Electrotechnologies for Clean Water

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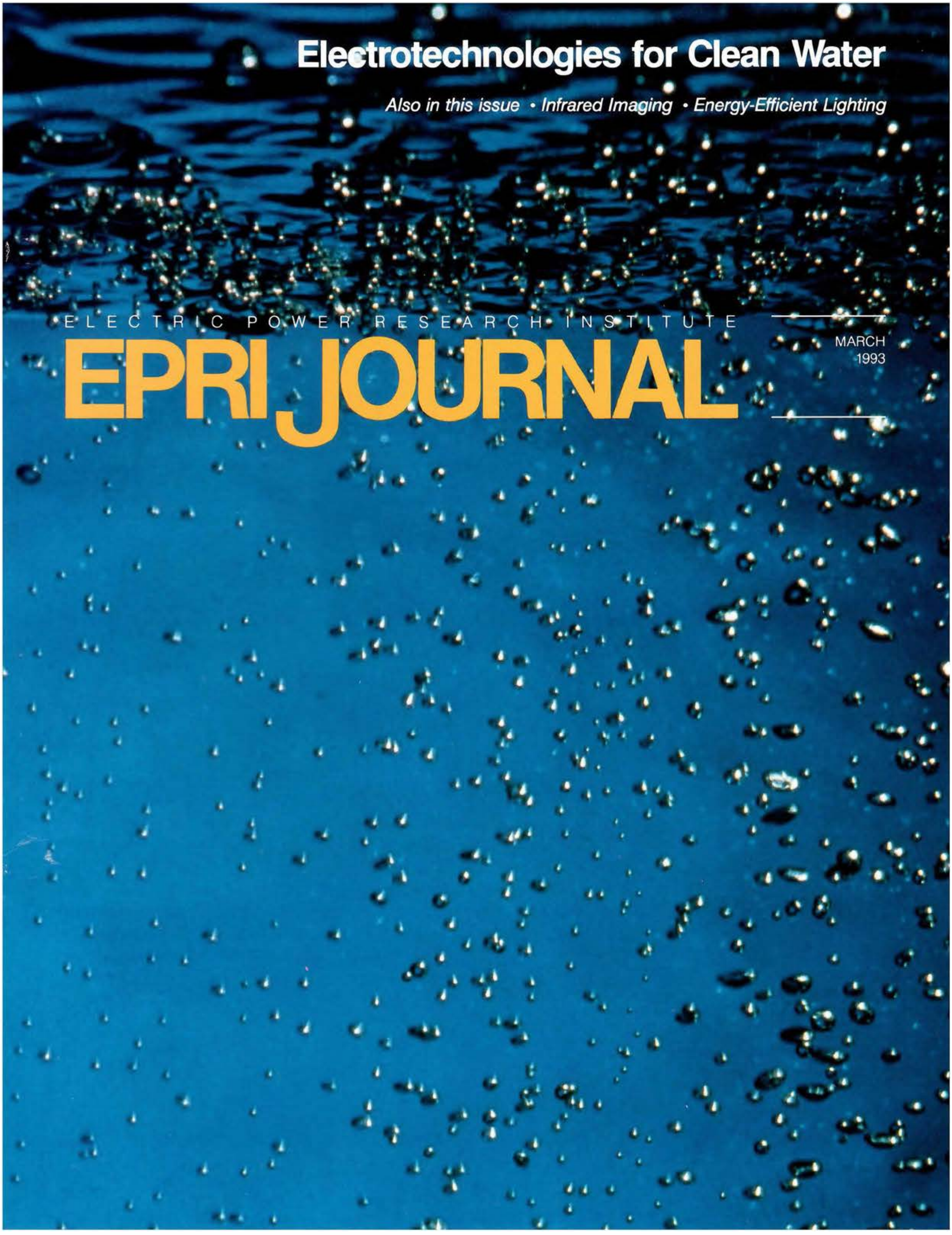

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Cover: Disinfecting potable water by bubbling ozone through it is a highly effective and environmentally superior alternative to chlorination.

Opportunity for Partnerships

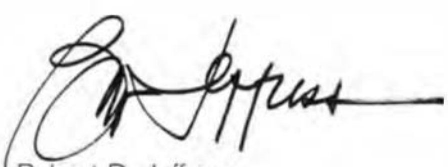
The water and wastewater industries servicing our nation's communities are undergoing rapid transformation, as existing water treatment systems are being modified or replaced to meet stringent new federal and state environmental regulations. Most technologies to be adopted will be electrically rather than chemically based, and as this month's cover story points out, that presents unique opportunities for electric utilities to work with a major customer class for mutual benefit and community progress.

Recognizing the importance of maintaining and improving the urban infrastructure for the benefit of all citizens, EPRI and its members have taken the lead in developing partnerships toward the development and deployment of new technologies that water and wastewater utilities can use in support of their local communities. Many of our R&D efforts have focused on new technologies needed for environmental compliance—ozone treatment for potable water, ultraviolet treatment of wastewater, and advanced reverse-osmosis designs for desalination facilities, among others.

However, potential opportunities extend beyond water treatment technologies. Currently 3% of the electric power consumed in the United States is used for water treatment. Efficiency improvements now available for such mundane items as pumps and air compressors can substantially reduce water facilities' operating costs while supporting electric utilities' demand-side management objectives. Significant cost reductions can often be achieved immediately through the use of advanced motors and adjustable-speed drives. In some seacoast regions where potable water is in short supply, it may make economic and environmental sense for water and power utilities to become even more closely connected—through the construction of desalination facilities right at electric power plants.

Perhaps most important are the strong partnerships EPRI has formed with the American Water Works Association Research Foundation, the Water Environment Research Foundation, and several dozen other participants in the Industrial Program's Municipal Water and Wastewater (MWW) Project. Through this project, electric utilities and water-related utilities are working together to address shared concerns about the environment, the public service infrastructure, and rising costs.

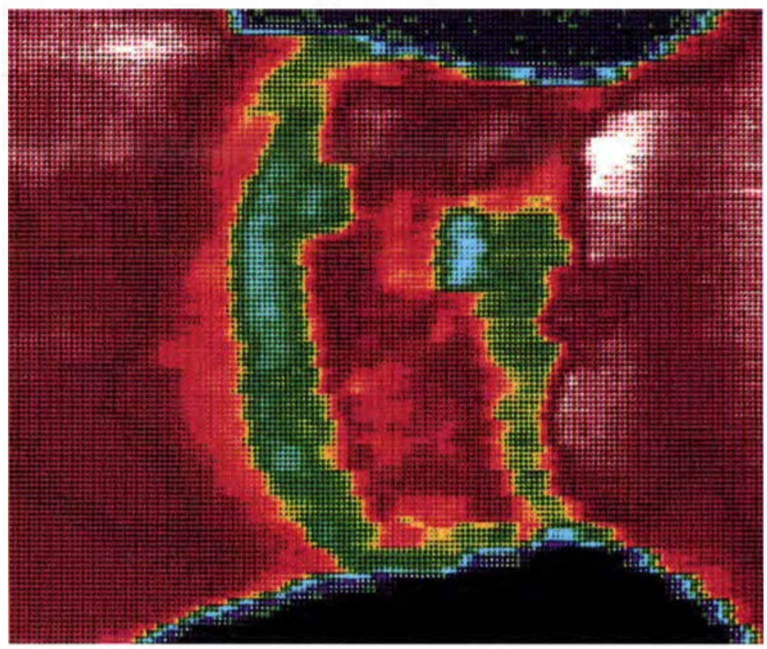
Changes in water and wastewater treatment requirements represent only one of a growing number of infrastructure challenges to the nation's urban environment. Our objective is to build on the experience with the MWW Project to establish a new center—the Community Environmental Center—that will expand opportunities for partnerships into such areas as solid waste management and medical waste disposal. I urge other interested EPRI members to join us in this effort.



Robert D. Jeffress
Manager, Industrial Program
Customer Systems Division

22 Compact Fluorescents

RESEARCH UPDATE



14 Infrared Imaging

DEPARTMENTS

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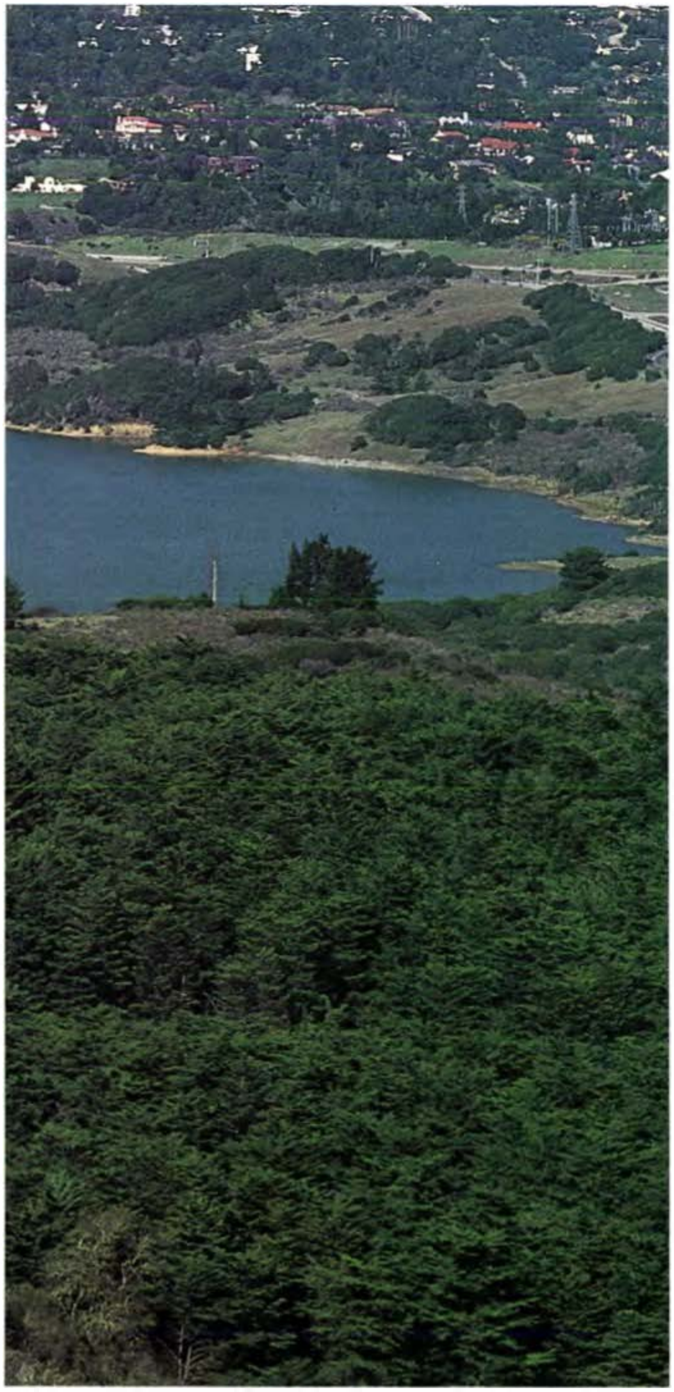
Volume 18, Number 2 March 1993



4 Water Treatment

Electrotechnologies

by John Douglas

THE STORY IN BRIEF Water and wastewater utilities face major changes in their treatment systems as a result of recent environmental regulations. Not only do these new rules specify reduction requirements for contaminants not previously regulated, they also target the by-products of chlorination, which has been the basic disinfection technique in this country since the early days of municipal water treatment. As a result, EPRI has been working with the American Water Works Association Research Foundation and the Water Environment Research Foundation to support the development of advanced treatment alternatives and improve energy efficiency at treatment facilities. The work has identified a number of innovative, electrically based treatment technologies that provide the additional capabilities required, promote higher efficiency in treatment processes, and serve electric utilities' demand-side management objectives.

for Water Treatment

A hallmark of the complexity of modern life is that many things once taken for granted can no longer be ignored. Consider safe drinking water, for example. Various means of disinfecting water have been used since the mid-nineteenth century, and the first continuous chlorination of a public water supply in the United States was inaugurated in 1908. Disinfection processes then changed little until the 1970s, when the development of advanced analytical equipment led to the discovery that chlorine could react with organic material in water to form compounds, such as chloroform, that are carcinogenic. By the 1980s, more concerns had arisen about whether conventional water treatment, designed to kill bacteria, was also adequate to protect the public against infection by parasites and viruses.

As a result of these and other health and environmental considerations, new regulations affecting the treatment of both drinking water and wastewater have recently been imposed. For many municipal water utilities, these regulations mean that additional treatment steps must be added and that new technologies will be needed—generally increasing both energy consumption and treatment costs.

Because the potable water and wastewater treatment industries consume approximately 2–3% of total U.S. electric power, electric utilities have an important stake in these changes; moreover, this segment of electricity demand is expected to grow by some 40% over the next 20 years, in part because of the new regulations and in part because of population growth. Consequently, EPRI has been working with the American Water Works Association Research Foundation (AWWARF) and the Water Environment Research Foundation (WERF) to improve energy efficiency at treatment facilities and to support the development of advanced treatment alternatives. This collaborative effort, initiated in 1990 and called the Municipal Water and Wastewater (MWW) Project, will help water and wastewater utilities reduce electricity and environmental compliance costs while enabling electric utilities to meet demand-side management (DSM) objectives (see sidebar). The project currently has 42 participants, including individual electric utilities, state and federal agencies, and private research organizations.

"Most water and wastewater utilities are having budget problems, and since energy is a major cost, that's where changes can be made that will benefit both the utilities and their ratepayers," says Charles Noss, director of research at WERF. "The MWW Project helps fill a gap in research that other funding agencies are not addressing. EPRI is looking at fundamental development issues, taking new technologies from the laboratory and putting them into useful demonstration."

Regulations and treatment strategies

Most of the drinking water used by large community systems comes from surface sources, such as lakes and rivers. Many smaller systems and a few large systems rely on groundwater from wells. The treatment of water from surface sources usually involves both the physical removal of suspended material, through sedimentation and filtration, and chemical disinfection, usually with chlorine. For many groundwater systems, disinfection is the only treatment, and some groundwater is not treated at all.

Many water utilities are having to make major changes in their treatment procedures because of 1986 amendments to the Safe Drinking Water Act. In particular, numerous treatment facilities will have to be upgraded by June 1993 to meet new requirements for the reduction of viruses and cyst-forming parasites, such as *Giardia lamblia*. By 1996, water utilities will also have to comply with new regulations for limiting by-products of disinfection, such as chloroform, in potable water.

On the wastewater side, treatment in the United States has already been going through major changes for several years, and more improvements will soon be required. In response to the federal Clean Water Act of 1972—the goal of which was to achieve "fishable and swimmable" surface waters throughout the country—the number, size, and complexity of wastewater treatment facilities have already grown rapidly. More recently, the Water Quality Act of 1987 strengthened federal water quality regulations and placed new emphasis on the control and disposal of sludge formed during wastewater treatment.

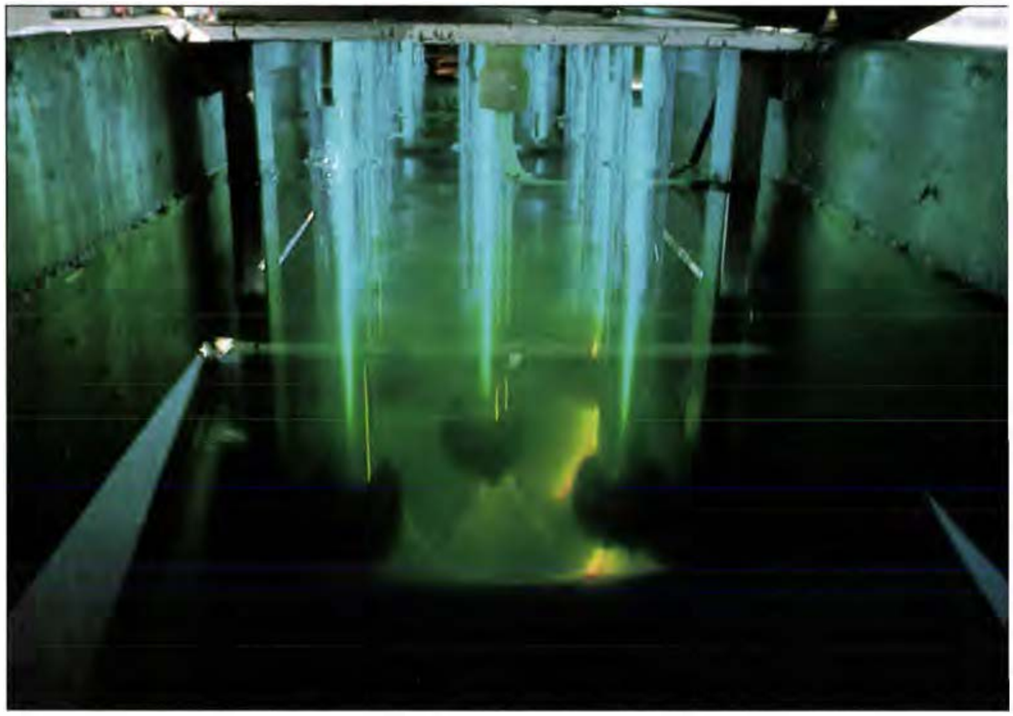
Virtually all wastewater systems use some form of preliminary treatment—the removal of coarse solids, such as debris and grit—and primary treatment, in which screening and sedimentation are

Ozonation pilot plant, Kansas City, Kansas

OZONE DISINFECTION The use of ozone to disinfect drinking water, practiced in Europe for a century, is just now being pursued in the United States as a substitute for less-expensive but environmentally problematic chlorination processes. Ozone is produced by electric corona discharge through air or oxygen and is then bubbled through water to inactivate *Giardia* cysts and destroy organic materials and herbicide residues.

Producing ozone with corona discharge

UV DISINFECTION Ultraviolet light will quickly kill bacteria and viruses, which are the primary contaminants in wastewater. The water is channeled through a bank of several thousand fluorescent lamps made from special quartz glass that transmits 90% of UV light. Unlike chlorination approaches, UV treatment leaves no residual contaminants.



UV system at Central Contra Costa Sanitary District, California

used to remove a portion of the suspended solids and organic materials. Because this level of treatment allows a considerable amount of organic material to remain in the effluent, however, plants that rely only on these two steps will generally have to be upgraded under the new regulations by adding secondary and advanced treatment.

Secondary treatment is directed principally toward the removal of biodegradable organics and suspended solids and toward disinfection. Secondary treatment usually involves aeration of the wastewater, separation of sludge, and chlorination of the final liquid effluent. Procedures for the removal of nitrogen and phosphorus nutrients may also be included to prevent blooms of algae and aquatic plants in lakes or other deleterious effects in streams and groundwater. Advanced wastewater treatment is defined as the need for processes beyond conventional secondary treatment in order to remove nutrients, toxic compounds, organic material, and suspended solids. The number of secondary and advanced treatment facilities is expected to grow significantly during the next several years, together with a need for new ways to treat and dispose of the increased amount of sludge that will be produced.

Some of the changes required in the treatment of water and wastewater can be implemented by enhancing or modernizing existing facilities. In some cases, however, new technologies will be needed.

Electrotechnologies for disinfection

Disinfection is the key to water and wastewater treatment. As new regulations place tighter restrictions on the treatment of potable water, wastewater, and sludge, several new technologies offer attractive alternatives to traditional treatment methods, some of which have changed little in the last hundred years. Most of these new technologies are electrically based in order to achieve greater effectiveness, higher efficiency, lower environmental impact, or some combination of these factors. EPRI has been actively involved in the evaluation of these electrotechnologies and, in some cases, is sponsoring demonstrations in cooperation with member utilities.

Although chlorination remains the leading generic disinfection treatment for potable water, a search is under way to find alternatives that are more effective against *Giardia* and viruses and that produce fewer disinfection by-products (DBPs). All public water systems using surface water must now achieve a 99.9% reduction of *Giardia* cysts and a 99.99% reduction of viruses. Current regulations limit the maximum levels of certain DBPs to 100 parts per billion, but a much more restrictive rule to limit combined *total* DBPs to 50 ppb is under consideration.

For inactivation of *Giardia* cysts, disinfection with ozone (O_3) can be 100 to 300 times more effective than disinfection with chlorine, while reducing DBPs. Ozonation also destroys many of the organic materials in drinking water that can give it an objectionable taste or odor. The reduction of herbicide residues in water supplies can also be achieved with ozonation, as demonstrated in an EPRI-funded project with Union Electric Company and the St. Louis County Water Company. Ozone has been used to disinfect potable water since 1893 in Europe, where such treatment is now quite common. Only a few ozonation facilities are currently operating in the United States, but a number are either under construction or being designed.

Ozone is produced from oxygen by means of an electric discharge through air or pure oxygen that is passing between concentric tubular electrodes. (Ozone generators differ primarily in the percentage of initial oxygen enrichment, the frequency and voltage of power supplied, and the configuration and materials used in the generator cells.) The ozone-enriched gas is then bubbled through water, and the residual ozone is destroyed or recycled. Since ozone treatment leaves no residual disinfection capability in the water, a small dose of chlorine or a chlorine compound is usually added to the purified

Help for Small Community Systems

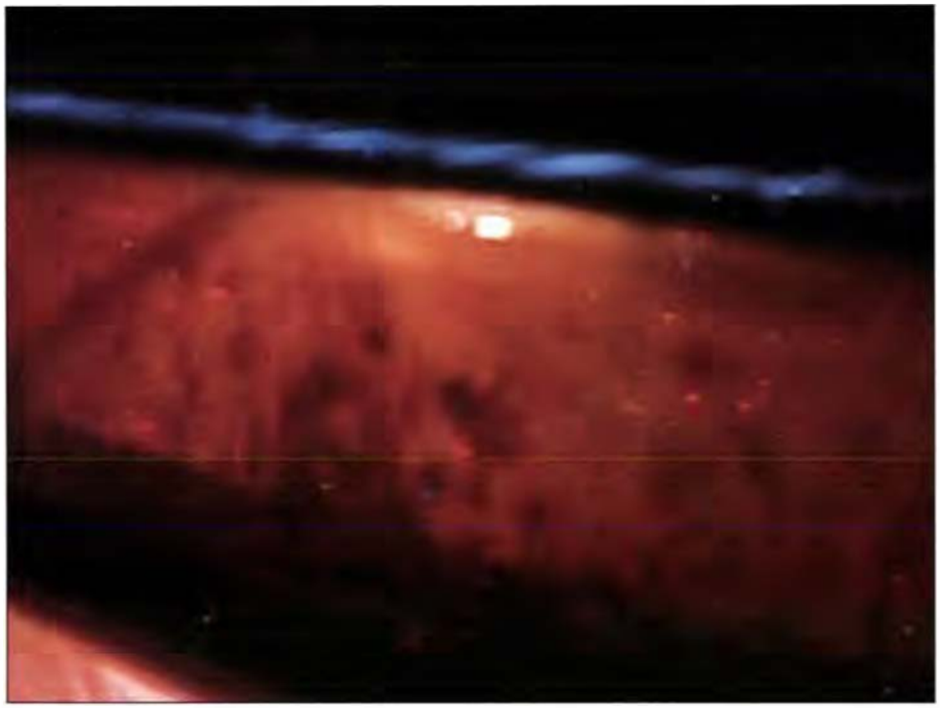
Many small U.S. communities lack the financial resources to bring their water and wastewater facilities into compliance with new regulations. As a result, these communities are responsible for some 90% of current water quality violations. To see how electric utilities could help, EPRI, the Environmental Protection Agency, the American Water Works Association Research Foundation (AWWARF), and the National Rural Electric Cooperative Association (NRECA) sponsored a study of small community treatment systems and identified both short- and long-term actions that water and electric utilities can undertake cooperatively.

The depth of the problem is illustrated by considering the case of Oregon, a relatively rural state with one major urban corridor. Approximately 90% of the total water systems in the state serve populations of under 3300. The total cost of improving these small systems is estimated to be $225 million—as much as $12,000 per person served. The median family income in the rural areas affected, however, ranges from about $20,000 to $31,500. In other words, for a family of three, the prorated cost of improving community waterworks would exceed median family income. In addition, some of the technical and managerial skills required to upgrade water and wastewater facilities may not be available in many of these communities.

