupture relationships for low-alloy steels. These correlations make it possible to select the appropriate Larson-Miller plot corresponding to a given hardness level, which can be used for calculating remaining life.

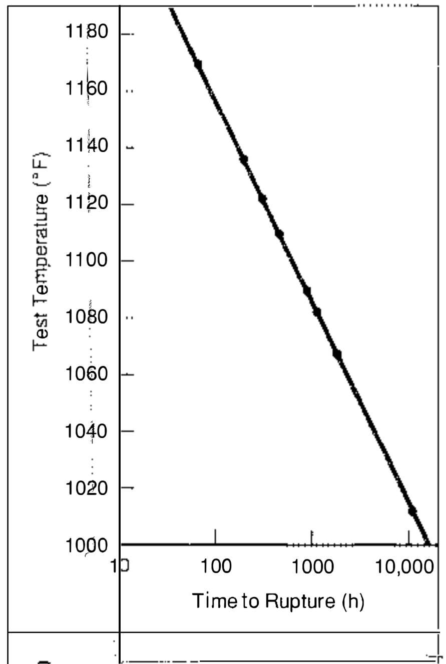
An accurate procedure for determining creep life expenditure involves accelerated stress-rupture testing of samples at temperatures higher than the service temperature, at a constant stress level close to the service stress. This method, known as the isostress method, offers the advantage of not requiring a database on virgin-material properties. Furthermore, no damage summation rules are used because remaining-life estimates are obtained directly from the data.

In the isostress method, the log of time to rupture is plotted against test temperature. This plot can then be extrapolated to service temperature in order to estimate remaining life (Figure 1). Such plots have been observed to be linear for many of the ferritic steels.

Because extraction of large samples from critical components is not practical, the use of miniature specimens has been demonstrated. As shown in Figure 2, miniature-specimen tests conducted in inert environments yield results identical to those obtained from conventional samples tested in air (CS-5588, Vol. 2).

EPRI research has made considerable progress in the area of creep-crack-growth analysis: methodologies have been developed for estimation of remaining life for a given initial flaw size (CS-4688), and the extensive crack-growth-rate data available in the literature have been analyzed and consolidated (CS-5585). Crack-growth-rate data have been generated by analyzing service-retrieved header materials, and the toughness characteristics of aged headers have been delineated. Since creep-crack-growth analysis involves creep-rate data, miniature-specimen creep testing can be used to estimate component-specific rates. Differences in crack growth rates between base metal, weld metal, and heat-affected-zone material have been identified, and a deterministic PC-based code that can model one-dimensional crack growth to wall rupture has been developed. It includes a leak-before-break analysis known as SLIC (steam line inspection code). A guideline document for evaluating hot reheat piping has been issued (CS-4774).

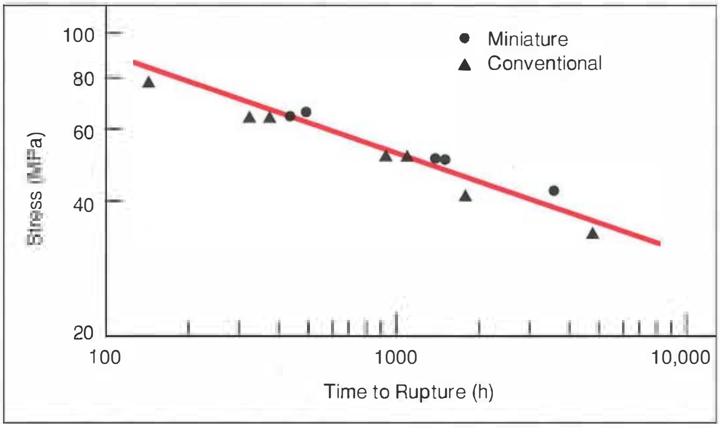
Figure 1 The isostress method of determining creep life expenditure. Accelerated stress-rupture testing of retired header samples is conducted at temperatures higher than the service temperature, at a constant stress level close to the service stress. The plot of the test data can then be extrapolated to the 1000°F service temperature in order to determine expended life.



Ligament cracking of headers

EPRI research during the last few years has been addressing a new problem, ligament cracking (Figure 3). Header ligament cracks generally begin in the tube bore holes and are oriented parallel to the axes of the holes. The initial cracks usually are numerous and may extend to the inside surface of the header, exhibiting a characteristic starburst pattern when viewed from inside the header. Some of

Figure 2 Results of stress-rupture testing of conventional and miniature specimens of 1 Cr–½ Mo steel at 630°C (1165°F).



the initial cracks subsequently grow deeper into the ligaments between the holes, both inside the bore and on the inside surface of the header. Link-up of cracks between holes on the inside surface then leads to propagation of cracking from the inside of the header to the outside. When these cracks link up with those associated with the outside surface stub-tube welds, steam leakage may occur, causing extended forced outages.

Industry experience has shown the problem to be widespread. Approximately 30–40% of the headers inspected have been found to be cracked. Cracking occurs more often in headers made of P11 steel (1¼ Cr–½ Mo) than in those made of P22 steel (2¼ Cr–1 Mo), though neither steel is immune to cracking. Cracking is not related to the age of the plant and can occur in as few as 15 years under cyclic operation. Secondary superheater outlet headers are more prone to cracking than other headers, presumably because of higher pressures (and hence increased header thickness and increased thermal stress). Headers designed with radial tube holes adjacent to nonradial holes have been shown to be the most susceptible to cracking.

Extensive metallographic characterizations of cracked ligaments have been performed. The oxide layer on the inner wall of the header has been found to be thickest at locations where ligament cracking is observed. This implies that cracking is associated with locally high metal temperatures. The mechanism of crack propagation is clearly transgranular fatigue, which is characterized by beach markings on the fracture surface.

Oxide dating has shown that crack initiation could occur as early as 95,000 h (50% of header life); slow crack growth may then follow (at rates of about 3.7×10^{-6} cm/h). The fact that this considerable life remains after cracks have formed enables utilities to take timely remedial action following crack detection.

Local metal temperatures based on thermocouple measurements on actual headers, as well as ramp rates at bore hole locations, have been found to be much higher than those suggested by bulk steam temperature measurements. This finding is supported by the observation that oxide scale thicknesses are higher at crack locations. Calculations using the local metal temperatures and ramp rates show that crack initiation in the time framework of concern can be explained in terms of startup-shutdown transients. Although thermal fatigue initiates cracking, the major damage mechanism is the creep that occurs during the stress relaxation part of the cycle. The transgranular nature of cracking can be explained by the fact that damage occurs during the high-stress portion of relaxation.

EPRI research has provided utilities with a methodology for identifying the headers that are at risk and the critical locations for detailed nondestructive evaluations. Since the susceptibility to cracking could be related to locally high metal temperatures on the inside walls of the headers at the tube intersections, and to the type of tube penetration design, ultrasonic examination of tubes to characterize the oxide scale thickness (and hence temperature) and design drawings can be used to pinpoint the locations in the header that need further evaluation.

Current practices for disposition of cracked headers include immediate retirement, changes in operating strategy, or continued operation. A fracture-mechanics-based methodology for making these decisions is being developed (RP2253-10) and will be integrated into the boiler evaluation and simulation system (BLESS) code.

The BLESS code

BLESS is an evaluation tool for the life management of key components of fossil-fuel-fired power plant boilers. A preliminary version, covering header ligaments, is expected this month. The code is applicable to main steam and reheat steam headers and piping. It predicts time to failure, or time to a specified

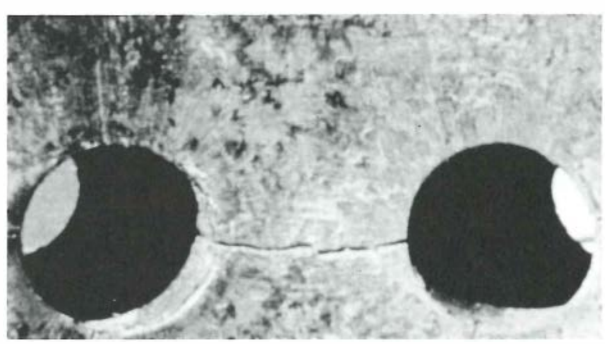


Figure 3 Ligament cracking as seen from the inside surface of a header.

damage level, on the basis of inputs readily obtainable by the boiler operator. A probabilistic treatment is included in the code that makes it possible to calculate component reliability and perform cost/benefit analyses. BLESS can be run on a desktop computer.

The user inputs required by the program include simple definitions of steam system geometry, component material, material condition, and component service loading. Default values for material properties and loading conditions are supplied. Alternatively, data from surface replication, mechanical tests, and other assessment methods can be input to define the current state of the material. Nondestructive examination may also be used to define the current distributions of flaws and cracks. Load histograms are defined from standard operating events using measured values of steam or metal temperature, where available, or from default definitions within the program.

The code output may be used as input to run/repair/replace decisions for plant life management. Assigning cost values to actions (such as nondestructive evaluation, sample removal and testing, repair, and replacement) associated with component performance makes it possible to perform cost/benefit analyses. BLESS also offers the decision maker the ability to investigate various scenarios of future operation in the search for optimal procedures for component life management.

Life assessment technology for tubes

Creep rupture failure of superheater/reheater tubes is a major cause of forced outage of boilers. Deciding when to replace particular tube circuits before failure occurs has largely been a matter of guesswork in the past. Removal of sacrificial tube samples followed by destructive tests has produced accurate estimates of remaining life. Given the wide variations in temperature distribution in the tube bank, however, proper selection of sacrificial samples is crucial. Identification of the tubes in distress by means of nondestructive methods, followed by destructive testing of judiciously selected samples, would be the best approach for evaluating tubes.

Under RP2253, EPRI has developed a methodology and a PC-based computer code, TUBELIFE, that uses measurements of oxide scale thickness on the steam side to estimate remaining life (CS-5564). EPRI has also validated the use of ultrasonics to nondestructively measure oxide thickness. Consequently, wide-coverage ultrasonic testing can now be carried out to identify tubes that are at risk. This can be followed up by tube sample removal at selected locations and accelerated rupture testing. EPRI has identified the appropriate formula for oxide scale growth from among several formulas, and has also identified the correct stress formula for the calculation of the uniaxial equivalent stress of a pressurized tube. These refinements have led to the elimination of undue conservatism.

