Maintenance Optimization

Also in this issue • Office Lighting • Small-Business Wastes • Steam Generator Research

ELECTRIC POWER RESEARCH INSTITUTE

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Cover: The rise of competition in the utility industry has intensified pressure to reduce maintenance costs across all aspects of power generation and delivery. Photo: Chipp Jamison (Atlanta)/INPO.

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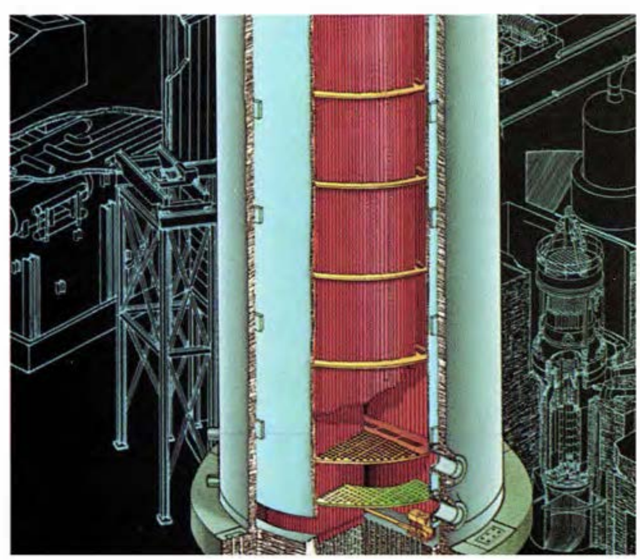

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PRODUCTS

EPRI-sponsored deliverables now available to utilities and their customers

Survey of Innovative Rates: 1994 Update

Innovative rate design is playing an increasingly important role as utilities market a growing number of service options, fine-tune their demand-side management programs, and generally position themselves to meet competition. This report (TR-104491), an update of a similar survey conducted in 1991, gives an overview of the 1095 innovative rates implemented by 135 utilities surveyed in 1994. An accompanying diskette contains a database of detailed rate information that users can search by utility name or rate type. Utilities can build on the information provided to enhance their own rate structures or create entirely new rate options.

For more information, contact Perry Sioshansi, (415) 855-2329. To order, call the EPRI Distribution Center, (510) 934-4212.

Steam-Sampling Nozzle

High levels of impurities in turbine steam cause corrosion and efficiency problems that cost electric utilities and other industries an estimated $1 billion annually. Although monitoring steam chemistry is perhaps the best way to prevent such problems, there traditionally has been no reliable method available for steam sampling; sampling techniques tended to interrupt steam flow, resulting in samples that were not representative. EPRI has overcome such problems with the introduction of its new steam-sampling nozzle. The innovative design of this nozzle enables it to provide truly representative samples of both saturated and superheated steam, allowing operators to respond quickly to system chemistry problems and avoid long-term turbine damage. The design pictured can be modified to fit any turbine.

For more information, contact Barry Dooley, (415) 855-2458. To order, call Jonas, Inc., (302) 478-1375.

Electricity and the Environment

Created to help utilities communicate their support for a cleaner energy future, this information folder—*Electricity & the Environment: Powering a Sustainable Future* (AP-104455)—contains an overview leaflet describing electricity's environmental benefits, as well as 12 flyers detailing beneficial technologies for the generation and use of electricity. The technologies covered range from state-of-the-art photovoltaic panels to the electric arc furnace. The package is ready for distribution to a variety of educated lay audiences, such as local communities, government officials, the media, public utility commissioners, and utility employees.

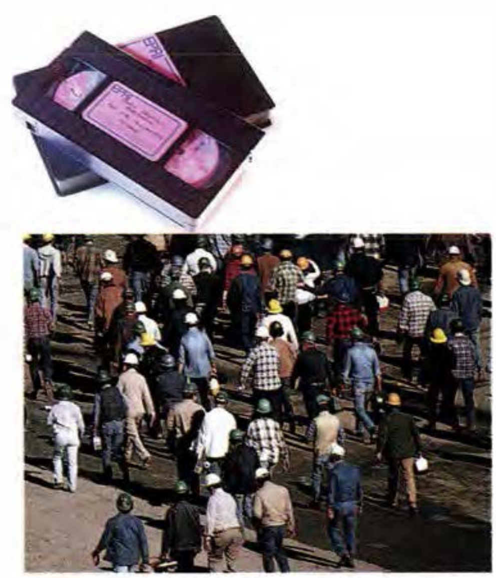
For more information, contact Lucy Sanna, (415) 855-2732. To order, call the EPRI Distribution Center, (510) 934-4212.

ESPRE 2.1 for Residential Energy Decisions

In the average U.S. household, the heating and/or cooling system is the biggest single energy user, representing about half the charges on the monthly utility bill. To help utilities assist customers in their decisions on the purchase of such systems, EPRI developed ESPRE, the EPRI Simplified Program for Residential Energy. The program uses national meteorological data and building-specific information to calculate residential heating and cooling loads. ESPRE can also analyze the type of spaceconditioning equipment selected and estimate its operating costs to determine whether it is the best choice for a specified site. The technologies included range from oil-, propane-, and gas-fired furnaces to electric resistance heaters and electric heat pumps.

For more information, contact John Kesselring, (415) 855-2902. To order, call the Electric Power Software Center, (800) 763-3772.

Shift Rotation Video



The safe and efficient operation of a power plant requires an alert and responsible work force. Yet the physical and mental demands of the rotating, around-the-clock shifts that plant operators work can take a heavy toll. If shift workers are not careful, they may fall into unhealthy eating and sleeping habits that can affect their state of mind on the job. Their unusual work schedules may also conflict with family and social life. But as explained in this recently released video (VT-104468), shift workers can take action to reduce or eliminate some of these difficulties. Advice offered in the video is based on research results and on the practical experiences of shift workers. Utilities have used the video successfully to train workers and to brief their spouses on strategies for coping with shift work. A related report (NP-6748) offers moredetailed information.

For more information, contact Lewis Hanes, (415) 855-2527. To order, call the EPRI Distribution Center, (510) 934-4212.

EPRI and Westinghouse Form Alliance for Advanced Power Control Technologies

An alliance to develop advanced power electronics controller technologies for high-power applications has been formed between EPRI and Westinghouse Electric Corporation. The new company—Sure-Tech LLC—will focus primarily on developing new distribution and transmission technologies called Custom Power and FACTS (flexible ac transmission system) technologies.

Custom Power technology will help stabilize voltages over wide areas in electricity distribution systems to meet the needs of customers who use computers and other sensitive equipment. FACTS technology holds major promise for increasing the overall efficiency of existing electricity transmission systems by redistributing power flows, eliminating bottlenecks, and facilitating transfers of electricity between utility systems. Westinghouse recently developed a key component of FACTS technology—a solid-state static condenser called STATCON—that is beginning prototype field demonstration on the Tennessee Valley Authority system.

"Sure-Tech will be a leader in an important new industry," says Frank Bakos, president of the Westinghouse Power Generation Business Unit. "Power electronics systems offer new solutions to problems in managing high levels of electric energy that the industry has faced since its beginning."

Karl Stahlkopf, EPRI vice president for power delivery, notes, "FACTS and Custom Power provide an opportunity to fundamentally redesign power delivery. These systems can redirect transmission network current flows in a fraction of a second or smooth out disturbances on a distribution system before they reach sensitive customer equipment." He says that "the Sure-Tech alliance is noteworthy because it is the first agreement of its type between a major equipment manufacturer and the electric utility research organization. This agreement symbolizes the beginning of a new era of cooperation."

Initially, Sure-Tech's efforts will be focused on a suite of four related products: STATCON, solid-state breakers, the unified power controller, and the dynamic voltage restorer. Says Stahlkopf, "Sure-Tech offers a way to develop these power control devices in a coordinated fashion, creating a technological synergy that will provide customers with lower-cost, higher-quality electricity."

The main office of Sure-Tech will be located in Orlando, Florida. The company will be owned on an equal basis by Westinghouse and EPRI.

Power Delivery Agreement Signed With Electricité de France

EPRI and Electricité de France have signed a cooperation agreement to jointly conduct power delivery research during the next two years. Building on years of collaborative research, Electricité de France and EPRI signed agreements in 1994 that focused primarily on nuclear power and fossil fuel power plants.

The latest agreement, signed in New York last February, expands the existing agreements to include transmission, substations, distribution, and system planning. Among the new research areas are underground cables, devices to allow more power to be transmitted on existing overhead lines, and computer codes to evaluate the actual costs of power transmission. Electricité de France and EPRI contribute a total of about $13 million annually to their joint research.

Electricité de France generates, transmits, and distributes more than 400 billion kWh for France and neighboring countries. Its R&D division spends $90 million a year on power delivery research. The French national utility's American subsidiary is Electricité de France International North America, based in Washington, D.C.

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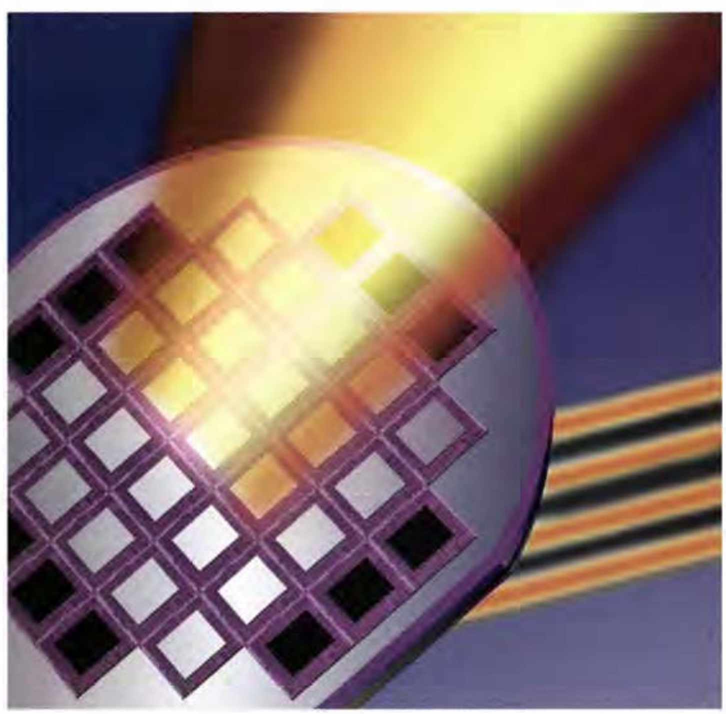


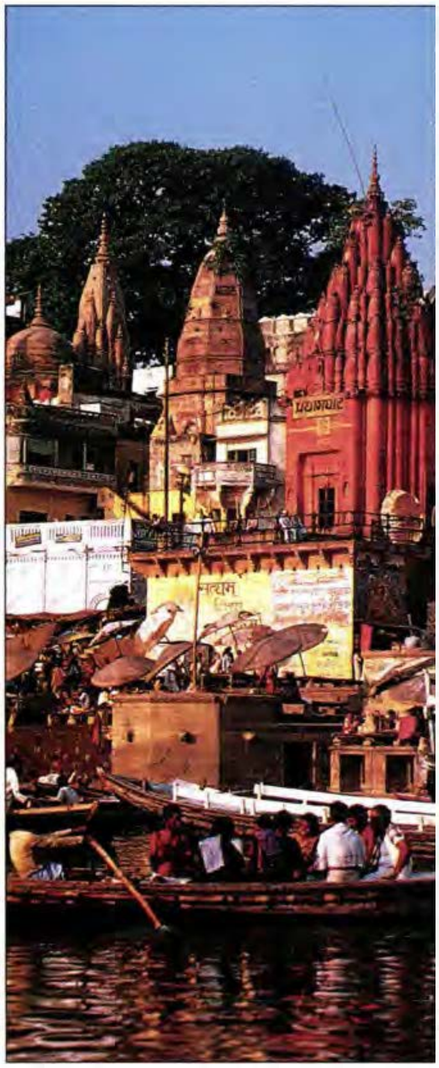
Expanding Relationships in India

EPRI senior managers recently executed several important memorandums of understanding (MOUs), primarily involving renewable energy technology projects, with government and industry organizations in India. EPRI was the lead U.S. signatory in 6 of 23 new projects announced in February during a visit to India by a U.S. delegation headed by Energy Secretary Hazel O'Leary. The 6 new MOUs followed 2 other MOUs between EPRI and Indian organizations signed in December 1994, when Krishna Kumar, minister of state for nonconventional energy sources and agriculture, visited the United States, leading an Indian delegation on renewable energy development.