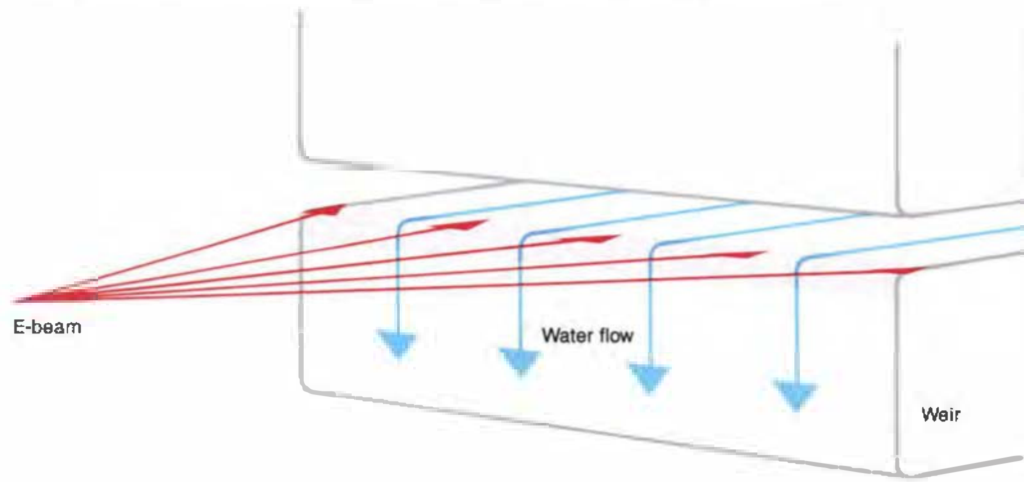
Although many of the institutional and political problems posed by the new regulations remain to be solved, local electric utilities can provide help to many small community water and wastewater systems in a variety of ways. Almost immediately, they can offer technical assistance in developing plans for system upgrading, financial assistance through the design phase, and administrative assistance once a project is completed. Already some utilities, including Buckeye Power in Ohio and Dixie Electric Cooperative in Alabama, have assisted communities in developing improved water systems. Over the long term, utilities can help communities overcome institutional barriers, introduce new technologies, and consolidate treatment systems—either physically or administratively—into more-efficient entities. For example, a utility might undertake monitoring and maintenance duties for several community facilities. Further research on such long-term options is currently being conducted with funding from EPRI, NRECA, and AWWARF. □

water before distribution to prevent recontamination. The small amount needed for this use, however, should remain well below problem levels for chlorine.

The main drawback of ozonation is that its capital and operating costs are considerably higher than those of chlorination. Using ozone to disinfect potable water is about twice as expensive as using chlorine. About 75% of the operating cost is for electricity, however, so specific costs depend on local electricity rates and other factors. Unfortunately, from a DSM point of view, ozone must currently be produced on-site for immediate use, since storage is difficult and dangerous because of its high reactivity. Power use for ozone water treatment therefore generally coincides with the daily utility peak demand—the most expensive time to be buying electricity.



ELECTRON-BEAM DISINFECTION EPRI has sponsored tests of an experimental wastewater disinfection approach that involves bombarding the water with high-energy electrons from a particle accelerator. The fast-moving electrons and the chemical radicals created by their impact have been shown to destroy both microorganisms and organic contaminants. While E-beam disinfection is an intriguing idea, more work will be required to demonstrate its practicality. The blue light in the photo reveals the line where electrons strike the water flowing over the weir.

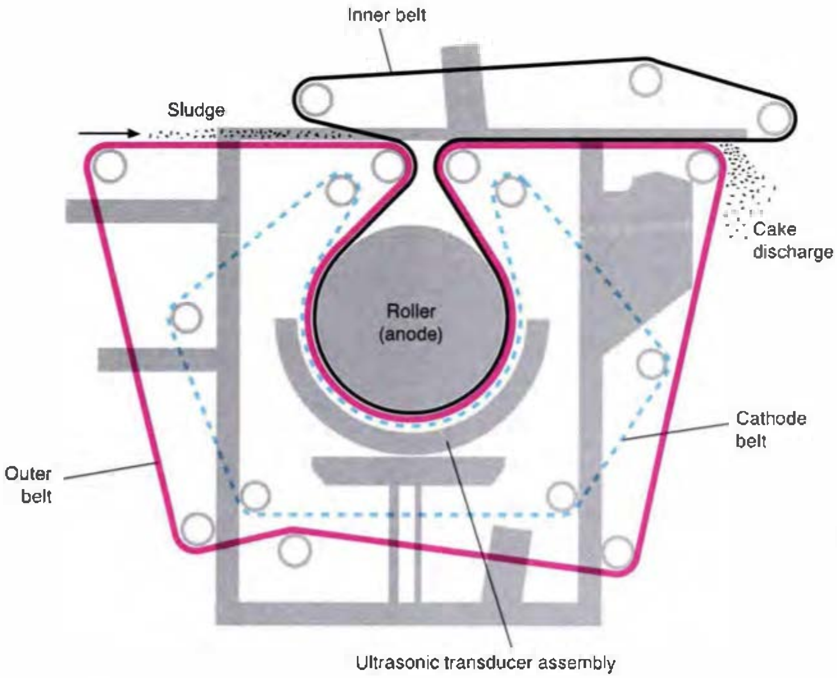


For the disinfection of wastewater, ultraviolet (UV) treatment not only offers several advantages but also promises to be less costly, especially in terms of capital investment for new facilities. Compared with chlorination, UV offers these advantages: it disinfects wastewater without the need to store or handle dangerous chemicals; the short contact times needed with UV make it practical to reduce the size of treatment tanks; and the absence of moving parts considerably simplifies the operation. Because UV does not inactivate *Giardia* cysts, it is generally not a good candidate for treating potable water from surface sources, but it may be an option for disinfecting groundwater where *Giardia* is not a problem.

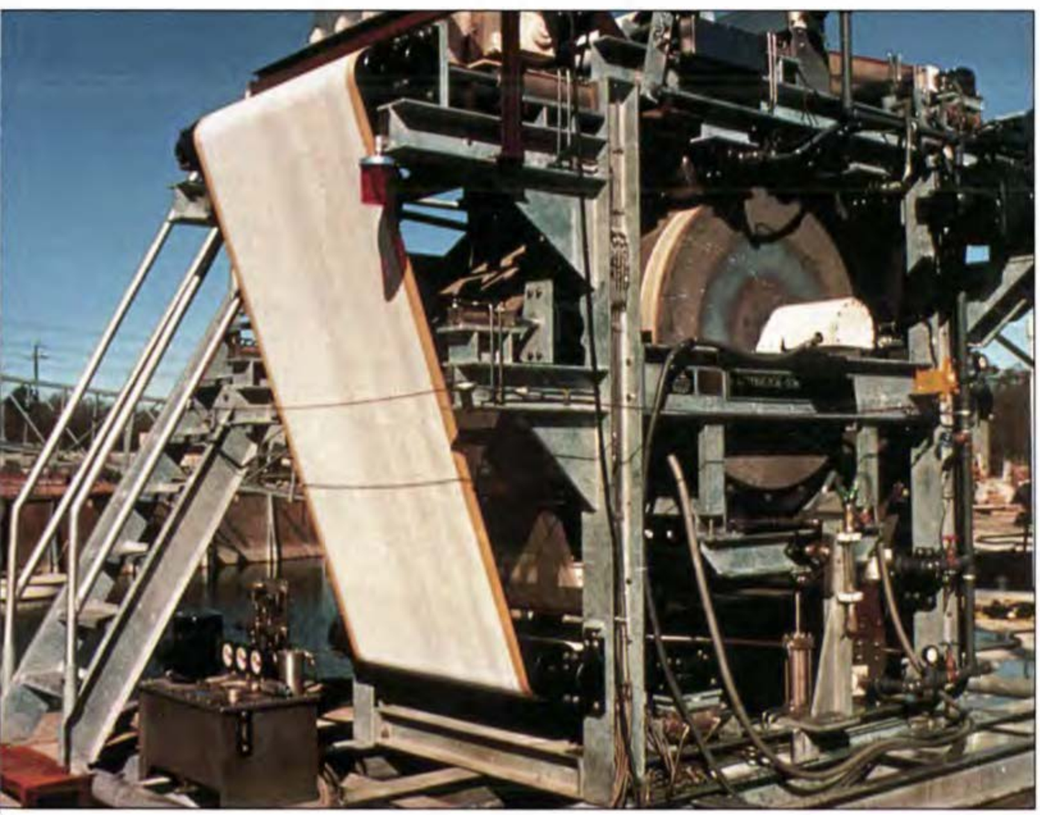
UV disinfection systems consist of a network of several thousand fluorescent lamps with special quartz glass that transmits 90% of UV light. Wastewater is channeled between the lamps, where exposure to UV quickly kills the bacteria and viruses that are the predominant contaminants. The absence of any chlorine byproducts means that treatment facilities using UV do not have to dechlorinate the effluent after disinfection to prevent environmental damage. Current regulations limit total residual chlorine to 19 ppb for effluents discharged to fresh water and 13 ppb for those discharged to salt water. As a result, many wastewater facilities are either installing dechlorination equipment or seeking residual-free alternatives, such as UV treatment. An EPRI evaluation of ozone and UV systems for disinfection has been completed.

An experimental electrotechnology that can disinfect wastewater while also destroying toxic organic compounds has recently been demonstrated with EPRI funding. Called electron-beam (or E-beam) disinfection, this process involves the use of an accelerator that shoots high-energy electrons into wastewater. E-beam technology has long been used in manufacturing plastics, where the electrons break long molecular chains, creating cross-links to strengthen polymers. More recently, electron beams have also been used to sterilize medical equipment and food.

In wastewater, the fast-moving electrons and the chemical radicals created by their impact destroy both microorganisms and the organic molecules often found in industrial waste. During February 1992, EPRI sponsored multiple tests of E-beam disinfection on wastewater at the Palo Alto, California, Regional Water Quality



ELECTROACOUSTIC SLUDGE DEWATERING
In electroacoustic dewatering, sludge is sandwiched between two belts that are pressed against a large roller and subjected to an electric field and ultrasonic sound. The mechanical pressure and high-frequency sound waves separate the solid and liquid fractions of the sludge, and the electric field pulls the fractions in opposite directions.



Control Plant, using a 1-kW linear accelerator developed by Nutek Corporation of Palo Alto. These tests established the E-beam dose required for disinfection and also showed that system effectiveness is extremely sensitive to flow control configuration and beam shape. EPRI is considering further demonstrations of this technology with higher-power E-beam generators.

Dealing with sludge

The big problem with sludge produced as a by-product of water and wastewater treatment is, of course, how to get rid of it. Currently, some of it is composted, some landfilled, some incinerated, and some spread on land. If better methods could be found to dewater sludge, its disposal costs would be reduced, and beneficial uses—for example, as a soil amendment or fertilizer—would be promoted. EPRI is supporting the development of two promising electrotechnologies for sludge dewatering.

In electroacoustic dewatering (EAD), sludge is sandwiched between two belts that are pressed against a roller while being subjected to an electric field and ultrasonic sound. The high-frequency sound waves agitate and separate the solid and liquid fractions of the sludge, and then the electric field pulls the fractions in opposite directions. An EPRI-sponsored demonstration of EAD is expected to begin in 1993 at three municipal sewage treatment plants in North Carolina; the equipment is manufactured by Ashbrook-Simon-Hartley of Houston, Texas, and Duke Power Company is the host utility.

Testing of a mechanical freeze/thaw dewatering process is under way at the New Jersey American Water Company with EPRI funding. Jersey Central Power & Light Company is the host utility. In this technique, a slurry of water treatment sludge is dropped into the refrigeration chamber of a commercial ice maker. As the sludge freezes on the surface of refrigerated plates in the chamber, the solids agglomerate and become easy to separate from the liquid fraction.

Photos courtesy of Ionics, Inc. (Mark Mattivi)

Reverse-osmosis units at Diablo Canyon nuclear plant

Santa Barbara, California, desalination facility

REVERSE-OSMOSIS DESALINATION Advanced designs have made reverse osmosis and other processes more economical for seawater desalination projects and for the reclamation of wastewater at power plants. Studies have shown that locating power and desalination plants at the same site can lower costs by minimizing power distribution costs and enabling shared use of expensive intake and discharge structures.

Desalination and water reuse

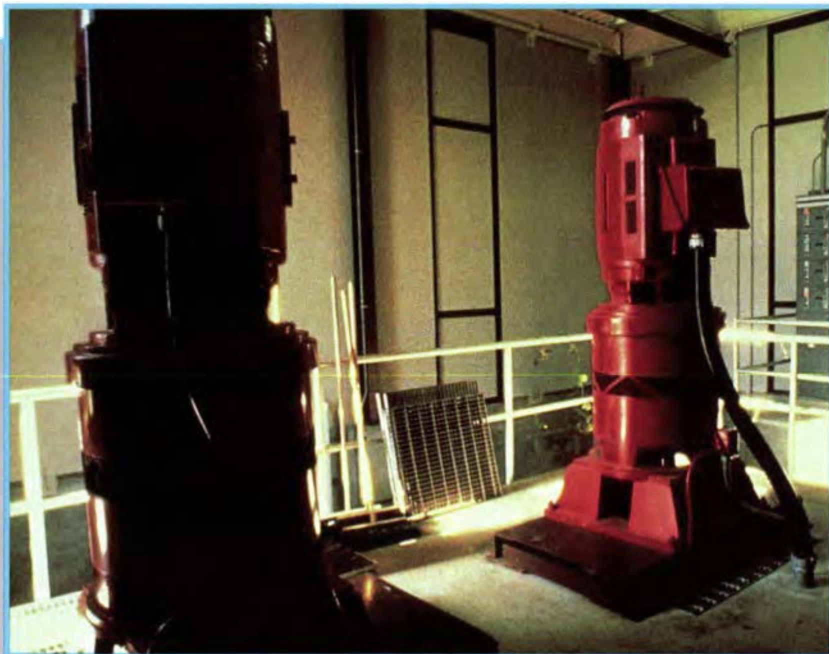
In coastal areas with limited freshwater resources—including some heavily populated regions of the East Coast, the Gulf Coast, and California—utilities can play an even more direct role in providing potable water, through the desalination or reclamation of wastewater at power plants. A lack of sufficient water supplies has impeded economic development in some impacted areas. Since all desalination and water-recycling processes are energy-intensive, some advantages of such combined power and water facilities are obvious: either waste heat or electricity could be provided with minimal distribution costs and losses. As recent studies conducted for EPRI and Florida Power & Light Company (FPL) show, however, the potential synergism goes even deeper.

Siting power and desalination plants together also provides an opportunity for the sharing of facilities that would otherwise be duplicated. Probably the most important of these are seawater cooling intake and discharge structures, which typically represent some 20% of the capital cost of a desalination plant. Adding such a facility to an existing power plant can eliminate the need for building new intake and discharge structures. Combining these facilities could also have environmental benefits. Warm effluent from a power plant normally flows near the ocean surface after discharge, while the dense brine produced by desalination sinks quickly to the ocean floor. Mixing the two could more closely approximate neutral buoyancy, enabling the combined effluent to mix more rapidly with the surrounding water and thus minimizing ecological effects.

Technological developments, too, have stimulated interest in combining power and desalination facilities. Low-temperature, multieffect distillation (LT-MED), for example, can make more-efficient use of relatively low-temperature steam from a power plant. Because of its high energy efficiency and suitability for cogeneration, LT-MED has largely displaced older, high-temperature flash evaporation methods, except in energy-rich countries of the Middle East.

Another technological advance, desalination through reverse osmosis (RO), involves the use of electric power directly. In ordinary osmosis, a semipermeable membrane separating plain water and salt water inhibits the passage of dissolved solids but allows water to flow from the region with lower salt concentration to that with higher concentration. This flow can be reversed, however, by applying high pressure to the seawater side—essentially pushing fresh water through the membrane while leaving the salt behind.

At first, RO desalination used flat membranes, which proved to be uneconomical. More recently, however, two advanced designs have made RO more competitive. In a spiral-wound RO module, a layer of porous material that will carry the freshwater product is sandwiched between two membranes. These, in turn, are covered by spacer sheets that provide an inlet for feedwater, and the whole assembly is wound around a hollow tube. Fresh water from the porous central layer of the spiral winding flows through holes into the hollow tube. Such assemblies can withstand pressures as high as 1000 pounds per square inch (psi), enabling them to achieve high flow rates. Spiral-wound RO units are used mainly for desalinating brackish water, which has a lower salt concentration than seawater.



Improving Energy

Most existing water and wastewater facilities were not built with the efficient use of energy in mind. As new and more expensive treatments are required, however, the cost of energy is becoming a more important consideration for plant operators. At the same time, many electric utilities are actively seeking ways to influence the demand for electricity through demand-side management (DSM) programs. Specific DSM objectives differ considerably among utilities, but common goals include strategic energy conservation to reduce the need for adding new facilities and load-shape management to lower demand peaks.

"Water utilities and electric utilities share a mutual area of concern in energy management," says Elizabeth Kawczynski, a senior project manager at the American Water Works Association Research Foundation. "By working with electric utilities, we can take advantage of what they already know about demand-side management. In addition, EPRI offers a lot of expertise about electrotechnologies that we can use to good advantage."

Potable water treatment facilities are particularly attractive candidates for introducing more-energy-efficient technology, since electricity represents about 20–30% of plant operating costs, and 80% of the electric power is used for just one application—pumping water. Under such circumstances, the installation of high-efficiency motors for pumps or of adjustable-speed drives (ASDs) to optimize the performance of existing pump motors can result in significant reductions in energy use and savings on power bills. In many applications, payback periods may be less than three years. Installing more-sophisticated instrumentation and controls to monitor and optimize system operations can facilitate both energy conservation and load-shaping efforts. And if the difference between peak and off-peak power rates is particularly great, the construction of increased storage capacity that can be filled by pumping during periods of low demand may be justified.

In any case, the development of a DSM strategy begins with an energy audit in which the electric and water utilities cooperate to analyze how power is being used and what potential benefits could be achieved by implementing changes. Some electric utilities also offer incentives for industrial customers to undertake DSM measures, including loans or rebates for purchasing high-efficiency equipment. These initiatives can be supplemented by special rate structures that would be applicable to water facilities, such as time-of-use charges and interruptible service discounts.

In a recent example of such efforts, Jersey Central Power & Light Company has been cooperating with the New Jersey American Water Company. After conducting an energy audit, the utilities proposed undertaking a variety of DSM projects. In four projects now completed, ASDs were installed to control several pumps; the result was annual savings of more than $100,000. Other projects currently under evaluation include energy recovery with a turbine generator and replacement of conventional air conditioners with water-source heat pumps. Using commercially available heat pumps to recover heat from treated water to meet process and space-heating needs appears to be a promising DSM option for both water and wastewater treatment facilities.

In wastewater systems, the largest single user of electricity is the aeration system, which accounts for 50–60% of operating costs. Here the challenge is to optimize power utilization in an air compression system that may have a ninefold fluctuation in demand over the course of a day. The installation of dissolved-oxygen monitors and of ASDs that can adjust the operation of aeration equipment as needed can substantially enhance system performance and provide energy savings. Replacing conventional coarse-bubble aeration systems with fine-bubble equipment has resulted in energy savings of 20–35% for many plants. Also, peak load can be reduced by adding wastewater storage ahead of aeration tanks.

Efficiency

Pumping systems and sludge processing are also significant users of electricity in wastewater treatment. In the case of sludge, one valuable DSM measure is to use a lower-horsepower belt press for thickening instead of large centrifuges or filters. The performance of pumps used to move sludge can also be improved significantly through the use of high-efficiency motors and ASDs.

The effectiveness of DSM for wastewater systems was demonstrated at the treatment facility of the city of Columbia, Tennessee, in cooperation with the Tennessee Valley Authority. The project not only saved significant fractions of the plant's energy consumption but also provided improved process control and a reduction in labor costs. The addition of ASDs to some pumps reduced their power consumption by nearly one-quarter. Dissolved-oxygen monitors were also installed, which helped reduce the operator time devoted to adjusting aeration equipment. On the basis of energy savings alone, the payback period for the purchase of the new equipment was expected to be four years.

A study of DSM options for water and wastewater treatment facilities has been completed, with results to be published this year. Myron Jones and Paul Meagher of the Customer Systems Division are the EPRI project managers. The study report concludes: "Utility experience with DSM in the water and wastewater treatment industries has been limited to date. Most of the experiences have been as part of general industrial programs. Because of the industry-specific processes found in water and wastewater treatment, it may be useful for utilities to target these industries specifically." □

The other advanced RO design uses membranes composed of hollow fibers. These fibers have an outer diameter of only 0.1 mm and can withstand pressures as high as 1500 psi. Under pressure, water permeates the fibers and flows down their centers for collection at the end of a bundle of fibers. Hollow-fiber membranes are currently favored for seawater desalination because of their suitability for high-pressure operation and relatively high recovery rates for fresh water.

In the studies for EPRI and FPL, LT-MED and RO desalination systems were evaluated for use at specific power plants for both brackish water and seawater. The results showed that RO technology is less expensive than LT-MED for both water sources because of its lower capital requirements. For seawater desalination, an RO plant can produce fresh water for 20–30% less than LT-MED. Other advantages of RO include ease of implementation, a smaller installation footprint, and greater operating flexibility.

Detailed case studies at particular plants indicated that a 50-million-gallon-per-day desalination plant based on RO technology could produce fresh water at \$1.50–\$2.00 per 1000 gallons from brackish water and at \$2.00–\$3.00 per 1000 gallons from seawater. For comparison, the next-most-efficient technology—LT-MED—would produce fresh water from seawater at about \$2.50–\$5.00 per 1000 gallons. Such figures may seem high in comparison with the average retail cost of water in the United States—about \$1.00–\$1.50 per 1000 gallons—but that cost is the result of heavy government subsidization for such capital projects as aqueduct construction.

EPRI is also sponsoring studies of membrane applications in wastewater reclamation, including the use of reclaimed water for recharging groundwater aquifers or industrial use. Consideration is also being given to the funding of other technologies.

Future initiatives

The diverse research taking place under the Municipal Water and Wastewater Project is currently being coordinated by a project office in Oakland, California, under the direction of a steering committee representing project participants. Plans are now being made to establish a permanent center to manage the MWW Project and related areas of collaborative research, such as solid waste management and medical waste disposal. The new Community Environmental Center is expected to become operational in 1993; like other EPRI technology applications centers, it will provide technical support to member utilities, foster technology transfer, and facilitate collaborative research projects involving multiple industries.