EPRI research in the area of component life assessment has significantly advanced the state of the art and thus has made it possible for utilities to make independent and informed decisions concerning the fate of their critical boiler components. The resulting products include reports, test techniques, and computer codes for monitoring the health of the boiler components. EPRI is now launching a project, jointly funded by Empire State Electric Energy Research Corp., for technology demonstration of these products at several host utility sites. By documenting the benefits at the host sites, this project will allow utility engineers and planners to estimate the value of component life assessment programs at their power plants.

Power System Operations

Training Dispatchers for Interconnected Power Systems

by David Curtice, Electrical Systems Division

In recent years, growth in the interchange of power among utilities belonging to the same power pool and the wheeling of power across utility transmission lines has far exceeded the growth rate of load and generating capacity. Now, over 30% of the power generated by major utilities is sold to other utilities. In part because environmental and economic constraints have restricted construction of new transmission facilities, the burden on existing lines (some originally designed for local supply) has grown. As a result, an increasingly complex system of interconnections is operated ever closer to system limits, and with increased vulnerability to outages caused, for example, by system instability or voltage collapse.

Importance of system dynamics

Virtually all power that flows on transmission lines in the United States is scheduled and coordinated by system dispatchers at about 150 control centers. Relying on computers and on automatic control equipment, dispatchers maintain a careful balance between generation and loads while keeping the scheduled power system frequency very near 60 Hz.

The normal role of the system dispatcher is to continuously monitor the system and to implement actions that are, for the most part, preplanned. These preplanned actions are based on operations studies of the system, studies that consider likely planned and forced outages. However, the dispatcher must

ABSTRACT *As the complexity of interconnected power systems grows, and as those systems are operated closer to system limits, the possibility of dynamic phenomena interrupting customer service or damaging equipment also increases. Yet most power system dispatchers lack direct experience with dynamic events in power systems and effective training in recognizing and responding to such events. A recently published EPRI tutorial is the first book to present comprehensive coverage of power system dynamics for an audience of system dispatchers.*

be ready to take corrective action in response to dynamic conditions in which the system undergoes large, often sudden changes. The understanding of system dynamics is crucial here: to perform successfully in dynamic situations, dispatchers must be able to recognize significant variations in system operation, quickly diagnose developing problems, and quickly decide which corrective measures are likely to be effective.

The likelihood of power system dynamic contingencies grows as system complexity and loading increase. For instance, with such increases power systems become more susceptible to instability in the presence of small signals, and thus system reliability and security are threatened. Also, as transmission lines are loaded more heavily, the difficulty of maintaining proper systemwide voltages can increase dramatically. Further, while voltage problems were once associated primarily with transmitting power long distances to load centers, voltage concerns are now a consequence of dense, strongly interconnected networks whose facilities are fully utilized. Voltage control problems are compounded by the desire to maximize transfers on existing networks not already operating at stability or thermal limits.

Meanwhile, as the likelihood of dynamic events grows, several utilities find that system dispatchers often take early retirement. To replace them in the control room, these utilities need dispatchers who understand system dynamics and can respond to dynamic events effectively.

Other pressures have been mounting on system dispatchers, and these pressures also contribute to the importance of understanding system dynamics. The emergence of cogenerators and non-utility-owned generators and increases in the commercial interchange of energy have increased the complexity of information processing and decision making facing system dispatchers. At the same time, the appearance of new power suppliers and increases in commercial power transfer have opened opportunities for utilities to wring economic benefits from system operation decisions. Dispatchers, who are responsible for directing the delivery of power to customers not only reliably but economically, can play a critical role here. For the dispatcher, system security concerns take precedence over economic considerations. But to the extent that security, transmission system, and other constraints allow, dispatchers can implement increasingly sophisticated strategies designed to optimize economic dispatch in today's competitive economic environment. Thus, for example, dispatchers might eventually be expected to implement complex, multifaceted long-term fuel strategies rather than to strive to minimize moment-to-moment production costs.

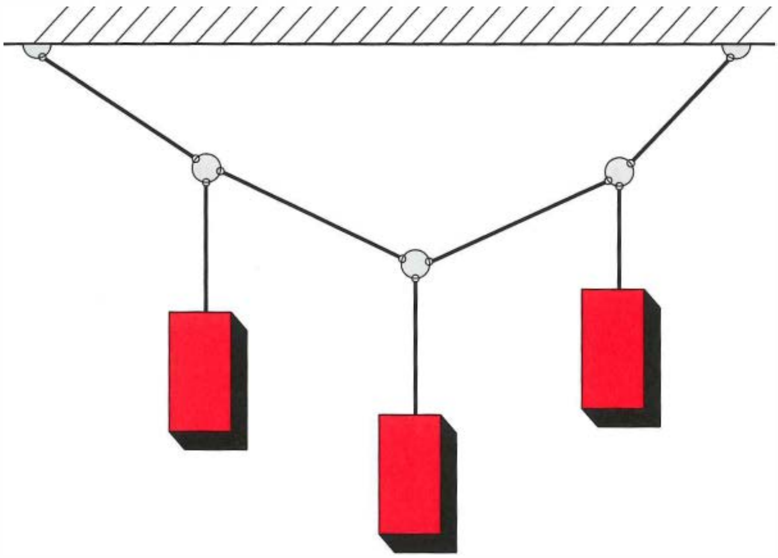


Figure 1 The tutorial uses mechanical analogies to explain complex electrical phenomena. In this weight–rubber band analogy, the weights represent the rotating mass of the turbine generators and the rubber bands are analogous to the inductance of transmission lines. Any disturbance—a "pull" on a weight—causes oscillations to be set up in all synchronous machines in the system.

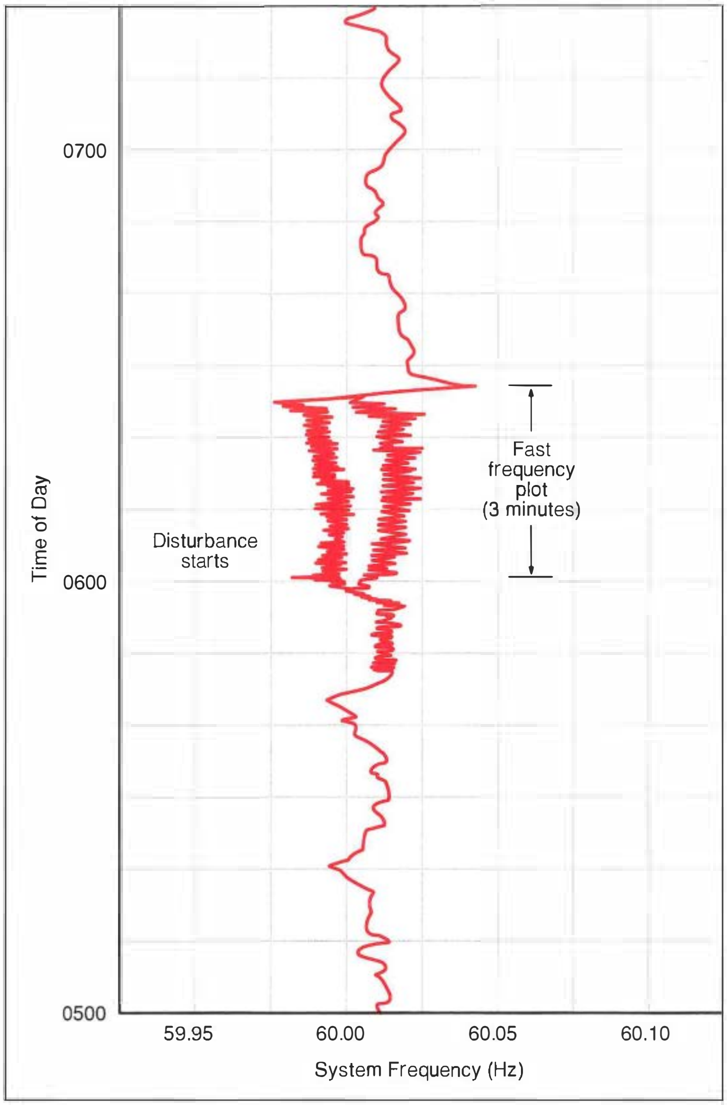
System dynamics tutorial

The major part of an average dispatcher's career is spent performing three broad functions—system security monitoring, generation dispatch, and interchange scheduling—under normal, steady-state system conditions. Few dispatchers have had any direct experience with abnormal, dynamic power system events. Further, because training materials commonly make extensive use of mathematics and engineering terminology to describe system dynamics and do not use terminology and approaches familiar to dispatchers, most dispatchers do not receive effective training in how to recognize and respond to dynamic events. In view of the growing need for such training, EPRI has developed a practical tutorial (EL-6360-L) that explains the important dynamic phenomena in interconnected power systems as an aid in training system dispatchers. The tutorial can also help power plant operators understand the effects of system events on the operation and safety of generating units.

Often, authors of research reports present research results without focusing on how to apply those results in action, problem solving, or decision making. Consequently, research reports by themselves have not generally been effective technology transfer tools. By contrast, EL-6360-L, *Dynamics of Interconnected Power Systems: A Tutorial for System Dispatchers and Plant Operators,* expressly addresses specific utility needs and was designed to serve as a technology transfer vehicle. The authors organized and presented the material with action-oriented training objectives in mind. When appropriate, the authors discuss the role of the system dispatcher in solving system problems as they arise. The authors carefully lead the reader through the tutorial, developing concepts in a coherent sequence and reinforcing those concepts through the liberal use of examples and scenarios; the main lessons are frequently reinforced through summaries.

To define the format and scope of the tutorial, the project team interviewed power system dispatchers and power plant operators, and their supervisors and trainers, at six utilities. The discussions revealed the need for a tutorial written from the viewpoint of system dispatchers on shift in the control room—one substituting physical analogies (Figure 1), technically accurate intuitive reasoning, and case histories for engineering terminology and equations. As the tutorial was written, project advisers from the North American Electric Reliability Council's (NERC's) Interconnection Dynamics Task Force reviewed the content, tone, and vocabulary of each section for compliance with training objectives.

Figure 2 Plot of an actual frequency disturbance. In the system dynamics tutorial, real-life examples such as this help illustrate engineering concepts.



The system dynamics tutorial, the first book that presents comprehensive coverage of power system dynamics to system dispatchers, is an EPRI "best-seller." Over 2000 copies were circulated in the first six months following publication—perhaps the best distribution rate ever for an EPRI research project report. The training book is available to EPRI member utilities and to nonmembers who belong to NERC, which played a key part in developing the tutorial.