"The relationships we are implementing with Indian organizations provide EPRI and its members the opportunity to enhance our technology portfolio, to reduce project costs by expanding the market base, and to help improve global economic and environmental conditions through electrification," says George Preston, EPRI vice president for generation. Preston suggests that India is an ideal location for the expanded use of renewable energy technologies because of its excellent resource base; the match between the small, modular capacity of renewables-based electricity generation and the needs of remote villages; the country's overall shortage of electricity generation; and the desire of Indian industry and government to work with U.S. organizations. The EPRI-Indian MOUs cover projects that involve the Institute's Generation, Customer Systems, and Power Delivery Groups.

The projects between U.S. and Indian organizations announced by the U.S. Department of Energy in February amount to $1.4 billion, raising to $10 billion the total value of projects in sustainable energy development for which organizations in the two countries have announced plans since Secretary O'Leary's first trip to India in July 1994. "Outcomes from this mission are strategic, integrated, and balanced," O'Leary said of the most recent initiatives. "These projects are diverse—utilizing sustainable development technologies, demand-side management programs, and renewable energy to meet the needs of India." They include projects on hydro, solar, wind, and other renewables, as well as energy efficiency programs, she noted. Officials estimate that the projects will result in the creation of 20,000 jobs in India, in addition to increasing the export of U.S. high-technology equipment as India expands its electricity generation, transmission, and distribution infrastructure.

Among the renewable energy initiatives signed by EPRI is a plan to establish a broad collaborative relationship with the Indian Renewable Energy Development Agency for technology evaluation and transfer. The development of a renewable energy training center in India is expected to be one of the cooperative activities that will be pursued. Meanwhile, EPRI plans to establish a similar relationship—covering wind energy, photovoltaics, and biomass—with India's Ministry of Nonconventional Energy Sources.



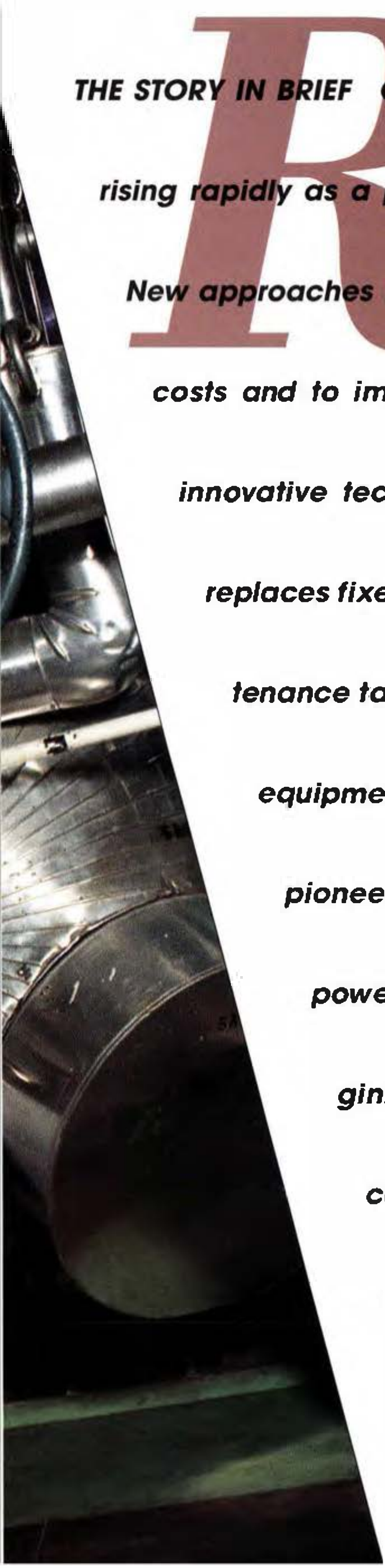
In addition, a limited-liability company jointly owned by EPRI and Sargent & Lundy will introduce to the Indian market EPRI's SOAPP (State-of-the-Art Power Plant) software—advanced engineering software for the design and evaluation of new and retrofit power plants. This initiative is expected to bring about the first commercial use of an EPRI-developed technology in India.

EPRI and Thermax, Ltd., plan an alliance for the development in India of electrotechnology applications in water purification, medical waste sterilization, and food processing. Also, EPRI will work with Renewable Energy Systems, Ltd., on the design, installation, and evaluation of a 2-MW photovoltaic power project. The Institute will explore joint activities in wind, integrated high-concentration photovoltaics, and amorphous silicon photovoltaic technology with Bharat Heavy Electricals, Ltd., a major industrial firm in India. In another initiative, Bombay Suburban Electric Supply, Ltd., will evaluate the applicability of EPRI-developed transmission and distribution technologies, such as those aimed at reducing losses.

The Maintenance Revolution

Chipp Jamison (Atlanta)/INPO

BY JOHN DOUGLAS



RCM

THE STORY IN BRIEF ***Operation and maintenance costs have been rising rapidly as a proportion of total electric utility expenditures. New approaches to maintenance are helping both to reduce these costs and to improve the overall reliability of utility systems. One innovative technique—reliability-centered maintenance, or RCM—replaces fixed time intervals for performing various equipment maintenance tasks with intervals that depend on the condition of critical equipment, as determined by analysis of past performance. EPRI has pioneered the use of RCM in power plants and, most recently, in power delivery systems. In addition, new diagnostic systems are beginning to provide an unprecedented ability to monitor equipment condition directly and establish a program of predictive maintenance, or PDM, which enables a utility to make more-timely maintenance decisions and prevent costly equipment failures.***

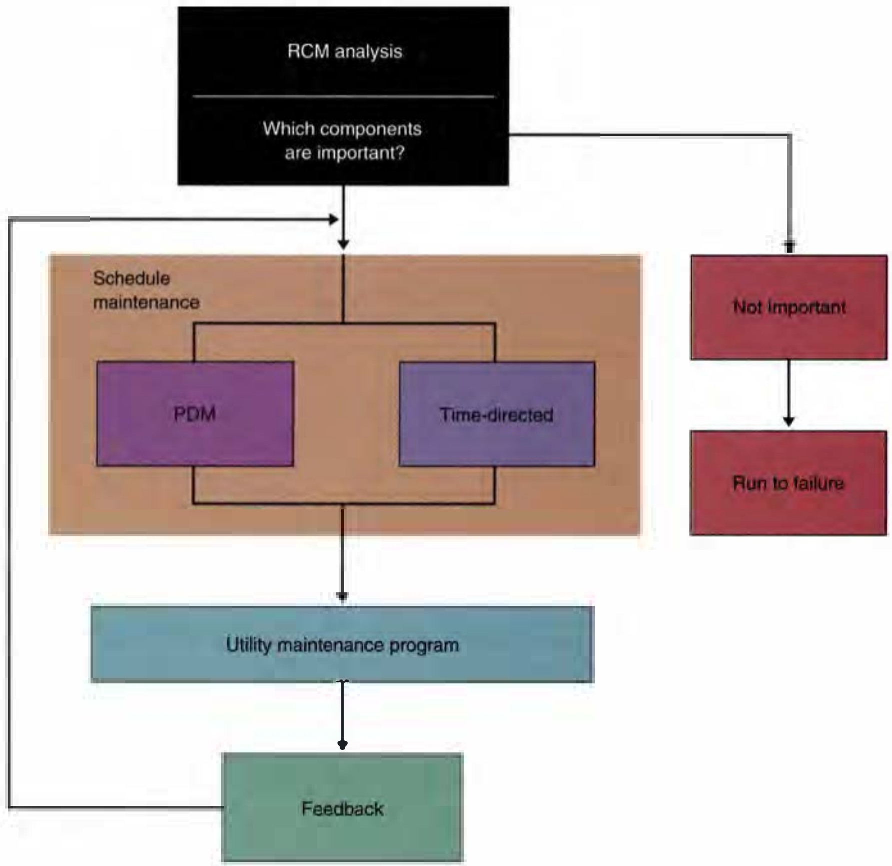
PDM

As competition heats up in the electric utility industry, cost considerations are becoming paramount. Largely as a result of rate regulation, the retail price of electricity may vary by a factor of 2 between neighboring utilities, so the prospect of competing for customers who may soon have the ability to choose their provider is driving many utilities to cut costs as quickly as possible. Unfortunately, most of the price differences in electricity depend on circumstances over which utilities have little control, such as geography or sunk investment in high-cost generation units. The biggest exception is operation and maintenance costs, which are now yielding to a variety of new technologies.

The relative importance of O&M expenses has been rising for more than a decade. At nuclear plants, for example, the O&M portion of power production outlays grew by more than 120% between 1981 and 1991—to a level more than twice as great as the fuel cost component. The challenge of controlling O&M costs also weighs heavily for utilities with older fossil power plants and aging power delivery equipment. Relief may be on the way, however, in the form of a two-part initiative that promises not only to reduce the cost of maintaining equipment but also to improve the overall reliability of power generation and delivery systems.

One component of this initiative is reliability-centered maintenance (RCM), a technique initially developed by the commercial airline industry that focuses on preventing failures whose consequences are likely to be the most serious. The other component involves the use of a variety of new, high-tech diagnostic systems, which provide unprecedented ability to monitor equipment condition in real time and to spot trends that indicate incipient failure. The advantage of these diagnostic technologies is that they essentially enable equipment to send out a call for help, making timely maintenance possible while avoiding unnecessary maintenance and overhauls. This approach is referred to as predictive maintenance (PDM). Eventually, the additional information provided by both RCM and PDM can lead to improved equipment designs and thus further reduce maintenance costs.

MAINTENANCE OPTIMIZATION **The ultimate goal of EPRI's maintenance-related research is to help utilities lower costs by optimizing their overall maintenance process. The process begins with a reliability-centered maintenance (RCM) analysis of plant systems to determine critical system components. Maintenance intervals for these components are then set on the basis either of fixed time intervals or of equipment condition as determined by predictive maintenance (PDM) diagnostic techniques. Finally, a self-improving, "living" maintenance program is continually updated by feedback of information from subsequent maintenance experience.**



The roles of RCM and PDM can perhaps most easily be illustrated through an analogy with car maintenance. For many years, the standard practice—for both cars and utility equipment—has been to perform preventive maintenance at specified intervals on just about all components, regardless of the equipment's functional importance or the need for maintenance. RCM improves on this scenario by using analysis of, or actual experience with, a particular model of automobile or turbine generator to determine what types of failure are likely to occur and which ones most threaten the overall mission. On the basis of this information, a new maintenance schedule can be devised that is tailored to the strengths and weaknesses of that model. The result is to lower costs by eliminating unnecessary overhauls, optimizing the frequency of required overhauls, and reducing the chance of sudden failure.

Further savings can be realized by using diagnostics judiciously to establish a more advanced program of predictive maintenance. In some cars, for example, a sensor warns when brake pads are getting too worn and need to be replaced. Similarly, a new sensor inserted into transformer oil can detect the evolution of gases that indicate arcing and other developing problems, thus enabling corrective action well in advance of transformer failure.

"The maintenance revolution we are witnessing provides an example of EPRI research at its best," says Karl Stahlkopf, vice president for power delivery. "First, EPRI's nuclear staff pioneered the introduction and adaptation of the RCM approach from another industry and worked with staff members in fossil generation and power delivery to help apply RCM to a wide spectrum of utility activities. Second, the Institute is leading the development of PDM methods for utility applications by taking advantage of recent breakthroughs in diagnostic technology—including advanced sensors newly declassified by the military or made available from the space program. Through this kind of forward-looking stewardship and cooperative effort, EPRI staff in many specialties have brought exciting new technologies to bear on the increasingly difficult problem of how to contain rising O&M costs throughout the industry."

RCM: from jets to nuclear plants

The RCM strategy was developed in the late 1960s, when wide-body jets were introduced to commercial airline service. Because of the increased size and complexity of the jumbo jets, airlines feared that continuing to use traditional maintenance methods would make the new planes uneconomical. Previously, preventive maintenance programs relied heavily on time-directed tasks—overhauling certain equipment after so many hours of flying time. In contrast, the RCM approach was condition directed—with maintenance intervals based on actual equipment criticality and performance data. After adopting this approach, the airlines found that maintenance costs remained roughly constant but that the availability and reliability of their planes improved because more effort was being spent on the equipment most likely to have severe problems. As a result, RCM is now standard for most of the world's airlines.