"The field of water and wastewater treatment offers significant opportunities for electric utilities to work with a major industrial customer to the benefit of the whole community," says Myron Jones, project manager for environment and energy management in EPRI's Industrial Program. "Environmental concerns, an aging infrastructure, rising costs, and new regulations have created serious problems for water and wastewater utilities across the country. Finding solutions for these problems will require research and coordination efforts that reach across traditional industry boundaries. Electric utilities can play a major role, as we have already seen in the MWW Project. Once the Community Environmental Center is established, we will be able to expand this work substantially in response to a growing demand for cooperation in providing essential community services." ■

Further reading

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Background information for this article was provided by Myron Jones, Customer Systems Division.

by Taylor Moore

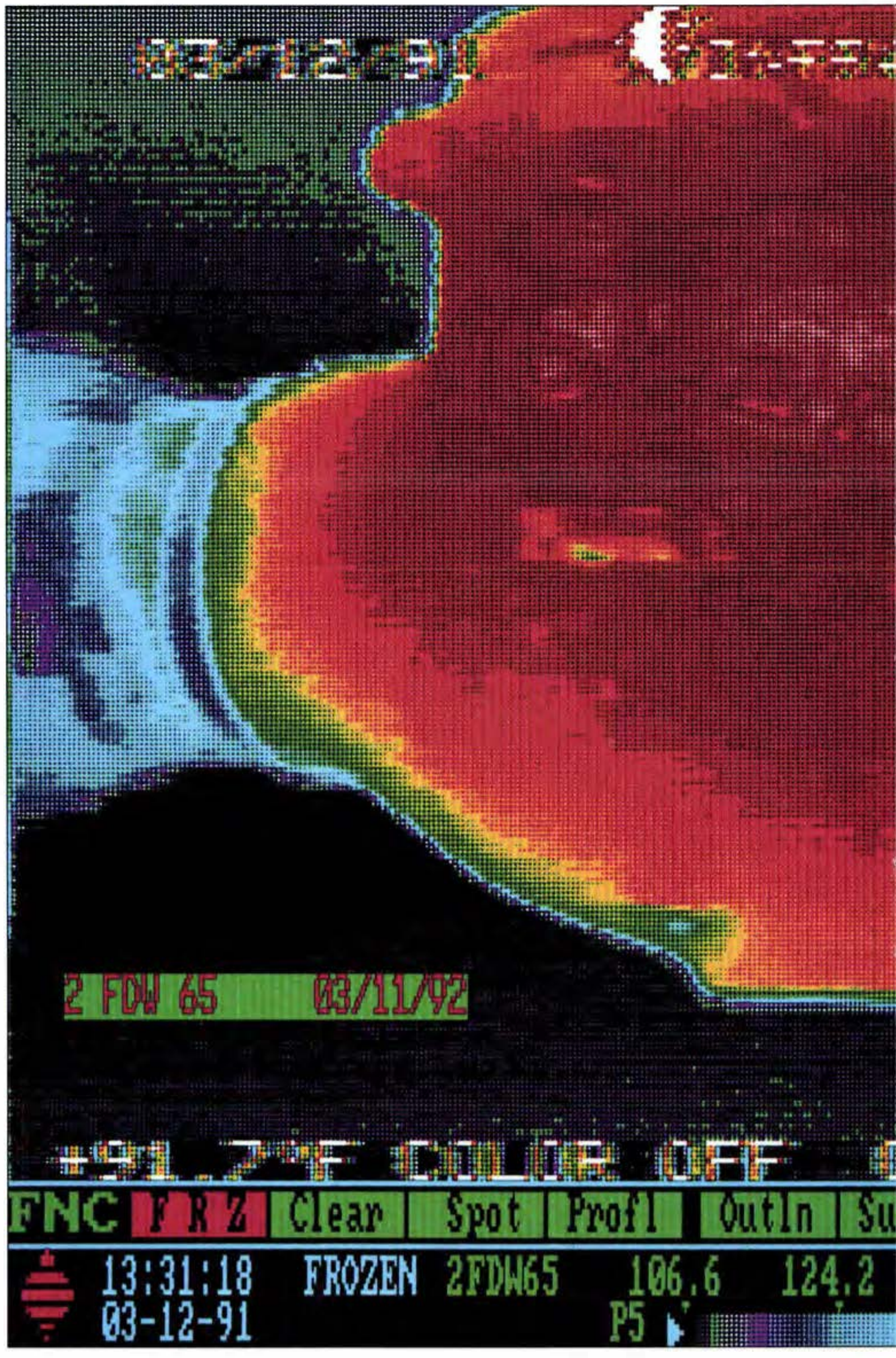
Images in Infrared

Electronic sensors and imaging systems that respond not to visible, reflected light but to the slightly-longer-wavelength infrared radiation emitted by warm or hot objects have been used in military applications ranging from early night-vision scopes to heat-seeking missiles. Telescopes incorporating such technology have peered into the far reaches of the universe to see planets and stars that are optically obscured by interstellar dust.

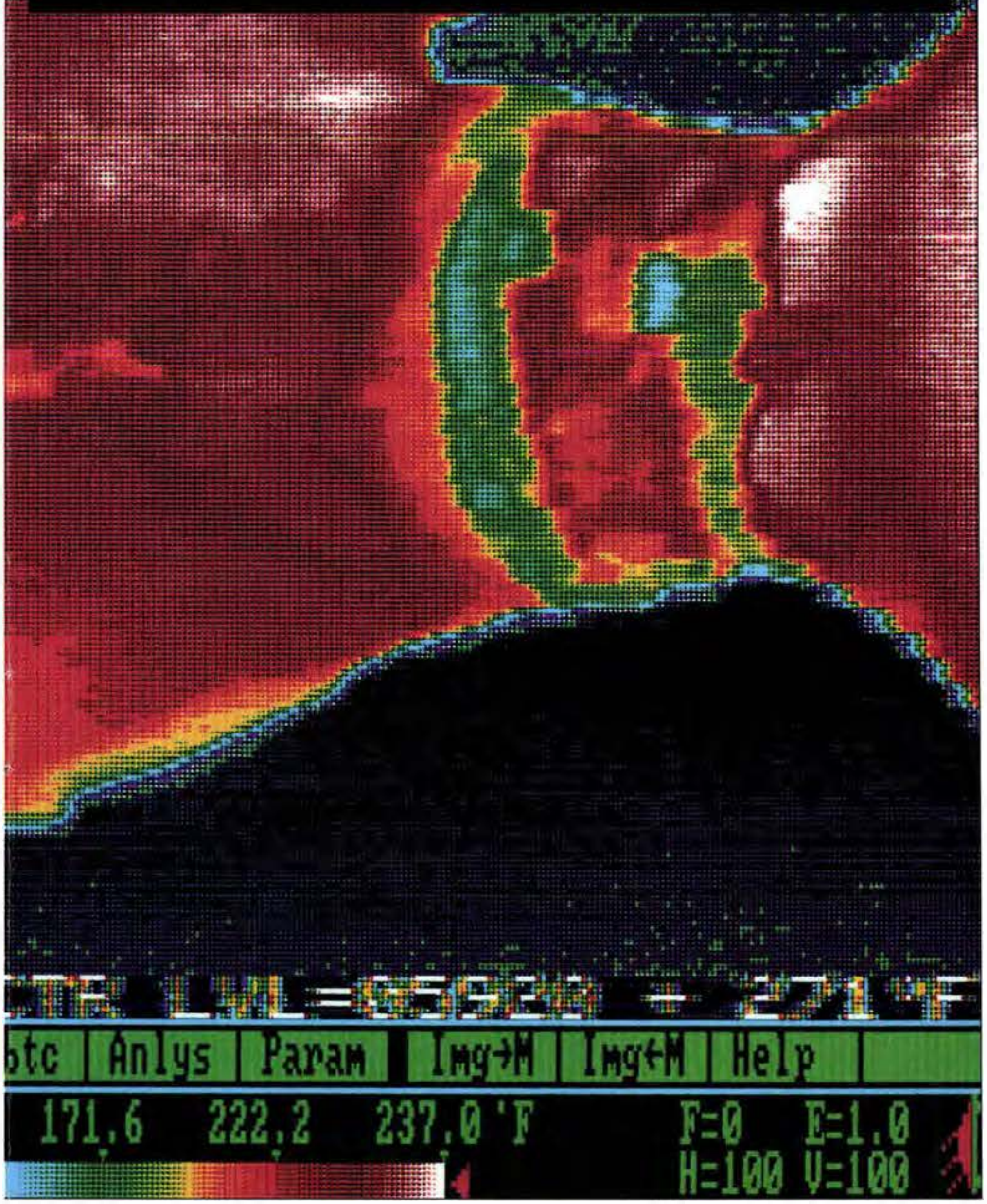
Over the past 15 to 20 years, infrared (IR) imaging systems have also come to be used in a broadening spectrum of industrial and manufacturing applications in which the ability to visualize heat flow or a thermal anomaly can yield valuable, but otherwise invisible, information. One of the most familiar uses of these thermographic systems is gauging heat loss through the doors and windows of buildings as part of efforts to control energy costs.

Now, electric utilities are increasingly turning to IR as a powerful tool for nondestructive evaluation (NDE), both in power plants and for transmission and distribution systems. They are documenting substantial benefits from using IR in predictive, preventive maintenance strategies that try to avoid the premature repair or replacement of components while minimizing failures that can take down related equipment or systems. In fact, utilities are finding that the value of the information available from IR systems can far exceed the capital investment for the equipment itself. Nonetheless, effective inspection programs that yield the maximum benefit from IR technology require an investment in personnel and training as well as in hardware.

Many utilities routinely survey distri-



THE STORY IN BRIEF **Electronic heat-imaging systems that work by sensing the infrared energy emitted by objects are being broadly applied in the electric utility industry in a variety of diagnostic maintenance applications. Infrared (IR) detectors range from simple qualitative devices to scanning imaging systems with color video output. EPRI is playing a supporting role in fostering utility use of IR systems with publications and hands-on training to familiarize utility personnel with such equipment and its many possible diagnostic uses. And work is planned to develop expert system software to aid utility engineers in comparing different thermal images to spot early signs of wear or needed maintenance.**



bution lines and substations with van- or truck-mounted IR scanners, looking for hot spots that are a sign of higher-than-normal resistance to current or of loose, corroded, or worn connections. One utility has mounted a unit at a substation to perform continual freeze-frame scanning of a busbar to record the location of flashovers. Utility or contractor crews in helicopters with gimbal-mounted IR scanners fly over transmission lines. In a substation, an IR scanner can identify a blocked cooling fin in a large transformer long before the transformer itself would overheat and fail.

The practice of using IR in troubleshooting a wide range of power plant equipment, both electrical and mechanical, began and grew in nuclear stations. Now the trend is spreading to fossil units, as operations and maintenance (O&M) staffs in those plants become familiar with the technology and its potential. Many IR applications—from examining cables, steam pipes, valves, and motors to locating steam traps and scoping switchgear, transformers, and fuse boxes—are similar for both nuclear and fossil plants. And other applications with potential for both kinds of plants are being explored and developed—for example, the use of IR to recognize small temperature differences for leak detection among hundreds of condenser tubes. Moreover, except for applications that involve steam, power plant uses of IR apply equally to hydro stations.

"Infrared thermography is becoming an important diagnostic tool that is not equipment-specific—it can be applied to virtually the whole spectrum of equipment in power plants," says John O'Brien, EPRI program manager for nuclear plant operations and maintenance. Adds Larry Nottingham, a manager at EPRI's Nondestructive Evaluation Center in Charlotte, North Carolina: "Just about any kind of problem you can imagine that manifests itself by some temperature change is a candidate application for infrared inspection."

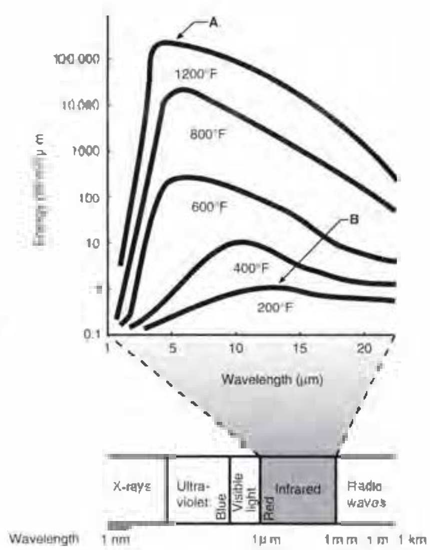
EPRI's Nuclear Maintenance Applications Center (NMAC), located at the NDE Center, has produced the *Infrared Thermography Guide,* which gives utilities the basics of IR theory, covers instruments and applications, and provides guidance on how to set up in-house IR inspection programs. An updated, expanded version of the guide, including full-color coverage of new applications, is in preparation. NMAC also sponsors, in cooperation with EPRI's Generation & Storage Division, workshops and training courses on IR thermography at EPRI's Maintenance & Diagnostic (M&D) Center at the Eddystone station of Philadelphia Electric Company.

Meanwhile, plans are under way to increase the sophistication of IR thermography as a plant diagnostic tool by developing expert system software that can manage and interpret massive databases of stored thermographic images. Also, in the electrical systems area, there are plans to include IR technology in a detailed evaluation of advanced assessment and inspection methods for overhead transmission lines. There is even hope that IR thermography can be used to make accurate measurements of conductor temperatures to help determine line current loadings.

Heat beyond the light

Our understanding of the fundamental relationship between light and heat can be traced to the early nineteenth century, when the English astronomer Sir William Herschel used a thermometer to show that the red end of the spectrun emerging from a prism was warmer than the blue end. Herschel found still-higher temperatures just beyond the red, where no light was visible. Hence, the invisible light below the red, or *infrared.* A theoretical explanation for the relationship came a century later, when the German physicist Max Planck described how a perfect absorber of incident electromagnetic radiation—a blackbody—emits radiation at infrared wavelengths (1–20 micrometers) as a function of its temperature.

The earliest infrared camera had an oil-coated membrane and sensed thermal energy directly as the oil evaporated. By World War II, sensors that detected photons of infrared light with a metal-cathode vacuum tube were being used to track ships and tanks. It was several more decades, however, before electronic detector arrays based on semiconductors and coupled with microprocessors were developed that offered the spectral response and spatial uniformity necessary for high-performance IR cameras.



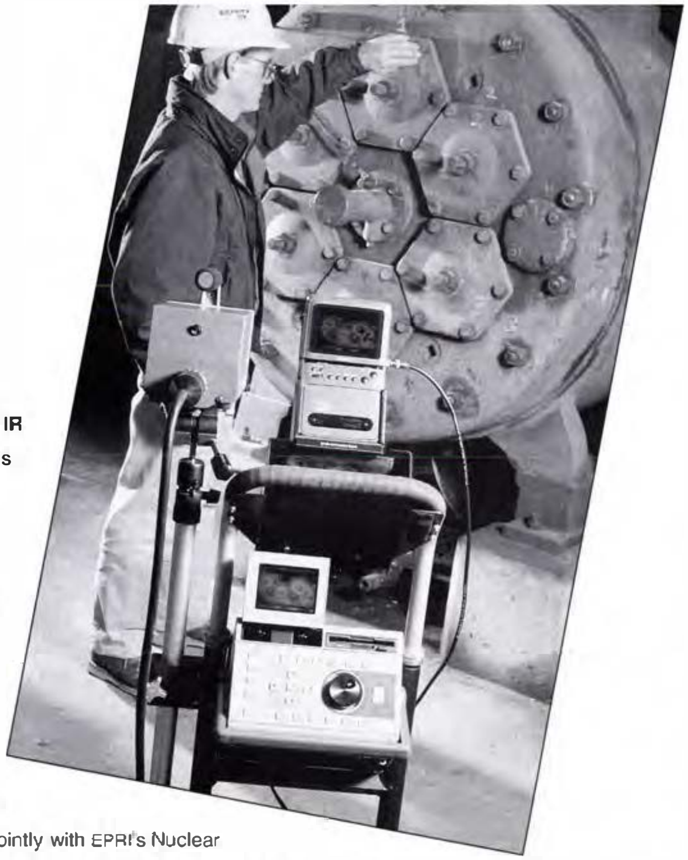
DETECTING LIGHT BELOW THE RED
A chart of the electromagnetic spectrum shows where the infrared region is located, just beyond the red end of the visible spectrum. IR inspection systems can detect hot spots because hotter objects radiate more of their energy at shorter wavelengths (point A, closer to the wavelength of visible light) while cooler targets radiate more energy at longer wavelengths (point B). Most IR thermal imagers used in power plants or other utility applications operate in the spectral region of 3–5 or 8–12 micrometers.

Today there are several mature IR detector technologies based on such semiconductor combinations as platinum-silicide, indium-antimonide, and mercury-cadmium-telluride. In this country alone, IR instruments and cameras of various kinds and specifications are available from three or four dozen manufacturers, including Agema, FLIR Systems, Inframetrics, and ISI. These products range from pocket-sized probes and gun-type radiometers for spot measurements (both of which provide a digital temperature readout of whatever they are aimed at) to scanning IR imaging systems that—on a single computer chip—electronically process and integrate the signals from thousands of detectors to generate a digital thermographic data image. Such images can be stored on videotape or computer disk, printed, or digitally manipulated and analyzed using special software. Most IR thermal imagers are designed to respond to the spectral region of either 3–5 or 8–12 micrometers.

For most utility applications, there are two broad types of IR thermographic imaging systems: qualitative and quantitative. In general, the former are designed to assist in visual inspections for obvious temperature anomalies, while the latter are capable of making fairly precise measurements (±0.1°C) of what the cross hairs are trained on. In addition to generating black-and-white IR images, both types can assign colors to different temperature ranges along the so-called steel scale from very cool to very hot (blue to green to red to yellow to white) to heighten contrast and so emphasize the thermal patterns.

IR systems are far more versatile and durable than physically attached thermocouples. As a noncontact, nonintrusive tool for temperature measurement, IR can be used on normally operating equipment that is in motion, is electrically energized, or is too fragile, hot, or remote for thermocouples.

But with any IR sensor or scanner, the accuracy of temperature measurement depends on proper calibration of the instrument. That requires determining as precisely as possible the emissivity of the surface to be measured, taking into account



HANDS-ON TRAINING IN IR THERMOGRAPHY EPRI's Maintenance & Diagnostic Center at Philadelphia Electric Company's Eddystone station puts on three-day workshops for member utility personnel in the application of thermography in the early detection of equipment anomalies. The workshops are presented jointly with EPRI's Nuclear Maintenance Applications Center, located in Charlotte, North Carolina. Classroom sessions cover theory and equipment, and field demonstrations using power plant mechanical and electrical equipment give participants hands-on experience in thermography applications. The M&D Center also conducts more-extensive IR training in two five-day courses directed toward ASNT Level I and Level II certification.

background thermal radiation reflected from the surface or transmitted through the component.

For example, polished aluminum has a much lower emissivity than anodized aluminum because it reflects more incident radiation. A widely used technique for reducing reflection and improving emissivity for thermography is to spray a surface with foot powder or dye-check developing fluid.

The complexities of instrument calibration and of techniques for obtaining accurate temperature measurements have led to a demand for technical training for IR thermographers. In addition to conducting an annual three-day workshop on IR thermography, EPRI's M&D Center now offers five-day courses directed toward Level I and Level II thermography certification by the American Society for Nondestructive Testing (ASNT). The first Level I course is scheduled for this May. Such training is also commercially available from several firms, some of which also do technical consulting on IR applications or will contract to conduct IR surveys.

The ASNT accepts IR thermography as a valid NDE method, and it has issued recommendations for various levels of IR training and suggestions for inspection program design. It is expected to eventually outline formal guidelines for training and certification.

Quantitative IR imaging systems of the sort favored by many utilities for power plant applications can be purchased for about $50,000–$70,000; additional features and software can bring the cost to as much as $100,000. Because the semiconductor detectors in such imaging systems must operate at a low temperature to adequately sense infrared photons, most of the early systems introduced in the 1970s required liquid nitrogen cooling, which can be cumbersome and impractical. More-recent IR systems, however, feature onboard electric coolers that can be powered for several hours by a battery belt-pack.

The technology is catching on

"IR imaging systems have been around for a long time, but they've really caught on with utilities in just the last few years," notes Paul Zayicek, a technical specialist in IR at EPRI's NDE Center. "EPRI has been promoting the technology because it has turned out to be a very valuable tool for predictive maintenance."

Zayicek observes that there are probably as many utilities using IR in transmission and distribution applications as in power plants. "The electrical equipment area, including T&D and power plant applications, seems to most easily lend itself to IR inspections, and the images seem to be the most easily interpreted." Typical examples of electrical applications, besides those already mentioned, include inspections for corroded, loose, or undersized conductors; open conductor strands; or hot spots from induced currents. IR can also be used to detect a phase imbalance in a three-phase circuit (because one conductor will glow hotter with infrared energy than the others). And battery cells with high internal resistance because of a connection problem can be identified by comparing their IR readings with those of other batteries.

Major types of mechanical equipment are amenable to IR inspection as well. IR systems can detect friction heating of such rotating or moving equipment as motors; discern leaks or blockages in valves, pipes, and boiler tubes; inspect pipe or valve insulation for integrity; and assist in various building inspection jobs. Besides pinpointing heat losses in buildings as part of energy conservation efforts, IR imaging systems can be used to locate air loss or ingress, poor insulation, and wet roofs.

IR imagers have also been used in inspecting condensers for vacuum leaks. And systems have been taken aloft in a helicopter or plane to observe a plant's thermal plume to help verify compliance with environmental discharge limits. Some IR applications are unique to nuclear power plants. For example, an IR imager with a telescopic lens can be used to observe hydrogen igniters inside containment or to monitor the flow of heated air pumped through containment spray header nozzles to verify that they are unblocked.

To assess the overall implementation status of IR technology in nuclear plants, NMAC recently surveyed member utilities and asked them to describe all their current and planned applications. According to the responses received—from 15 boiling water reactor plants and 37 pressurized water reactor plants—IR is used more at PWRs, for reasons that are not readily apparent. About two-thirds of the plants responding indicated that a formal IR inspection program was either under way or planned. Despite the fairly extensive use of IR at nuclear stations, the range of applications remains somewhat narrow, probably owing to a lack of experience with other applications.

That situation is changing, however, as more plant O&M personnel get up to speed with IR technology, says the NDE Center's Zayicek. "A lot of the people who are trained in IR thermography are self-starters, and as they become more comfortable with the technology in their hands, they take the equipment out into the plants and try it in different situations on their own."

One plant that has had IR equipment for some time and is considered one of the most aggressive in applying it is the Southern Company's Farley nuclear plant near Dothan, Alabama. The plant volunteered to host an EPRI demonstration involving a comprehensive inspection with IR systems. An initial survey to identify temperature anomalies that pointed to potential equipment failure was followed up four months later to determine whether corrective actions were effective.

The inspections at Farley led to an immediate benefit in that the site's annual insurance premium was reduced by approximately $20,000 as a result of including specific equipment for examination in the inspection program. Another quantifiable benefit resulted from identifying an overheated terminal board connection in one of the cabinets housing the control rod drive system. The anomaly could have eventually resulted in a plant trip. Taking startup and troubleshooting time into account, discovery and repair saved over $200,000. Other potential problems identified at Farley or in subsequent inspections at other plants operated by Southern Nuclear have included high-resistance connections in electrical control circuits, condenser air in-leakage (some leaks being less than 1 standard cubic foot per minute), high-resistance connections on a 4160-kV bus, and leaking feedwater heater shell relief valves.

"My feeling is that we have just skimmed the surface with IR inspections and that their use in the plant will go a lot deeper," says Don Mansfield, manager of Farley's nuclear maintenance support group. "If temperature is involved with a problem or can tell you that you have a problem, you can use IR for troubleshooting. The project with EPRI has given us a much better understanding of what the equipment can do for us. Since then, we've formed a task force and shared the technology with the company's Hatch and Vogtle nuclear plants in Georgia as well."

Al Hammett, a nuclear specialist with Southern Nuclear, says the Farley and Vogtle plants recently purchased new IR equipment, while a third system was purchased for use by Southern Nuclear's inspection and testing group for routine plant surveys at all three sites. Hammett

PG&E VAN CUSTOMIZED FOR IR INSPECTION

Like a growing number of other utilities, Pacific Gas and Electric routinely uses IR imaging detectors to inspect lines and components on its distribution system for hot spots—signs of wear, corrosion, or needed maintenance. The utility has put five IR inspection systems on wheels for greater flexibility and speed. PG&E's Mission Division office in Hayward, California, uses a modified 1-ton, natural-gas-fueled service van equipped with a roof-mounted, remotely operated video camera and IR image scanner; conveniently arranged inside the van are color video and IR image monitors, plus video recording, color printout, and remote control equipment. IR and video images can be compared side by side on a single screen to quickly identify hot spots. Supervisor Bob Loggins says that virtually all substations and distribution lines, as well as some transmission equipment, can be viewed from the truck with a zoom lens; also, the camera heads can be lowered and directed out the back of the van to inspect underground equipment.

notes that once personnel are adequately trained in using the IR systems, "the most difficult decisions are not related to the technology. The hardest part is dedicating the man-hours and deciding what to look at first. There are so many components to inspect, you have to prioritize and focus on those things with the greatest payback. It must be a flexible program that allows components to be easily added or removed or their inspection frequency changed."

Hammett says one lesson about IR inspection programs already learned at Southern Nuclear is that the expertise and knowledge of the personnel trained in the use of the technology and in the interpretation of IR images are too valuable to let easily or quickly slip away. "You have to have people who are knowledgeable about plant equipment as well as IR theory. But if they're soon promoted or transferred or otherwise leave, the effectiveness of an IR inspection program will decline drastically."