The tutorial explains dynamic phenomena using everyday dispatch terminology, illustrates system dynamics with real-world examples (Figure 2), and discusses the actions available to dispatchers responding to system disturbances. Disturbances explained in the tutorial include all events that disrupt the steady-state condition of the power system and range from subtle operational changes to major equipment failures. From the dispatcher's perspective, the interval from 30 seconds to 30 minutes after a disturbance is of special concern, because actions can be taken then to improve system conditions. The tutorial covers that interval and also discusses automatic control actions that occur before the dispatcher can respond. The tutorial outlines what the dispatcher can expect from these control actions and how they affect the postdisturbance state of the system.

To prepare readers for more detailed sections, the tutorial first reviews the essential concepts of power system operation; it uses an overview of power system dynamics to put this broad topic in perspective. The tutorial then treats specific dynamic phenomena, including frequency and voltage deviations, voltage collapse, and power system oscillations. A separate section describes the effects of power plants and power plant control systems on power system dynamics, emphasizing interaction between the power plant and the power system. The tutorial explains both the response of power system controls to power system disturbances and the effects of system events on plant operation. It also covers HVDC dynamics and solar magnetic disturbances.

Actual case histories then tie together the concepts. To provide a convenient, quick reference, the tutorial also contains a glossary of system dynamics terms and descriptions of equipment and control devices.

Further support for dispatchers

The tutorial can be thought of as an essential tool in the comprehensive training of dispatchers. Although the tutorial can serve to improve classroom and on-the-job training, such training cannot fully prepare dispatchers to respond to the entire range of power system dynamics. For doing that, computer-based training simulators are vital. They can help prepare power system dispatchers to handle emergencies as well as steady-state operations, and going through the tutorial can be a key step in preparing trainees for simulator work.

EPRI expects some members to use their own system dynamics data (e.g., from actual voltage collapses) to simulate dynamic events, and to coordinate work on the training simulator with work in the tutorial on the corresponding type of event. Thus, in effect, words in the tutorial will prepare trainees for experiences of simulated dynamic events. EPRI expects the tutorial to be supplemented in other ways, too: some firms have expressed interest in developing training tools—videotapes and computer-aided instruction—around tutorial topics.

The tutorial complements a number of products developed in other EPRI projects undertaken to support system dispatchers: an advanced dispatcher training simulator (RP1915), an expert system for fault analysis and power restoration (RP1999), human factors guidelines for the design of dispatch control centers (RP1354), and a handbook for use in designing CRT displays for dispatchers (RP2475).

Land and Water Quality Research

Manufactured Gas Plant Site Investigations

by Ishwar P. Murarka, Environment Division

Throughout most of the 1800s and the first half of the 1900s, the generation of gas from coal, coke, or oil at numerous sites across the country resulted in the production and on-site disposal of large volumes of byproducts such as coal tar and purifier-box wastes. These residues were frequently left on-site in pits or containers, placed in nearby ponds or lagoons, or taken to off-site areas for land disposal. Since all of these disposal methods have the potential to contaminate soil and groundwater, EPRI research has focused on developing cost-effective site investigation methods and on quantifying the nature and extent of the release and migration of coal tar constituents in the soil and groundwater at several manufactured gas plant (MGP) sites. Successful delivery of the products of this research should help utilities manage these sites more effectively.

The determination of the fate of coal tar constituents is complicated by the fact that coal tar is a generic term for complex mixtures containing hundreds, if not thousands, of organic compounds. Each of these compounds has its own physical, chemical, and microbial transformation properties, some of which have been derived in laboratory experiments with single compounds. These single-compound results, however, may not give an accurate picture of how complex mixtures underground may actually behave and what risks are posed by the mixtures.

From the time of disposal, physical, chemical, and microbial processes affect the manner and magnitude in which coal tar chemicals are released to the environment, transformed into other compounds, and transported in the subsurface. Such processes as volatilization, dissolution, dispersion, adsorption, advection, and microbial transformation play an important role in determining the ultimate fate of coal tar constituents. Researchers are seeking to understand these processes, not only in order to try to predict how coal tar constituents are likely to change and move in the subsurface, but also in order to assess how well potential methods for remediation might work at specific sites under various circumstances.

Although there has been some theoretical study of these natural processes by means of model simulation or laboratory experimentation on individual coal tar constituents, very little field-scale research had been carried out on the complex mix of coal tars until EPRI initiated its work (RP2879). This research is providing a basis for understanding the natural processes of movement and change, as well as insight into the estimation of associated parameters, such as solubility, decay rate, chemical attenuation rate, and groundwater flow velocity, which are measures of these processes.

ABSTRACT *Utilities are facing decisions about the remediation of sites where town gas was produced in the 1800s and the first half of the 1900s. To assess the nature and extent of environmental contamination and health risks at these sites, the utilities need methods and information for conducting site investigations. EPRI research has developed innovative field methods that make it possible to rapidly extract and analyze soil and water samples at substantially reduced costs. Moreover, EPRI's MYGRT code provides an efficient method for analyzing field data and evaluating the performance of potential remediation alternatives. Research to date has shed light on biotransformation, a promising remediation technique, and on the role of solubility in the release of polycyclic aromatic hydrocarbon compounds to groundwater.*

Field site and objectives of research

About 25 years ago, coal tar residue from a holding tank at an MGP site was trucked to a rural area in the Northeast, deposited in a large trench just to the side of the road, and covered with native soil. Although the trench is estimated to have been about 30 by 100 feet, no records are available that state the actual size or how much coal tar was deposited there. Anecdotal evidence suggests that several truckloads of coal tar were placed in the trench.

Evidence of this coal tar deposit was found by the owner utility in the early 1980s. During the resulting site investigation, organic compounds derived from coal tar were detected in groundwater thought to be downgradient from the general location of the suspected coal tar deposit. In late 1987, with the cooperation and support of the host utility, EPRI began research at this site, known as EBOS Site 24, as part of its Environmental Behavior of Organic Substances project (EBOS RP2879). Contractors are Cambridge Analytical Associates, Atlantic Environmental Services, and Meta Environmental. The objectives of this research are to examine and evaluate conventional and innovative methods for sampling and analysis at MGP sites and to help understand how coal tar constituents are released, transformed (chemically and microbiologically), and transported in a subsurface environment.

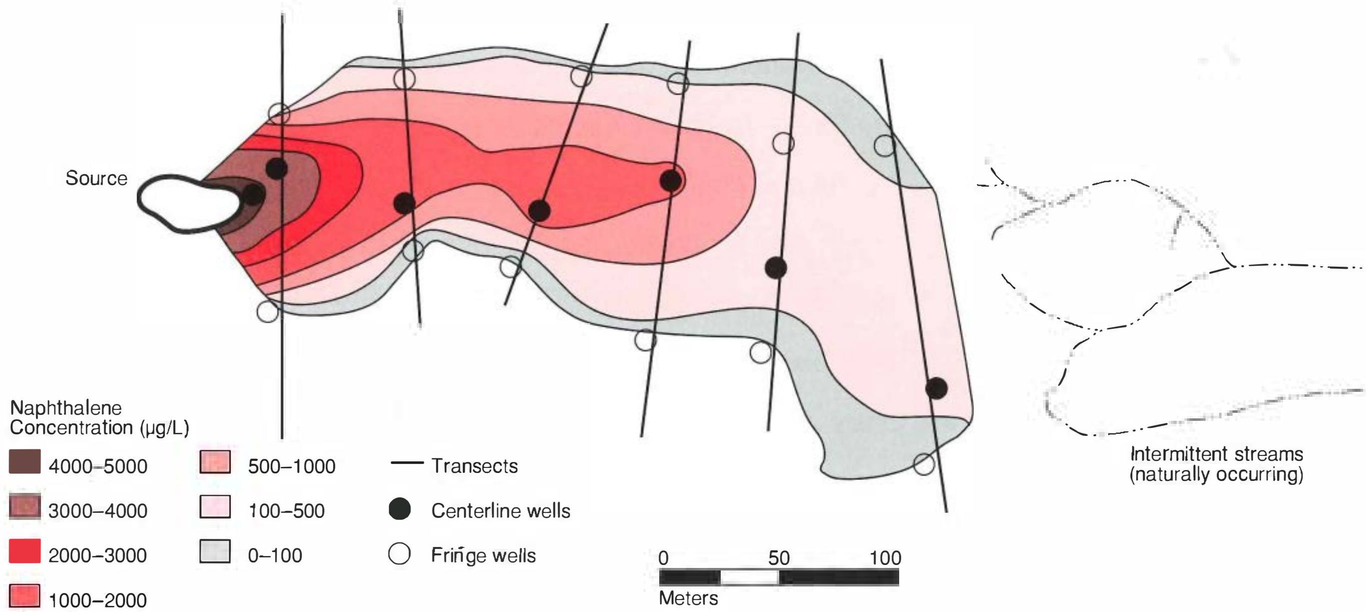
Extensive hydrologic, soil, and groundwater sampling was carried out to define the environmental changes related to the coal tar deposit. Microbiological characterization and mineralization rate studies were also conducted to quantify the biotransformation rates that affected the development or dissipation of groundwater plumes of several organic solutes at this site. The utility is expected to remove the coal tar source material late in 1990; its removal will afford a unique opportunity for continuing research to validate predictions concerning dissipation of the groundwater plume.

Source location and definition

Before a study of the movement or transformation of coal tar constituents could be made, it was first necessary to determine where the source material originally was placed. Information from a former utility employee indicated that the coal tar trench was north of the road, in a clearing to the west of a small stand of trees. Efforts to define the location of the source initially concentrated in that area.

Once a site grid was established, the first method used to help define the source deposit was a series of soil gas surveys. Although such surveys have proved valuable at some MGP sites (particularly sites where there is asphalt or some other surface barrier to gas venting), the results of the soil gas surveys done at this site were of little value. The primary reason is that after deposition most of the coal tar, being more dense than water, moved vertically downward to well below the water table. The composition of the residue left in the soils of the unsaturated zone changed over time. Some of the tar constituents were dissolved by recharge water perco-

Figure 1 Aerial view of EBOS Site 24. The indicator compound naphthalene has moved in a fairly narrow plume away from the source material in the direction of groundwater flow.



lating through the sandy soil, while some were volatilized and escaped from the soil surface or were transformed by microbial and geochemical reactions. The material remaining in the unsaturated zone after about 25 years was consequently highly weathered and contained only very low concentrations of the volatilizable lightweight compounds most likely to be detected during a soil gas survey. Furthermore, over time the bulk of the tarry material moved sufficiently far below the water table that the concentrations of volatile components at the air/water interface were low, thereby reducing the likelihood that such compounds would be detected in the unsaturated zone.