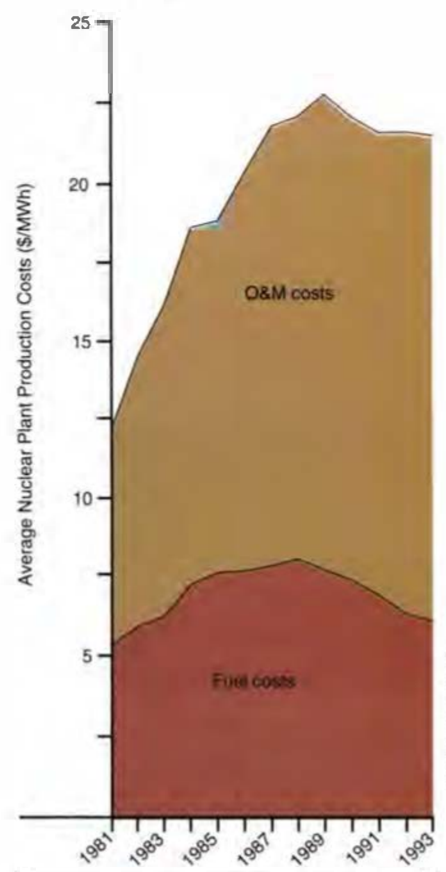
In 1984, EPRI introduced the RCM approach to the nuclear power industry. The rationale was that the preventive maintenance programs at most nuclear plants were based on vendors' overly conservative recommendations, applied to individual components without sufficient consideration of actual duty cycles or overall system functions. Often the result was that too many routine maintenance tasks were being performed without creating a comparable gain in reliability. At other times, too little preventive maintenance was performed on key components that had not been identified as critical, leading to failures that increased corrective maintenance costs and further reduced unit availability. Finally, utilities were concerned about the impact of unnecessary maintenance in terms of worker exposure to radiation.

By applying RCM in demonstration programs sponsored by EPRI, nuclear utilities were able to overcome these disadvantages in a way that addressed cost, reliability, and safety concerns together. As the demonstration programs showed, RCM typically streamlines preventive maintenance at a nuclear plant through careful analysis of equipment and system failure histories. About 80% of the time required to implement RCM is focused on the following three tasks. Failure modes and effects analysis (FMEA) identifies the pieces of equipment that are critical for each overall system function. Logic tree analysis is used to identify the most effective maintenance tasks for preventing failure of the critical system components. Finally, the actions suggested by RCM analysis are integrated with a facility's previous maintenance program.

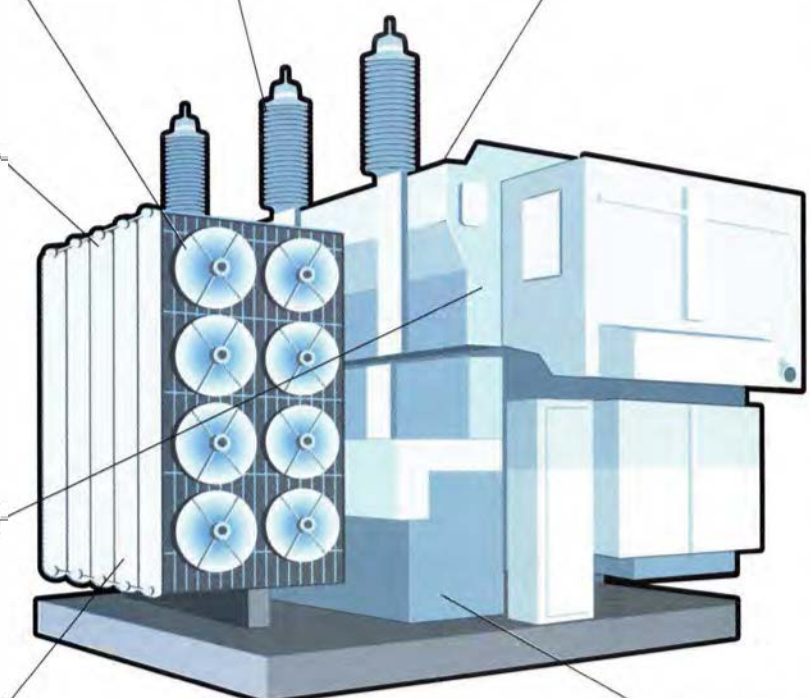
Unlike the airline industry, which had the advantage of being able to work with manufacturers to create an RCM program for a new generation of equipment, the utility industry had to adopt RCM as a modification of long-established maintenance practices at existing plants. Despite significant startup costs resulting from this circumstance, however, the RCM programs at nuclear power plants generally proved cost-effective from the beginning. A 1991 EPRI survey of six utilities that had implemented RCM programs found that one-time startup costs averaged about $100,000 per plant system involved. Annual savings in maintenance costs alone—excluding the benefits from improved plant availability—were found to be $21,500 per system, implying a payback period of about four and a half years. (Full implementation of RCM at a nuclear plant typically involves about 50 component systems.)

The contributions of RCM to reducing forced outages and improving system reliability are difficult to separate from the contributions of other factors. At the Callaway nuclear plant of Union Electric Company, for example, the outage rate dropped from over 5% to below 2.3% during a period in which RCM and other productivity-enhancing programs were instituted. Says the utility's Donald Schnell, senior vice president, nuclear, "There's no question that RCM has helped us focus on those plant components that needed the most attention, but the overall effect is hard to quantify." Adds Mike Taylor, assistant manager for work control at the Callaway plant, "We estimate that RCM saves us half a million dollars per

THE GROWING IMPORTANCE OF O&M COSTS A major incentive for research on maintenance optimization for power industry applications is the rising proportion of utility expenditures required for operations and maintenance, as shown here for nuclear plants.



POWER DELIVERY APPLICATIONS **Reliability-centered maintenance, which has been successfully used in nuclear and fossil power plants, is now being applied to substations—where it is expected to lower costs and help prevent unexpected failures, such as the transformer fire shown here.**



RCM analysis defines the criticality of equipment components and helps identify failure modes, underlying causes, and appropriate mitigation procedures. In a power transformer, for example, a fan rates low on criticality, since there is redundancy and since failure means only a slight decrease in cooling efficiency. On the other hand, gasket failure, which leads to the leakage of transformer oil, is a highly critical occurrence, involving potential adverse publicity, extreme economic penalties, and endangerment of the environment.

year in direct maintenance costs, and it has also been an important part of the larger maintenance optimization process that has contributed to the reduction of forced outages to zero for the last two years."

Reducing implementation costs

Recent EPRI research on RCM in nuclear applications has focused on reducing its implementation costs and on helping utilities optimize maintenance and respond to a new Nuclear Regulatory Commission maintenance rule (10 CFR 50.65), which is safety directed. Cost reduction efforts have centered on finding ways to standardize and streamline the tasks that require the largest effort in an RCM program. For example, preliminary evaluation of the importance of various system functions (rather than treating all system functions as equal) can reduce the time required to perform FMEAs by half. To save time in performing logic tree analyses, maintenance templates developed for several generic component types can be used to identify the most applicable and effective maintenance tasks for these components.

Descriptions of the streamlined methodologies and other improvements are being incorporated into EPRI's *RCM Technical Handbook* and RCM Workstation. A large demonstration project to refine the use of these and other cost reduction techniques for RCM is almost finished at PECO Energy Company's Limerick nuclear plant. Using advanced implementation methods, company personnel have reduced the nonrecurring analysis costs by a factor of 4, and the payback period for RCM has now been shortened to about 2 years. A previous cost-benefit study conservatively indicated that five typical nuclear plants should save a combined net total of $15 million in maintenance costs over a 10-year period by using RCM. Other utility experience has shown that use of the RCM Workstation can reduce by half the effort needed to complete an RCM analysis.

Complying with the NRC's new maintenance rule requires a wide-ranging effort at every nuclear plant, involving not only preventive maintenance but also changes in operations, administration, and training. EPRI provided technical support for the

Nuclear Energy Institute's efforts to prepare an implementation guide for the maintenance rule. In addition, EPRI has been working with Boston Edison Company to develop a "living" preventive maintenance program that will coordinate all activities related to the maintenance rule and ensure that maintenance procedures are constantly improved over time. A major demonstration of this program is under way at Boston Edison's Pilgrim station. The results of this work are being shared with other utilities through their participation in the EPRI Maintenance Optimization Group (formerly the RCM Users Group).

"As RCM becomes standard practice in the nuclear power industry, we're beginning to take a more encompassing look at maintenance optimization," says John Gisclon of EPRI's Nuclear Power Group. "In particular, our efforts to streamline the RCM process through the use of component templates and self-improving programs are helping create the maintenance system of the future, which will satisfy new NRC regulations while making nuclear plants more cost-effective."

The effects can already be seen, according to EPRI's Norris Hirota, manager for nuclear operations and maintenance technology. "After watching nuclear O&M costs climb sharply for more than a decade, we're finally beginning to see them level off," he says. "You can't attribute this to any one cause, but it's clear that EPRI's work on maintenance optimization—including both equipment RCM and improved worker productivity—has made a positive contribution."

FAULT GAS ANALYZER **A new microelectronic device can provide real-time measurement of the four key gases associated with fault currents in transformers. The device features tiny sensors that are inserted directly into transformer oil and transmit data to an externally mounted analysis unit.**

David Morin

Toward broader applications

On the basis of the successful use of RCM in the nuclear power industry, efforts have recently been undertaken to adapt the process for fossil power plants and power delivery systems. Because these facilities face a less restrictive regulatory environment, they should be able to directly apply the streamlined forms of RCM recently validated at the Limerick nuclear plant.

In one of the streamlined versions, for example, the FMEA and logic tree analysis steps have been combined into one process called criticality analysis. This process enables a utility analyst to focus on dominant failure effects, identifying the causes and appropriate preventive maintenance tasks in one step. Later, a separate analysis of noncritical components is used to determine a cost-effective balance between applying preventive maintenance and allowing the components to run to failure. As in the nuclear case, documentation accompanying the RCM process can provide the basis for a living program of continually improving preventive maintenance at a fossil plant.

The revised RCM process has recently been the subject of pilot projects at several utilities. One of these focused on the ash transport system at a 12-year-old coal-fired plant, resulting in a 30% reduction in the number of annual maintenance tasks. In addition, the results provided the utility with a guide for using new diagnostic technologies in a redirected PDM program. A second project concentrated on the wastewater treatment system at a new cogeneration facility. Compared with the vendor recommendations, RCM reduced the number of annual maintenance tasks by a factor of 5, placing more emphasis on surveillance and less on equipment overhauls. In a more extensive project, involving eight major component systems at two generating units, the host utility estimated that it would realize net savings of about $215,000 per year by using RCM rather than previous maintenance methods, with additional savings expected through increased plant availability. EPRI is currently seeking additional host sites to apply the streamlined RCM techniques.

"The RCM pilot projects at fossil plants have been very promising, and we've received a lot of interest from other utilities," says project manager Russ Pflasterer of EPRI's Generation Group. "In the hope of making the RCM process even more cost-effective, we plan to develop equipment maintenance templates and modify the existing RCM Workstation for fossil plant applications. In addition, we have initiated several pilot projects on plant maintenance assessment and work process improvement, as part of an overall maintenance optimization effort."

A project to apply the RCM methodology to substations was initiated in 1994. Initial efforts have focused on learning which methods can usefully be applied to systems that are fundamentally different from those in power plants. A major complication is that current substation maintenance approaches vary widely, with many utilities employing a strategy of corrective maintenance—waiting until equipment fails. Objectives of the new project thus include developing specific RCM methods and tools for use in substation applications, standardizing procedures for reporting equipment failures, and establishing industry "best practices" for maintaining substation equipment.

"We will have an RCM substation handbook and workstation available by the end of this year," says project manager Magda Hammam of EPRI's Power Delivery Group. "By 1997, a more comprehensive workstation, called the Maintenance Management System, will be available; it will include modules on PDM, RCM, and life extension. Eventually, substation maintenance costs may be reduced by at least 25% by using the RCM approach."

Progress in predictive maintenance

A natural outcome of an RCM study is the implementation of a PDM program. EPRI's Predictive Maintenance Advisory Group has concluded that condition monitoring information is essential to quality maintenance programs. The use of diagnostic monitoring technologies—such as vibration monitoring, thermography, and lube oil analysis—is an important part of a PDM program.

Many of these diagnostic technologies can provide accurate and valuable long-lead-time information for timely maintenance decision making. Permanent, on-line diagnostic systems often provide good long-term information with a high level of automation. Such systems can provide 24-hour coverage of critical plant systems. Periodic systems tend to be cheaper to install initially, but they are more labor-intensive in the long term. Both types of diagnostic monitoring systems require training for the proper interpretation of measured data.

Even with automated and effective diagnostic systems in place, however, plant personnel sometimes experience difficulty evaluating the data. This occurs when diagnostic systems provide more data than maintenance personnel have time to evaluate, or when the systems provide inaccurate or conflicting data—making analysis impossible. In both these cases, the PDM tasks intended to reduce costs increase the workload, thereby raising costs without

DIAGNOSTIC SYSTEMS FOR PREDICTIVE MAINTENANCE **Advanced techniques are becoming available to monitor equipment conditions directly and provide real-time information for a PDM program. Infrared thermography, for example, indicates hot spots, where problems may occur. Other diagnostic equipment can provide information on electric resistance changes, abnormal vibrations, or the presence of moisture. Such diagnostic systems are evaluated at EPRI's Monitoring & Diagnostic Center, located at PECO Energy's Eddystone plant in Pennsylvania, while new sensor and control system technologies are being developed at the Instrumentation & Control Center at TVA's Kingston plant in Tennessee.**

Kingston plant

Eddystone plant

providing compensatory benefit to the plant.