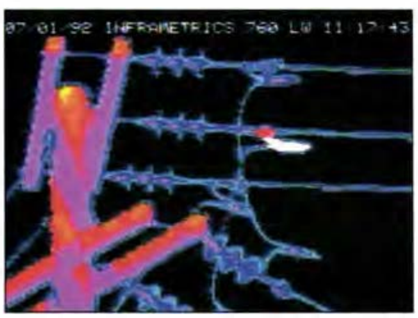
Duke Power is another nuclear utility aggressively using IR inspections. Marc Snyder, an IR thermographer and nuclear maintenance specialist at the utility's three-unit Oconee station in South Carolina, says the plant has been using IR systems for less than two years and has documented over $1.5 million in savings from avoided equipment failures in just the last year. In one recent outage alone at Unit 2, he says, IR inspections (combined with ultrasound scanning) of the unit's four main steam bypass valves revealed that only two required teardown and rebuilding, saving the utility over $100,000 in deferred work.

Snyder says that some of Duke's nuclear thermographers recently took their equipment to several of the utility's hydroelectric dams and in two months of inspections identified anomalies worth an estimated $1 million in avoided repair costs. The hydro maintenance group "was really impressed, and we've since helped them get their own IR program started. They're now using IR extensively in a preventive maintenance program, along with vibration analysis." Snyder also gets involved in IR surveys of Duke's substations, although most of the surveys of T&D lines are handled by contractors.

Speaking from the perspective of 18 years' experience in the power generation field, Snyder says "the evolution in the technical capabilities of the IR equipment that is available now has been amazing and parallels that of the computer. Each year it seems there's a new generation of systems with better electronics, better detectors, better storage, and better graphics software. And the resolution is so much better now." But the cost of IR systems has followed the climb in functionality and image quality, he adds. "You can get a high yield in terms of image quality with a low to moderate investment in a qualitative IR system if you just want to hunt for hot spots and follow a seek-and-repair strategy. But if you want to do quantitative IR thermographic surveys, you need to have a program and some full-time people."

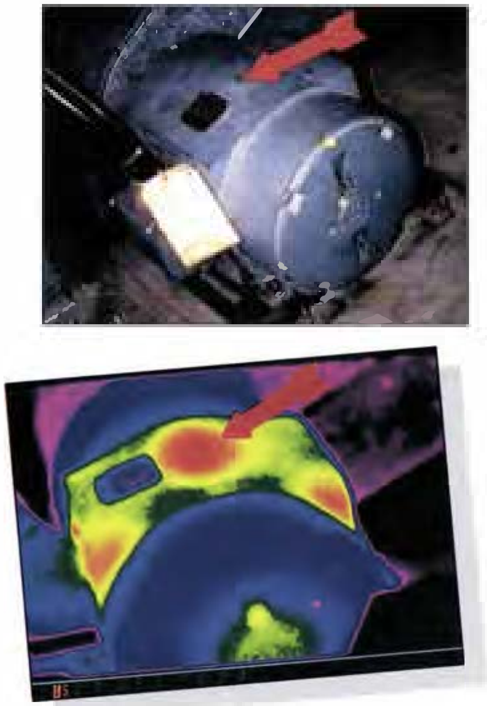
Working with utilities to extend IR's reach

Although IR technology already is used fairly routinely in most nuclear plants and on most utility T&D systems, there are still significant opportunities to refine and extend its utility applications. EPRI is pursuing some of these opportunities through a combination of efforts, including the IR workshops at the Eddystone M&D Center, collaborative projects with several utilities, and new work to demonstrate additional applications and develop advanced IR diagnostic capabilities using expert system software.

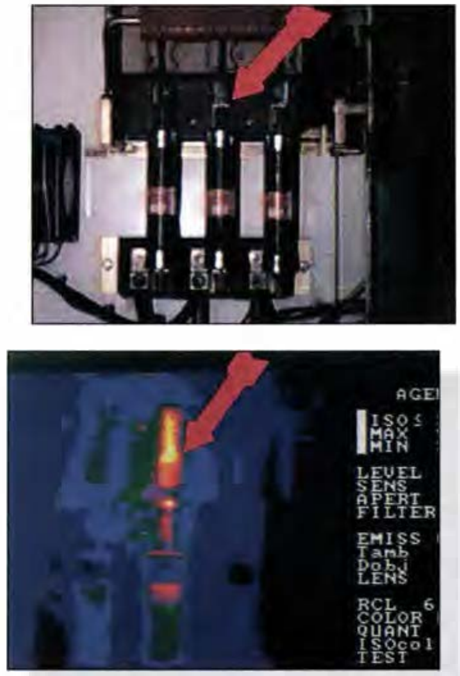


Ron May

Typical hot spots on normally operating motor



Deteriorated fuse-holder connection in threephase service panel



A SAMPLER OF IMAGES A few selections from the current and forthcoming editions of EPRI's *Infrared Thermography Guide* (NP-6973)—produced by the Nuclear Maintenance Applications Center to help utility personnel apply IR systems—illustrate the variety of situations in which the ability to visualize temperature differences can have great value from a preventive maintenance perspective. More-general uses of IR scanners include visualizing heat loss from buildings.

"In fossil plants, IR has the potential for becoming a major diagnostic tool, although utilities have not yet applied it to the optimal extent," says Rob Frank of the M&D Center's staff. "An IR system that costs $50,000–$70,000 has the potential for saving on the order of over a million dollars a year per plant."

Such an estimate has been substantiated by direct experience at the Eddystone station, where Philadelphia Electric documented over $1.2 million in savings last year from IR inspections of Units 1 and 2. Temperature anomalies were identified in equipment that ranged from electrical gear to vacuum-pump valves to motor bearings. As part of EPRI's threeday IR inspection workshop at the M&D Center—a showcase for the full range of fossil plant monitoring and diagnostic techniques—attendees are taken through the Eddystone plant for hands-on IR demonstrations.

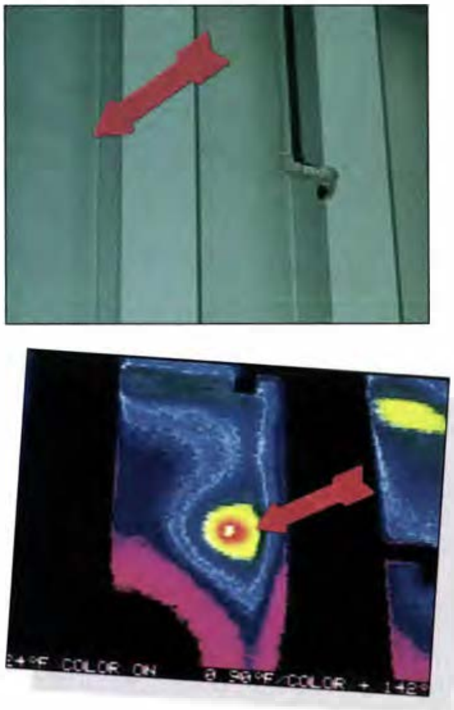
But EPRI is not just waiting for utility personnel to go to Philadelphia to learn what IR can do for their plants. The M&D Center's IR specialists are currently working with several utilities at individual power plant sites to further expand the technology's capabilities. They are conducting combination IR plant surveys and intensive training designed to jump start in-plant inspection capabilities. The participants include Pacific Gas and Electric, Florida Power & Light, Toledo Edison, and Philadelphia Electric. The plants include both fossil and nuclear units. "Most of them have already purchased equipment. We help them get it up and running and show them what to look for," says Frank. "But as we survey the plants, we're also building a database of leak detection techniques and IR images."

At Unit 7 of PG&E's gas-fired Contra Costa plant, an IR team from the M&D Center helped utility personnel look for hot spots in a variety of mechanical equipment, as well as for air in-leakage in the condenser and associated air ejectors. "One of the main goals of the collaborative effort here with EPRI is to find out if we can use IR to reliably and repeatedly find these types of leaks," says Mike Teskey, an NDE supervisor in PG&E's Technical and Ecological Services Department. "You have to be able to discern a tenth of a degree difference between ambient temperature and the component temperature in locations that are difficult to access. When you look at the condenser box with an IR viewer, it seems to breathe and pulsate with the heat flow. We've recorded these different images on videotape."

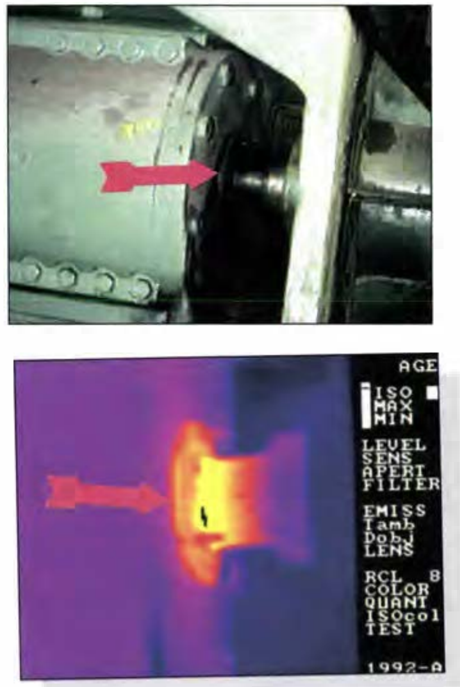
Frank, of the M&D Center, says that many of the thermograms being generated in the collaborative efforts with utilities are added to a growing database of images for various applications. Eventually, researchers hope to use the thermographic database in the development of expert system software that can help thermographers and engineers interpret images for equipment diagnostics. Image processing and diagnostic software already available from IR systems manufacturers can analyze each pixel of an image and present a variety of information to the user. But an expert system, programmed with a rule-and-knowledge base, conceivably could rapidly analyze many different images taken at different times, comparing them in detail to a baseline image and perhaps recommending, on the basis of the severity of observed temperature anomalies, when to replace a component. The U.S. Army pioneered such differential thermographic techniques for identifying defective components on the surface of a printed circuit board.

At EPRI's NDE Center, a program in el-

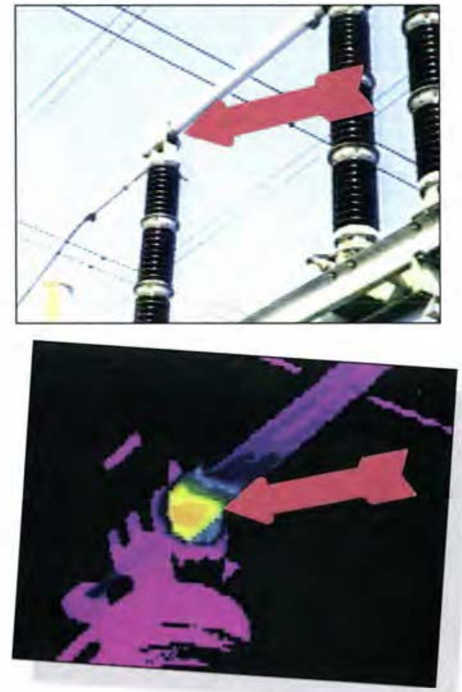
Localized hot spot in 250-kV, single-phase main transformer



Hot spot in pulverizer worm-gear bearing



Loose or corroded connection on transformer bus air brake



ement diagnostics is investigating utility use of differential thermography in electronic, electrical, and mechanical applications. The NDE Center, the M&D Center, and NMAC are jointly developing a predictive maintenance guide for implementing and executing power plant IR inspection programs and are also investigating advanced IR techniques for detecting such problems as pipe thinning.

Avtar Singh, a Nuclear Power Division project manager in human and component reliability, says that an expert system module has already been developed for diagnosing problems with various types of valves, and modules for several other power plant components are planned over the next two to three years. EPRI hopes to have an IR thermographic expert system module in the pilot stage this year, he adds.

EPRI's John O'Brien says building a plant database of IR images is something that utilities already using IR should consider. "While the IR gear is not equipment-specific, the interpretation of the thermal images that you get with this technology will become equipment-specific. To do an IR inspection program right should include creating a database of images and acquiring the trained expertise over time in comparing different images. Eventually, an expert system of the type EPRI is developing may assist in this interpretation."

There are also new developments in IR technology in utility T&D systems. For example, an IR system for continual freeze-frame scanning of substation equipment was developed through EPRI support and recently commercialized by Xedar Company of Colorado. The first unit is now in operation at an SF_6-insulated enclosed substation on Louisiana Power & Light's transmission system, according to EPRI program manager Stig Nilsson. Protective relays activate the IR image recorder with millisecond speed in time to reveal the exact location of an incipient flashover inside a metal busbar.

Meanwhile, work is under way in a two-year project to evaluate advanced assessment and inspection methods for transmission lines. IR systems are one of several technologies that will be explored for their potential to more accurately assess the condition of conductors and associated equipment and possibly determine the line current loadings themselves. Some utilities are already taking their IR equipment to EPRI's Transmission Line Mechanical Research Center in Texas to calibrate the instruments for determining the temperature of transmission lines under various conditions.

Seeing the future in a warm glow

From all indications, IR thermography is a maturing, yet still evolving, diagnostic tool with a future that is bright across a broad spectrum of utility plant and T&D applications. Experts say IR thermography may eventually become as standard at electric utility facilities as any other inspection technique, in many cases complementing other methods, in other cases yielding unique insights from an otherwise invisible world of light below the red.

Further reading

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Background information for this article was provided by Mike Downs and John O'Brien, Nuclear Power Division.

Shedding Light on the

THE STORY IN BRIEF Through a series of in-depth surveys, EPRI researchers have learned that many U.S. consumers are dissatisfied with currently available compact fluorescent lamps (CFLs), a technology commonly promoted through utilities' efficient-lighting programs. Complaints include the high cost of CFLs and their inability to be used with dimmer switches. Despite such drawbacks, Japanese consumers have displayed a healthy appetite for compact fluorescents, to the extent that this technology now accounts for more than 80% of home lighting in Japan. Manufacturers have already begun to work on improvements to CFLs that will address some of the consumer concerns. In the meantime, EPRI researchers are using the results of the Institute's studies to help determine the most effective next step for U.S. utilities' efficient-lighting programs.

Compact Fluorescent

by Leslie Lamarre

Nearly a decade of utility programs to encourage the use of compact fluorescent lamps (CFLs) has boiled down to this: many folks just haven't warmed up to them in the United States. In Japan, on the other hand, they're selling about as fast as raw fish at a sushi bar. Now, from the vantage point of 10 years of utility experience with this technology, EPRI is beginning to draw conclusions about the U.S. phenomenon, with the intention of laying the groundwork for the next step in efficient-lighting programs for the residential sector.

Aside from being expensive (costing up to 40 times as much as incandescents), currently available CFLs may not fit into existing light fixtures for the home, cannot be used with dimming devices, and may not produce enough light for such tasks as reading. These were some of the concerns aired in a recent EPRI survey of nearly 400 consumers in five major markets across the United States. Overall, the study showed that when offered three types of lighting technology (incandescents, fluorescents, and CFLs), 43% of compact fluorescent users and 53% of nonusers were "least likely" to buy CFLs in the future. Even those who had tried this technology and indicated that they were satisfied users rated CFL lighting poorly.

"Are we saying that some utility lighting programs failed?" says John Kesselring of EPRI, manager of residential systems. "Absolutely not. We're saying the technology was not ready for a broad, energy-disinterested public and simply did not live up to the high expectations the industry had for it. The lighting programs still succeeded from an educational standpoint in that they introduced thousands of U.S. consumers to advanced lighting technology." In fact, despite the consumer dissatisfaction, utility lighting programs saved 300 million kWh of electricity in 1990, which is enough to meet the residential electrical needs of 80,000 people for one year.

Kesselring notes that the lamps were successful for a small group of consumers. About 25% of CFL users said that, given the choice of incandescents, fluorescents, and CFLs, they were "most likely" to buy compact fluorescent products in the future. These users cited long-term energy savings and concern for the environment as issues that make CFLs "worth the extra effort."

Utility action

Back in the early 1980s, when utilities began to launch efficient-lighting programs for the residential sector, CFLs certainly seemed alluring. Up to four times more efficient than incandescent bulbs, they also have the potential to last 10 times longer. Making them even more attractive, some models can be screwed directly into incandescent sockets—ballasts and all.

Utilities were drawn to compact fluorescents like environmentalists to solar power. Across the country, utilities began to establish efficient-residential-lighting programs that revolved around compact fluorescent technology. In fact, a recent EPRI study (TR-101221) reports that 27 of the 29 utility programs surveyed featured CFL technology.

As with other efficiency improvement efforts—part of the industry's demand-side management initiatives—the intent of these programs was to save energy and help postpone the need to build new power plants. To encourage the use of CFLs in the home, utilities disseminated educational material on the technology, offered rebates to customers who purchased the lamps, and sometimes even gave them away free. Public interest groups heralded the arrival of such programs, as did public utility commissions, which encouraged—and even mandated—their implementation. In recent years, some commissions have offered financial incentives for utilities to sponsor such programs.

Today, 133 U.S. utilities offer 196 efficient-residential-lighting programs, the oldest of which date back to 1983. But as EPRI's recent customer survey revealed, the CFLs promoted by these programs haven't always been well received. (This survey, documented in TR-100734, was part of a broader initiative to investigate the impact of utility lighting programs featuring CFLs.)

The survey found a widespread perception among consumers that CFLs fall short of manufacturers' claims for light output, life expectancy, and versatility. The resulting dissatisfaction has caused many consumers to return to the use of the relatively inefficient incandescents, which makes it difficult for utilities to gauge the impact of efficient-lighting programs. Another problem making such evaluation difficult is the snapback phenomenon—a change in energy use patterns that follows the implementation of energy efficiency measures and results in the loss of part or all of the energy savings. For example, a consumer who is dissatisfied with a CFL may wind up using supplemental incandescent light to make up for diminished lighting intensity. One utility reported a snapback rate as high as 33% for its residential lighting program.

Kesselring points out that some problems result from a lack of communication. For instance, although the claims of longevity for CFLs may be technically accurate, the frequent turning of a lamp on and off can significantly shorten its life span. Similarly, CFL light output can be reduced by up to 30% if a lamp is installed in a fixture that directs the light upward. "Consumers need to be informed about these kinds of things," says Kesselring, who notes that EPRI is now producing

PERCEPTIONS OF RESIDENTIAL LIGHTING TECHNOLOGIES EPRI-funded researchers asked 178 users of compact fluorescent lamps (CFLs) to rate three residential lighting technologies on the basis of several attributes. The chart lists some of these attributes, indicating the percentage of CFL users who favored compact fluorescents, incandescents, and fluorescents in each category. While CFLs did well in some categories and poorly in others, conventional incandescents were preferred overall by a significant margin.

Attribute	CFL (%)	Incandescent (%)	Fluorescent (%)
Most modern looking	64	16	20
Most expensive to buy	60	15	26
Uses least energy	57	9	34
Most environmentally friendly	42	35	23
Best value	42	21	37
Best for homes	32	52	16
Best looking	26	53	21
Best for lights switched on and off	19	69	12
Easiest to install	13	78	10
Fits into most places/fittings	11	84	5
Comes on most quickly	8	85	7
Most likely to buy	24	67	9
Least likely to buy	43	17	40

brochures to help utilities address such issues. He believes it is important to be open with consumers about any drawbacks inherent in today's efficient-lighting technology. "We want to help ensure that the introduction of improved CFLs by manufacturers is met with greater enthusiasm by consumers."

The overriding drawback of current CFLs is their cost, which can be over $20 per lamp without utility subsidies. "Even at a price of $10, which is cheap for these lamps, most people aren't interested in buying them," says Michael Evans, a demand-side management expert at EPRI who collaborated with Kesselring on some aspects of the CFL initiative. "They think about paying $10 for a light bulb, and it just doesn't make sense. In their minds, light bulbs are supposed to cost under $1."

Indeed, consumers surveyed by EPRI considered prices of $10 or higher for compact fluorescents "outrageous." Few of the consumers who had tried CFLs paid full price for the lamps. Rather, they received them through utility programs, either free of charge or for a significantly reduced price. As Evans points out, the cost factor is linked to other concerns. "At prices over $10, consumers want to see guarantees on longevity, and they want to make sure these things don't break," he says. "But broken light bulbs are a fact of life. It's bound to happen to someone."

Meanwhile in Japan . . .

Despite the drawbacks of compact fluorescents, the Japanese have a seemingly insatiable appetite for them. CFLs now provide more than 80% of that country's home lighting, according to a new EPRI study (TR-100868) that is part of EPRI's CFL initiative. By contrast, the use of CFLs in U.S. homes is negligible, with the rare user typically employing only one or two lamps.

There are several reasons for this discrepancy. To start with, Japanese consumers are accustomed to residential fluorescent lighting. Acute energy shortages after World War II led to a massive campaign to encourage consumers to switch from incandescent to fluorescent lighting.

HERE VERSUS THERE Although the use of compact fluorescent lamps in U.S. homes is negligible, CFLs provide more than 80% of Japan's residential lighting. Acute energy shortages, high electricity rates, and a wide availability of sophisticated CFL fixtures in Japan are among the explanations for the sharp contrast, a recent EPRI report states. Cultural differences also play a significant role; on the whole, Japanese consumers are far more interested in high technology than the typical U.S. consumer.

Cost incentives and aesthetic improvements in lamps and fixtures helped the movement gain momentum.

Today, the relatively high electricity rates for residential consumers in Japan—their average rate is about twice the average U.S. residential rate—continue to encourage the use of efficient lighting. But perhaps more significant, there's a cultural difference between U.S. and Japanese consumers. The Japanese are keen on high technology, and lighting is no exception. "The Japanese are much more willing to try new technology," says Kesselring, noting that this cultural difference was pointed out by a consultant working on EPRI's study of lighting use in Japan. The consultant is a native Japanese who has also lived in the United States. "The Japanese take pride in having the latest technology in their homes, and they show it off," Kesselring says. For instance, while Americans hide their heating and cooling systems in basements and other out-of-the-way places, the Japanese put them in plain view. Indoor units, which are slim and attractive compared with U.S. models, are mounted on the walls of central rooms. Outdoor units typically hang on balcony railings.

Japanese consumers can't seem to get enough CFLs, and they are already demanding new technical advances, such as more-intense light, better color rendition, and higher efficiency. Their enthusiasm has led to the wide availability of CFL products, as Japanese manufacturers scramble to fill the market need and compete with one another to introduce entirely new residential product lines.

The situation in the United States is markedly different. U.S. lighting manufacturers focus almost exclusively on the incandescent market, with virtually all the CFL production stimulated by utility programs. Consumers cannot find CFLs in grocery stores and other outlets where they most frequently purchase light bulbs, and they face a dearth of options on attractive fixtures for the lamps. Indeed, according to EPRI's research, typically 90% or more of the stock at retail fixture outlets in the United States is dedicated to incandescent technology. Aesthetically pleasing fixtures are simply not being designed for use with compact fluorescents. Decorative wall and ceiling CFL fixtures are nonexistent.

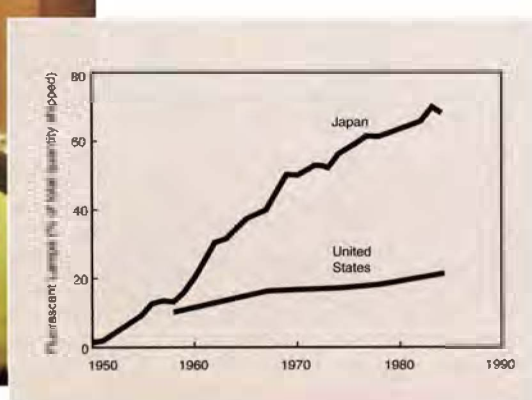
There are some fundamental inhibitors to the growth of the CFL market in the United States. To start with, the country's lighting industry is segmented, with lamps, ballasts, and fixtures produced by different companies with sometimes conflicting business philosophies. The result is a lack of synergism in the development and production of components and in their integration into complete lighting products. Also contributing to the confusion is the absence of standardization in the production process.

By contrast, well-defined lighting standards guide the production of CFLs in Japan. The CFL manufacturers are part of vertically integrated conglomerates that produce all the necessary lighting components and incorporate them into the finished products. Since the conglomerates manufacture other product lines that include components useful in lighting, R&D for advanced lighting technologies can be carried out at reduced risk and cost. Further lowering costs is the already-established large-volume production base for this technology.

Although it appears that U.S. and Japanese CFL technologies are comparable at this time, EPRI's report suggests that Japanese manufacturers' expertise in advanced, high-frequency fluorescent lighting technology will allow them to address the kinds of problems inhibiting purchases by American consumers. "If accompanied by appropriate marketing programs," the report states, "the introduction of low-cost high-frequency fluorescent lighting products into the American marketplace could be highly successful." The report does not specify how likely it is that the Japanese will pursue this path.