The situation at this site was further complicated by the large number of pine trees in the source area. The presence of naturally occurring terpene compounds from the pine needles interfered with the accurate detection of naphthalene, one of the soil gas survey compounds.

Since the soil gas survey did not provide sufficient information to locate the boundaries of the coal tar source, a series of trenches was made with a backhoe, starting in the designated clearing west of the trees. When it became apparent that the coal tar had not been placed in that area, additional trenches were made behind the stand of trees and in a clearing to the east of the trees. It was in the eastern clearing that the coal tar deposit was found.

After the source area was located and the groundwater flow direction was defined, field investigations were carried out by means of both conventional and innovative methods for sampling and analyzing soils and groundwaters. In addition, aseptic sampling of selected soil cores was carried out for purposes of microbiological characterization and defining the variability in biotransformation activities at the site.

Innovative field methods

Two new methods for field sampling and analysis at MGP sites were developed and tested. The first method was developed to assist in the accurate placement of groundwater monitoring wells laterally and vertically within the plume or at the plume edges. The second method was developed as a technique for rapid on-site extraction and chemical analysis of soil and groundwater samples. Both of these methods used naphthalene as an indicator compound because it was found in the highest concentration in the source material and because it is the most soluble and has the least potential for soil adsorption of all of the semivolatile coal tar compounds.

A multistep field procedure was used for determining where groundwater wells should be placed, both laterally and vertically, and what screen length should be used. The first step was to establish a series of transects that cut across the site in such a way that they were approximately perpendicular to the expected centerline of the groundwater plume (Figure 1). Next, several borings were made along each transect, starting from the edges and working toward the centerline of the plume. Soil samples were collected from each of the borings and taken to the field laboratory for rapid extraction and analysis. The results of soil sample analyses of some borings were used as a guide for determining where future borings would be made or from what depth samples would be collected for analysis. The use of the field laboratory and the microextraction method made it possible to obtain chemical analysis results within hours instead of the several days that would have been required by the conventional approach.

Along each transect, the soil core with the highest concentration of naphthalene indicated the centerline of the plume. By examining the vertical distribution of naphthalene in each such soil core, the field crew decided on the depth and screen length for the monitoring well that would place it in the zone of maximum naphthalene concentration. In general, two wells at different depths were placed at each location determined to be at or near the plume centerline. Single-depth wells were placed at the edges of the plume to clearly delineate its outer boundaries.

The other innovative development that resulted from the field efforts at Site 24 was the successful use of a field method for extracting organic compounds from soil and water samples and analyzing them by gas chromatography with flame ionization detection (GC/FID). This method was used to provide rapid on-site results, proved to be more cost-effective than comparable conventional laboratory analysis, and provided increased capability and flexibility and fewer compromised or lost samples. Since all the work was done on-site, the priority of samples to be analyzed could be changed quickly and as frequently as the conditions in the field required.

The method used for soils was a micro-extraction with a mixture of dichloromethane (methylene chloride) and acetone followed by GC/FID analysis. Up to 10 extractions could be carried out concurrently, and they took a total of about one hour to perform. Soil extracts were run on the GC continuously; an autosampler took quality assurance samples 24 hours a day, seven days a week. By this method, aromatic hydrocarbons of interest—from toluene to benzo(g,h,i)perylene—could be detected in concentrations as low as 10 ppb.

In addition, numerous split samples were sent to a conventional laboratory for Soxhlet extraction and analysis by gas chromatography/mass spectroscopy (GC/MS). The results of these confirmatory analyses indicated that the findings from the two methods were comparable, with the field method typically showing slightly higher concentrations of the lower-molecular-weight aromatic hydrocarbons and the conventional laboratory method showing higher concentrations of the higher-molecular-weight compounds.

Under a separate contract, Battelle, Pacific Northwest Laboratories, developed a field-portable extraction apparatus for using supercritical fluid (i.e., CO_2) to rapidly extract the analytes of interest from soil samples. The results from the supercritical-fluid extraction were comparable to those from the Soxhlet and microextraction techniques, with the added advantage of lower cost and quick turnaround. Utilities and contractors conducting field investigations should consider using these methods to reduce the costs of carrying out sampling and analysis at MGP sites.

Microbiological characterization and biotransformation

Between late 1988 and late 1989, three different sets of samples were obtained to characterize abundances of microorganisms in soils obtained from the groundwater plume and uncontaminated areas at Site 24. Biotransformation by microorganisms may be viewed as one of the promising aquifer remediation methods. The premise is that once geologic, hydrologic, geochemical, and contaminant distribution characteristics at a site are identified, one can manipulate the environment to enhance biotransformation rates by increasing microbiological activity.

The preliminary study of the microbiology at Site 24 was carried out by Cornell University. Core samples were obtained from inside and outside the plume on each of two sampling dates and were characterized for heterotrophic bacteria, actinomycetes, and fungi. Plate cultures were developed in the laboratory for microbial identification.

Selected plated samples were sent to the University of Tennessee at Knoxville for naphthalene gene probe analysis. Radio-labeled (1-^{14}C) naphthalene and (9-^{14}C) phenanthrene were used to perform biotransformation studies in experimental flasks in the laboratory. The key results are summarized in Table 1. Microbial population densities observed are typical of other shallow aquifer systems. The abundance counts indicate that heterotrophic bacterial numbers decrease with depth. Actinomycetes and fungi were detected only down to the vadose zone.

Biotransformation tests indicated that nei-

Table 1
MICROBIOLOGICAL PROFILES FROM THE EBOS SITE 24 SAMPLES

	June 1988 Samples Inside Plume*			June 1988 Samples Outside Plume*		
Zone	AODC (10^6/gdw)	% Naphthalene Mineralized	% Phenanthrene Mineralized	AODC (10^6/gdw)	% Naphthalene Mineralized	% Phenanthrene Mineralized
Surface	182	ND	ND	176	ND	ND
Vadose	29	0	0	49	0	0
Water table interface	13	10.3	10.0	41	0	0
Saturated	11	ND	ND	51	ND	ND
Saturated	17	11.1	12.7	13	0	0
Clay	38	0	0	36	0	0

	April 1989 Samples Inside Plume†			April 1989 Samples Outside Plume†		
Zone	AODC (10^6/gdw)	% Naphthalene Mineralized	% Phenanthrene Mineralized	AODC (10^6/gdw)	% Naphthalene Mineralized	% Phenanthrene Mineralized
Vadose	13	0	0	23	0	0
Water table interface	1.0	0	0	22	0	0
Saturated	9.0	10	20	1.0	0	0
Saturated	1.0	8	0	1.0	0	0

Definitions. AODC = acridine orange direct count (a measure of microbial population density), gdw = grams dry weight; ND = not determined.

*Experiment ended at 60 days. †Experiment ended at 21 days.

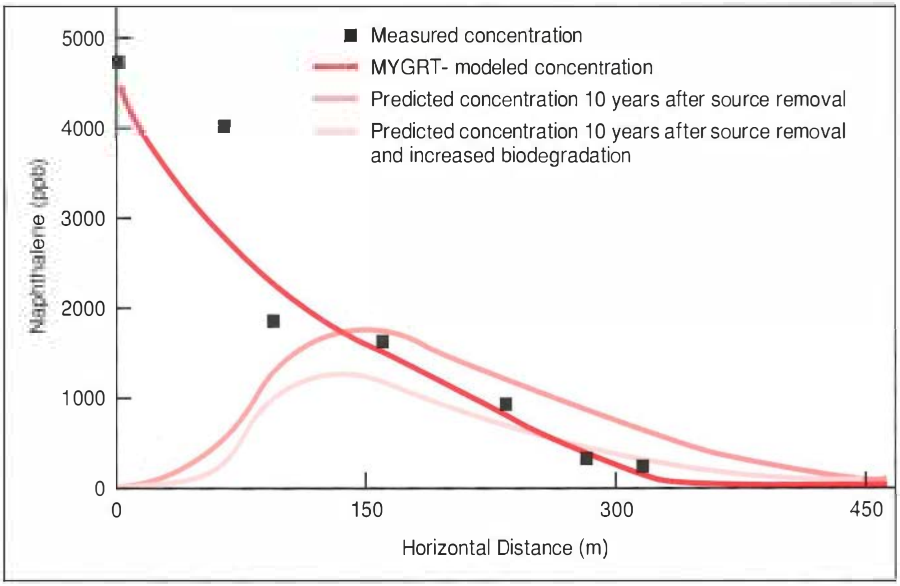


Figure 2 The measured and MYGRT-modeled groundwater concentrations of naphthalene along the centerline of the plume and the MYGRT-predicted concentrations that would remain after dissipation by means of two remediation strategies. Both source removal and a combination of source removal and increased biotransformation would take advantage of naturally occurring processes to greatly decrease groundwater concentrations of pollutants.

ther naphthalene nor phenanthrene mineralized (i.e., converted to CO_2) in soil samples from the uncontaminated area. Biotransformation of these two compounds did occur without a lag in soil samples from the water table and saturated zones of the contaminated plume area. The naphthalene gene probe analysis confirmed the presence of genes in the aerobic microorganisms that mineralized the naphthalene. It should be noted, however, that only 10–12% of the radio-labeled compounds actually biotransformed in the course of the experiments; this fact suggests that complete biotransformation of these compounds may be limited by various factors that control the relevant biochemical and geochemical reactions. Continuing field and laboratory research is focused on defining the biotransformation rates under different field conditions for the mobile polycyclic aromatic hydrocarbon (PAH) compounds. A report on the results is scheduled for this fall.

Groundwater plume

The results of this field investigation show that a fairly narrow plume of naphthalene has moved away from the source material (Figure 1) and that naphthalene has moved farther than any of the other PAH compounds studied. Other PAH compounds do not appear to move as readily as naphthalene, and some show no movement away from the near-source area. The release and migration of the PAHs in coal tar is also highly dependent on their water solubility. Those PAH compounds with relatively high solubilities, such as naphthalene, have been observed in groundwater wells along the entire length of the site (325 m). Of the lower-solubility compounds, only acenaphthalene was present in quantifiable concentrations in all groundwater wells.

Because of the dramatic role solubility plays in the release of PAH compounds in the groundwater at this site, it should be expected that groundwater and soil contamination at MGP sites would be limited to the more readily soluble compounds. Unless the dissolution of a coal tar constituent occurs, that constituent is not likely to migrate from the source area. Furthermore, most of the compounds of toxicological significance tend to have high molecular weights and low solubilities; these data suggest that such compounds are likely to remain in the source area for extended periods of time. This premise is borne out by the fact that benzo(a)pyrene, a known carcinogen, was not observed in any of the downgradient groundwater wells, including one that was only a meter away from the edge of the source tar deposit.