EPRI is addressing these problems in several ways. Since 1986, the Institute has operated the Monitoring & Diagnostic Center in Eddystone, Pennsylvania, to evaluate diagnostic systems that could improve both the operation and maintenance of fossil power plants. The M&D Center is operated in cooperation with the Eddystone generating station of PECO Energy, and approximately 40 diagnostic systems—both on-line and periodic—have been demonstrated at the plant. As a result of this effort, Eddystone has instituted an advanced PDM program that combines information from diagnostic systems with other data to determine maintenance requirements on the basis of equipment condition.

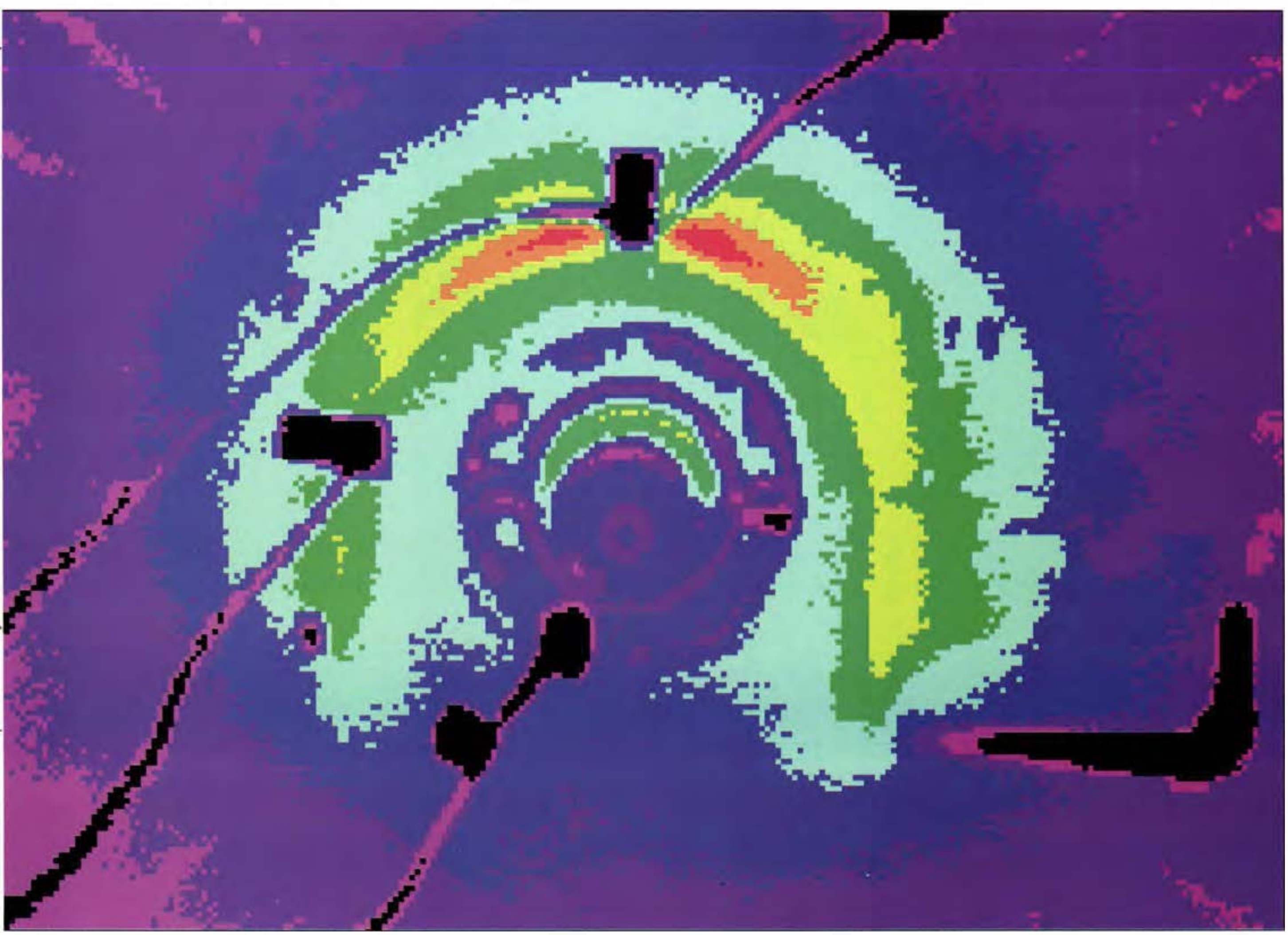
"Utilities can now implement PDM programs at their plants by using the experience gained at the M&D Center," according to EPRI's Rich Colsher, the center's manager. "To assist in this effort, in 1994 we published a comprehensive PDM guideline that covers both the implementation and technologies required for an optimum program."

Efforts to automate the PDM process are continuing at the M&D Center through development of the O&M Workstation. Using EPRI's open-system Utility Communications Architecture, the O&M Workstation brings information from various plant sources—such as maintenance management, vibration, lube oil, thermography, and process data—into a single computer environment for analysis and reporting.

One important example of the PDM initiatives coming out of the M&D Center is a new, comprehensive approach to electric motor maintenance, with emphasis on preventing unexpected failures in the very large motors used in power plants. Several independently scheduled tests are included in the program. Quarterly thermography surveys, for instance, involve the use of an infrared camera to detect hot spots that may indicate clogged air filters, abnormally high current flows, or elevated bearing temperatures. A series of electrical tests are conducted on a yearly basis, including winding resistance measurements, which can detect failing connections, and capacitance measurements on the winding insulation, which can indicate aging or the presence of moisture. In addition, twice a month a handheld accelerometer is used to detect abnormal vibrations in motor bearings.

"By applying this PDM program at the

Infrared thermography identifies hot spots in a motor.



Eddystone plant, PECO Energy estimates that it will save $1 million over five years through capital savings and avoided maintenance costs," says Colsher.

Nuclear PDM applications

In the nuclear power area, EPRI has pursued PDM by developing individual tools as part of a larger program to optimize maintenance tasks and provide technology to help lower O&M costs. Typical of this work is the use of infrared thermography on a variety of plant systems. At one nuclear station, thermography has been used to compile more than 200 records of off-normal conditions. Some of these instances have led to significant savings. The discovery of a faulty bushing on the plant's main step-up transformer, for example, averted imminent failure and saved an estimated $4.8 million in lost electricity production. At another nuclear plant, infrared thermography detected a telltale high-temperature condition in piping, which indicated a leaky valve upstream. Thermography was also used to identify high-temperature anomalies that indicated incipient failures in various electrical and mechanical equipment. That utility estimates one-time savings of $1 million from the detection of these anomalies, plus an estimated $200,000 in continuing annual savings.

Further work is needed, however, to translate such individual applications into a successful PDM program suitable for broad use in the nuclear power industry. EPRI has thus recently started a project with Duke Power Company to integrate PDM activities into an optimized RCM program at the company's seven nuclear units. As part of this project, previous PDM experience throughout the industry will be reviewed and the information used to develop standards for applying PDM to critical plant components. The M&D Center will develop the necessary database on the costs and effectiveness of various PDM applications and will help develop the new standards.

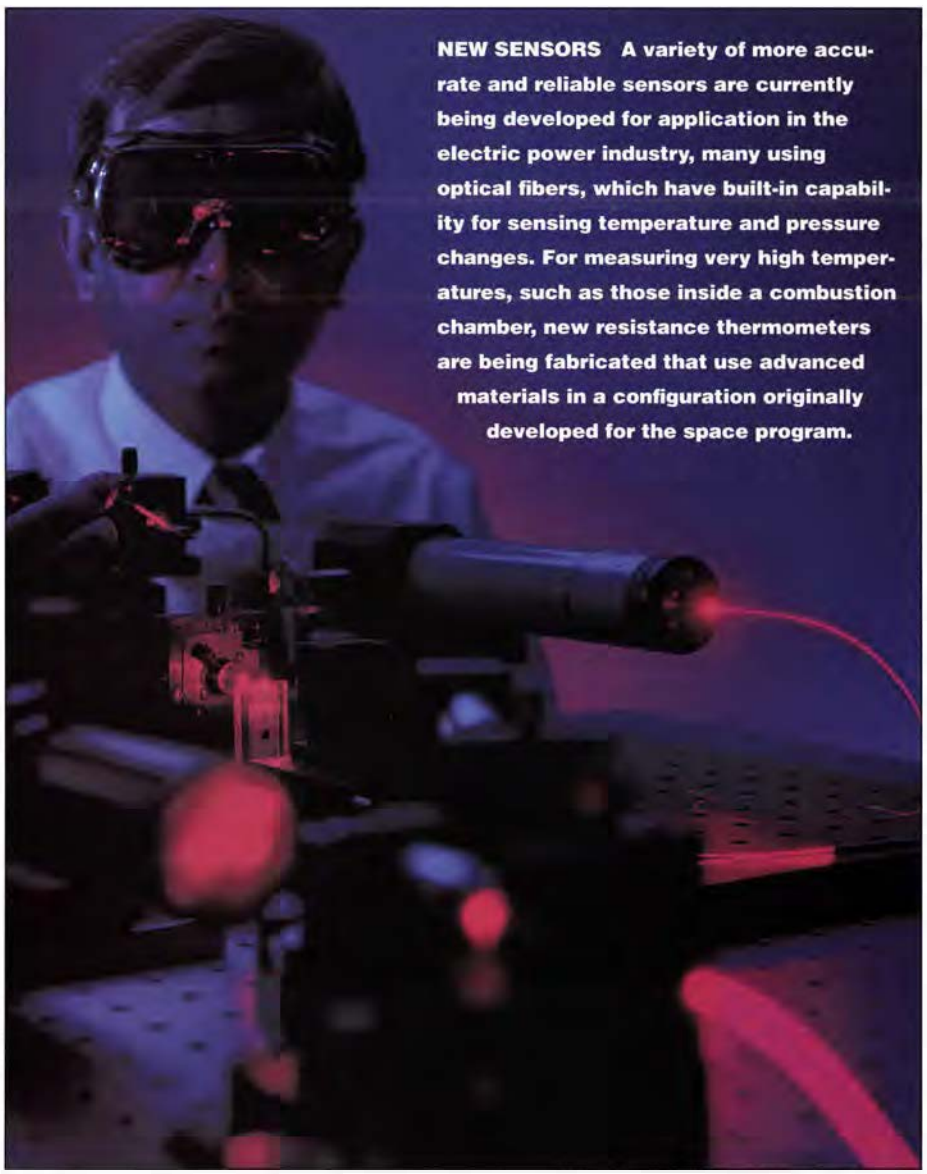
"Currently there is some lack of confidence in predictive techniques because utilities are not sure which methods are really cost-effective in which applications," explains James Lang, director of engineering and operations in EPRI's Nuclear Power Group. "One aim of our work with Duke Power is to develop the proper synergy between PDM techniques and other preventive maintenance techniques. This will enable utilities to focus their activities in areas where significant cost savings can be realized by replacing unnecessary, time-directed maintenance with condition-based maintenance."

New diagnostic technologies

Depending on its vintage, the average fossil or nuclear power plant has roughly 5000 sensors that monitor various operation and protection systems throughout the plant. In spite of this abundance of sensors, however, PDM programs based on the condition of monitored equipment have not been exploited at many utilities, even when RCM has already been implemented.

There are various reasons. One is that much of today's sensing equipment is antiquated, being based on technology that has changed little over the last two decades. As a result, many instruments are not accurate enough to provide the data needed either for efficient plant operation or for the detection of incipient equipment failure. In nuclear power plants, for example, process instrumentation has been cited as contributing up to 12% of lost power production.

In 1994, EPRI established the Instrumentation & Control Center in Kingston, Tennessee, to develop new sensors and control systems and to enhance the way these tech-



NEW SENSORS A variety of more accurate and reliable sensors are currently being developed for application in the electric power industry, many using optical fibers, which have built-in capability for sensing temperature and pressure changes. For measuring very high temperatures, such as those inside a combustion chamber, new resistance thermometers are being fabricated that use advanced materials in a configuration originally developed for the space program.

Mechanical Technology Inc.

nologies are used in automated plant control. The I&C Center is operated in cooperation with the Kingston steam plant of the Tennessee Valley Authority. This center and the M&D Center cooperate closely in their development and testing activities. For instance, the diagnostic capabilities of a new sensor created at the I&C Center may be integrated into the PDM network at the M&D Center.