Like their counterparts in the United States, utilities in Japan actively promote advances in lighting. However, Japanese utilities are able to maintain a stronger alliance with manufacturers to ensure the continued development of advanced lighting products. This is partly because the same firms that manufacture lighting equipment also manufacture utility equipment, so utilities represent a significant market for them. In the United States, CFL production, marketing, and distribution are plagued by a lack of coordination among manufacturers, utilities, and retailers. This creates a number of problems for utilities—for example, the availability of products that generate harmonic distortion, which can interfere with the smooth operation of electronic appliances in customers' homes.

A high-tech Japanese kitchen illuminated by advanced lighting



Sources: U.S. Department of Commerce, 1958–1984; Illumination Engineering Institute of Japan, 1950–1984. Figures include standard fluorescent lighting technology as well as CFLs

Efficient Lighting for the Home

Compact fluorescent lamps (CFLs) are only one type of efficient-lighting technology. Below are descriptions of the efficient-lighting technologies available for indoor residential use.

Fluorescents Standard 4-foot fluorescent tubes are four to five times more efficient than standard incandescent lamps and last up to 20 times longer. Commercially available since the late 1930s, the standard fluorescent tubes are filled with a mixture of gases, including mercury vapor, and coated on the inside with phosphors. During operation, an electric charge passes through the lamp and excites the mercury vapor, producing ultraviolet energy. The phosphor coating absorbs this energy and converts it into light. Fluorescent lamps require ballasts, which provide the high voltage needed to start the lamp and control the current provided to the lamp during operation. Advanced, electronic ballasts operate lamps at high frequency (20,000–60,000 Hz, compared with 60 Hz for conventional, magnetic ballasts). Fluorescent tubes come in a variety of sizes and are available in a U-shape to fit special fixtures.

Compact fluorescents Available since the early 1980s, CFLs are up to four times more efficient than incandescent lamps and last up to 10 times longer. They are single-ended, and most have a small-diameter tube coiled up to provide increased surface area (the light output of fluorescent lamps increases with surface area). Like standard fluorescent lamps, CFLs require a ballast for startup and operation.

Generally available CFLs fall into three categories. The T-4 twin-tube and quad-tube models measure ½ inch in diameter and use starter devices and magnetic ballasts. (Special T-4 lamps without starters can be used with certain dimmable ballasts that are now becoming commercially available.) The T-5 twin-tube lamps are ⅝ inch in diameter and are designed to operate with either magnetic or electronic ballasts. T-4 and T-5 models offer separate lamps and ballasts so that the lamps, which don't last as long as the ballasts, can be replaced as needed. The third category of generally available CFLs consists of models that integrate ballasts and lamps. These models, some of which mimic the shape of incandescent bulbs, screw directly into incandescent sockets.

Another type of CFL is the circular fluorescent, which offers about the same light output as other CFLs and has a slightly longer life (12,000 hours versus 10,000 hours). However, because these lamps are larger than other compact fluorescents, they fit into fewer fixtures.

Tungsten halogens A type of incandescent lamp offering an efficiency increase of about 35% over standard incandescents, tungsten halogen lamps have been commercially available since the late 1950s. Like standard incandescents, these lamps produce light when electricity passes through a coiled tungsten wire filament, heating it until it glows. In standard incandescents, the filament slowly evaporates, its residue accumulating on the bulb wall, reducing light output. In tungsten halogen lamps, halogen gases combine with the evaporated tungsten particles before they can accumulate on the bulb wall. This mixture then migrates to the hot filament, where the halogen separates from the tungsten and the process begins again. As a result of this continuous process, the quality of these lamps' light output does not degrade as rapidly as that of standard incandescents. Also, tungsten halogen lamps often last longer. Like standard incandescent lamps, many tungsten halogen lamps are dimmable, thus increasing the potential for energy savings.

A newer type of tungsten halogen lamp, the infrared parabolic aluminized reflector lamp, is designed for floodlight and spotlight applications. It uses an infrared-reflecting coating to direct much of the heat generated during lamp operation back into the filament. This increases the lamp's light output and efficiency by raising the temperature of the filament without requiring a higher wattage. These advanced tungsten halogens are 30% more efficient than standard tungsten halogens and have been available for about two years. □

Other groups have complaints as well. Retailers and distributors grumble about utility programs that circumvent their role as middlemen in the lighting purchase transaction. Manufacturers gripe about the typically short notice given for major utility orders; because CFLs are not yet in high-volume production in this country, a large order can tie up supplies for several weeks. Manufacturers are also concerned that short-term utility efforts may have created unrealistic price expectations among consumers and hurt the long-term potential for compact fluorescent products. They encourage utilities to collaboratively set product performance standards for CFLs and serve as industry watchdogs, restricting rebate and discount programs to high-quality lamps.

New directions

New utility efforts are addressing some of these concerns. For instance, Pacific Gas and Electric has initiated a program that offers cash incentives directly to CFL manufacturers to lower the cost the manufacturers charge retailers. The idea is that the lower cost will travel through the distribution channel to the shelves of retail outlets, where consumers will ultimately benefit. Susan Fisher, appliance efficiency program manager for PG&E, notes that the program allows the lamps to flow through distributors and retailers, middlemen who are excluded in conventional utility programs. The cash incentives to the manufacturers of the 320,000 CFLs produced for this program are $5 or $7 per lamp, depending on the lamp's efficiency. Retail prices range from about $4 to $13. PG&E will share its findings on the effectiveness of this program with fellow members of the California Compact—a consortium formed by five Pacific Coast utilities, the Natural Resources Defense Council, and Lawrence Berkeley Laboratory to promote the residential use of CFLs.

Acknowledging consumer dissatisfaction with CFL technology, Fisher says manufacturers are working on improvements that will be ready for future utility programs. "Our customers want CFLs brighter and smaller, and that's what we will be focusing on in the future. I think that in 1993 we're going to see significant changes to increase the application of CFLs." Already manufacturers have successfully addressed the issue of poor color rendition, an early CFL weakness (although not a cause of significant complaint among the consumers interviewed for EPRI's survey). Also, Fisher notes that at recent conferences sponsored by the California Compact, manufacturers have demonstrated dimmable and three-way CFL technology that they intend to make commercially available within the next few years.

EPRI's research shows that CFLs will not be widely adopted by consumers until certain technical drawbacks are addressed and the lamps become available for less than $10 through the retail outlets, such as grocery stores, where consumers normally purchase light bulbs. But compact fluorescents are, after all, only one type of efficient lighting for the home. Perhaps upcoming advances in CFL technology will keep it a favorite of utility programs, or perhaps utilities will opt for other technologies that are less efficient but that may prove more effective in meeting program objectives. One possible alternative is the tungsten halogen lamp, an efficient halogen-gas-filled incandescent.

Costing approximately five times the price of incandescent lamps, tungsten halogen lamps offer energy savings of about 35%. Although this is considerably less than the 75% savings offered by CFLs, tungsten halogens are more likely to be used throughout the home because they produce a white light similar to that of traditional incandescents—at an acceptable cost. Moreover, improvements are being made to these lamps to increase their longevity and light output. Says EPRI's Evans, "Maybe it's worth going after a technology that saves less energy but would be used more widely. If we can get a $2 bulb used for half the lighting in a home, that's better than a couple of $20 compact fluorescents that ultimately wind up on a closet shelf." (The sidebar offers more information on tungsten halogens and other efficient-lighting technologies for the residential sector.)

EPRI managers have been communicating with manufacturers about potential collaborative efforts to improve efficient-lighting technology. One possibility is to work together to increase the light output of CFLs. Currently, the lamps produce a maximum illumination equivalent to that of a 75-watt incandescent bulb. But consumers prefer the illumination of a 100-watt incandescent for certain tasks, such as reading. The Institute would also like to encourage the establishment of standards for CFL lighting. "I think there are too many options for manufacturers right now," says Kesselring. "The lamps can be any shape or any size, and they can plug in or screw in. Manufacturers need some kind of boundaries that will help limit those options and guide them in producing quality products." For example, standard testing could be instituted to help ensure that actual light output matches the output stated on lamp packaging.

But is it really worth the effort to search for energy savings in lighting, which accounts for only 10% of the electricity used in homes? "We certainly think so," Evans says. While it may sound like a small amount of electricity, this 10% represents about 94 billion kWh per year. A savings of just 20% of this sum would be about 19 billion kWh, or more than enough to meet the annual residential electricity needs of Chicago.

Further study is needed to determine precisely the appropriate course for utility lighting programs in the future. But, Kesselring says, EPRI's research has offered a good starting point, taking the first step toward moving the utility industry into a new phase in residential lighting programs—a phase that is almost certain to focus on the marketability of efficient-lighting products. "Utilities have been trying to introduce residential customers to the new technologies available," Kesselring says. "But they can't subsidize the technologies forever. They must begin to design programs that will stimulate the market so it can sustain itself. At some point the market must take over."

Background information for this article was provided by John Kesselring and Michael Evans, Customer Systems Division.

TECH TRANSFER NEWS

Timely Low-Level Waste Guidelines Help Utilities

With the recent closing of one of the three U.S. disposal sites for low-level radioactive waste, the impending closure of another, and the imposition of access restrictions at the third, utilities across the country are grappling with the issue of temporary on-site storage of low-level waste (LLW). To aid utilities with the technical and regulatory processes entailed in such interim on-site storage, EPRI recently released *Guidelines for Interim Storage of Low-Level Waste* (TR-101669).

The new guidelines provide a framework for utilities to use in planning for long-term interim LLW storage. Useful for utilities that are either developing, reviewing, or modifying on-site storage programs, the guidelines identify the significant planning issues to consider. They include an executive summary of a complete on-site storage project, as well as a flowchart showing the various phases of the planning and implementation process. An extensive lessons-learned section highlights significant issues that can impose limitations on storage facility operations. The guidelines also provide a means of evaluating ongoing storage projects and supply numerous references to applicable information in a related five-volume set of EPRI reports on LLW.

"Every utility faced with interim storage of low-level waste will need to evaluate its unique situation relative to disposal," says Carol Hornibrook of EPRI, manager of the project that produced the guidelines and related reports. "Utilities considering on-site storage will need to make informed decisions on licensing issues, facility design, storage duration and capacity, waste form, and other issues. These reports document industry experience and offer insight from LLW experts. Equipped with this comprehensive set of data, utilities can make decisions on the basis of the best available information without having to develop the information independently."

The five-volume series (TR-100298), to be used with the guidelines, presents the methodologies utilities need for interim storage planning. Volume 1 addresses the licensing and regulatory issues with which utilities must comply. Volume 2 has two parts. The first covers the range of design options for LLW facilities and lays out a technique for examining those designs to determine which one would best suit a utility's unique situation. Part 2 is a survey of existing on-site storage facilities.

The third volume also has two parts. Part 1 discusses how to estimate the volume of waste a utility is going to generate and offers a framework for managing the data on this waste during the storage period. Volume 3, Part 2, presents a computer program for projecting waste volumes. Volume 4, Part 1, addresses containers for interim storage, identifying various liners and coating materials to help utilities determine which type is appropriate for the kind of waste to be stored. Volume 4, Part 2, covers container monitoring, discussing the usefulness of currently available monitoring techniques. Volume 5 provides guidance on the form in which waste should be stored in order to optimize storage capacity and minimize the likelihood that waste will have to be reprocessed before disposal.

Several of the TR-100298 reports are already available. The remaining three—Part 2 of Volume 3, Part 2 of Volume 4, and Volume 5—will be published in August. ■ *EPRI Contact: Carol Hornibrook, (415) 855-2022*

EPRINET Bulletin Boards Get Utilities Talking

When a Carolina Power & Light employee recently wanted some information on reducing the moisture content of coal, he didn't pick up the telephone. Nor did he flip through an EPRI report. He simply keyed a brief question onto the screen of his computer.

The next day, a response came from George Wiltsee, the moderator of the electronic bulletin board that the CP&L employee had accessed—the Upgraded Coal Production and Utilization Bulletin Board. Wiltsee explained that EPRI's work on the removal of moisture from coal falls into two categories, and he provided a list of relevant EPRI reports. A couple of days after that, a Union Electric employee accessed the same bulletin board and added some information about his utility's exploration of this topic. He also offered his telephone number and encouraged others to contact him.

These two utility employees were taking advantage of just one of the 20 bulletin boards now available on EPRINET, the Institute's electronic information system. "The bulletin boards are among the most helpful services EPRINET offers, putting users in touch with one another and establishing professional relationships that can go beyond a mainframe terminal interaction," says D. W. Sohn, program manager for technology transfer systems marketing at EPRI.

EPRINET began offering electronic bulletin boards in 1990, about a year after it was launched. Today the system's bulletin boards cover timely topics ranging from electric and magnetic fields to distributed generation. Not everyone who subscribes to EPRINET can access the bulletin boards; this special form of service is reserved for member utilities and selected contractors.

Each EPRINET bulletin board has a moderator, typically an EPRI manager or contractor, who is responsible for checking in with the service regularly. The moderators oversee the daily interactions between those who access the bulletin boards and help ensure that participants stay on track.

EPRINET's moderators also initiate discussion on relevant topics and are available to answer questions and offer advice. Most of EPRINET's bulletin board moderators try to log on every day, although this is not always possible.

According to Sohn, EPRINET's bulletin board services are not nearly as popular as its news services at this time. "Our subscribers are accustomed to the news format, simply reading information provided," Sohn says. "We're trying to get them more interested in taking advantage of the great resources available through the more active involvement that our bulletin board services offer. Utility members in different parts of the country may be going through similar experiences and can really benefit from an interactive dialogue."

Subscribers don't necessarily have to actively participate to benefit from the bulletin boards. They can simply browse through the dialogue on any given topic and learn from the information relayed.

The Upgraded Coal Production and Utilization Bulletin Board, formerly called the Clean Coal Utilization Bulletin Board, is intended to help utilities develop cost-effective strategies for complying with the 1990 Clean Air Act Amendments. It breaks the main topic down into four areas for discussion, including low-rank-coal upgrading technologies and cost and performance impacts. Like other electronic bulletin boards on EPRINET, it also offers a place for comments about the bulletin board itself, such as reminders to the moderator and suggestions for bulletin board improvements.

The Upgraded Coal Production and Utilization Bulletin Board is relatively new to EPRINET, having come on-line late last December. Another new bulletin board is designed to help utilities characterize and resolve soil, surface water, and groundwater contamination at manufactured gas plant sites. Called the MGP Soil Cleanup Bulletin Board, it offers 15 subtopics for discussion, including cleanup technologies and health/ecological risk.

Conrad Kulik, a manager in EPRI's Generation & Storage Division who oversees these two new bulletin boards, notes that both Wiltsee and Jacques Guertin, the moderator of the MGP Soil Cleanup Bulletin Board, have worked for EPRI in the past. "They are first-class moderators," Kulik says. "Both of them are experts in their subject areas, they know the utility business, and they know what our members are looking for. They are good at critiquing suggestions and offering advice. It's like having a consultant at your fingertips."

Users can access EPRINET's electronic bulletin board services through the main EPRINET menu. For further information about the bulletin boards, contact the EPRINET help desk at (800) 964-8000.

BULLETIN BOARDS

- Utility Open
- EPRINET
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- Continuous Emissions Monitoring
- Environmental Externalities
- EPRI Software
- Integrated Utility Communication
- Fossil Plant Maintenance
- Asbestos Research
- Distributed Generation
- Biomass/Waste
- Storage and Renewables
- MGP Soil Cleanup
- Upgraded Coal Production and Utilization
- Steam Generator Reliability
- Commercial-Grade Items
- Managers of EPRI Technology Transfer
- Tailored Collaboration
- Technology Delivery Committee

EPRI Releases Waste-to-Energy Guide

The rapidly growing waste-to-energy business has drawn significant interest from the utility industry in recent years. A new EPRI report, *Waste-to-Energy Screening Guide* (TR-100670), and its associated software program provide utilities with the information and tools they need to quickly estimate the cost and performance of waste-to-energy projects. According to the report, despite their relatively high capital cost—typically two to three times that of conventional power plants—waste-to-energy plants can be cost-effective when payments, or "tipping fees," for waste disposal exceed $80 per ton.

EPRI has monitored and assessed developments related to the use of municipal solid waste (MSW) as a power plant fuel since the industry's first cofiring experiments at Union Electric in St. Louis in 1975. Commercial development of waste-to-energy plants accelerated rapidly in the mid-1980s. By 1991 more than 140 power plants in this country generated about 2000 MW from the combustion of MSW.

The screening guide consists of two volumes. The first is a guidebook that offers key descriptions of waste-to-energy technology, economics, and issues. It covers the six major technologies for converting MSW to energy and offers quantitative and qualitative information for utilities to use in screening waste-to-energy options. The data were developed from technical literature; from the experience of the contractor, Bechtel Group, Inc., in designing, building, and operating commercial plants; and from analyses conducted for this project.

The second volume, called *Data, Formulas, and Verification*, offers documentation for the software program, WTE SCREEN, a PC program that performs screening calculations. The volume contains data on cost, performance, MSW properties, and fuel properties. Among other things, the fuel module addresses issues that arise from recycling, enabling the user to see how different levels of recycling in different parts of the waste stream will affect the amount and quality of fuel available for combustion.

Also prepared as part of this project is a separate report—*Waste-to-Energy Permitting Sourcebook* (TR-100716)—on environmental and permitting issues, which are critical considerations in any utility evaluation of a waste-to-energy project. Other recent EPRI reports on waste-fired power plants and technology include CS-5754, GS-6994, GS-7538, and TR-100058. *EPRI Contact: Evan Hughes, (415) 855-2179*

Residential Program

Hydronic Thermal-Distribution Systems

by John Kesselring, Customer Systems Division

ABSTRACT *An EPRI study has shown that hydronic, or circulating-water, thermal-distribution systems compare favorably, on an economic basis, with other methods of distributing the output of residential heat pumps. Several other factors — including an increased concern with energy efficiency, a growing use of microprocessor-based space-conditioning controls in homes, and an emerging utility interest in load management options — make the use of hydronic heat pump systems even more attractive. Installation of these systems either during new construction or during home renovation — when home owners can replace fossil fuel systems with electrical systems — could offer customers greater energy efficiency and lower heating and cooling costs. The time seems ripe for bringing hydronic thermal-distribution technology to the residential heat pump market.*

For many years home heating and cooling were considered commodities, and space-conditioning equipment was purchased, not on the basis of individual product features, but with an eye toward minimizing the installed cost. As a result, home builders have typically packaged relatively inefficient gas furnaces with relatively inexpensive air conditioners and have installed networks of sheet-metal ducts for the distribution of conditioned air throughout homes. In the typical arrangement, a single thermostat controls the operation of all the space-conditioning equipment.

Changing approaches to home space conditioning

In recent years, at least five developments have forced home builders and space-conditioning equipment manufacturers to reconsider the traditional approach and have stimulated interest in hydronic, or circulating-water, thermal-distribution systems.

First, the National Appliance Energy Conservation Act has mandated that all newly manufactured residential heating and cooling equipment meet specified minimum efficiency levels. This has increased consumer interest in energy efficiency.

Second, "smart" microprocessor-based controls are now available for application in many home functions, including space conditioning, and they are expected to grow in power and sophistication. As a result, there is increased interest in optimizing residents' options for improving both comfort and energy efficiency. Using advanced controls, residents can easily control space conditioning on a room-by-room basis. Different notions of comfortable temperature can be accommodated, and energy consumption can be reduced by adjusting temperature settings in unoccupied rooms.

Third, the appearance on the market of so-called ductless mini-split air conditioning and heat pump systems (which move refrigerant from one air conditioning zone to another) has drawn attention to the advantages of using liquids rather than air for thermal distribution. Fluid lines are less bulky than air ducts, do not leak supply air into unconditioned spaces, and do not collect dust and build up mold. However, widespread concern about the release of chlorine-based refrigerants to the atmosphere may well preclude this approach, which requires installers to make many, potentially leaky, refrigerant-line connections on-site.

Fourth, as an outgrowth of consumer concern with energy efficiency, several manufacturers have developed multifunction appliances. For instance, water heating has been combined with space heating in some devices and with both air conditioning and heating in advanced, highly efficient heat-pump-based systems. Such equipment can offer greater energy efficiency and smaller size.

Fifth, because of delays in nuclear plant construction and difficulties in financing new plants that meet increasingly stringent emissions regulations, capacity margins for U.S. utilities are shrinking. Seeking ways to flatten peak load and to defer the building of new generating capacity, utilities are encouraging the use of heat- and cool-storage equipment and of devices that facilitate the implementation of utility load management options.

Comparison of thermal-distribution systems

In hydronic systems, water (or water with an antifreeze additive) is used to distribute thermal energy. This approach avoids several drawbacks associated with air distribution.

Air ducts tend to leak supply air, often into unconditioned spaces, and the resulting static pressure variations can promote infiltration, which imposes an additional load on the space-conditioning system. Further, zoned control in an air distribution system requires dampers, and unless these are of relatively expensive construction, they tend to leak when closed.

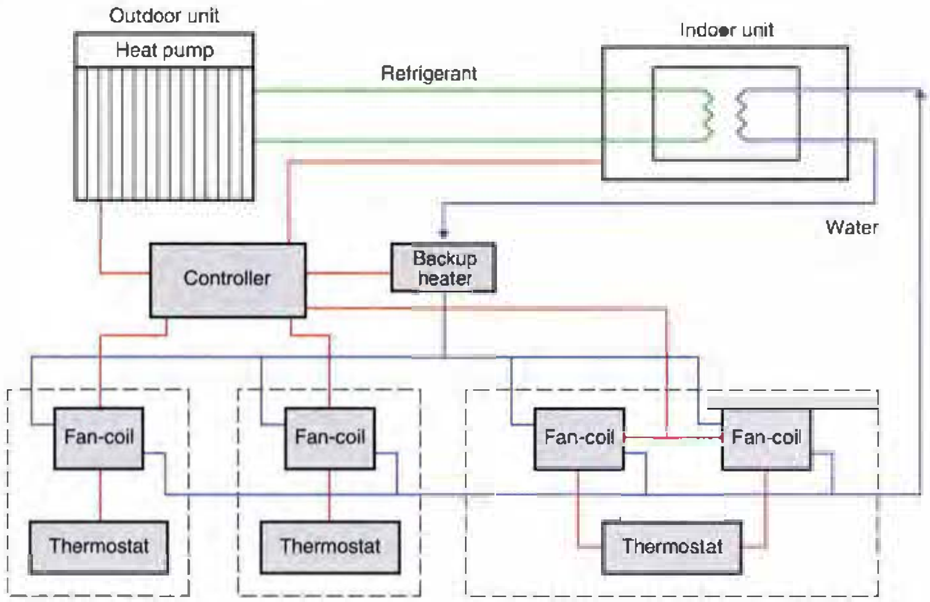
Under EPRI sponsorship, Tecogen, Inc., is developing hydronic systems for linking heat pumps with conditioned spaces. These systems represent a cost-effective and energy-efficient approach to residential zoned control. While providing the benefits of multifunction appliances, this approach does not involve the movement of refrigerants through residential systems, and it could eventually help utilities exercise some control over residential load.

As documented in a two-volume EPRI report (CU-6962), Tecogen sought to identify cost-effective thermal-distribution systems for use with electric heat pumps. Researchers performed detailed cost analyses for several options, including conventional and hypothetical air distribution systems; individual distributed heat pumps; refrigerant distribution systems; and hydronic distribution systems. The researchers studied applications in houses with single-zone control and with multiple-zone control.

The cost study indicated that for single-zone systems, an improved air distribution system—one designed to be easier to install than sheet-metal ducts—would constitute an attractive approach. A patent was assigned to EPRI for a design featuring plastic ducts and terminals that could be installed very quickly in a typical residence. A review of applicable building codes, however, indicated that the all-plastic construction would not prove acceptable, and it has not been pursued. (Plastic flex-duct is currently in use, but it is wire-reinforced and is considered acceptable under National Fire Protection Association codes.)

The results on hydronic distribution systems were encouraging. The study found that when operated from a single thermostat, a hydronic system—which obviates the need for expensive, bulky, and potentially leaky air ducts—is competitive with a single-zone air distribution system. The study further concluded that hydronic systems represent a flexible, cost-effective, energy-efficient approach for multiple-zone applications as well.