On the basis of research carried out at EBOS Site 24, it is apparent that the primary mode of release of coal tar constituents to the environment is dissolution. The solubility of a particular constituent therefore dictates how much of that compound may be allowed to move with the groundwater. Once dissolved, the material moves along with the groundwater flow in an advective manner, with little vertical or transverse dispersion. And since this site contains very little organic carbon, adsorption does not appear to play a role in retarding the movement of the dissolved constituents with the groundwater.

Modeling and options for remediation

The groundwater quality data and the hydrologic measurements from Site 24 were used in the application of EPRI's MYGRT™ code (Version 2.0) to the analysis of the transformation, transport, and distribution characteristics of dissolved organics. Very little chemical attenuation and biological decay have occurred at this site. Figure 2 shows both the measured and the MYGRT-calculated concentrations of naphthalene in the groundwater along the centerline of the plume. The MYGRT code was also used to evaluate the environmental response to two remediation options: source containment or removal, and source containment or removal together with increased biotransformation. The figure shows predictions of the changes in groundwater concentrations in response to these two remediation options. The results for both options indicate that because of the naturally occurring hydrologic, geochemical, and microbiological processes, there will be large decreases in the groundwater concentrations of naphthalene. Beyond this simple example, other remediation options may be considered. To provide broader assessment capabilities, a remediation options assessment model (ROAM) is being developed for commercial release in 1991.

When the host utility removes the coal tar source material from EBOS Site 24, researchers will have a unique opportunity to validate their predictions of plume movement and dissipation. Once this material is removed, a field effort will be instituted to monitor existing plume wells and perform a limited number of soil borings over a period of about five years. The data will be used to validate the MYGRT and ROAM models. In addition, another eight MGP sites will be investigated to produce a statistically valid database on the distribution of organic compounds, their behavior in the environment, and how remediation strategies can dissipate the organic compounds in soils and groundwaters. Three reports on the research completed through March 1990 are to be published this year.

Power Electronics and Controls

Nonintrusive Appliance Load Monitoring System

by Larry Carmichael, Customer Systems Division

ABSTRACT *An inexpensive method for obtaining residential load data of high quality, without intruding on customer privacy, has been developed by EPRI and field-tested in two utility service territories. The microprocessor-based device, known as the Nonintrusive Appliance Load Monitoring System, can be mounted in the existing kilowatthour meter socket. Without the need for additional in-house wiring, NIALMS records data on power transitions caused by the operation of individual appliances within the house. Initial comparison of these NIALMS measurements with conventional measurements of end-use loads at 10 residential sites indicates that NIALMS can accurately measure most large end-use loads within the house.*

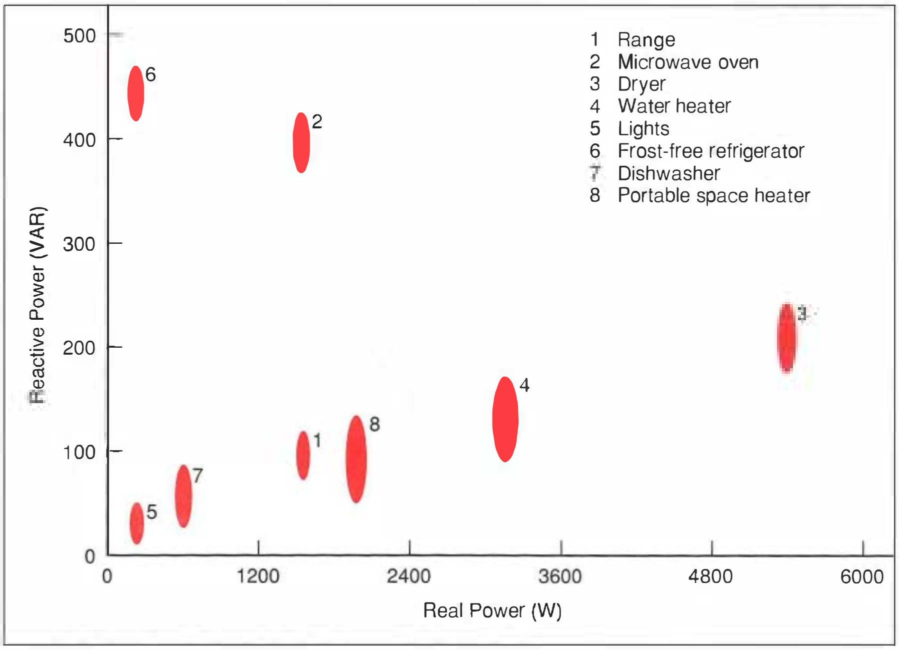
The Nonintrusive Appliance Load Monitoring System (NIALMS) is designed to replace conventional load-monitoring systems, which typically have consisted of individual watthour meters, pulse initiators, and magnetic-tape or solid-state recorders. Although advances have been made in such equipment in the last few years, it has remained necessary either to isolate appliances on separate circuits at the building's distribution panel or to install a power transducer or current transformer between the electrical outlet and the appliance being monitored. Data measured by conventional means must be transmitted to the central recording device either over dedicated twisted-pairs wiring, specifically installed in the building for this application, or over the building's own ac wiring by means of power-line-carrier communications. In either case, the equipment installed in the building is both intrusive to the customer and costly to install and maintain. The first cost of conventional load-monitoring equipment is directly related to the number of end-use loads monitored. Cost, available space, and the complexity of the measurement system have typically limited systems to measuring only a few of the largest end-use loads within the building.

In contrast to conventional monitoring techniques, NIALMS does not require connections to the individual loads, and the number of end-use loads that can be monitored is limited only by the resolution of the detection algorithms. All necessary measurements, data processing, and storage can take place in a single microprocessor-based device located at the kilowatthour meter. Load data can then be recovered at the meter site either manually, by means of a handheld storage device, or remotely, over the telephone or other utility communications system.

Pattern recognition algorithms developed by EPRI research enable the NIALMS device to determine appliance usage without reliance on additional wiring of the customer's building. NIALMS contains a mathematical estimator that, when given certain observations (measured load changes) and a class of appliance load models (discrete-state models), can determine the parameters of the appliance models that best describe the observations. The key to NIALMS is its estimation algorithm for analyzing the aggregate load. This algorithm can be summarized in terms of the following three operations:

- Aggregate load is analyzed for step

Figure 1 The NIALMS mapping of appliance signatures. These signatures are developed by comparing real and reactive power consumption.



changes, which indicate the times at which appliances change operating state.

- The sizes of the step load changes (in both real and reactive power consumption) are analyzed statistically by means of cluster analysis to separate the unique "signatures" of the appliances present (Figure 1) and identify which step-change events correspond to the operation of a particular appliance. Each appliance's energy usage is then determined from the time interval between matching "on" and "off" load changes.
- Statistics relating to an appliance's energy consumption versus time, as well as correlation with local temperature and voltage, are developed and reported.

Two-state algorithms

The discrete-state appliance models in the current NIALMS estimation algorithms are based on the premise that each of the appliances, connected in parallel across the incoming legs of the power lines, behaves as an on-off device and draws a definite, repeatable amount of real and reactive power when operating at nominal voltage. In simple terms, all that is necessary is to detect step changes in real and reactive power, match "ons" with "offs," and then process the data on the times appliances are used. Implicit in the current estimation algorithms is the assumption that all the appliances monitored can be modeled as two-state (on-off) finite state machines (FSMs). While most appliances can be adequately described by two-state FSM models, machines such as dishwashers, washing machines, and heat pumps may require more complicated, multistate FSM models to adequately represent their behavior. Although research now progressing will make it possible to include multistate FSM appliance models in the monitor's algorithms, an algorithm for appliance estimation using two-state FSM models has been implemented and has undergone preliminary testing with good results.

Field demonstration

Feasibility tests were conducted to assess the potential applicability of the NIALMS algorithms, but the results were not sufficiently conclusive to confirm commercial viability. First, during the course of the experimentation it became evident that because of limitations imposed by the computer hardware available at that time, many of the innovations needed to improve the accuracy of the algorithms could not be implemented. Second, the researchers were limited in their ability to assess the overall accuracy of the method. The accuracy was in fact inferred from the unmatched transition data and not from actual, measured appliance energy usage. In 1987, EPRI contracted to construct 10 prototype NIALMS devices incorporating the latest versions of the algorithms. These prototype devices stored time-stamped real and reactive power transition data on RAM cartridges for later processing on an IBM PC.

Two utilities, Rochester Gas & Electric (RG&E) and New England Power, agreed to participate as host utilities for the field testing of the prototype devices. In each case the host utility installed conventional load-monitoring equipment side by side with NIALMS equipment in test houses to provide benchmark measurements of the important appliance loads in order to evaluate the accuracy of the NIALMS algorithms.

Demonstration test results

The prototype NIALMS monitors were installed at 10 residential test sites in the service territories of RG&E and New England Power. The appliance energy usage data gathered by the prototype NIALMS equipment and software were compared with the data gathered by the conventional monitoring equipment. A few of the prototype units experienced minor installation problems, but the majority functioned correctly for the duration of the tests.

Comparison of the NIALMS data with the conventionally obtained data showed NIALMS to be successful in deciphering the energy-use patterns of many two-state appliances. The average error for two-state appliances ranged from –1.4% for small kitchen appliances to 15.3% for lights. Not surprisingly, the average errors for multistate appliances were generally higher than those for two-state appliances. The average error for multistate appliances ranged from –2.8% for washers to 46.7% for electric ranges. The average error for total household energy consumption was –6.3%, an accuracy of almost 94%.

Commercialization plan

Nine utilities and two research organizations have already expressed interest in purchasing NIALMS for load monitoring. EPRI has organized a consortium of these interested parties, and consortium members have agreed that if NIALMS is manufactured to meet their product specifications, they will each purchase a certain number of the monitoring systems, thereby assuring prospective manufacturers of an initial market. Present requirements for the commercialized version of NIALMS include simplified installation, rugged and reliable components, compatibility with existing load analysis software, and remote data access.

EPRI expects NIALMS to cost approximately $2500 per unit in commercial production—about one-third the capital cost of conventional equipment for monitoring the same number of end-use loads. NIALMS installation and maintenance costs are also expected to be significantly lower than those of conventional equipment.