One instrument now being prepared for testing at the I&C Center is a high-temperature strain sensor based on fiber optics and having a built-in resonance chamber. Such sensors can be attached directly to boiler tube headers; as a header expands with strain, the frequency of the light reflected back from the resonance chamber through the fiber is altered. Another new instrument, originally developed for a proposed orbiting nuclear reactor, will use platinum wire resistors protected by aluminum oxide insulators to measure power plant combustion chamber temperatures with an accuracy of within 1%.

According to EPRI's Joseph Weiss, manager of the I&C Center, the contribution of the new center to PDM programs is likely to come in two areas: long-term research on sensor development, and integration of the controls and diagnostic information into the plant control system for improved plant O&M planning. "Before, we had to rely primarily on what instrument vendors provided, which tended to be generic sensors aimed at a broad spectrum of applications," says Weiss. "Our intention is to have the I&C Center work with vendors to develop sensors that meet the specific needs of the electric power industry and then integrate them as quickly as possible into the PDM work at the M&D Center."

PDM in power delivery

EPRI's Power Delivery Group is playing a lead role in the development of PDM programs for substation equipment. One such program, under way at the M&D Center in cooperation with PECO Energy and five other utilities, involves the use of advanced sensors, wireless data transmission, and other technologies for equipment condition analysis.

For power delivery applications, which usually involve fundamentally different equipment from that found in power plants, new types of sensors may be required in order to implement PDM programs. Some of these represent the state of the art in high-tech electronics.

An example of such a sensor, now entering utility demonstration, is the transformer fault gas analyzer. This microelectronic device provides real-time measurement of the four key gases associated with fault currents in transformers: carbon monoxide, hydrogen, acetylene, and ethylene. The analyzer uses a metal-insulator-semiconductor sensor, which is inserted into the transformer oil through a small valve opening. The sensor provides on-line, in situ data that indicate not only present condition but also critical trends, such as an increase in individual gases. Previous measurement techniques required sampling the oil for later laboratory analysis.

The first field prototype of the fault gas analyzer was delivered in 1993, and more than a dozen are now in utility use. The next step in the development of this technology is to incorporate an additional sensor to detect the presence of moisture, which can reduce dielectric strength and lead to failure. The enhanced monitor will be used with another device that measures the transformer loading so that the evolution of key gases and moisture can be characterized as a function of the load. This information, in turn, will enable the development of short-term ratings above the nameplate specifications so that specific transformers can safely be loaded to higher levels in response to changing power delivery system conditions.

"In its present configuration, the fault gas analyzer helps identify maintenance needs and helps extend the useful life of transformers," according to project manager Stan Lindgren. "With the moisture sensor and load current monitor, we will be able to develop accurate criteria for loading transformers under stressful conditions, rather than having to rely on the overly conservative ratings now provided."

Another PDM technology that has recently found use in substations is a transformer winding hot spot detector. This device features a small temperature-sensitive probe, which is placed in close contact with the windings and is connected to outside monitoring equipment by an optical fiber. Several utilities are now using this detector to manage transformer loading and head off overheating problems.

Looking further into the future, EPRI is collaborating with the National Science Foundation to sponsor exploratory research on advanced sensors and control systems. Progress in several promising technical areas was reviewed at joint EPRI-NSF workshops held in Washington, D.C., in December 1993 and February 1995. Phosphors that fluoresce in response to ultraviolet light, for example, may someday be used to measure both temperature and strain in equipment subjected to stressful power plant environments. A direct method for remotely measuring electric and magnetic fields may be provided by changes in the polarization of light passing through an optical fiber. Thin films of piezoelectric materials, deposited on metal surfaces and connected to external monitoring equipment, have the potential to measure corrosion or the buildup of particulates.

"New sensors will provide information that we've never had the ability to acquire before," concludes Karl Stahlkopf. "By using these sensors to expand the horizons of predictive maintenance and then integrating this information into a reliability-centered maintenance program, EPRI is helping utilities reduce costs in one of the most important areas of expenditure that remain under their control. We will also be able to help engineers develop new equipment that uses the information from RCM and PDM programs to build more-robust systems that need less maintenance from the start." ■

Background information for this article was provided by Karl Stahlkopf, Magda Hammam, and Stan Lindgren of the Power Delivery Group, James Lang, John Gisclon, and Norris Hirota of the Nuclear Power Group; and Joseph Weiss, Russ Pflasterer, and Rich Colsher of the Generation Group.

by Taylor Moore

Environmental Technology for Small Businesses

THE STORY IN BRIEF Small businesses are now facing the kinds of environmental regulations that used to be of concern only to large smokestack industries. Helping these establishments navigate the web of technology choices and economic variables involved in regulatory compliance presents opportunities for utilities to encourage the application of electrotechnology-based solutions while building better customer relations. EPRI's support of such utility marketing efforts, which began with an environmental solutions handbook for eight key business sectors, is expanding to include information on a broader spectrum of small businesses. In addition, collaborative work with utilities is developing specific information on the marketing opportunities for electrotechnology solutions in individual service territories. The bottom line is to help member utilities build load while they, in turn, help their small-business customers become more energy-efficient and competitive.

Ron May

The aroma wafting from the local bakery is, alas, a reminder that by-product emissions of ethanol from leavening yeast make many bakeries a significant source of volatile organic compounds—chemicals involved in the formation of urban smog. Another source of VOC emissions is the solvent-based paints used in virtually all autobody and repair shops. Dry-cleaning shops, meanwhile, routinely use a chlorinated organic solvent that is considered a probable carcinogen. Almost all the chemicals and solutions used in wood preserving, electroplating, and photofinishing are classified as toxic or hazardous or both. And commercial laboratories and medical clinics can generate a wide spectrum of infectious and hazardous wastes.

These seemingly disparate industries have several key features in common. All are characterized by a large number of small to medium-sized firms. Most business establishments in each industry employ fewer than 20 workers. In the past the disaggregated structure of these industries tended to shield them from strict environmental regulation of waste streams. But that is no longer the case. Laws passed in the 1970s that originally applied to factories and power plants have been expanded to cover nearly every small business in America. Amendments to four of five of these key federal environmental laws have significantly increased the compliance burden on small businesses, forcing near-term decisions that will affect their productivity and, ultimately, their long-term profitability and continued existence. Small businesses are now affected by regulations implementing the latest revisions to the Clean Air Act and the Clean Water Act, as well as major laws covering solid and hazardous waste disposal. The 25-year-old Occupational Health and Safety Act's regulation of worker exposure to hazardous substances also extends to most small businesses.

"Utilities have a significant stake in such compliance decisions, since the stability and growth of their commercial customer base are affected by the survival of these businesses," says Morton Blatt, manager of the Residential & Small Commercial Business Unit in EPRI's Customer Systems Group. "Assisting these small-business customers in complying successfully with environmental regulations presents unique opportunities for electric utilities. Since many of the traditional as well as emerging environmental solutions rely on electricity-based technologies, marketing these technologies can not only help smaller commercial customers navigate the maze of environmental regulations but also assist the utility in managing and building its load."

Electrotechnologies are increasingly being applied in innovative ways to reduce energy consumption, improve product quality, decrease production costs, boost productivity, and comply with environmental regulations. Many of their advantages stem from an ability to use electricity efficiently. In many cases they represent logical applications of conventional electricity-based technologies—for example, heat pumps—in new areas, such as metals reclamation from electroplating and solvent recovery in dry cleaning.

Supporting electrotechnology marketing

EPRI is expanding its support of utility electrotechnology marketing efforts aimed at small businesses. This support is building on the technical and market information assembled and integrated for the first edition of the *Guidebook of Environmental Solutions for Small Businesses* (TR-102843), published in 1993. The guidebook covers these eight wide-ranging businesses (ranked by total number of establishments in the country): medical clinics and laboratories; auto body paint shops; dry-cleaning plants; nonmedical, nonuniversity R&D laboratories; photofinishing laboratories; electroplating shops; wholesale bakeries; and wood-preserving shops.

"The guidebook is intended to provide utility marketing managers, market planners, and account representatives with information that will help them ensure that their small-business customers successfully meet their environmental challenges and, when appropriate, use electrotechnologies," says Wayne Krill, the EPRI project manager. "We tried to identify the technical issues that these eight small-business sectors are facing, which are primarily environmental, identify potential opportunities for electrotechnologies, and match up specific technologies that utilities can consider recommending."

Krill notes that there are few utility electrotechnology programs that specifically target small businesses, in part because of the diversity of the process streams and technologies involved and in part because of the lack of integrated information resources. "Up to now, utilities have tended to focus their marketing efforts on industrial and large commercial customers," he says. But that is changing, as the critical role of small businesses in sustaining economic growth is increasingly recognized in the policies and development programs of state and federal government agencies. "There's a lot going on around the country that is aimed at providing assistance to small businesses—financial, technical, and otherwise," explains Krill. "We are trying to contribute to that in a complementary way."

The small-business segments covered in the guidebook were chosen on the basis of a classification of their environmental problems. Drawing on 1990 census data, the EPRI contractor reviewed nearly 80 industry segments and identified 8 with environmental problems addressable with electricity-based solutions. Several of these segments, including wood-preserving shops, dry-cleaning plants, and auto body paint shops, have been targeted by the U.S. Environmental Protection Agency as high-polluting small businesses.

Although all eight segments can realize environmental benefits from the application of electrotechnologies in their operations, some segments have the potential to gain other benefits as well. For example, by switching from solvent-based paint and air drying to waterborne paint and infrared curing, an auto body paint shop can increase productivity at the same time that it reduces VOC emissions and limits the generation of hazardous solid waste.

The guidebook focuses on electricity-based technology solutions that will have a significant impact on a small business and the way it uses electricity. Both the size of the electrical load and its role in the solution determined which technologies appear in guidebook profiles. Generally, small-business applications of electrotechnologies involving typical loads of 5 kW or more are profiled.

Environmental challenges for bakeries

While the chemicals used in photofinishing, electroplating, and wood preservation have obvious environmental risks, the problems and concerns associated with some other small-business processes are less obvious. Take, for example, the large and decentralized U.S. wholesale baking industry, which has plants near consumers in virtually all American cities to enable the delivery of fresh products. The industry is coming under increasing pressure from state and local environmental regulatory bodies to reduce emissions of ethanol, one of the VOCs targeted in the 1990 Clean Air Act Amendments. But since no modified yeast, additive, or enzyme has been identified that lowers ethanol emissions without altering the taste of bread and other baked products, process changes are not considered feasible and, in some cases, costly emissions control technologies have been required. Many bakeries also face increasingly strict pretreatment standards for the discharge of process wastewater to publicly owned treatment works. Some bakeries are considering installing pretreatment systems in order to meet such standards and avoid having to pay surcharges.

Although only the largest bakeries are likely to be forced to control ethanol emissions in the near future, the trend in environmental regulation is to focus on smaller and smaller sources of pollution. The control technology currently recommended by the EPA is thermal oxidation (i.e., incineration). However, most large bakeries that are required to limit ethanol emissions have installed catalytic oxidation units. These systems draw ethanol-laden air from a bakery oven and inject it into a natural gas burner, using a catalyst to accelerate the ethanol's oxidative reaction to carbon dioxide and water at a lower temperature than is involved in fuel-fired incineration.

Charles Gupton/Uniphoto

BAKER'S YEAST: NO CHANGING THE RECIPE **Process changes that would reduce bakery emissions of ethanol from leavening yeast would also alter the quality and taste of bread and other products. Technologies like catalytic oxidation are used by large wholesale bakeries to control ethanol emissions. These are not considered practical for smaller bakeries, however, and new methods of oxidation—including photolysis, electron-beam irradiation, and supercritical water oxidation—are being evaluated.**

Waste heat recuperators are also used to boost overall efficiency.

The nearly two dozen catalytic oxidation units installed to date are large and had a high capital cost; the EPA has determined that they would not be cost-effective for smaller bakeries. Other commercial technologies for controlling VOC emissions are believed to be inapplicable or uneconomical for use by bakeries.

EPRI and the National Science Foundation are sponsoring R&D on a number of electricity-based advanced oxidation technologies for VOC control in general. These include photolysis, electron-beam irradiation, and supercritical water oxidation. It has not yet been determined if any of the technologies would be applicable to bakery VOC emissions.

As for bakery wastewater, there are a number of options for reducing its volume and strength and for treating it before discharge. The installation of pretreatment technology should always come after the application of all appropriate housekeeping measures that minimize wastewater generation. For bakeries where such measures are not enough to comply with the discharge standards of public treatment plants, pretreatment systems are available.