Figure 1 A multiple-zone heat pump system with hydronic distribution. In a heat exchanger housed in a compact indoor unit, thermal energy is transferred between refrigerant and water, which is circulated to space-conditioning zones with fan-coil units under thermostatic control. Flexible multichannel cables contain both the water passages for thermal distribution (blue) and the electrical wires used in system control (red).



Hydronic system design

Figure 1 shows the principal components of a multiple-zone hydronic distribution system. The heat pump's indoor unit is built around a refrigerant-to-water heat exchanger. The water is circulated through compact, easy-to-install hydronic lines to terminal fan-coil units, and thermostats control individual or clustered terminal units as appropriate. The indoor unit is slightly more complex than units in air distribution systems, but it is not larger, since, in the absence of airflow, less space is required for heat exchange and no blower is necessary.

The outdoor unit may be a conventional single-speed unit, a multispeed unit, or a unit that can vary speed continuously. The precision with which the heat pump system can follow the variable indoor load depends on the degree of control that can be exerted over the outdoor unit's motor speed. (Variations in load reflect changes in the mix of terminal units operating in response to the individual thermostats.) When control over the outdoor unit is limited (i.e., when a single-speed motor is used), the value of a thermal buffer, such as a small water storage tank, becomes apparent.

To ensure proper control of the system, a thermostat must communicate with the indoor unit, which then sends a signal that switches the fan-coil on or off. The ideal interface between the fan-coils and the indoor unit is a flexible multichannel cable with both fluid passages and electrical wiring. Such cable will have two fluid passages (supply and return) and perhaps a third, depending on how the condensate is handled in the air conditioning mode. (The condensate can be drained directly to the outdoors at the fan-coil, or it can be returned to the indoor unit and drained there.) Typically, the cable will also have three or four electrical wires, depending on how the system controls the fan-coils. If the installation is in a smart house, however, communication can take place through the house network and only fluid passages are necessary. In any case, system designers prefer to use a continuous cable between the central unit and each fan-coil to avoid having to make connections in difficult-to-reach places.

In addition to avoiding problems inherent in air distribution systems, hydronic distribution systems present opportunities. For example, given a simple hydronic system, one could easily incorporate heat pump water heating from the heat exchanger and could add dual-fuel capability by installing a fossil fuel water heater in the circuit (which could serve as a utility-commanded demand control device).

Further benefits could be realized by using a water-to-water heat pump as the heart of the system. Such a dual hydronic system uses water to connect to the ambient (ground, groundwater, or air) as well as to distribute thermal energy throughout the home. The terminal fan-coil units are the same as in the simpler system. Now, rather than reversing the heat pump to switch between heating and cooling, the valves in the hydronic circuit can be repositioned to redirect condenser and evaporator water. Because the switching is done on the hydronic circuit, not on the refrigerant circuit, the latter can be factory-sealed; the installer has to make only water connections at the site, and the risk of refrigerant escaping to the atmosphere is minimized. Also, the performance of the evaporator and the condenser can be optimized for component function and for relative load, instead of reversing the loading on each component and having them serve dual functions. Further, this arrangement simplifies heat pump water heating off the condenser in the air conditioning mode.

Future prospects

Compared with heat pump systems using conventional air distribution, systems using hydronic distribution could offer a lower first cost, improved efficiency, and greater comfort. To gather more data on this technology, EPRI installed a multiple-zone hydronic distribution system in an unoccupied test house in Gaithersburg, Maryland, in late 1992 and is conducting extensive performance testing. The field test system features a two-speed outdoor unit and a supplemental heater that is housed in a small but adequate water storage buffer. Test results will be available late this year.

Hydronic distribution represents a new approach that will take time to gain acceptance, but ongoing changes in residential heating, ventilation, and air conditioning practices and technology will speed that acceptance. In the coming years, the installation of hydronic heat pump systems during new construction and during renovation or expansion of existing homes could increase the electric utilities' share of the home space-conditioning market.

Electrical Systems Software

ESWorkstations: The Next Generation

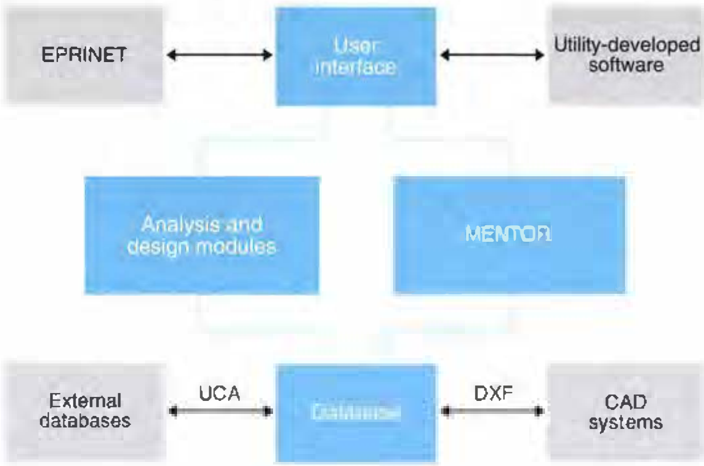
by Giora Ben-Yaacov, Electrical Systems Division

ABSTRACT *Utilities have responded positively to the first generation of Electrical Systems Workstations (ESWorkstations), integrated packages of computer programs that address various engineering functions. Now EPRI is making these software tools even more useful and accessible. In response to utility suggestions, the next generation of the workstations will include knowledge bases, on-line reference and engineering tools, and standard data links to other software. What's more, the EPRI workstation programs are being designed to be compatible with software developed in-house at utilities. These enhancements will enable more utility personnel to use the workstations more efficiently.*

Over the years, utilities have used computer programs in a variety of tasks, ranging from generation planning to equipment troubleshooting. Developed one at a time, these programs use differing databases and interfaces. As a result, utility personnel have had to learn how to use a variety of programs and have had to develop data to input into each program.

To facilitate and expand software use, EPRI has developed integrated packages of programs, each package related to a common engineering function—for example, system grounding. Known as Electrical Systems Workstations (ESWorkstations), these packages of software allow users to perform a number of related and interdependent tasks much more efficiently than if the programs were used individually. Taking advantage of a standard interface and a common database, these software workstations (not to be confused with hardware workstations) reduce the time spent learning individual programs and developing input data. Because they integrate programs that address various aspects of a given engineering function, ESWorkstations can help utilities develop more-comprehensive designs and solutions to problems.

Figure 1 The next generation of ESWorkstations will feature a built-in expert advisor called MENTOR, will be compatible with utility-developed software, and will have standard links to external databases (using the Utility Communications Architecture) and to CAD systems (using the Data Exchange Format). Also, users will be able to exchange information electronically via EPRINET.



Industry response to these integrated software packages has been positive. From 25 to 150 utilities are using the six original ESWorkstations, and utility benefits are mounting. For example, by using EPRI's DYNAMP program, a dynamic ampacity module in the Transmission Line Workstation (TLWorkstation™), the Salt River Project expects to save $8.6 million in deferred and canceled transmission projects during the next four years. In another case, Southern Company Services used the Extended Transient–Midterm Stability Program (ETMSP) and the Small Signal Stability Program (SSSP)—two EPRI software modules that will be incorporated into the Power System Analysis Workstation—to develop an alternative strategy to building a new transmission line, thereby deferring an estimated $120 million in line construction costs.

As utility personnel with an increasingly wide range of technical backgrounds and computer experience use the ESWorkstations, and as utilities find new ways to apply these tools, new areas for software R&D are being identified. On the basis of this experience, EPRI's Software Advisory Committee, composed of utility representatives, has suggested various ways to make the workstations even more useful.

These suggestions have led to the development of the next generation of workstations (Figure 1). The new workstations will operate on standard computer systems, incorporate open-systems technology, and feature graphic user interfaces. They will be compatible with software developed in-house by utilities. Equally important, the workstations will have standard links to utility databases, to external computer-aided design (CAD) systems, and to EPRINET (EPRI's electronic information and communications network). At the core of each of the next-generation workstations will be a built-in expert advisor called MENTOR (for methods, engineering tools, and on-line reference).

A MENTOR for users

Designed to complement the analysis and design modules of a workstation (i.e., its engineering resources), MENTOR can act as a tutor, a calculator, a gateway to other software tools, and a comprehensive reference library. The goal is to enable utility personnel who are not well versed in the technology of the analysis and design software to use the next-generation workstations.

The methods portion of MENTOR includes a knowledge base, a handbook with step-by-step instructions, and case studies to illustrate software use. For example, the CUFAD (compression and uplift foundation analysis and design) module in the TLWorkstation aids in the design of transmission and distribution pole foundations. With the addition of a knowledge base, the module has been substantially upgraded so that novice designers can use it. The enhanced module, which is called CUFAD+, guides users through the design or analysis of a given structure one step at a time, providing explanations as necessary.

MENTOR's engineering tools include links to external applications software, such as spreadsheets and word processors. They also include easy-to-use calculators. For example, the soon-to-be-released Electric and Magnetic Fields Workstation, Version 2, contains a power line calculator to help users compute unbalanced loads in a three-phase system. Using a few relatively simple equations, this calculator eliminates computational errors and provides handy information quickly and easily.

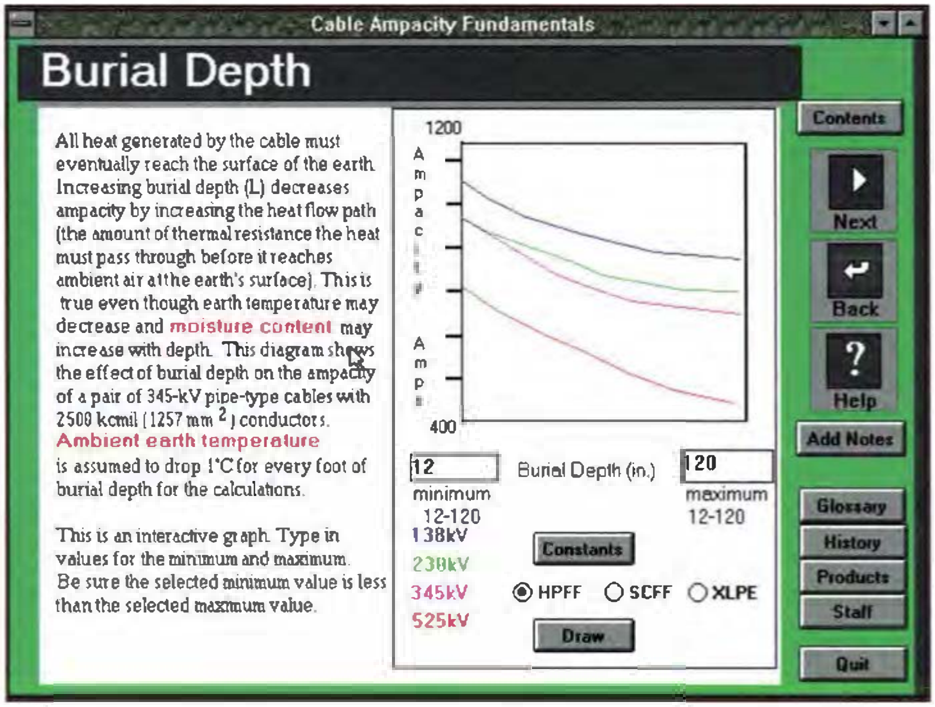
As an on-line reference, MENTOR provides tutorials, lists of references for obtaining more information, and a section where users can enter notes during software application. For example, a module in the Underground Transmission Workstation consolidates information on cable ampacity from several reports and presents it on-line in an easily accessible format (Figure 2). Users who know nothing about cable ampacity can learn its basics quickly, while experienced users can just as quickly expand their knowledge on the subject.

An open architecture

A key attribute of the next generation of ESWorkstations is compatibility with utility-developed software. Many utilities have modified existing software or have developed their own computer programs, often investing years of staff time in the process. For this software to operate with the workstations (i.e., to use common interfaces and databases), the workstations must have an open-systems architecture. This means that standard, commercially available computer hardware, operating systems, communications hardware and software, databases, and user interfaces must be used. The Distribution Engineering Workstation for designing and analyzing distribution facilities will be one of the first new workstations to feature such an open architecture.

The need for easy access to data stored

Figure 2 The on-line reference capabilities of MENTOR are illustrated in this interactive screen from a tutorial on cable ampacity fundamentals for the Underground Transmission Workstation.



in other utility files will be addressed by developing standard links to both CAD systems and external databases. To link with CAD systems, the workstations will use the Data Exchange Format (DXF). Because detailed substation specifications are typically stored in CAD systems, one of the first workstations that will be linked to CAD data by using DXF is the Substation Grounding Workstation (SGWorkstation). This data link will eliminate the need to reenter substation data; specifications can be transferred directly from a CAD system to the SGWorkstation database.

The Utility Communications Architecture (UCA) will be used to link workstations with external databases. As part of an effort on integrated utility communications, EPRI has undertaken the UCA project to design an architecture that meets the complete range of utility communications needs. This architecture is based on the Open Systems Interconnection, or OSI, reference model, which was established by the International Organization for Standardization at the urging of computer users and vendors worldwide.

Other important features of the next generation of ESWorkstations are easy-to-use graphic user interfaces and access to EPRINET. Electronic bulletin boards for exchanges of information and data between EPRI and users will soon be established as part of EPRINET.

EPRI plans to upgrade each of the six original ESWorkstations to incorporate MENTOR and the other new features. New workstations, 12 of which are in various stages of development, will include these features from the start. By 1994 nearly a score of these integrated software packages will be available, making EPRI's electrical systems software easier to use than ever before.

Land and Water Quality

Degradation of Organic Compounds in Contaminated Soils

by Ishwar P. Murarka, Environment Division

Organic compounds can be converted, or degraded, to other compounds by physical, chemical, and biological means. For example, microorganisms (particularly bacteria and fungi) can biodegrade a wide variety of organic compounds, converting them to carbon dioxide and water. Research over the past decade has explored the possibilities of bioremediation—active management to enhance the biodegradation of organic compounds in contaminated soils and water.

Bioremediation is becoming a popular method for cleaning up sites contaminated with various organic compounds. Through 1991, bioremediation was specified as a treatment in 10% of Superfund cleanups. And more than 20% of the technologies being developed under the U.S. Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) Program include some form of on-site or off-site bioremediation. Considering all federal programs mandating soil cleanups, more than 130 sites are using or planning to use bioremediation.

To date, the largest bioremediation experiment has been the cleanup of the 11-million-gallon Exxon Valdez crude oil spill of 1989. Because large-scale efforts to enhance biodegradation by applying fertilizers appeared to succeed in some areas of the Valdez spill but not in others, the EPA's Science Advisory Board concluded that enhancing biological breakdown involves more than simply adding nutrients. The advisory board recommended that research focus on evaluating the large number of factors that can affect the success of bioremediation.

Although cleaning up a site with contaminated soil presents a smaller-scale problem than cleaning up the Valdez spill, soil bioremediation can involve even more factors. Given such complexity and uncertainty of success, why is bioremediation becoming an attractive technology for soil cleanup? The primary reason is that it is perceived to be an extension of a natural process, resulting in the conversion of toxic materials into benign end-products. Also, in many cases it promises to be less costly than other methods, such as incineration, although this has yet to be verified for the wide variety of chemical compounds and contaminant mixtures that have been encountered at soil contamination sites.

Ongoing projects in EPRI's Land & Water Quality Studies Program are exploring both natural and enhanced biodegradation processes. This research focuses on a handful of organic compounds important to the utility industry: polycyclic aromatic hydrocarbons (PAHs) found at old manufactured gas plant (MGP) sites; wood preservatives (pentachlorophenol and creosote) associated with utility poles; petroleum hydrocarbons associated with fuel storage; and polychlorinated biphenyls (PCBs) associated with dielectric fluids.

ABSTRACT *Organic compounds from utility operations may contaminate soils and water. EPRI-sponsored researchers are exploring ways to degrade these contaminants by enhancing the natural activity of microorganisms in conjunction with physical and chemical amendments. This research is focusing on polycyclic aromatic hydrocarbons, wood preservatives, petroleum hydrocarbons, and polychlorinated biphenyls. Laboratory studies have shown encouraging results, most notably for the preservative pentachlorophenol. Future studies will test successful degradation strategies (combining physical, chemical, and biological processes) on a larger scale at field sites.*

Technical considerations

Biodegradation caused by naturally occurring organisms is well documented for many organic compounds in soils and water. While the occurrence of biodegradation is undisputed, its rate and its importance in regulating contaminant migration and removal are less clear. The primary factors controlling biodegradation in soil are as follows:

- Types of microorganisms present
- Accessibility of the target compound
- Nutrients present (nitrogen, phosphorus, potassium)
- Electron acceptors present (usually oxygen)
- Soil chemical conditions (pH, redox, acidity/alkalinity, organic matter)
- Soil physical conditions (texture, moisture content, temperature)
- Supplemental organic compounds present

Depending on these factors, an organic compound may completely biodegrade in a matter of days or weeks or may persist unchanged for a long period of time. As a result, biodegradation rates reported in the literature span several orders of magnitude, reflecting variability among chemicals, sites, and experimental conditions.

Bioremediation seeks to stimulate or enhance biodegradation rates through the active management of factors that control naturally occurring microbial activity. While it is relatively easy to enhance biodegradation rates under controlled laboratory conditions, achieving enhanced rates in large-scale field operations has proved to be considerably more difficult.

Successful bioremediation requires that a target organic compound be accessible to microorganisms present in the soil. Organic compounds can reside in the soil environment in many phases, some of which are more readily accessible than others. Compounds can reside in the aqueous phase, the nonaqueous liquid phase, the adsorbed phase, and the soil humic matter (solid) phase. Organic compounds in the aqueous phase are generally the most readily accessible to microorganisms, while chemicals in the soil-bound and nonaqueous liquid phases are the least accessible. If the concentration of a contaminant compound is too high, it may be toxic to microorganisms in the soil; if its concentration is too low and it is dispersed, it may not support an active community of biodegraders.

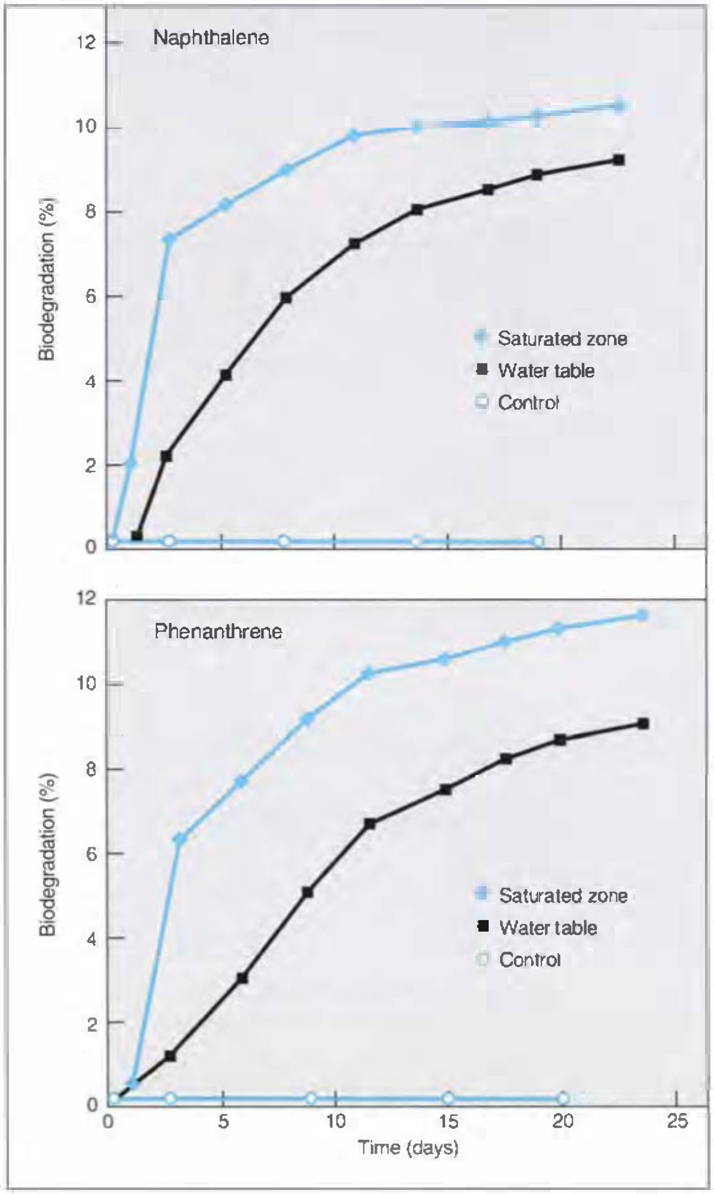
Bioremediation relies on the activity of organisms with affinity for the target compounds. Adapted or introduced microorganisms must be able to compete successfully with indigenous organisms to maintain their niche. Furthermore, their activity depends on having the right mix of nutrients and soil properties to provide optimal living conditions for a healthy microbial community.

In bioremediation, one additional and very important factor to consider is the biodegradation pathway. Ideally the biological breakdown of organic compounds proceeds to mineralization (100% biodegradation to carbon dioxide and water), but complete biodegradation occurs rarely for most compounds. Instead, stable intermediate compounds form that are persistent and can sometimes be more toxic than the original compound. In evaluating either natural or enhanced biodegradation, it is critical to assess the toxicity, persistence, and behavior of such stable intermediates.

Coal-tar-contaminated soils

One focus of research has been a coal tar disposal site (called Site 24) in a forested

Figure 1 In laboratory tests, naphthalene and phenanthrene were added to soil cores from a coal-tar-contaminated site to study degradation by naturally occurring bacteria. Both compounds were rapidly biodegraded in water table interface and saturated-zone samples from inside the plume. No biodegradation of these compounds was observed in control tests using samples from two other soil layers in the plume area (the unsaturated zone and the underlying clay layer) and samples from a core collected outside the plume.



rural area in New York. In the early 1960s, about 10,000 gallons of coal tar wastes from an MGP holding tank were placed in a rectangular trench beside a country road and covered with sand. The trench was left undisturbed for more than 20 years, until groundwater contamination was discovered downgradient from the trench and an investigation was begun.

Because of its age and remote location, as well as its single, well-defined tar source and its well-developed contaminant plume, Site 24 provided an ideal location for evaluating the effects of natural biological processes on coal tar degradation. The narrow plume, which stretched to a series of seeps about 400 meters downgradient from the tar source, contained several PAHs, including naphthalene, phenanthrene, and acenaphthene. The plume was confined to a shallow, sandy aquifer overlying a sequence of interbedded silts and clays.

One objective of the research at Site 24 was to describe the natural biological degradation processes that had developed in response to the presence of coal tar. A total of nine soil cores were collected—three from near the source, three from elsewhere inside the plume, and three from outside the affected area. Using aseptic techniques to avoid contamination, the researchers extracted several samples from each core and subjected them to chemical and biological analyses.

Microbiological analysis revealed an abundance of active PAH-degrading microorganisms within the plume. Below the biologically active surface soil horizon, the numbers of viable bacteria were largest at the water table interface and declined rapidly with depth in the saturated sand. PAH degradation by these bacteria was studied in laboratory tests in which carbon-14-radiolabeled naphthalene and phenanthrene were added to Site 24 soil samples. In these tests, the naphthalene and phenanthrene were biodegraded in samples from certain soil layers inside the plume, but not in samples from outside the plume (Figure 1). These results indicate that the natural microbial community had adapted to the presence of the coal tar and that bacteria were actively consuming PAHs emanating from it.