Manufacturers will be asked to submit proposals; the selected manufacturer will then produce a limited number of upgraded NIALMS units for product testing by consortium members. EPRI expects that field-proven NIALMS designs resulting from this testing will move quickly to commercial production.

Basic Fuel Research

Will LWR Fuel Cladding Withstand the Requirements of High-Duty PWRs?

by Odelli Ozer, Nuclear Power Division

ABSTRACT *As a result of recent trends toward higher efficiency in PWR design and longer operating cycles, fuel is now being required to operate in a more hostile environment for longer periods of time. EPRI has monitored the buildup of cladding corrosion on test fuel assemblies exposed to very high burnup levels in a high-duty PWR, considered to be one of the lead plants from the standpoint of corrosion. Data obtained from this project will provide guidance for estimating appropriate exposure limits for fuel in such plants.*

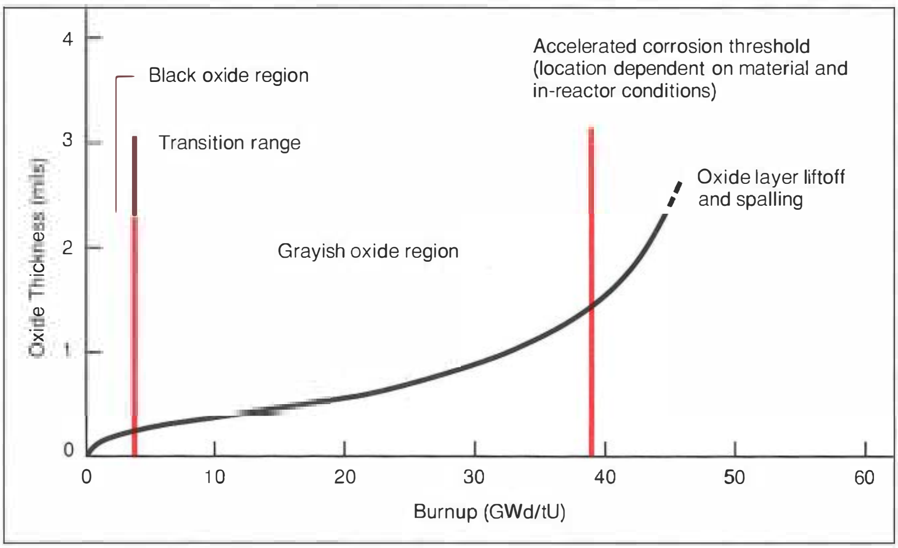
LWR fuel consists of UO_2 pellets encapsulated in a thin zirconium alloy cladding tube (typically Zircaloy-4 for PWR fuel). Since the cladding tube is the principal barrier to the release of radioactive fission products from the fuel pellets into the reactor system, it must be designed to maintain its integrity under all anticipated (normal or design-basis-accident) operating conditions.

The most important mechanism that could potentially limit the life of Zircaloy cladding under normal operating conditions is corrosion (oxidation and hydriding) of its external surface, which during operation is exposed at high temperature to the reactor coolant water. Nevertheless, Zircaloy is a strongly corrosion resistant material, and excessive waterside corrosion of cladding has not been a significant source of fuel failures in the past. PWR fuel has been shown to be capable of withstanding long exposures without excessive oxide layer buildup and loss of integrity. However, recent trends toward higher efficiency in PWR plant design, operating strategy, and fuel cycle design require that the corrosion issue be reexamined.

The most recent PWRs are designed to operate with higher coolant temperatures than older PWRs and under conditions that even allow some localized subcooled boiling, which the earlier designs did not allow. Furthermore, the tendency toward longer fuel cycles and higher burnups has resulted in the exposure of fuel under these more severe conditions for longer periods of time than in the past. Zircaloy corrosion is strongly dependent on temperature and the length of exposure. The occurrence of boiling at the metal-water interface further accelerates corrosion.

The buildup of corrosion is believed to follow a behavior schematically shown in Figure 1. Following an initial period during which a thin, protective oxide layer is developed rather rapidly, the oxidation slows down and there is a transition into a range where the buildup becomes more or less linear with time. The slope of the curve in this range—the rate of corrosion buildup—is dependent on the microstructure, or quality, of the cladding as well

Figure 1 General form of Zircaloy corrosion behavior. After rapid initial oxidation, there is a transition to a relatively linear buildup with time. Once the oxide level begins to significantly impair heat transfer, oxidation accelerates, leading to the spallation of oxide flakes and ultimately to clad failure.



as on various in-reactor conditions, including the temperature and chemistry of the coolant. There are also indications that beyond a certain point, the oxide layer will become thick enough to start having a significant and detrimental feedback effect on the heat transfer properties of the fuel. At that point the cladding temperature can be expected to start to increase, and corrosion to become much more rapid, resulting in the detachment of some of the oxide layer, spallation of oxide flakes, and eventually clad failure.

The behavior of in-reactor oxidation is well supported by measurement data from the early, transition, and linear corrosion ranges, but little information is available about the behavior in the range where corrosion could be expected to accelerate. It is not known when acceleration will begin and how fast it will proceed. It is in precisely this range of uncertainty that fuel will be required to operate when pushed into high burnups in the most recent, high-temperature, high-duty plants.

PWR Zircaloy corrosion monitoring

To address the concern about the possible existence of an accelerated corrosion range at high burnups, EPRI has initiated a research project aimed at monitoring the buildup of corrosion in a high-duty U.S. PWR (RP2757-1). This project, for which Westinghouse is the contractor, identified the North Anna Unit 1 reactor, operated by Virginia Power, as the lead unit from the standpoint of corrosion. Although a few, more recent units with operating temperatures even higher than those of North Anna-1 have been coming on-line, these units are not expected to reach the same levels of corrosion until a later time. The information gained from the study of North Anna-1 is expected to be of critical importance for these reactors.

Whereas PWR fuel assemblies are typically discharged after three cycles of irradiation at burnups in the range of 40–50 gigawatt-days per metric ton of uranium (GWd/tU), as part of the monitoring program two lead test assemblies of a standard Westinghouse 17 × 17 design employing Zircaloy-4 cladding have been exposed through four 18-month cycles of irradiation to assembly-average burnup levels in excess of 58 GWd/tU. (This burnup level constitutes a world record for an assembly average.) Two additional assemblies were exposed for only two cycles but in accelerated, high-power locations, which allowed their burnups to reach 40 GWd/tU. The project consisted of inspections of the test assemblies during two refueling outages—following the third and fourth exposure cycles for the high-exposure assemblies. The inspections included measurements of the oxide-

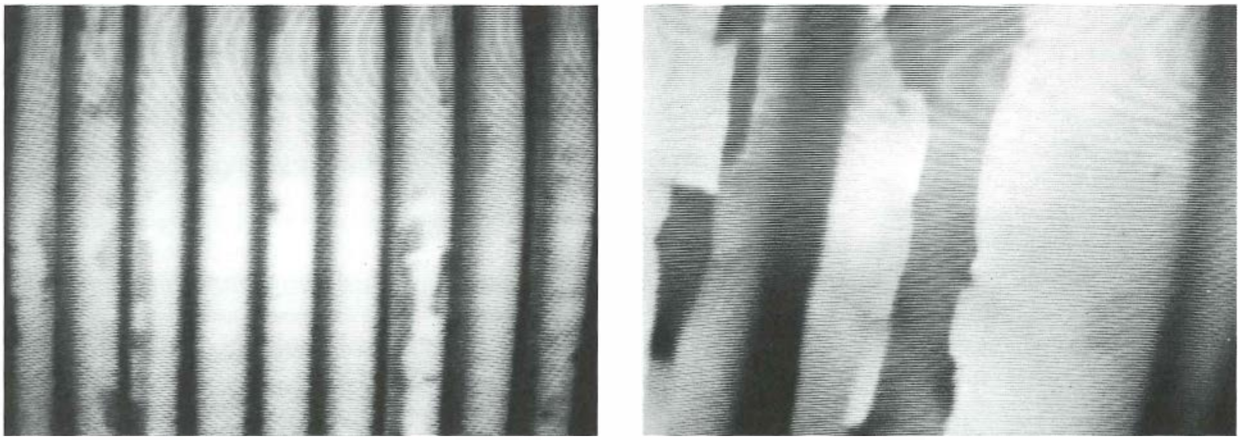


Figure 2 Spalling corrosion film on four-cycle fuel assembly, shown at approximate magnifications of 0.8 (left) and 8 (right).

layer thickness on peripheral rods of the test assemblies using an eddy-current technique.

Test results

At the interim point, after three cycles of irradiation, all assemblies appeared to be in good condition, adequate for reinsertion for an additional 18-month cycle. The measured oxide thicknesses were high but were not outside the expected range. The buildup of oxide appeared to be consistent with the linear functional behavior, with no clear indication of the existence of an acceleration range.

The observations made after the fourth, final cycle, on the other hand, were dramatically different. The test assemblies were still in good mechanical condition, with no indications of excessive radiation-induced growth or assembly bow. The amount of oxidation, however, was observed to have increased significantly (Figure 2). In fact, oxide thickness measurements indicated that the amount of oxidation accumulated during the fourth cycle was more than double that built up during the previous three cycles of operation. At the highest power elevations of the assemblies, the oxide layer on fuel rods was flaking off and spalling, giving the fuel rods the appearance of being covered with old, dried-out paint. Some incipient spallation was detected even on the two-cycle, high-power assemblies at 40 GWd/tU.

These measurements indicated the oxide layer to be clearly thicker than expected according to the linear buildup assumption; this finding confirmed the existence of a zone of accelerated corrosion. It appears that the North Anna-1 test assemblies have exceeded what should be a recommended exposure limit for this type of cladding in high-duty plants. Although the fuel rods did not develop any leaks, operating with this amount of corrosion is clearly not desirable because of the possibility of cladding-integrity loss and the potential impact of oxide spallation on the balance of the plant.

The information obtained from this project is being used to extend theoretical, predictive models so that they will be applicable to high-duty plants at extended burnups. A predictive algorithm is under development to allow utility engineers to estimate, on a plant-by-plant basis, whether their specific fuel management strategies and planned exposures will result in excessive corrosion, and if so, to provide them options to avoid it.

The response to the question of whether cladding will withstand the requirements of high-duty PWRs must be a qualified yes—qualified, that is, by the provision that exposures at high power not exceed those indicated as appropriate by the North Anna-1 experience. Going to higher burnups will require further improvements in the corrosion performance of Zircaloy-4 through compositional changes (other EPRI-sponsored projects have determined that reducing the specification on tin content in Zircaloy-4 improves performance) or the development of more-resistant alloys.