Dissolved-air flotation and biological oxidation systems are commonly used to control the strength of bakery wastewater. Flotation has limitations and disadvantages in some applications but can reduce the ultimate costs of processing wastewater. Biological oxidation uses bacteria, algae, or fungi to degrade fats, oils, grease, and other organic matter in bakery wastewater so that it can be discharged directly into municipal sewers. Some systems are said to achieve reductions of up to 95% in such key measures of wastewater potency as biological oxygen demand (BOD), total suspended solids, and fats, oils, and grease. Systems may be aerobic, producing a residual sludge for disposal or for use as fertilizer, or they may be anaerobic, yielding a methane-containing biogas that must be vented or burned.

Ultrafiltration is a relatively new technology, not yet widely used by bakeries, that employs permeable polymeric membrane systems to filter selected components

Stephanie Scarborough

A PRESSING PROBLEM FOR DRY CLEANERS **Many dry-cleaning plants have installed dry-to-dry cleaning machines or activated-carbon adsorbers to limit vapor emissions of cleaning solvent. Increasingly, however, many are being required to install still newer technology—closed, no-vent dry-to-dry models with a refrigerated, internal solvent condenser and an integrated carbon adsorber, like the machine shown here at Parkside Plaza Cleaners in San Mateo, California.**

from wastewater under pressure maintained by electric pumps. Self-contained, modular ultrafiltration systems could be used to reduce the levels of dissolved solids and BOD in bakery wastewater, leading to reduced surcharge payments for public discharge. Ultrafiltration falls between reverse osmosis and microfiltration—two other membrane separation processes—in terms of the size of the particles that are allowed to pass through the membrane filter. Ultrafiltration units use little energy, requiring only electricity for the pumps to maintain adequate pressure, and have very low maintenance costs.

The guidebook's section on wholesale bakeries includes fact sheets for both biological oxidation and ultrafiltration for wastewater treatment. The fact sheets describe each technology's status, basic principles, cost, and electrical requirements.

Pressure on dry cleaners

Dry-cleaning plants, which far outnumber commercial bakeries, electroplaters, or even photofinishing labs, exemplify the small businesses that are suddenly coming under strong regulatory scrutiny and pressure to strictly limit emissions. The EPA estimates that close to 30,000 dry-cleaning plants are currently in operation in the United States. About 9 out of 10 use the chlorinated organic solvent perchloroethylene (perc) because of its cleaning and operational properties, including nonflammability—even though perc is classified by the EPA as a probable human carcinogen. Other chlorinated compounds used as alternative dry-cleaning solvents are being phased out because of concerns over ozone depletion.

The solvents used in dry cleaning can result in hazardous air emissions, endangering workers and the public and contaminating wastewater and solid wastes. The solvents can also contaminate groundwater resources if not disposed of properly. But the cost of meeting new and existing regulations on solvent emissions and wastes could put some dry cleaners out of business.

Nearly 90% of all dry cleaners already use filtration and/or distillation systems to regenerate their cleaning solvents for reuse. Cartridge filters remove dirt and other contaminants from the solvent and are, in turn, disposed of as hazardous waste. The solvent is also distilled to remove impurities; volatilized vapors are condensed and reclaimed, and residues are disposed of as hazardous waste, usually by a licensed solvent recycler. Nearly 85% of dry-cleaning solvent is believed to be recycled nationwide. The residues from conventional solvent recovery methods are burned as fuel in cement kilns, one of the few approved disposal alternatives for such organic solvents. Solvent recovery also results in the generation of wastewater containing small amounts of solvent, most of which is removed by gravity separation before the water is discharged to a public sewer.

The operators of many existing dry-cleaning plants have already taken steps to reduce solvent use, emissions, and waste generation from solvent recovery. In fact, the use of newly made perc is decreasing because of greater recycling and the pressures to limit atmospheric emissions. And new dry-cleaning plants are now required to use self-contained, dry-to-dry cleaning machines that perform cleaning, extraction, drying, and aeration within the same unit

SMALL-BUSINESS ENVIRONMENTAL SOLUTIONS

	Segment	Number of Establishments	Customer Technology Application Opportunities
	Wholesale bakeries	2,500	Catalytic oxidation for ethanol VOC emissions control; other oxidation technologies being explored for small bakeries. Dissolved-air flotation, biological oxidation, and ultrafiltration for wastewater treatment.
	Wood-preserving shops	500	Ultraviolet, biological, and supercritical oxidation methods for site remediation and cleanup.
	Electroplating shops	3,200	Electrolysis, vacuum evaporation, and microfiltration for wastewater treatment.
	Dry-cleaning plants	17,600	Dry-to-dry cleaning machines with refrigerated solvent condensers and add-on or integrated carbon adsorbers.
	Photofinishing laboratories	6,200	Ion exchange, electrolysis, and vacuum evaporation for process solutions and wastewater treatment.
	Auto body repair and paint shops	30,500	Infrared paint curing, solvent incineration, and carbon adsorption.
	Medical clinics and laboratories	401,300	Steam sterilization and incineration for infectious wastes. Emerging technologies are microwave sterilization and resistance pyrolysis.
	R&D laboratories	14,900	Can be a proving ground for a variety of cutting-edge technologies for emissions control, wastewater treatment, and infectious wastes.

and that employ refrigerated solvent condensers. These units produce only about one-tenth the solvent-contaminated wastewater produced by dry-cleaning machines with carbon adsorbers for solvent recovery.

Quite apart from federal and state environmental regulations, economic factors have motivated some dry cleaners to voluntarily install emissions control devices or switch to more-efficient dry-cleaning machines, such as the dry-to-dry units. But regulations implementing recent amendments to the air quality, solid waste disposal, and occupational safety and health laws are expected to lead to further equipment installation and switching. All dry cleaners, for example, must install refrigerated solvent vapor condensers by 1996. Industry equipment manufacturers are providing add-on control systems for older equipment and offering new equipment with integrated vapor recovery systems.

Solvent vapor recovery technologies such as carbon adsorption, refrigerated vapor condensation, a new process called SOLVATION™, and solvent recovery heat pumps can reduce solvent concentrations in emissions by as much as 95%. Slightly more than a third of the dry-cleaning machines that have vapor recovery controls use adsorption by activated carbon in an add-on device that captures 95–99% of the vapor. Steam is required to regenerate the carbon adsorbers, producing some solvent-contaminated wastewater.

The level of control achieved by a carbon adsorber has been proposed by the EPA as the national emissions compliance standard for dry-cleaning plants, although the technology's shortcomings make it undesirable as a long-term solution for solvent emissions control. The compliance standard requirements may also be met with dry-to-dry, refrigerated, no-vent dry-cleaning machines. These can achieve 95% vapor control and typically use less than half the amount of perc for cleaning that a transfer machine with separate units for cleaning-extraction and drying-aeration uses. But dry-to-dry machines are not inexpensive; a unit sufficient for the needs of a typical suburban dry cleaner may cost as much as $50,000. Such systems with internal refrigerated solvent recovery units require about 10 kW, which includes the power for pumps and motors for cleaning operations.

Other technologies in limited use or under consideration for use by dry cleaners include the SOLVATION process, which uses a closed system instead of normal aeration to reduce the amount of solvent vapor vented to the atmosphere; a solvent recovery heat pump that uses a reverse Brayton cycle as an alternative means of condensing solvents from vapor; and a solvent recovery heat pump using the Rankine cycle. (An entirely different alternative—replacing the solvent-based dry-cleaning process with a water-based, ultrasonic washing process—is also being explored.)

A consortium that includes the U.S. Department of Energy, EPRI, 3M, Nucon, and Southern California Edison Company is currently working on a Brayton-cycle condensing system for such small-business applications as dry-cleaning solvent recovery. The technology, which uses a dry, inert nitrogen stream to remove solvent from adsorbent beds and achieves 99% recovery, is expected to become commercially available within a few years.

Expanding support to utilities

EPRI is working this year to expand and update the guidebook, extending coverage to additional small-business sectors and developing more in-depth information for all the sectors covered—information that will help give utility marketing personnel the capability to recommend specific electrotechnologies and equipment in consultations with their small-business customers. More-targeted local and regional marketing demographic information for utilities is also being developed.

"We are conducting a deeper assessment of the potential business opportunities for utilities in marketing electrotechnology environmental solutions to small businesses on the levels of both the individual utility service territory and the country as a whole," says EPRI's Wayne Krill.

While coverage of the original eight business sectors is being updated with additional energy use information and customer case studies, new guidebook sections are being developed to describe the processes and environmental challenges of other industries and to identify electrotechnology solutions. These sections will cover food service establishments, commercial and industrial laundries, garment manufacturing, convenience stores, small metals-finishing shops, commercial printing, electronics fabrication, and furniture refinishing.

"We're receiving increasing support for expanding our small-business research," says Krill, "including tailored collaboration funding from utilities and collaborative support from EPA and DOE. Together with our base funding, this support will allow extended coverage of additional small-business sectors and help develop an understanding of how each utility can best penetrate its small-business markets. We will also work with our tailored collaboration utilities and their specific customers to evaluate equipment and conduct case studies. We are responding to the need for quality technical information that will support our members' customer marketing efforts."

The focus of EPRI's work this year will be on developing information about the technologies and energy requirements of additional small-business sectors. The goal is to identify new opportunities to increase load and improve efficiency for such utility customers. Krill says that EPRI will conduct market analyses for each utility participant to identify the utility's best opportunities for applying electrotechnologies in its service territory. The research is expected to yield high-quality customer marketing information for utilities in general.

Beyond that, EPRI will undertake product development of high-benefit technologies and will identify and provide additional customer marketing tools for specific small-business needs. Depending on the level of supplementary funding, Krill says, EPRI could develop prototypes of some of the promising emerging electrotechnologies for small businesses.

The *Guidebook of Environmental Solutions for Small Businesses* (TR-102843) is available from the EPRI Distribution Center, (510) 934-4212. ■

Background information for this article was provided by Wayne Krill of the Customer Systems Group's Residential & Small Commercial Business Unit.

LIGHTING THE OFFICE ENVIRONMENT

by Leslie Lamarre

THE STORY IN BRIEF Now that the video display terminal is as common as the telephone in office environments, properly lighting these spaces has become a critical task. Overillumination—the most common problem—can create glare and reflections on computer screens and generate too much contrast between a VDT and the surrounding area. Not only do such effects make work more difficult to complete, but they can also make workers uncomfortable, causing headaches, weariness, and other problems that affect well-being and productivity. An EPRI collaboration with Lightolier has resulted in a new line of luminaires and controls especially designed for use with VDTs. Adding to the attractiveness of these lighting systems are their energy efficiency and a single-source warranty.

There once was a time when an office chair was just a chair and a desk was just a desk. But this era of service industries has taught us that an ergonomic office environment can influence productivity as much as good nutrition.

What's true for office furniture is true for lighting too. Workers have certainly experienced a dramatic improvement in lighting quality since the days of oil and gas lamps. According to an 1882 account, reading by gas lighting was "irksome," while incandescent bulbs made reading "a delight." As tasks in the U.S. workplace became more sophisticated and demanding, lighting conditions continued to improve. Eventually, long-tube fluorescent lamps replaced bare incandescent bulbs, providing the more uniform illumination available in today's business offices.

Modern-day demands keep pushing the state of the art in office lighting technology, providing the impetus for further changes and refinements. As Karl Johnson, EPRI's manager for commercial building systems, puts it, "Lighting is not just something by which to see anymore. Today lighting is an environment."

One of the greatest challenges in properly illuminating the contemporary working environment is posed by the pervasive video display terminal (VDT). "Personal computers first began trickling into office buildings decades ago," says Johnson. "Today these buildings are flooded with PCs, and yet in many instances, the lighting systems in the buildings are the same ones that existed before PCs entered the scene. It's simply been assumed that the lighting systems that served workers at typewriters and adding machines are appropriate for those working with computers."

As employers and building owners are now learning, this is not the case. Workers have complained of eye strain, caused by glare on computer screens, and visual fatigue, often brought on by too much contrast between VDT screens and the surrounding environment. Such lighting problems can lead to headaches, weariness, and other complications. The toll on productivity can be considerable. Lighting experts estimate that employers' out-of-pocket costs due to VDT-induced errors may be \$5–\$10 per square foot annually—a significant amount in comparison with typical lighting costs of \$1–\$2 per square foot.

Fortunately, lighting designers, architects, corporate real estate managers, and others responsible for lighting environments now have a selection of VDT-friendly lighting systems from which to choose. Among them is a new line of luminaires and controls resulting from an EPRI collaboration with the lighting manufacturer Lightolier. Currently being rolled out across the U.S. market, this product line consists of a variety of complete lighting systems for commercial and institutional applications. Marketed as "vision smart" and "energy smart," these systems provide quality lighting for VDT environments while offering high energy efficiency.