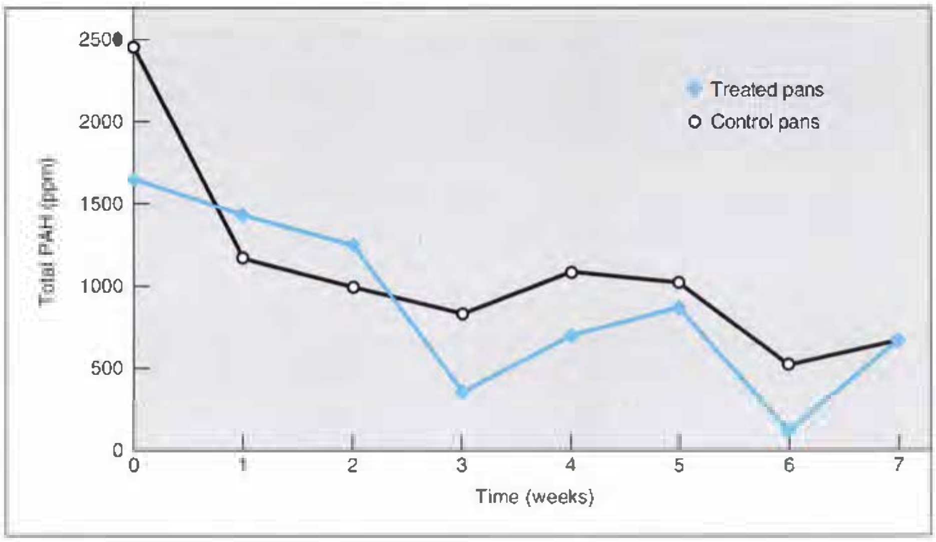
The laboratory experiments showed that, under optimal conditions, biodegradation would eliminate 50% of the carbon-14-radiolabeled naphthalene in 8 to 50 days. But the persistence of naphthalene and other PAHs at Site 24 suggests the operation of other factors, such as constant delivery of new PAHs from the source and/or physiological limitations of the microbial community. These issues are currently being investigated.

Soil texture was the most influential environmental factor in determining the distribution of microorganisms at Site 24. Biological activity was greatest where the sand content of the soil was highest. Conversely, the decline in viable organisms with depth in the saturated zone was probably related to an increase in the soil's silt and clay content. Dissolved oxygen and nutrient availability did not appear to be limiting factors for PAH biodegradation at Site 24.

While the Site 24 research focused on natural biological processes, a laboratory study involving another MGP site in the northeastern United States yielded encouraging results on the potential of bioremediation using fungus. The investigators found biodegradation of more than 85% of the PAH compounds in soils inoculated with a white rot fungus in test tubes.

After determining that the white rot fungus could be transported and successfully transplanted under carefully controlled conditions, EPRI researchers conducted a field study on the use of the fungus for biodegradation of coal-tar-contaminated sediments under both aerated and unaerated conditions. In a series of experiments, six pans (three treated with fungus and three controls) were sampled weekly. Slight reductions in PAHs (apparently caused by the volatilization of two-ring compounds) were observed in all the pans; there was no significant difference between fungus-treated and control pans (Figure 2). The use of a slightly different method of handling the fungus, together with scaling difficulties, may have been responsible for the inability of the white rot fungus to biodegrade PAH compounds in these pan experiments. The results of this study illustrate the sensitivity of biodegradation processes to even small perturbations in conditions.

Figure 2 In pan experiments with coal-tar-contaminated soil from a manufactured gas plant site, some pans were inoculated with white rot fungus. PAH degradation results for these treated pans were similar to results for the control pans, indicating that the fungus did not enhance degradation. The observed PAH losses were attributed to the volatilization of two-ring compounds from both sets of pans.



PCP-contaminated soils

The utility industry is keenly interested in the degradation of pentachlorophenol (PCP) because of its widespread use as a wood preservative on distribution and transmission poles. Previous research has shown that PCP is highly susceptible to degradation processes. In response to the industry's critical need for information, EPRI has initiated research on the physical, chemical, and biological conversion of PCP in contaminated soils.

In the first phase of study, EPRI researchers conducted laboratory flask and pan studies on soil samples collected from Iowa and Washington. In order to achieve a complete mass balance, carbon-14-radiolabeled PCP was used in some of the experiments. The soils had PCP concentrations ranging from less than 1 mg/kg to 9000 mg/kg.

The effectiveness of the following measures in enhancing PCP biodegradation was evaluated: adding nutrients to the soils to stimulate indigenous microorganisms, exposing the soils to ultraviolet (UV) light, and adding chemical oxidants to the soils. (Inoculating the soils with the PCP biodegraders *Flavobacterium* and white rot fungus was also tried; however, initial tests indicated that inoculation did not enhance the biodegradation process, and it was not pursued.) Since PCP strongly adsorbs to soils, an ethanol-water mixture was added during some of the tests to enhance PCP solubility.

The results of these laboratory studies were very encouraging. The addition of a solution containing nutrients and ethanol to soils inhabited solely by indigenous microorganisms resulted in the enhanced biodegradation of PCP and PCP intermediates. Two PCP intermediates of potential concern—2,4,5-trichlorophenol and 2,4,6-trichlorophenol—did not appear to accumulate during PCP biodegradation. The experiments yielded a first-order biodegradation rate of 0.015 to 0.030 per day and a half-life of 23 to 46 days. The addition of the ethanol-water mixture and exposure to UV light increased the rate of PCP degradation significantly over rates achieved solely with indigenous microorganisms. The use of oxidants in conjunction with the ethanol-water mixture produced the best PCP degradation results (Figure 3).

In the second phase of study, EPRI re-

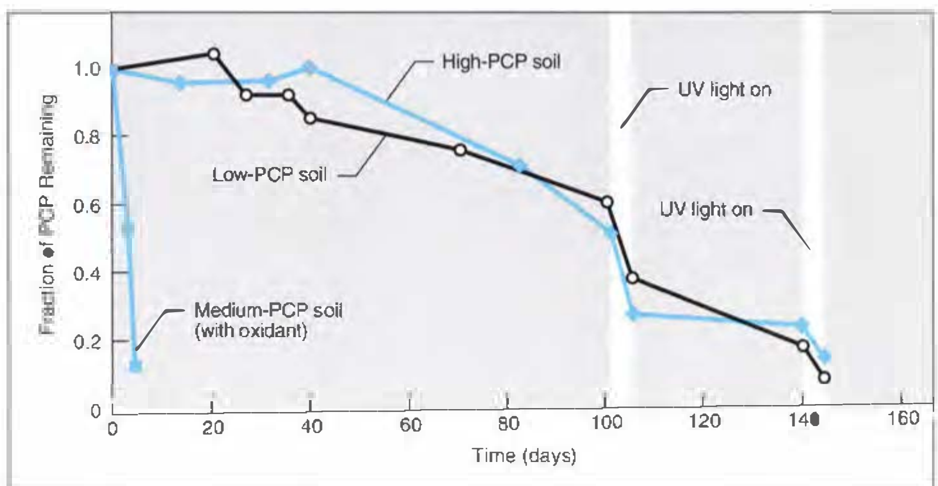


Figure 3 Laboratory results on enhanced biodegradation of pentachlorophenol (PCP) in contaminated soils. A nutrient solution was added to all soil samples in conjunction with various other measures. The best results were obtained for medium-PCP soil to which oxidants and an ethanol-water solution were added at the beginning of testing. For high- and low-PCP samples, adding the ethanol-water solution (in this case at day 30) also enhanced biodegradation, as did exposure to ultraviolet (UV) light. (The early upturns in these curves are the result of sampling and analysis variability.)

searchers are scaling up these experiments and taking them to the field; on-site studies are being performed in Washington with soils treated in pans and boxes. In developing treatment combinations, the researchers are focusing on varying the concentrations of oxidants, the exposure to UV light, and the stimulation of indigenous bacteria. The ethanol-water mixture is added in all cases.

Petroleum hydrocarbons and PCBs

EPRI recently initiated research to assess the biodegradation of petroleum hydrocarbons and PCBs. In the case of petroleum hydrocarbons, investigators are looking at the use of non-white rot fungus (strain GMB-6) to remediate soils contaminated by motor oil released during the maintenance of railroad cars. The efficacy of amending soils with GMB-6 will be studied in five field plots with total petroleum hydrocarbon concentrations in excess of 2000 mg/kg. Fungus spores and nutrients will be tilled directly into the contaminated soils. The goal of the project is to reduce total petroleum hydrocarbon concentrations to below 200 mg/kg.

In a collaborative effort with the Tennessee Valley Authority, EPRI will also evaluate the potential for on-site bioremediation of PCB-contaminated soils. While it has long been known that PCBs can be biodegraded, their environmental persistence indicates resistance to the biodegradation process. This resistance arises largely from the strong sorption of PCBs to soils and from the complex mixtures of congeners found in most PCB-containing oils. For example, the more highly chlorinated congeners (those with more than four chlorine atoms) are less susceptible to biological attack. This research project is designed to characterize PCB biodegraders, develop methods in the laboratory to enhance the biodegradation process, and assess those methods at field scale.

Taking research to the field

In summary, recent EPRI research on the degradation of organic compounds has yielded encouraging results, particularly for pentachlorophenol. PCP has been found to be highly susceptible to chemical and photolytic degradation in conjunction with biodegradation, and work is now focused on developing practical methods of exploiting these processes in field-scale soil remediations. At MGP sites, the natural biodegradation of some PAH compounds (notably naphthalene, phenanthrene, and acenaphthene) was observed, but initial efforts to enhance biodegradation rates by introducing fungus have met with limited success.

While the literature contains many examples of enhanced biodegradation in laboratory studies, successes at field scale are less common. It has become clear that transferring promising laboratory findings to a field setting requires more than simply scaling up a treatability study. The complex interaction of physical, chemical, and biological factors at a site must be considered in order to maximize the likelihood of success. Over the next few years, EPRI researchers hope to learn enough about this complex interaction to achieve successful implementation of field-scale treatments.

Steam Generator Corrosion Control

PWR Secondary Water Chemistry Guidelines

by Christopher J. Wood, Nuclear Power Division

In December 1988, EPRI published *PWR Secondary Water Chemistry Guidelines, Revision 2* (NP-6239). The purpose of that document was to provide operational chemistry guidance to the electric utility industry for minimizing localized corrosion in steam generators and turbines. Since 1988, utility conformity to the guidelines on impurity values has been excellent, with most steam generator blowdown concentrations at or below 10% of the guideline values.

Many forms of corrosion have affected steam generator performance over the years. The move to a slightly alkaline, reducing water chemistry has eliminated most of these problems, and the dominant issues in PWR secondary systems today are intergranular attack (IGA) and stress corrosion cracking (SCC) of steam generator tubing at crevices formed by tube-tube support plate intersections. Despite the good performance of plant chemistry programs, there has recently been a rapid increase in IGA/SCC, as indicated by data on the sleeving or plugging of damaged steam generator tubes (Figure 1). Although the percentage of tubes removed from service remains small, the accelerating trend demands attention. There have been some isolated instances of IGA/SCC in once-through steam generators, but of primary concern are occurrences in recirculating steam generators.

Chemistry to control IGA/SCC

Recent research has focused on understanding the causes and growth patterns of IGA/SCC. One significant factor is crevice chemistry, especially electrochemical corrosion potential (ECP) and pH (Figure 2). Given that the total concentration of impurities in feedwater has decreased, the ability of a small imbalance of one impurity—for example, sodium—to affect crevice pH has increased. This is believed to be one of the reasons for the increasing incidence of IGA/SCC.

There are essentially three approaches to controlling crevice corrosion, at least two of which will be necessary at most PWRs with

ABSTRACT *Corrosion damage in PWR steam generators has been a costly problem for the industry, necessitating more-frequent inspection and repair and, in several plants, complete steam generator replacement. With many forms of corrosion now well controlled, chemistry guidelines for the secondary systems of PWRs are focusing on reducing intergranular attack and stress corrosion cracking at tube–tube support plate intersections in steam generators. These guidelines signal a new approach to plant chemistry programs—an approach emphasizing proactive management and plant-specific optimization.*

susceptible materials. The first approach focuses on cleanliness: avoiding the buildup of sludge and minimizing the ingress of ionic impurities (particularly lead) that accelerate attack. Sludge accumulates in low- and restricted-flow areas — at tube–tube support plate intersections, in tube-tubesheet crevices, and on top of the tubesheet. Aggressive impurities then concentrate in these crevices and sludge piles, leading to IGA/SCC problems.

Sludge is composed of corrosion products (primarily iron oxides) released from the construction materials used in the low-temperature parts of the secondary system, such as the moisture separator drain reheaters. This type of corrosion is reduced by a factor of about 10 for each 1-unit increase in feedwater pH. Major advances in pH control are occurring at this time. The ammonia all-volatile treatment (AVT) has been replaced by morpholine in nearly half the PWRs in the United States, and testing of ethanolamine (ETA), which appears to be superior in several respects to morpholine, started in 1992 at three plants. (Other amines are also under test at plants in the United Kingdom and the United States.)

As noted above, the continuing improvement in feedwater quality has had the undesirable effect that even small impurity increases cause much bigger swings in crevice pH than in earlier times, when the overall mix of impurities buffered the system. The second approach to reducing crevice corrosion therefore is to control the cation/anion balance, particularly by avoiding caustic conditions. This approach, which has been adopted by several U.S. plants and by most Japanese plants, involves reducing sodium ingress, measuring hideout return to determine actual crevice chemistry, and, if necessary, increasing chloride concentrations slightly.

The third approach to crevice corrosion control is to add inhibitors to the feedwater to reduce the effects of aggressive species present in the crevice environment. Boric acid provides some buffering, thereby helping to avoid extremely caustic conditions, but a more effective additive would be desirable. In laboratory tests sponsored by EPRI, titanates have greatly reduced IGA/SCC, with no identifiable adverse effects. Qualification testing on titanates is continuing, and the first plant tests are planned for 1993.

Other factors influencing IGA/SCC

The growing incidence of IGA/SCC may be partly the effect of better detection procedures; the continuing improvement in eddy-current inspection techniques provides utilities with more-sensitive procedures for detecting this type of damage. In addition, the higher operating temperatures of newer plants can result in shorter times to failure and increased sensitivity to the crevice environment.

Laboratory studies and field experience suggest that resistance to IGA/SCC also depends on the tubing material and the tube support design. The following tubing materials are ranked in order of increasing resistance to IGA/SCC: low-temperature mill-annealed Alloy 600, high-temperature mill-annealed Alloy 600, thermally treated Alloy 600, and Alloys 690 and 800. The following tube support designs are also ranked in order of increasing resistance to IGA/SCC: carbon steel drilled hole, stainless steel drilled hole, eggcrate (carbon or stainless steel), and quatrefoil broach. (The last two designs have about the same resistance.)

Several other factors influence plant susceptibility to IGA/SCC, most notably the balance-of-plant (BOP) design. For example, the presence of copper alloys in the system

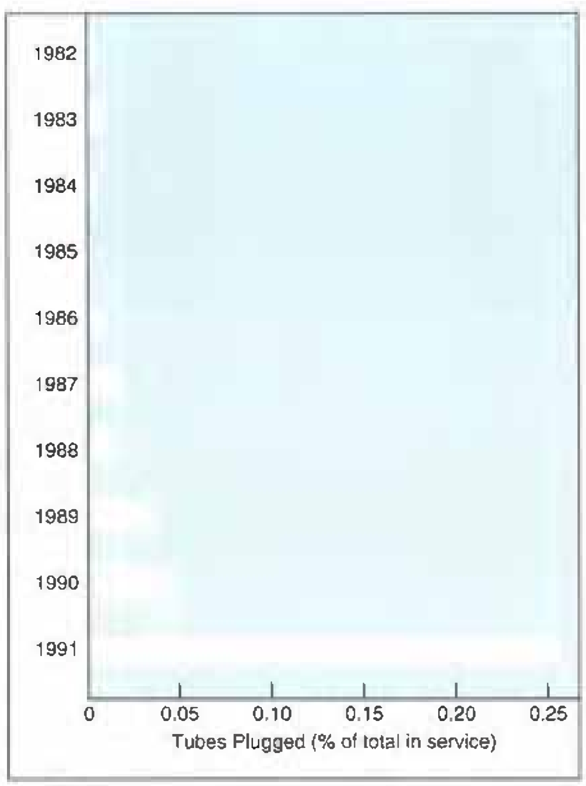
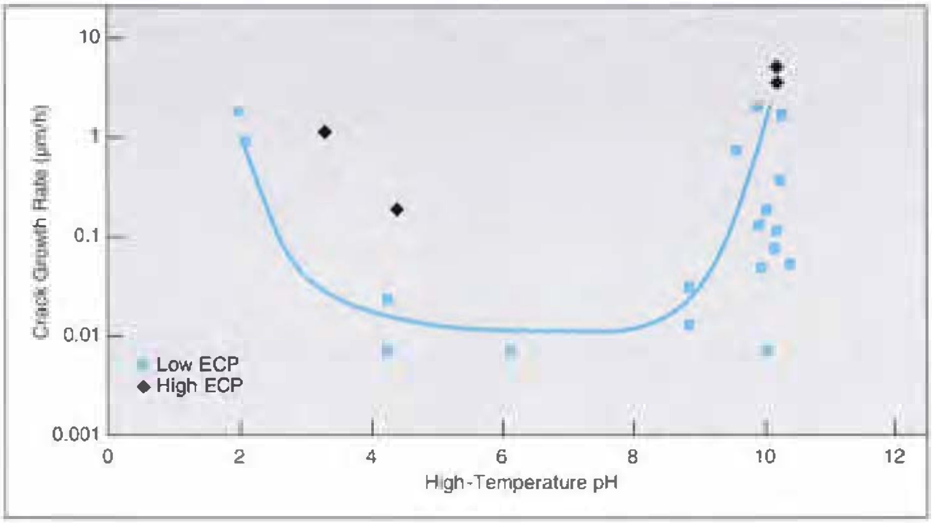


Figure 1 Percentage of steam generator tubes plugged and removed from service at U.S. PWRs because of IGA/SCC. Although the percentage of tubes affected is small, the upward trend has spurred the development of revised secondary water chemistry guidelines to minimize IGA/SCC damage.

Figure 2 Stress corrosion cracking rate versus pH. Shown are laboratory crack growth rate data for mill-annealed Alloy 600 under low and high electrochemical corrosion potential (ECP) conditions, which correspond to fully reducing and fully oxidizing conditions, respectively.



increases susceptibility by raising crevice ECP.

Chemistry guidelines

The increase in steam generator tube degradation and a desire to improve plant chemistry programs have prompted a revision of the water chemistry guidelines. *PWR Secondary Water Chemistry Guidelines, Revision 3* (TR-102134, forthcoming, spring 1993) revisits all the material in the 1988 revision to make the guidelines consistent with current understanding. The new EPRI report develops concepts first presented in *Interim PWR Secondary Water Chemistry Recommendations for IGA/SCC Control* (TR-101230, September 1992), which was prepared on an accelerated schedule to help the industry move quickly to control the rising incidence of IGA/SCC.

Both the new revision and the interim report it supersedes were produced by an industry committee consisting primarily of representatives from utilities, vendors, the Institute of Nuclear Power Operations, and EPRI. The following sections summarize the main technical recommendations of the new guidelines.

Hydrazine concentration Because IGA and SCC accelerate in oxidizing environments, hydrazine is added to feedwater to produce reducing conditions. Previously, sufficient hydrazine to reduce oxygen in the bulk water was recommended. However, because crevice ECP influences IGA/SCC, it is beneficial to increase the hydrazine concentration further, to at least 100 ppb, to ensure that reducing conditions are maintained in the steam generators. It is not desirable to operate with high levels of hydrazine under all circumstances, though, and this recommendation is subject to plant limitations and environmental constraints.

Feedwater iron and copper limits Reducing sludge, by controlling feedwater iron to 25% of the previous limit, should reduce impurity concentration in crevices. Reducing copper will lower crevice ECP. The new limits — 5 ppb for iron and 1 ppb for copper — are still higher than the levels achievable in most plants, but this recommendation emphasizes the desirability of controlling pH in the BOP (to minimize corrosion product input) and eliminating copper alloys.

Boric acid treatment Boric acid is used in many plants and appears to reduce plugging and sleeving rates. Thus the guidelines recommend its use in plants with IGA/SCC problems. This recommendation applies especially to plants with copper alloys in the BOP, most of which are already using the treatment.

Monitoring of cation/anion ratio This is the key recommendation, since an imbalance in this ratio can result in high crevice pH. At planned shutdowns, plant personnel can monitor the return of impurities from crevices to the bulk water (hideout return) in order to obtain important information for relating blowdown chemistry data to what is actually concentrating in the crevices. The MULTEQ computer code can then be used to model the crevice chemistry (*EPRI Journal*, March 1992, p. 41). The starting point in managing the cation/anion ratio is to minimize the ingress of caustic impurities from the plant cleanup system. Controlled chloride ingress is being considered at some plants with caustic conditions.

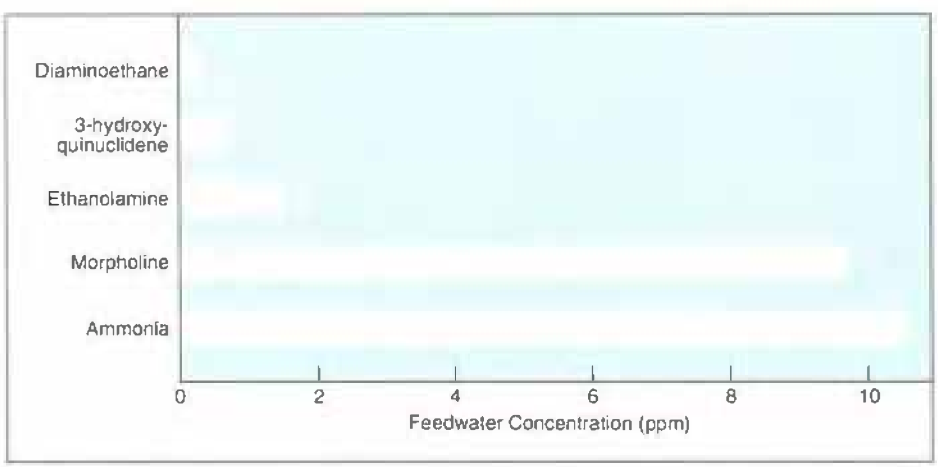


Figure 3 Calculated concentrations of alternative feedwater additives required to produce a high-temperature pH of 6.6 in moisture separator drain reheaters. U.S. PWRs now use either ammonia or morpholine for pH control, but ethanolamine is under test as an attractive replacement candidate. Other additives show promise but require more study; the compatibility of diaminoethane with some cleanup systems still must be resolved, and 3-hydroxyquinuclidene is not commercially available.

Phosphate chemistry Phosphate was historically used to inhibit corrosion in PWR steam generators; in the late 1970s, however, it was replaced by ammonia AVT at U.S. plants because of wastage problems. Two plants in Europe are still using a modified phosphate treatment, which appears to merit consideration for plants where IGA/SCC is more life limiting for steam generators than wastage is. An appendix to the revised guidelines outlines recent experience with phosphate chemistry and lists factors to be considered before implementing this treatment.

Improved pH control Corrosion products, primarily insoluble iron species, are transported from the BOP to the steam generators via the feed train. Ammonia AVT has been used to control feedwater pH and thus minimize secondary-system corrosion. Ammonia is volatile, however, and tends to distribute in the steam phase in two-phase regions of the circuit. As a result, little protection is provided in wet steam areas, which are the source of much of the corrosion material that eventually forms sludge in the steam generators.

Over 30 plants are currently using morpholine, an organic amine compound that is less volatile than ammonia and hence reduces corrosion significantly. However, other amines with more favorable properties than morpholine have been identified in EPRI research and evaluated in a simulated secondary-system loop. In-plant testing of one of the most promising of these amines, ETA, is under way at three PWRs—Duke Power's Catawba Units 1 and 2 and Toledo Edison's Davis Besse plant. Using ETA instead of morpholine results in a higher pH, reduced iron input from flow-assisted corrosion, and a smaller increase in cation conductivity. Moreover, the fact that significantly less ETA than morpholine is required to maintain a given pH in the BOP (Figure 3) results in several operational advantages. Revision 3 of the guidelnes offers the options of ETA, ammonia AVT, and morpholine.

The future

The philosophy of chemistry control has changed substantially since the first edition of the guidelines, which essentially provided one specification for all plants. Advances in technology have resulted in alternative approaches, which have undoubtedly contributed to the overall improvement in steam generator performance. As a result of these developments, the latest guidelines include several options, which should be evaluated on a plant-specific basis. The list of choices will become longer as improved inhibitors are qualfied. To help utilities evaluate the new developments, application guidelines are being prepared. For example, guidelines on amine application, to be published in the second quarter of 1993, will present a methodology and essential data for use in evaluating alternatives to morpholine.

Looking further ahead, improved tools are needed to help utilities optimize water chemistry for specific plant situations. With increasing understanding of the interaction between chemistry and corrosion, accurate modeling of the entire secondary system is becoming a possibility. Computer modeling of system chemistry—for example, by extending the CHECWORKS family of codes—is a challenging goal, but the result promises to be a valuable tool for utility use in optimizing water chemistry.