New Contracts

Project	Funding/ Duration	Contractor/EPRI Project Manager
Customer Systems		
Advanced Electric Griddle Development (RP2890-14)	$250,000 26 months	Metcal, Inc./*K. Johnson*
Foodservice Industry Research (RP2890-17)	$160,800 12 months	Hart, McMurphy & Park, Inc./*K. Johnson*
Energy Management Applications in PSI Connersville Service Building (RP2892-10)	$100,000 23 months	Public Service Co. of Indiana, Inc./*L. Carmichael*
Power Electronics Technology Development Program at PEAC: Technical Support (RP2918-10)	$76,900 10 months	Tennessee Center for Research and Development/*B. Banerjee*
Environmental Impact of Adjustable-Speed-Drive Applications (RP2951-11)	$105,000 11 months	Jarsco Engineering Corp./*M. Samotyj*
Water Heating Analyses (RP2958-10)	$59,300 10 months	Andrew Lowenstein/ *C. Hiller*
Demand-Side Planning and Integrated Resource Planning (RP2982-8)	$140,700 22 months	Oak Ridge National Laboratory/*P. Hanser*
Electric Vehicle Battery Test and Development (RP3150-1)	$1,500,000 35 months	Argonne National Laboratory/*R. Swaroop*
Environment		
Utility Responses to Greenhouse Gas Issues (RP1433-3)	$78,800 6 months	Pros & Cons Consulting/ *C. Whipple*
Air Emissions Risk Assessment Model (RP2141-16)	$284,800 38 months	Seacor, Inc./*C. Whipple*
Sensitivity of Long-Distance Water Vapor Transport to Climate Change (RP2333-6)	$317,900 35 months	Columbia University/ *C. Hakkarinen*
Analysis of Arctic Climate Trends (RP2333-7)	$91,400 21 months	NOAA Environmental Research Laboratories/ *C. Hakkarinen*
Measuring Dissolved Gases and Testing Electromigration Methods in Groundwater (RP2485-20)	$238,500 26 months	University of Colorado/ *I. Murarka*
Power Systems Characterization of Chemical Substances: Risk Assessment (RP3081-1)	$596,300 26 months	ENSR Consulting and Engineering/*C. Whipple*
Exploratory Research		
Fracture Mechanics of Concrete Gravity Dams: Dynamic Loading and Three-Dimensional Analysis (RP2426-26)	$150,000 23 months	University of Colorado/ *D. Morris*
Behavior of Ammonium Salts in Steam Cycles (RP8000-55)	$200,000 24 months	Martin Marietta Energy Systems, Inc./*B. Dooley*
Ice Crystal Nucleation, Growth Structure, and Adhesion in Aqueous Solutions (RP8000-56)	$104,700 15 months	University of Missouri/ *R. Wendland*
Dissolution of Oxides in Molten Carbonate (RP8002-21)	$284,000 35 months	University of Minnesota/ *G. Cook*
Generation and Storage		
Generator Retaining Ring Life Assessment Code (RP2719-2)	$159,800 10 months	Structural Integrity Associates/*J. Stein*
Advanced Wall-Fired Combustion Techniques Project: Plant Hammond, Georgia Power Co. (RP2916-12)	$1,000,000 30 months	Southern Company Services, Inc./*D. Eskinazi*
Gas Turbine Expert Systems Planning, Testing, and Assessment (RP3031-5)	$162,300 12 months	Cameron Engineering/ *G. Quentin*
Wind Turbine Technology Development (RP3062-2)	$900,000 56 months	U.S. Windpower, Inc./ *E. DeMeo*
Atmospheric Fluidized-Bed Combustion Testing and Evaluation Concept (RP3162-1)	$108,100 12 months	Combustion Systems, Inc./*C. Siebenthal*
Engineering and Economic Evaluation of Photovoltaic Power Plants (RP3166-1)	$363,300 16 months	Bechtel Power Corp./ *C. McGowin*
Organic and Inorganic Hazardous Waste Stabilization Using Fossil Fuel Combustion Waste Materials (RP3176-3)	$188,200 34 months	Western Research Institute/*D. Golden*
Utility Integration of Photovoltaic Systems (RP3179-1)	$144,800 8 months	Electrotek Concepts, Inc./ *J. Bigger*
Coal-Upgrading Technology Market Study (RP3198-1)	$50,000 5 months	Energy Ventures Analysis, Inc./*W. Weber*
Production Potential of Central Appalachian Low-Sulfur Coal (RP3199-3)	$175,000 20 months	Hill & Associates, Inc./ *J. Platt*
Reliability Prediction Methodology for a Gasification–Combined-Cycle Power Plant (RP3199-5)	$250,000 12 months	ARINC Research Corp./ *J. Weiss*
Integration of Coal Supply Perspectives (RP3199-6)	$86,000 14 months	Resource Dynamics Corp./*J. Platt*
Coal Markets Under Environmental Legislation (RP3199-8)	$85,000 10 months	Energy Ventures Analysis, Inc./*J. Platt*
Nuclear Power		
Zeta Potential Measurements (RP3097-2)	$189,000 21 months	SRI International/ *H. Ocken*
Individual Plant Examination and Fire Probabilistic Risk Assessment Studies (RP3114-29)	$962,200 17 months	Science Applications International Corp./ *J. Haugh*
Evaluation of Operational and Risk Perspectives of Interfacing System LOCAs (RP3114-33)	$75,000 13 months	Erin Engineering & Research, Inc./*N. Dietrich*
Thermal-Hydraulic and Safety Support (RP3114-34)	$100,000 12 months	DuPage Computer Applications, Inc./ *B. Chexal*
Fire Protection Engineering Support (RP3114-36)	$58,900 9 months	Impell Corp./*J. Haugh*
Operating Experience Insights for Individual Plant Examinations (RP3114-38)	$187,000 15 months	Individual Plant Evaluation Partnership/*N. Dietrich*
Stress Corrosion Cracking Testing of Alloy 718 (RP3154-3)	$194,600 24 months	Babcock & Wilcox Co./ *L. Nelson*
Development of a Stable High-Temperature Reference Electrode (RP3173-2)	$262,000 35 months	SRI International/ *T. Passell*
Common Cause Database Enhancement (RP3200-2)	$75,300 3 months	Pickard, Lowe, and Garrick, Inc./*B. Chu*
Site Support for Monitoring and Diagnostic Center (RP3232-2)	$121,400 12 months	Advanced Technology Engineering Systems/ *J. Weiss*
Nonintrusive Check Valve Diagnostic Test Program (RP3233-1)	$128,700 2 months	Utah State University Foundation/*J. Hosler*
Residual Stress Measurement (RPC102-5)	$174,800 24 months	J. A. Jones Applied Research Co./*W. Childs*
Stress Corrosion Cracking Behavior of High-Chrome Welding Alloys (RPC103-5)	$60,000 11 months	Babcock & Wilcox Co./ *L. Nelson*
Characterization of Consolidated Sludge (RPS403-8)	$106,400 13 months	Atomic Energy of Canada. Ltd./*L. Williams*
Diagnostic Technology for AVB Gap Spacing and Tube Wall Measurement (RPS404-27)	$179,000 14 months	NUCON Inspection Services, Inc./*C. Welty*

New Technical Reports

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

CUSTOMER SYSTEMS

Guide for the Selection of Supermarket Refrigeration Systems
CU-6740 Final Report (RP2569-6); $100
Contractor: Foster-Miller, Inc.
EPRI Project Managers: M. Blatt, M. Khattar

Food Industry Scoping Study
CU-6755 Final Report (RP2782-9); $100
Contractor: Resource Dynamics Corp.
EPRI Project Manager: A. Amarnath

Pinch Technology: A Primer
CU-6775 Final Report (RP2783-13); $100
Contractor: Linnhoff March, Inc.
EPRI Project Manager: A. Amarnath

Packaged Terminal Heat Pump Assessment Study
CU-6777 Final Report (RP2480-2); $100
Contractor: Joseph A. Pietsch, P.E.
EPRI Project Manager: M. Blatt

Future Cogeneration Technologies
CU-6795 Final Report (RP2950-3); $995
Contractor: SFA Pacific, Inc.
EPRI Project Managers: H. Gransell, W. LeBlanc

ENVIRONMENT

Environmental Research Conference on Groundwater Quality and Waste Disposal
EN-6749 Proceedings (RP2485); $62.50
EPRI Project Manager: I. Murarka

Sulfur Dioxide and Ozone Effects on Crops
EN-6785 Final Report (RP2371-3); $32.50
Contractor: Cornell University
EPRI Project Manager: L. Pitelka

The Phytosystem as a Sink for Carbon Dioxide
EN-6786 Special Report; $25
Contractor: J. L. Kulp
EPRI Project Manager: R. Perhac

The Prediction and Interpretation of Chemical Movement Through Porous Media: The Transfer Function Model Approach
EN-6853 Final Report (RP2485-6); $25
Contractor: University of California, Riverside
EPRI Project Manager: D. McIntosh

ELECTRICAL SYSTEMS

Conductor Fatigue Life Research
EL-6607 Final Report (RP1278-1); $70
Contractor: Auburn University
EPRI Project Manager: J. Porter

CRAFT: On-Line Expert System for Customer Restoration and Fault Testing, Vol. 1
EL-6680 Final Report (RP2944-1); $25
Contractor: University of Washington
EPRI Project Manager: D. Curtice

Security Analysis Software Needs: Survey Results
EL-6753 Final Report (RP2473-37); $25
Contractor: EPIC Engineering, Inc.
EPRI Project Manager: D. Curtice

Photovoltaic Generation Effects on Distribution Feeders, Vol. 1
EL-6754 Final Report (RP2838-1); $25
Contractor: New England Power Service Co.
EPRI Project Manager: W. Shula

EXPLORATORY RESEARCH

Specific Biocatalysis for Coal Sulfur Speciation and Removal
ER/GS-6624 Interim Report (RP2655-19; RP8003-16); $25
Contractors: Johns Hopkins University; National Institute of Standards and Technology
EPRI Project Managers: L. Atherton, C. Kulik

Alternative Cathodes for Molten Carbonate Fuel Cells
ER/GS-6831 Final Report (RP2278-7); $25
Contractor: Ceramatec, Inc.
EPRI Project Manager: W. Bakker

GENERATION AND STORAGE

Power Plant Performance Monitoring and Improvement, Vol. 8: Characteristics Needed for Dispatch
CS/EL-4415-L Final Report (RP1681-2; RP2153-2); $32.50
Contractor: Potomac Electric Power Co.
EPRI Project Managers: R. Leyse, D. Maratukulam