As Mort Blatt, manager of EPRI's Residential & Small Commercial Business Unit, explains, this product line is part of a broader EPRI plan to encourage an integrated approach to lighting—an approach that combines various components, including controls, to facilitate the implementation of sophisticated lighting systems and to help make such systems more reliable and less expensive. As part of this broader plan, EPRI member utilities, including Consolidated Edison Company of New York and Duke Power Company, will host demonstrations of the new lighting systems in their service territories. Also, EPRI is working with its member utilities, the federal government, and others to establish standard criteria that utility customers can recognize and specify. The criteria would ensure the reliability, quality, and efficiency of integrated lighting systems.

Energy-effective lighting

Since the 1970s, electric utilities have sponsored programs to encourage the more efficient use of electricity. In the commercial sector—a critical part of the market for Lightolier's new luminaires—lighting has always been a popular program target, largely because of its significance. Lighting represents more than one-third of the energy used by commercial establishments (and accounts for more than 20% of the country's overall energy use).

The utilities' efficiency programs typically offered rebates to customers who installed energy-efficient lighting equipment. The majority of these rebates were for individual components, such as lamps, ballasts, and reflectors. The idea was to provide an incentive to customers, offsetting what would otherwise be a higher capital cost for the more efficient equipment. Utilities benefited too, since the costs of their efficiency programs were significantly lower than the costs they would have incurred in building new power plants to handle the greater demand of less efficient systems.

The rebate programs were never in-

ON DISPLAY Fixtures and controls selected from Lightolier's Advanced Lighting Systems product line were installed in executive offices at EPRI, including President Richard Balzhiser's office, shown here. Two direct/indirect pendants hung over the work area provide general illumination, while wall washers (recessed into the ceiling on two sides of the room) alleviate shadows on the upper walls and brighten the room's appearance.

tended as a permanent solution to getting consumers to use electricity more efficiently. Rather, program planners anticipated that the market for these technologies would ultimately have to support itself, without the help of utility subsidies. To some extent, the rebate programs succeeded in this mission. For example, when electronic ballasts and T-8 lamps, relatively new technologies a decade ago, became widely adopted in the marketplace, their costs came down to such an extent that their purchase is now market driven.

But as Arthur Kressner, a manager in customer systems research and development at Consolidated Edison, points out, there were some problems with the utility programs too. For instance, the programs typically subsidized individual components of a lighting system, such as ballasts, reflectors, lamps, or the control system. Not only did this practice lead to problems of compatibility among the various components, which in turn could severely detract from the energy savings that had been promised, but there was no single manufacturer responsible for the entire system. "When something went wrong," says Kressner, "customers could wind up bouncing from ballast manufacturer to fixture manufacturer to control system manufacturer and back again without ever getting their problems resolved."

EPRI analyzed such problems in detail, drawing information from utilities and their customers through conferences and focus groups. On the basis of this feedback, the EPRI-utility team devised a plan for an advanced lighting system that would provide significant energy savings while offering a sleek, state-of-the-art combination of components and controls. One of the most important requirements the team had for this new system was that it have a single-source warranty—that is, one manufacturer should be responsible for the ballast, the fixture, and the controls. "Utilities saw a need for a transition from rebate-driven programs to market-driven programs, given the increasing competition in the industry," Johnson says.

Kressner agrees. "The advanced lighting system represents the model for future programs that utilities can offer as a value-added service to their customers," he says. "Even though the component-based rebate programs of the past saved energy, they sometimes compromised quality. The advanced lighting systems developed under the EPRI project represent the first fully integrated approach to addressing quality as well as saving energy."

"Lighting is an area that commercial customers really care about, since it represents approximately 30% of the electrical load in any building," adds Peter Jacobson, a manager in energy services at Consolidated Edison. "For this reason, it's absolutely essential for good customer service and long-term accounts that lighting be one of the major areas in which utilities get involved. Customers will turn to utilities for advice on lighting, so it is critical that utilities and trade allies work together to promote better solutions for their customers."

A product is born

EPRI approached Lightolier about developing an advanced lighting system in 1991. EPRI selected Lightolier not just because of the company's history of leadership in lighting technology development but also because Lightolier has a strong controls program and was interested in offering the single-source warranty EPRI and its members sought.

At the time, Lightolier's product development team was introducing a sophisticated line of energy-efficient lighting systems through a program called energy-smart lighting. Launched in 1991, the program focused on architectural lighting such as recessed downlights, track lighting, and decorative ceiling fixtures. Architectural lighting was ripe for efficiency improvements, since incandescents commonly illuminated hotel lobbies, multifamily residences, restaurants, and nursing homes, with some of the lamps burning around the clock. Office lighting was not initially the main thrust of Lightolier's program. However, EPRI-funded R&D showed that efficiency could be significantly enhanced without compromising lighting quality.

Adding to the incentive to pursue the office lighting market were two events: the passage of the Energy Policy Act of 1992 and the 1993 publication of the American National Standard Practice for Office Lighting. Among other issues, the Energy Policy Act addressed the common problem of overillumination in office environments, which is often responsible for glare on computer screens and is wasteful of energy. "With the passage of the Energy Policy Act," notes Zia Eftekhar, president of Lightolier, "energy conservation became a matter of law, as well as of good economics and environmental responsibility." The act includes a mandate for states to enact rigorous building energy codes that set limits on lighting power density, among other requirements. Similarly, the American National Standard Practice for Office Lighting, developed by the Illuminating Engineering Society and known as ANSI/IES RP-1, recommends standards to ensure VDT-friendly lighting in office spaces.

A three-year collaboration with Lightolier resulted in the Advanced Lighting Systems product line, a collection of energy-

AT YOUR FINGERTIPS An important aspect of the Advanced Lighting Systems is their line of controls. The most sophisticated of these is the PhotoSet control, which has only two components—a wall module and a photocell. Among PhotoSet's features are occupancy sensing and automatic dimming (to respond to varying daylight or to the weaker output of aging lamps). The wall module contains the brains of the system. Unlike other controls with automatic dimming, PhotoSet can be calibrated from the wall module; no ladders or complex procedures are required.

Photocell

PhotoSet control

Exposed control panel

efficient and VDT-friendly systems that enables users to mix and match components and features to find the appropriate lighting for a given area. In parallel with EPRI's efforts, Niagara Mohawk Power Corporation helped to sponsor the development of some of the components in the product line. The complete line includes modular parabolic troffers, linear parabolic troffers, indirect/direct pendants, wall washers, and task lighting.

Controls too

The other major component of the product line is the control technologies. The most sophisticated of these is a two-part system consisting of a wall switch and a photocell. This system offers occupancy sensing to automatically turn lights off when people leave a room, as well as automatic dimming—also called daylight dimming—which maintains the desired light level as the daylight level changes or as lamps age and dirt accumulates on fixtures, reducing light output. Although daylight-dimming controls have been available for over a decade, one problem with this technology is the tendency of photocells to overdim in response to increased daylight. In a significant technological innovation, Lightolier resolved this problem by developing an automatic correction circuit that sends the ballast the input it needs—based on the light reading from the photocell—to dim the light output to the appropriate level.

The new circuit also makes it easier for users to adjust the system. Because all the "brains" of the control system are located in the space behind the 4.5-square-inch wall switch plate—a space just 2.5 inches deep—adjustments can be made directly from the wall panel, with no need to access the luminaire itself. "With other lighting systems that offer a daylight-dimming feature, you typically need two people to commission or adjust these things, one person up on a ladder and one person at the wall switch," notes Steve Carson, general manager for Lightolier controls. "This new system makes adjustments easy. All you need is one person at the wall plate."

Other features of Lightolier's control system include a manual override that allows occupants to dim the lights to below the set

IN A DIFFERENT LIGHT These photographs illustrate the difference lighting can make to an employee working at a video display terminal. The photo on the top shows illumination from a modular parabolic troffer in the Advanced Lighting Systems product line. The photo on the bottom shows the illumination from a more typical parabolic fixture designed for use with VDTs. With such conventional lighting approaches, overillumination and too much contrast between the brightness of the VDT and that of the surrounding area make the page and the screen difficult to read.

level. The on switch for Lightolier's system is activated manually—the rationale being that people don't always want the lights to come on when they enter a room, especially if they are simply stopping by to pick something up. The ability to turn lights on manually also offers occupants a sense of control over their lighting environment.

Overall, Lightolier's Advanced Lighting Systems luminaires are almost twice as efficient as older, obsolete luminaires and 12% more efficient than other luminaires currently on the market. Even more important, however, is the enhanced lighting quality offered by the systems. Indeed, at EPRI's request, the Advanced Lighting Systems line was designed to comply with ANSI/IES RP-1, which includes specific recommendations for lighting spaces with VDTs, including the amount of light, the brightness of objects and surfaces (including contrast between them), and the control of glare. Other systems currently on the market meet only the glare control requirements of RP-1 but not the contrast requirements. RP-1 specifies a "preferred" quality level, applicable to areas in which the use of VDTs is continuous or intensive, as well as a "basic" quality level, applicable to areas in which their use is intermittent and less intensive. Corresponding to these criteria, the Advanced Lighting Systems product line offers "preferred" and "basic" fixtures.

Beyond all the technical bells and whistles of the new systems is the advantage of the single-source warranty, which covers everything except the lamps themselves. Eftekhar notes that standard T-8 or T-5 fluorescent tubes will work with the fixtures and controls in the Advanced Lighting Systems line. "It used to be that lighting designers and corporate real estate managers had to search long and hard to find various components that would work together in the desired way," he says. "Bringing the critical variables together in a single system makes good and reliable lighting so much easier to achieve." According to Eftekhar, this product line is the only one on the market today with a single warranty for luminaires and controls. EPRI's hope is that other manufacturers will follow suit, offering similarly integrated systems.

To encourage the use of energy-effective, integrated systems, EPRI is working with the Empire State Electric Energy Research Corporation to develop two guidebooks to assist utilities, engineers, designers, architects, manufacturers, and others involved in specifying lighting systems. The first guidebook, a lighting controls book (due out in 1996), will condense lighting expertise into typical installation patterns to guide those who are designing and installing integrated lighting systems. The second guidebook, a daylight engineering workbook (due out in 1997), will assist lighting designers by presenting simplified and reliable methods of integrating daylighting with artificial interior lighting.

How did they do that?

Producing such high-quality lighting while improving energy efficiency was not easy. Contractors for EPRI and Lightolier performed hundreds of computer runs to optimize the designs of these systems. Part of the secret of the recessed fixtures is the specular aluminum from which the louvers are made. Specular aluminum is commonly used in the louvers of other recessed fixtures on the market. The aluminum louvers in the Lightolier product line, however, have a special finish that reduces specularity so that less of the light is directly reflected—that is, some of it is diffused. This difference reduces the dark appearance of the fixture, a common problem with conventional specular reflectors.

Working in collaboration with EPRI, engineers for the Advanced Lighting Systems line also developed an optical design for the reflectors inside each fixture—a design that controls the luminaire's light output to prevent glare while still providing wide light distribution. The reflectors in the one-lamp and some of the two-lamp fixtures employ a mylar film with 95% reflectivity to increase light output. (The reflectors in the other fixtures have a standard white painted finish, which is about 87% reflective.) Most of the Advanced Lighting Systems products require only one or two lamps rather than the three or four typically required by other fluorescent systems on the market.

Advanced features like the reflector optics and dimmable electronic ballasts make Lightolier's new product line more expensive than other systems on the market —25% more expensive, on average. But Lightolier believes that the high quality of the light output, especially in this era of emerging new regulations for VDT environments, will win over the decision makers for office and institutional lighting. The dollar savings in operating costs should also attract some buyers. "This is something the building owner can clearly understand," says Eftekhar. "It takes less energy to power two lamps than it does to power three."