New Contracts

Project	Funding/ Duration	Contractor/EPRI Project Manager
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Municipal Waste and Water Treatment Project (RP2662-34)	$218,300 10 months	Metcalf & Eddy/*M. Jones*
Non-Vapor-Compression Heating/ Cooling-Cycle Investigations (RP2792-24)	$74,100 7 months	Foster-Miller/ *S. Kondepudi*
Demonstration of Hydronic Heat Pump System (RP2892-27)	$248,400 12 months	Geomet Technologies/ *J. Kesselring*
Water Heater Biomitigation Studies, Phase 1 (RP2958-17)	$130,200 14 months	University of Pennsylvania/*C. Hiller*
Ice Storage System Test Facility (RP3280-25)	$397,800 28 months	Martin Marietta Energy Systems/*R. Wendland*
Advanced Instrumentation for Visualization and Evaluation of the Airflow Performance of Cold Air Diffusers (RP3280-35)	$90,100 15 months	Colorado State University/ *R. Wendland*
Application of Quality Function Deployment to DSM Program Design at PSI Energy (RP3310-5)	$97,800 4 months	Putnam, Hayes & Bartlett/ *T. Henneberger*
Adjustable-Speed-Drive Applications in Thermomechanical Pulp Refining (RP3328-5)	$55,000 5 months	Georgia Tech Research Corp./*A. Amarnath*
Scoping Study on the Bleaching of Wood Pulp (RP3328-7)	$50,000 5 months	Institute of Paper Science and Technology/ *A. Amarnath*
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Electrical Systems		
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Integrated Graphic Display for Distribution Automation Data (RP2949-13)	$240,000 18 months	Power System Engineering/*B. Blair*
UCA Revision for Water Industry Requirements (RP2949-19)	$200,000 9 months	EMA Services/*R. Iveson*
Branched Polyethylenes for High-Voltage Cable Insulation (RP2986-8)	$300,000 32 months	University of Tennessee/ *B. Bernstein*
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Analysis Team for MECCA (Model Evaluation Consortium for Climate Assessment) (RP3267-21)	$713,600 37 months	Macquarie Park Research/*C. Hakkarinen*
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Global Stress-Modeling Library for Assessment of Plant and Forest Response (RP3316-1)	$284,500 24 months	Boyce Thompson Institute for Plant Research/ *L. Pitelka*
Feasibility of Decision Analysis Framework for Ozone Management Photochemical Model (RP3429-2)	$107,500 5 months	ENSR Consulting and Engineering/*R. Goldstein*
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EPRI Project Manager: D. McIntosh

Applications Handbook for FASTCHEM™, Vol. 2: Chemical Transport Modules
TR-101218 Final Report (RP2485-19); Vol. 2, $200
Contractor: Lawrence Berkeley Laboratory
EPRI Project Manager: D. McIntosh

EPRI High-Sulfur Test Center: Mini-Pilot Thiosulfate Test Results
TR-101351 Final Report (RP1031-9); $200
Contractor: Radian Corp.
EPRI Project Managers: R. Moser, D. Owens

Physical Model Studies of Dense Solute Plumes in Porous Media
TR-101387 Final Report (RP2938-1); $200
Contractor: Auburn University
EPRI Project Manager: D. McIntosh

A Survey of Daily Asthmatic Activity Patterns in Cincinnati
TR-101396 Final Report (RP940-5); $200
Contractor: Roth Associates, Inc.
EPRI Project Manager: A. Silvers

Effect of Targeted Chlorination on the Corrosion Behavior of Copper-Nickel Condenser Tubing
TR-101405 Final Report (RP2300-17); $200
Contractor: Ocean City Research Corp.
EPRI Project Managers: B. Syrett, W. Chow

Assessment of Children's Long-Term Exposure to Magnetic Fields (The Geomet Study)
TR-101406 Final Report (RP2966-4); $200
Contractor: Geomet Technologies, Inc.
EPRI Project Managers: S. Sussman, R. Kavet

Assessment of Children's Long-Term Exposure to Magnetic Fields (The Enertech Study)
TR-101407 Final Report (RP2966-6); $200
Contractors: Enertech Consultants; General Electric Co. (High-Voltage Transmission Research Center)
EPRI Project Managers: S. Sussman, R. Kavet

Power Line Calculator for DOS
TR-101409 Interim Report (RP2966-7); $200
Contractor: Enertech Consultants
EPRI Project Managers: S. Sussman, R. Kavet

GENERATION & STORAGE

High-Temperature Gas Filtration, Vol. 2: Operating Performance of a Pilot-Scale Filter
GS-6489 Final Report (RP1336-7); Vol. 2, $200
Contractor: Rheinisch-Westfälische Technische Hochschule Aachen
EPRI Project Managers: O. Tassicker, S. Drenker, R. Brown

High-Temperature Gas Filtration, Vol. 4: Mechanical and Thermal Design of a Pilot-Scale Filter
GS-6489 Final Report (RP1336-7); Vol. 4, $200
Contractor: Rheinisch-Westfälische Technische Hochschule Aachen
EPRI Project Managers: O. Tassicker, S. Drenker, R. Brown

High-Temperature Gas Filtration, Vol. 5: Mechanical and Thermal Design of High-Temperature Tier Filter Modules
GS-6489 Final Report (RP1336-7); Vol. 5, $200
Contractor: Rheinisch-Westfälische Technische Hochschule Aachen
EPRI Project Managers: O. Tassicker, S. Drenker, R. Brown

Evaluation of 450-MWe BGL GCC Power Plants Fueled With Pittsburgh No. 8 Coal
TR-100376 Final Report (RP2525-22); $200
Contractors: Bechtel Group, Inc.; British Gas plc; Lurgi GmbH
EPRI Project Manager: M. Epstein

Waste-to-Energy Permitting Sourcebook
TR-100716 Final Report (RP2190-5, -7); $200
Contractor: Bechtel Group, Inc.
EPRI Project Manager: E. Hughes

Utility Motor and Generator Predictive Maintenance Workshop
TR-100952 Proceedings (RP2591); $200
EPRI Project Manager: J. Stein

Survey of Landfill Gas Generation Potential: 2-MW Molten Carbonate Fuel Cell
TR-101068 Interim Report (RP1677-21); $200
Contractor: Resource Management International, Inc.
EPRI Project Manager: E. Gillis

Yttrium-Iron-Garnet as a Molten Carbonate Fuel Cell Cathode
TR-101069 Final Report (RP1085-14); $200
Contractor: Ceramatec, Inc.
EPRI Project Manager: R. Goldstein

Molten Carbonate Fuel Cell (MCFC) Porous Electrode and Kinetic Studies
TR-101070 Final Report (RP2278-3); $200
Contractor: Institute of Gas Technology
EPRI Project Manager: R. Goldstein

Performance Potentials of Solid Oxide Fuel Cell Configurations
TR-101109 Final Report (RP1676-15); $200
Contractor: Ulf G. Bossel
EPRI Project Manager: D. Rastler

Unit Commitment DYNAMICS: User's Manual
TR-101229 Computer Code Manual (RP3116-2); $500
Contractor: Decision Focus, Inc.
EPRI Project Manager: R. Schainker

Demonstration of EPRI Heat Rate Guidelines at Southern California Edison Ormond Beach Unit 2
TR-101249 Final Report (RP2818-1); $200
Contractor: Southern California Edison Co.
EPRI Project Manager: J. Tsou

Proceedings: Fossil Plant Layup and Reactivation Conference
TR-101250 Proceedings (RP2819-20); $200
Contractor: Encor-America Inc.
EPRI Project Managers: J. Tsou, J. Bartz

Evaluation of Silicon Carbide Candle Filters
TR-101331 Final Report (RP1336-12); $200
Contractor: Semler Materials Services
EPRI Project Managers: W. Bakker, R. Brown

Composting of Coal Tar Contaminated Soils, Phase 1: Biotreatability Studies
TR-101352 Final Report (RP3119-1); license required
Contractor: Michigan Biotechnology Institute
EPRI Project Manager: S. Yunker

Detection of Fouling in Coal Gasification Ducts Using Acoustic Ranging
TR-101359 Final Report (RP1654-46); $200
Contractor: NV Kema Technology and Service Division
EPRI Project Manager: W. Bakker

Thick-Section Welding of Modified 9Cr-1Mo (P-91) Steel
TR-101394 Interim Report (RP1403-14); $200
Contractor: ABB Combustion Engineering Systems
EPRI Project Manager: W. Bakker

Engineering Autotrophic Microorganisms for a New Electrotechnology
TR-101414 Final Report (RP8003-30); $200
Contractor: Clemson University
EPRI Project Manager: S. Yunker

Technical and Economic Assessment of Molten Carbonate Fuel Cell Manufacturing Costs
TR-101525 Final Report (RP1677-22); $200
Contractor: Michael A. Cobb & Co.
EPRI Project Manager: E. Gillis

Compressed-Air Storage With Humidification (CASH) Coal Gasification Power Plant
TR-101584 Final Report (RP2834-1); $200
Contractor: Energy Storage & Power Consultants, Inc.
EPRI Project Manager: A. Cohn

Engineering Evaluation of Prenflo-Based Integrated Gasification–Combined-Cycle (IGCC) Power Plant Designs
TR-101609 Final Report (RP2221-20); $200
Contractor: Sargent & Lundy Engineers
EPRI Project Manager: N. Hertz

CRFLOOD: A Numerical Model to Estimate Uplift Pressure Distribution in Cracks in Concrete Gravity Dams, Vol. 4
TR-101671 Final Report (RP2917-7); Vol. 4, $200
Contractor: University of Colorado
EPRI Project Manager: D. Morris

Photovoltaic System Performance Assessment for 1990
TR-101678 Final Report (RP1607-6); $200
Contractor: New Mexico State University, Southwest Technology Development Institute
EPRI Project Manager: J. Bigger

Evaluation of Strobe Lights for Fish Diversion at the York Haven Hydroelectric Project
TR-101703 Final Report (RP2694-1); $200
Contractor: Stone & Webster Environmental Services
EPRI Project Managers: C. Sullivan, J. Mattice

NUCLEAR POWER

Emergency Battery Lighting Unit Maintenance and Application Guide
TR-100249 Final Report (RP2814-47); $7000
Contractor: Edan Engineering Corp.
EPRI Project Manager: W. Johnson

Interim On-site Storage of Low-Level Waste, Vol. 2, Part 1: Facility Design Options
TR-100298 Final Report (RP3800-2); Vol. 2, Part 1, $200
Contractor: Sargent & Lundy Engineers
EPRI Project Manager: C. Hornibrook

Interim On-site Storage of Low-Level Waste, Vol. 2, Part 2: Survey of Existing On-site LLW Storage Facilities
TR-100298 Final Report (RP3800-1); Vol. 2, Part 2, $200
Contractor: Sargent & Lundy Engineers
EPRI Project Manager: C. Hornibrook

Interim On-site Storage of Low-Level Waste, Vol. 4, Part 1: Waste Containers for Extended Storage
TR-100298 Final Report (RP3800-4); Vol. 4, Part 1, $1000
Contractor: J. E. Cline & Associates, Inc.
EPRI Project Manager: C. Hornibrook

Ductile Tearing Resistance of Flawed Pipes
TR-100374 Final Report (RP2455-17); Tier 1, $200, Tier 2, license required
Contractor: Novetech Corp.
EPRI Project Manager: T. Griesbach

Modeling of Ground-Motion Attenuation in Eastern North America: Validation of Techniques and Sensitivity Analysis
TR-100410 Final Report (RP2556-50); Tier 1, $200; Tier 2, license required
Contractor: State University of New York
EPRI Project Manager: J. Schneider

Verification of EPRI's Nuclear Power Plant Emergency Operating Procedure Tracking System (EOPTS)
TR-100648 Final Report (RP2347); $200
Prepared by: Wann-Ching Chang
EPRI Project Manager: C. Lin

Coolant Radiolysis and Boiling in Water-Cooled Reactors
TR-100789 Final Report (RP2816-1); $1000
Contractor: AECL Research
EPRI Project Manager: T. Passell

Effects of Morpholine and Boric Acid Implementation on Secondary Chemistry and Corrosion Product Transport
TR-100791 Topical Report (RPS409-3); $200
Contractor: NWT Corp.
EPRI Project Manager: T. Passell

BWR Chromium Chemistry
TR-100792 Final Report (RP1447-1); $500
Contractor: GE Nuclear Energy
EPRI Project Manager: T. Passell

Fault-Tolerant Architecture: Evaluation Methodology
TR-100803 Final Report (RP3008-1); $200
Contractor: Oak Ridge National Laboratory
EPRI Project Manager: S. Bhatt

Proceedings: Advanced Digital Computers, Controls, and Automation Technologies for Power Plants
TR-100804 Proceedings (RP3208); $200
EPRI Project Manager: S. Bhatt

Utility Requirements for Human-Centered Automation in Surveillance Testing
TR-100814 Final Report (RP3185-1); $200
Contractor: Joseph Thie, Inc.
EPRI Project Manager: S. Bhatt

Characterization of the Resistance to PWSCC of Hydraulic Tube-Tubesheet Expansions
TR-100865 Final Report (RPS406-12); $1000
Contractor: Westinghouse Electric Corp.
EPRI Project Manager: A. McIlree

Stress Corrosion Cracking Resistance of Weld Metals 182, 72, and 308L
TR-100968 Final Report (RPC103-5); $25,000
Contractor: Babcock & Wilcox Co.
EPRI Project Manager: J. Nelson

Grain Boundary Segregation Studies of Irradiated Austenitic Stainless Steels and Nickel Base Alloys
TR-101009 Final Report (RPX102-3); license required
Contractor: Nuclear Electric plc, Berkeley Nuclear Laboratories
EPRI Project Manager: J. Nelson

Resin Oxidation Process Improvements
TR-101046 Final Report (RP1329-5); $1000
Contractor: Bradtec Ltd.
EPRI Project Manager: C. Wood

Design and Operation of the NAC-128 Spent-Fuel Storage Cask
TR-101091 Interim Report (RP2406-4); $200
Contractor: Virginia Power
EPRI Project Manager: R. Lambert

Consolidation and Disposal of PWR Fuel Inserts
TR-101092 Interim Report (RP2406-4); $200
Contractor: Virginia Power
EPRI Project Manager: R. Lambert

Welding of NOREM Iron-Base Hardfacing Alloy Wire Products: Procedures for Gas Tungsten Arc Welding
TR-101094 Interim Report (RP1935-19); $200
EPRI Project Manager: H. Ocken

Remedial Actions for Acidic Sulfate Corrosion
TR-101105 Final Report (RPS407-36); $1000
Contractor: Westinghouse Electric Corp.
EPRI Project Manager: P. Paine

Adsorption of Sulfate in PWR Steam Generators: Laboratory Tests
TR-101106 Topical Report (RPS407-37); $1000
Contractor: NWT Corp.
EPRI Project Manager: P. Paine

Effect of Crystal Orientation and Local Microplasticity on SCC Susceptibility of Austenitic Stainless Steel
TR-101161 Final Report (RP2614-71); $10,000
Contractor: Rutgers University
EPRI Project Manager: J. Nelson

Long-Term Capital Planning Considering Nuclear Plant Life-Cycle Management
TR-101162 Final Report (RP3343-1); $200
Contractor: Grove Engineering, Inc.
EPRI Project Manager: M. Lapides

Use of an Individual Plant Examination (IPE) to Enhance Outage Management, Phase 1
TR-101172 Interim Report (RP3323-2); $200
Contractor: Science Applications International Corp.
EPRI Project Manager: B. Chu

Fingerprinting the Thermal History of Polymeric Materials
TR-101205 Final Report (RP2614-32); $200
Contractor: University of Tennessee, Knoxville
EPRI Project Manager: G. Sliter

Interim PWR Secondary Water Chemistry Recommendations for IGA/SCC Control
TR-101230 Interim Report (RP2493, RPS401); $200
EPRI Project Manager: C. Wood

Identifying Prospective Antifouling Coatings for Venturis: Zeta Potential Measurements of Oxides at Elevated Temperatures
TR-101256 Final Report (RP3097-2); $5000
Contractor: SRI International
EPRI Project Manager: H. Ocken

Feedwater Flow Measurement in U.S. Nuclear Power Generation Stations
TR-101388 Final Report (RP2409-8); $200
Contractor: Ontario Hydro
EPRI Project Managers: J. O'Brien, G. Allen

Examination of Trojan Steam Generator Tubes, Vols. 1–3
TR-101427 Final Report (RPS413-2, -4); Vols. 1–3, $10,000 for set
Contractors: ABB Combustion Engineering; Rockwell International
EPRI Project Manager: A. McIlree

Hydrogen Water Chemistry Effects on BWR Radiation Buildup: Preliminary Evaluation of Plant Data
TR-101463 Interim Report (RP3313-1); $200
Contractor: GE Nuclear Energy
EPRI Project Manager: C. Wood

User's Guide for RAPID/TAG Software
TR-101561 Computer Code Manual (RP2508-4); license required
Contractor: Science Applications International Corp.
EPRI Project Manager: B. Chu

EPRI Events

MAY

5–7
Plant Communications and Computing Architectures, Control Rooms, and Workstations
Tampa, Florida
Contact: Linda Nelson, (415) 855-2127

9–13
12th International Conference on Fluidized-Bed Combustion
San Diego, California
Contact: Leslie Friedman, (212) 705-7788

10–11
Nuclear Plant Performance Improvement Seminar
Scottsdale, Arizona
Contact: Susan Otto, (704) 547-6072

10–14
FACTS: Power Electronics Applications for Electric Utilities and Large Industries
Madison, Wisconsin
Contact: Bill Long, (800) 462-0876

17–21
Thermography Certification Course (ASNT Level I)
Eddystone, Pennsylvania
Contact: John Niemkiewicz, (215) 595-8871

19–21
Troubleshooting Rotating Machinery Vibrations
San Diego, California
Contact: Susan Bisetti, (415) 855-7919

24–27
EPRI–EPA Joint Symposium on Stationary Combustion NO_x Control
Miami, Florida
Contact: Pam Turner, (415) 855-2010

JUNE

2–3
Application of Slagging Combustion for Utility Power
Minneapolis, Minnesota
Contact: Bill Weber, (205) 970-0294

2–4
Electric Dehumidification in Commercial Buildings
New Orleans, Louisiana
Contact: David Ross, (703) 742-8402

7–9
ISA POWID–EPRI Controls and Instrumentation Conference (Nuclear and Fossil)
Phoenix, Arizona
Contact: Lori Adams, (415) 855-8763

7–11
High-Voltage Transmission Line Electric Design Seminar
Lenox, Massachusetts
Contact: Joe Slocik, (413) 494-3320

8–10
Cooling Tower Performance Prediction and Improvement
Eddystone, Pennsylvania
Contact: John Niemkiewicz, (215) 595-8871

10–11
FACTS Impacts in the Control Center
Washington, D.C.
Contact: Gerry Cauley, (415) 855-2832

11–12
Electrical Injury: A Multidisciplinary Approach to Therapy, Prevention, and Rehabilitation
Chicago, Illinois
Contact: Marlene Goldberg, (312) 702-1056

14–16
Seminar on Advanced Concepts in Line Structure Evaluation Techniques
Haslet, Texas
Contact: Paul Lyons, (817) 439-5900

14–16
Technology Transfer Workshop
San Francisco, California
Contact: Susan Bisetti, (415) 855-7919

14–17
FACTS and HVDC Modeling Using TACS
Madison, Wisconsin
Contact: Bill Long, (800) 462-0876

15–16
Conference on Low-Level Mixed Waste
Boston, Massachusetts
Contact: Linda Nelson, (415) 855-2127

15–18
Boiler Tube Failures: Correction, Prevention, and Control
Eddystone, Pennsylvania
Contact: John Niemkiewicz, (215) 595-8871

16–18
EPRI–NAS National Biofuels Roundtable
Portland, Oregon
Contact: Cindy Farrar, (415) 855-2180

21–23
End-Use Metering: How to Get the Data You Need
Portland, Maine
Contact: Richard Gillman, (503) 274-4139

29–July 1
Heat Exchanger Performance Prediction
Eddystone, Pennsylvania
Contact: John Niemkiewicz, (215) 595-8871

JULY

13–15
2d International Conference on Managing Hazardous Air Pollutants
Washington, D.C.
Contact: Lori Adams, (415) 855-8763

19–21
ASME–EPRI Radwaste Workshop
Boulder, Colorado
Contact: Pam Turner, (415) 855-2010

20–23
Steam Turbine/Generator NDE, Life Assessment, and Maintenance
Albany, New York
Contact: Tom McCloskey, (415) 855-2655

22–23
Seminar on Management of Low-Level Waste
Boulder, Colorado
Contact: Pam Turner, (415) 855-2010

AUGUST

16–18
Radiation Field Control
Seattle, Washington
Contact: Linda Nelson, (415) 855-2127

17–19
Steam Generator NDE
Location to be announced
Contact: Ulla Gustafsson, (415) 941-8552

17–19
6th International Workshop on Main Coolant Pumps
Toronto, Ontario
Contact: Rick Sturkey, (704) 547-6043

24–27
EPRI–EPA–DOE 1993 SO_2 Control Symposium
Boston, Massachusetts
Contact: Pam Turner, (415) 855-2010

SEPTEMBER

8–10
EPRI's 9th Electric Utility Forecasting Symposium: Forecasting and DSM
San Diego, California
Contact: Lori Adams, (415) 855-8763

14–17
PCB Seminar
New Orleans, Louisiana
Contact: Linda Nelson, (415) 855-2127

19–24
In Situ Monitoring of Corrosion and Water Chemistry
Houston, Texas
Contact: Barry Syrett, (415) 855-2956

21–23
4th International Symposium on Biological Processing of Fossil Fuels
Sardinia, Italy
Contact: Stan Yunker, (415) 855-2815

29–October 1
Condenser Technology
St. Petersburg, Florida
Contact: Lori Adams, (415) 855-8763

Contributors


Jones


O'Brien


Downs


Kesselring


Evans

Electrotechnologies for Water Treatment (page 4) was written by science writer John Douglas with assistance from **Myron Jones**, manager for environment and energy management in the Industrial Program of EPRI's Customer Systems Division. Before joining the Institute in 1990, Jones was vice president of a subsidiary of Pacific Gas and Electric, where he was responsible for natural gas sales and corporate planning. He has also worked for Bechtel, Shell Development Corporation, United Technologies, and Rust Engineering in a variety of process design and R&D capacities. Jones holds an MS degree in chemical engineering from the University of Maine. ■

Images in Infrared (page 14) was written by Taylor Moore, *Journal* senior feature writer, with the guidance of two members of the Nuclear Power Division.

John O'Brien, manager of the Nuclear Plant Operations & Maintenance Program, has been with EPRI since 1979, specializing in human factors engineering. He previously worked for five years at the Westinghouse R&D Center and before that was a research analyst at the Center for Occupational Education at North Carolina State University. O'Brien received BA, MA, and PhD degrees in industrial and engineering psychology from North Carolina State University.

Mike Downs, manager of the Nuclear Maintenance Applications Center, joined EPRI in 1988, initially as a loaned employee from Bechtel Corporation, where he was chief engineer for plant startup and operating services. Downs worked for 20 years in nuclear plant operations and maintenance engineering at Bechtel. He studied mechanical engineering at George Washington University. ■

Shedding Light on the Compact Fluorescent (page 22) was written by Leslie Lamarre, *Journal* senior feature writer, with technical information from two members of the Customer Systems Division.

John Kesselring, manager for residential systems, came to EPRI in 1986 after four years as a vice president with Alzeta Corporation in Santa Clara, California. Before that, he was associate manager of the Combustion Technology Department at Acurex Corporation. Earlier he served as an assistant professor of mechanical and aerospace engineering at the University of Tennessee for five years. Kesselring holds a BS degree in aeronautical engineering from the University of Michigan and MS and PhD degrees in aeronautics and astronautics from Stanford University.

Michael Evans, manager for commercial demand-side management, came to EPRI in 1990 after six years with X-Cyte, an electronics manufacturing firm in Mountain View, California, where he ultimately became vice president of engineering. Before that, he was vice president of operations at a combustion technology R&D company. Evans has BA and BS degrees in mechanical engineering from Rice University and MS and PhD degrees in high-temperature gas dynamics from Stanford University. ■

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