Guidelines for Makeup Water Treatment
GS-6699 Final Report (RP2712-4); $1000
Contractor: Sheppard T. Powell Associates
EPRI Project Manager: B. Dooley

1989 EPRI Gas Turbine Procurement Seminar
GS-6745 Proceedings (RP2565-6); $2500
Contractor: Energy Systems Associates
EPRI Project Manager: H. Schreiber

NUCLEAR POWER

Guidelines for Performance-Based Supplier Audits (NCIG-16)
NP-6630 Final Report (RPQ101-19); $25
Contractor: Science Applications International Corp.
EPRI Project Manager: W. Bilanin

Effect of Different Thermal Treatments on the Corrosion Resistance of Alloy 690 Tubing
NP-6703-M Final Report (RPS408-2); $25
Contractor: Inco Alloys International, Inc.
EPRI Project Managers: C. Shoemaker, A. McIlree

Measurement of Surface-Induced Microplasticity in Alloy 600 C-Rings
NP-6705-M Final Report (RP2163-2; RPS406-1); $25
Contractor: Rutgers University
EPRI Project Managers: C. Shoemaker, A. McIlree

Microchemistry of Corroded Intergranular Surfaces: Tubes Removed From Point Beach Unit 1, Calvert Cliffs Unit 1, and Saint Lucie Unit 1 Steam Generators
NP-6709-M Final Report (RPS407-15); $25
Contractor: Calgon Corp.
EPRI Project Managers: C. Shoemaker, J. Paine

Evaluation of Upper-Shelf Toughness Requirements for Reactor Pressure Vessels
NP-6790-M Final Report (RP1757-78; RP2455-19; RP2975-10); $25
Contractors: Novetech Corp.; Materials Engineering Associates; Georgia Institute of Technology
EPRI Project Manager: T. Griesbach

Inspection of BWR Pressure Vessel Welds: The Monticello 1989 Reactor Pressure Vessel Examination
NP-6838-D Final Report (RPC105-4); $25,000
Contractor: Northern States Power Co.
EPRI Project Manager: M. Behravesh

Nuclear Power Applications of NASA Control and Diagnostics Technology, Vols. 1–3
NP-6839 Final Report (RP2902-1); Vol. 1, $32.50; Vol. 2, $25; Vol. 3, $25
Contractor: Technology Applications, Inc.
EPRI Project Manager: J. Naser

UTILITY PLANNING

1989 Utility Strategic Issues Forum: What Does the Future Hold for the Electricity Business?
OCSP-6757 Proceedings (RP2997); $100
EPRI Project Manager: S. Feher

Natural Gas Requirements for Electricity Generation Through 2000: Can the Natural Gas Industry Meet Them?, Vols. 1 and 2
P-6821 Final Report (RP2369-44); Vol. 1, $32.50; Vol. 2, $25
Contractor: Jensen Associates, Inc.
EPRI Project Manager: H. Mueller

CALENDAR

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

OCTOBER

16
Phased Construction of Coal Gasification–Combined-Cycle Power Plants
Palo Alto, California
Contact: George Booras, (415) 855-2471

16
Seminar: Highway Ash Utilization
Pittsburgh, Pennsylvania
Contact: Dean Golden, (415) 855-2516

16–18
Fuel Supply Seminar
Memphis, Tennessee
Contact: Howard Mueller, (415) 855-2745

16–18
Operator Training Simulator
Philadelphia, Pennsylvania
Contact: Neal Balu, (415) 855-2834

16–19
4th Annual EPRI/Utility EMF Seminar
Austin, Texas
Contact: Bob Black, (415) 855-2735

17–18
Coal Gasification Power Plants
Palo Alto, California
Contact: Neville Holt, (415) 855-2503

17–18
Utility Renewable Resources Association
Sunnyvale, California
Contact: Jonne Berning, (415) 855-2463

17–19
AIRPOL/90 Seminar: Solving Corrosion Problems in Air Pollution Control Equipment
Louisville, Kentucky
Contact: Paul Radcliffe, (415) 855-2720

22–24
Optical Disks: Information Technology for the Power Industry
Washington, D.C.
Contact: Lew Rubin, (415) 855-2743

23–24
Food Processing Industry Workshop
San Francisco, California
Contact: Ammi Amarnath, (415) 855-2548

30–31
Security Enhancement and System Operations Products
Denver, Colorado
Contact: Neal Balu, (415) 855-2834

30–November 2
Vibration Testing and Analysis
Eddystone, Pennsylvania
Contact: Sam Haddad, (415) 855-2172

31–November 1
1990 Fuel Oil Utilization Workshop
Arlington, Virginia
Contact: William Rovesti, (415) 855-2519

31–November 2
Wide-Area Disaster Preparedness
San Francisco, California
Contact: Ben Damsky, (415) 855-2385

NOVEMBER

1–2
T&D Cable Installation
St. Petersburg, Florida
Contact: Tom Rodenbaugh, (415) 855-2306

13–16
Symposium: Electric Utilities and Their Power Quality Program
Santa Barbara, California
Contact: Marek Samotyj, (415) 855-2980

14–16
Flexible AC Transmission (FACTS): System Considerations
Cincinnati, Ohio
Contact: Dominic Maratukulam, (415) 855-7974

14–16
1990 Electric Utility Market Research Symposium
Atlanta, Georgia
Contact: Thom Henneberger, (415) 855-2885

27–29
Thermography
Eddystone, Pennsylvania
Contact: Gordon Allen, (415) 855-2219, or Mike Downs, (415) 855-7940

28–29
NSAC/Operational Reactor Safety Engineering and Review Group Workshop: Self-Assessment During Plant Shutdown
Seattle, Washington
Contact: Bill Reuland, (415) 855-2977

DECEMBER

3–5
Symposium: Macrofouling
Orlando, Florida
Contact: Norris Hirota, (415) 855-2084

4–6
Fossil Fuel Plant Cycling
Washington, D.C.
Contact: Maureen Barbeau, (415) 855-2127

4–6
Workshop: Underground Cable Water Treeing
Phoenix, Arizona
Contact: Bruce Bernstein, (415) 855-5225

5–7
Workshop: Applications of Chaos
San Francisco, California
Contact: Jong Kim, (415) 855-2671

5–7
Workshop: Terry Turbine Controls
Orlando, Florida
Contact: Bob Kannor, (415) 855-2018

11–12
Diesel Generator Diagnostics
Eddystone, Pennsylvania
Contact: Sam Haddad, (415) 855-2172

12–14
Workshop: Fossil Fuel Plant Control and Automation
Phoenix, Arizona
Contact: Murthy Divakaruni, (415) 855-2409

JANUARY 1991

22–25
9th International Coal Ash Utilization Symposium
Orlando, Florida
Contact: Dean Golden, (415) 855-2516

FEBRUARY

6–8
Symposium: New Equipment and Services for Foodservice Customers
New Orleans, Louisiana
Contact: Karl Johnson, (415) 855-2183

MARCH

25–28
1991 Symposium on Stationary NO_x Control
Washington, D.C.
Contact: David Eskinazi, (415) 855-2918

APRIL

2–5
Improved Coal-Fired Power Plants
San Francisco, California
Contact: James Valverde, (415) 855-7998

16–18
Radiation Field Control
Palo Alto, California
Contact: Howard Ocken, (415) 855-2055

Authors and Articles

Geraghty

Young

Iveson

Malcolm

Carmichael

Esselman

Weiss

Cain

Reaching Out With Two-Way Communications (page 4) was written by John Douglas, science writer, with guidance from a number of EPRI staff members.

Dom Geraghty, director of EPRI's corporate and strategic planning since late 1989, served the previous three years as executive assistant to EPRI President Richard Balzhiser. Earlier he was a technical manager in the Institute's Utility Planning Methods Center, where he developed information on plant investment options, including analytical techniques and software to aid in decision making. He joined EPRI in 1977 after spending four years as an engineer and energy analyst with Irish government agencies.

Frank Young, director of the Electrical Systems Division since 1987, was EPRI's manager of strategic planning for the previous six years. He came to the Institute in 1975 after 20 years with Westinghouse Electric, where he became manager of UHV transmission research.

Bob Iveson, a staff technical adviser since 1988, formerly managed the Power System Planning and Operations Program. Iveson came to EPRI in 1980 after 20 years with New York State Electric & Gas. His work there included nine years as supervisor of transmission planning for the New York Power Pool.

Wade Malcolm, on loan from Philadelphia Electric, is focusing at EPRI on integrated utility communications and distribution system automation projects. As an engineer in Philadelphia Electric's Research Division and Electric Transmission and Distribution Department, he worked in a variety of areas, including radio communication systems and new uses of personal computers and minicomputers.

Larry Carmichael is a senior project manager in the Power Electronics and Controls Program, concentrating on the development and application of load control and metering equipment. Before joining EPRI in 1985, he was with Science Applications, Inc., for two years and with Systems Control, Inc., from 1979 to 1983. From 1962 to 1979, Carmichael was principal engineer with General Electric's nuclear utility operation in San Jose, California. ■

Optical Sensing for Power Plants (page 14) was written by David Boutacoff, *Journal* feature writer, with information provided by EPRI staff members.

Walter Esselman, consultant to the Office of Exploratory Research, has been with the Institute since 1975, serving successively as manager of R&D planning, director of strategic and assessment planning, and director of engineering assessment and analysis. Before coming to EPRI, Esselman was with Westinghouse Electric for 36 years, where he helped organize and staff the company's astronuclear laboratory, directed the Hanford Engineering Development Laboratory, and directed strategic planning for nuclear energy systems.

Joseph Weiss, a project manager for nuclear plant operations and maintenance, oversees research in instrumentation and diagnostics. He came to EPRI in 1987, following nine years at General Electric and five years in consulting, during which he worked on instrumentation issues for the nuclear power industry. ■

EPRIGEMS: Medium of Choice for Tech Transfer (page 22) was written by science writer John Douglas, with technical guidance from **David Cain**.

Cain has been involved in software applications development since joining the Institute's Nuclear Power Division in 1974. He initially specialized in instrumentation and control, real-time monitoring and diagnostics, and component aging, and he worked with the Nuclear Safety Analysis Center in 1979 on the investigation of the Three Mile Island accident. Subsequent projects have focused on applications of artificial intelligence technology. Since 1988 Cain has been manager of the Institute's EPRIGEMS project, working under the Membership Division in close cooperation with all of EPRI's technical divisions. ■

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