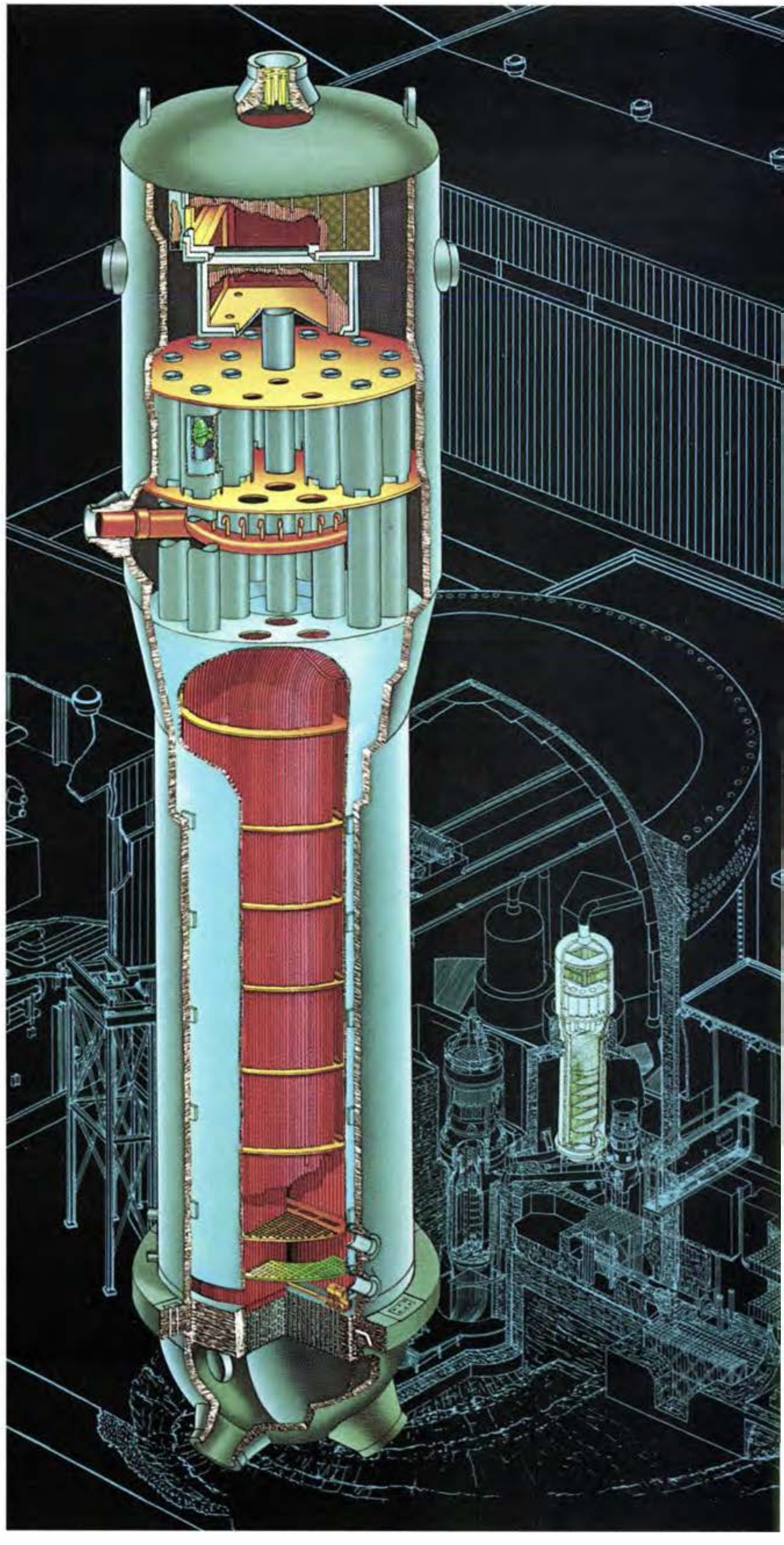
The systems are expected to be used mainly in new construction and significant remodeling projects. "The bellwether users will be large companies that typically serve as early adopters for other kinds of advanced technologies," says Eftekhar. "Once the lighting systems have been proven in these environments, other businesses will follow suit."

So far, Lightolier has sold about $1 million worth of lighting fixtures from the new product line. EPRI is helping to arrange for the demonstration of the systems at sites in utilities' service territories. Already, a school and two office buildings have agreed to demonstrate the systems. Additional host utilities are welcome to participate.

Surely only time will tell whether the new product line is a market success. But utilities are optimistic. "The Advanced Lighting Systems offer utilities a great opportunity to promote effective lighting and to position themselves as a source of information on good lighting technology," says Johnson of EPRI. "By participating in the development of this product line, utilities have gained a competitive advantage and added a valuable customer service that extends far beyond the traditional rebate programs." ■

Background information for this article was provided by Karl Johnson of the Customer Systems Group's Residential & Small Commercial Business Unit. Computer art on page 22 and photos on pages 25 and 26 courtesy of Lightolier and David Munson of the Advanced Technology Group at HOK, Architects, St. Louis. Photo on page 24 by Stephanie Scarborough.

THE STORY IN BRIEF Problems with steam generators have been a major source of forced outages and capacity factor loss in pressurized water reactors. Over the years, the leading forms of degradation affecting steam generators have changed: as scientists and engineers have discovered the causes and cures for one set of problems, other problems have arisen. All in all, much progress has been achieved. Replacement steam generators with improved materials and design features have experienced only minimal damage, and a developmental tube repair technique based on laser welding has the potential to reduce maintenance costs significantly. Some degradation mechanisms, however, have not yet been controlled and threaten to limit the useful life of many steam generators unless ongoing research discovers ways to manage them.



Westinghouse Electric Corp.

Solutions for Steam Generators

by John Douglas

One of the most persistent challenges facing utilities with pressurized water reactors is how to keep the steam generators that are an inherent part of this design from deteriorating prematurely. Over the years, problems with this key component have been the single greatest cause of capacity factor loss in PWRs, and as plants continue to age, new types of problems are appearing.

Since 1977, EPRI has conducted a major research program to help utilities improve the performance of their steam generators. As a result, most of the initial types of damage have been eliminated, and newer units—with designs incorporating lessons learned from the research—have been virtually trouble free. Many older units, however, have deteriorated to such an extent that some utilities now face a particularly difficult and expensive decision: whether to replace a plant's steam generators at a cost of around $100 million to $200 million, to derate the plant because of a reduction in heat removal capability as steam generator tubes are plugged, or, in certain cases, to shut the plant down entirely.

As industry needs have changed, EPRI's program has evolved through three distinct phases. By the mid-1970s, some of the steam generators that had been expected to last for the full 40-year design life of a nuclear plant were already beginning to deteriorate, sometimes within 8–10 years of commissioning. In response, EPRI and PWR operators formed the Steam Generator Owners Group (SGOG), which used funds primarily from the participating utilities to try to learn the causes of the difficulties and identify corrective actions. Then, in 1986, as new problems began to appear, EPRI assumed primary funding responsibility for follow-on work through the Steam Generator Reliability Project, with participation limited to EPRI members and certain international organizations.

Although this project was generally quite successful, in the early 1990s a large number of older plants experienced a major new kind of tube deterioration—secondary-side stress corrosion cracking—which is now threatening to limit the useful life of many steam generators unless a remedy can be found quickly. In January 1993, the Trojan nuclear plant of Portland General Electric Company became the first PWR to be decommissioned (at a projected cost of more than $400 million) principally because of steam generator problems. At the same time, improved knowledge about various failure modes prompted utilities to seek changes in long-standing generic regulations on how to conduct steam generator inspection and repair. Responding to these challenges, EPRI and participating member utilities are currently cofunding the Steam Generator Strategic Management Project, which has a broad mandate to complete the development of a balanced package of long-term and short-term options for addressing steam generator issues.

"Strategic management involves concentrating on three major activities," says Chuck Welty, manager of EPRI's steam generator reliability work. "First, we want to develop preventive measures, such as water chemistry control, to minimize further damage. Second, where problems are already occurring, we want to improve corrective maintenance procedures, such as tube inspection and repair. Finally, to provide for long-term management, we are developing improved designs for future steam generators and conducting support activities for utilities considering replacement."

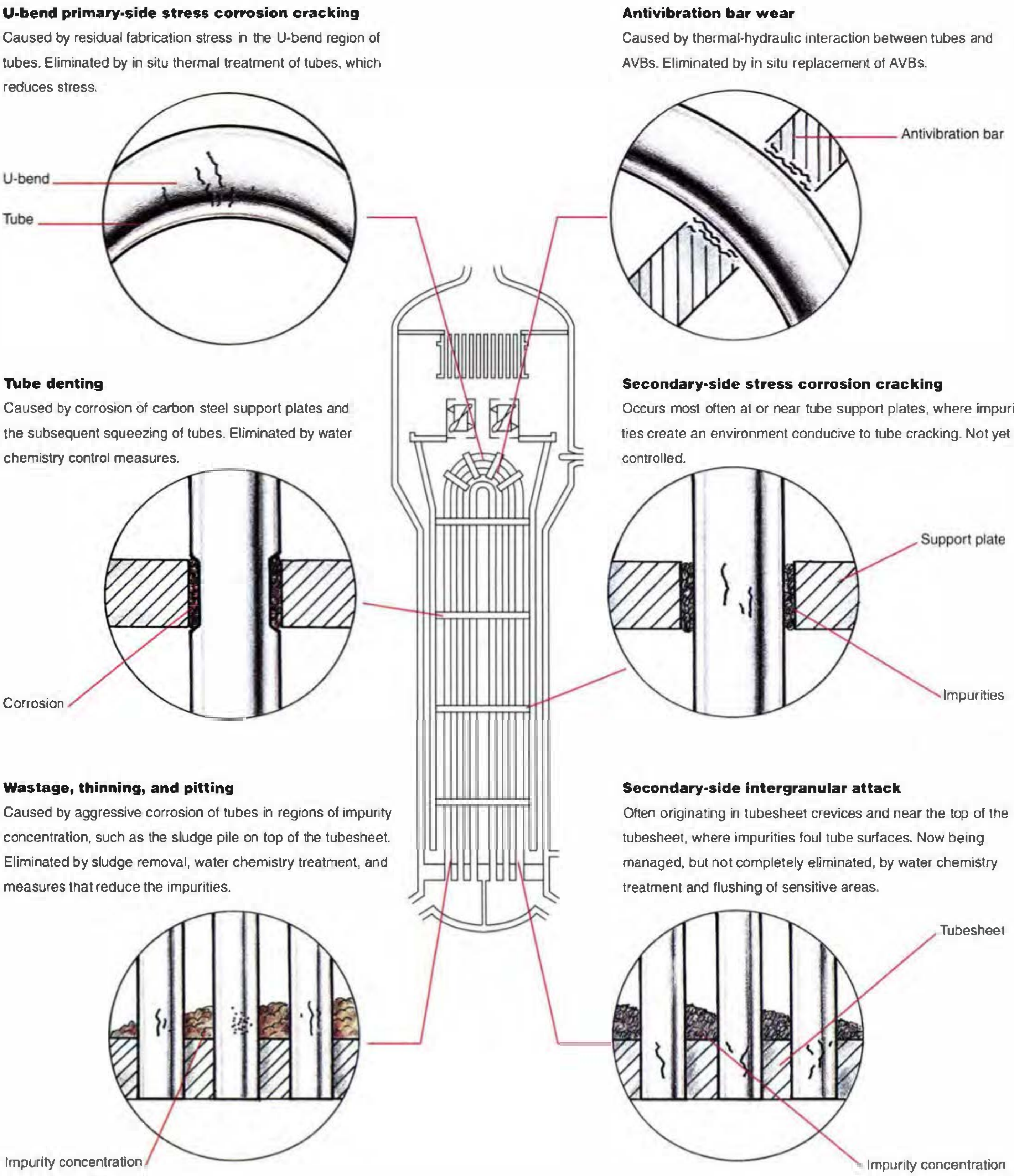
Corrosion in crevices

The design of PWR steam generators was originally adapted from that of drum boilers, which were used to produce steam in fossil-fired plants at the time when nuclear power was just getting started. In those conventional shell-and-tube boilers, furnace heat was used to raise the temperature of a bath of water inside a closed shell; steam for driving turbines formed inside the tubes. For nuclear plants, however, this basic scheme is reversed: primary water from the reactor flows through the tubes, and steam is generated in secondary water in the bath surrounding the tubes.

This change made it possible to keep the primary water in the tubes at a higher pressure (about 2250 psia) in order to minimize boiling in the reactor core, while keeping the secondary water at a lower pressure (about 770–1050 psia) and thus minimizing the shell wall thickness. The revised design also allowed a higher flow velocity for the primary water, enhancing heat exchange. Today, a large PWR typically has two to four steam generators inside its containment structure, holding a total of 15,000 to 30,000 tubes and standing considerably taller than the reactor vessel itself.

Unfortunately, forming steam outside the tubes means that boiling and dryout can occur in the many crevices between the tubes and their support structures. As a result, dissolved impurities in the water may become concentrated up to a millionfold or more in the crevices, greatly accelerating corrosion of the tubes at these locations. In addition, corrosion products from other parts of the steam cycle build up in sludge piles on the tubesheet at the bottom of the steam generator, further worsening crevice dryout and impurity concentrations where the tube ends are inserted into the generator. These sludge piles are much more difficult to remove than the corrosion products that form in heat exchangers with in-tube boiling, which have a "mud drum" to collect sludge deposits away from regions of high heat flux.

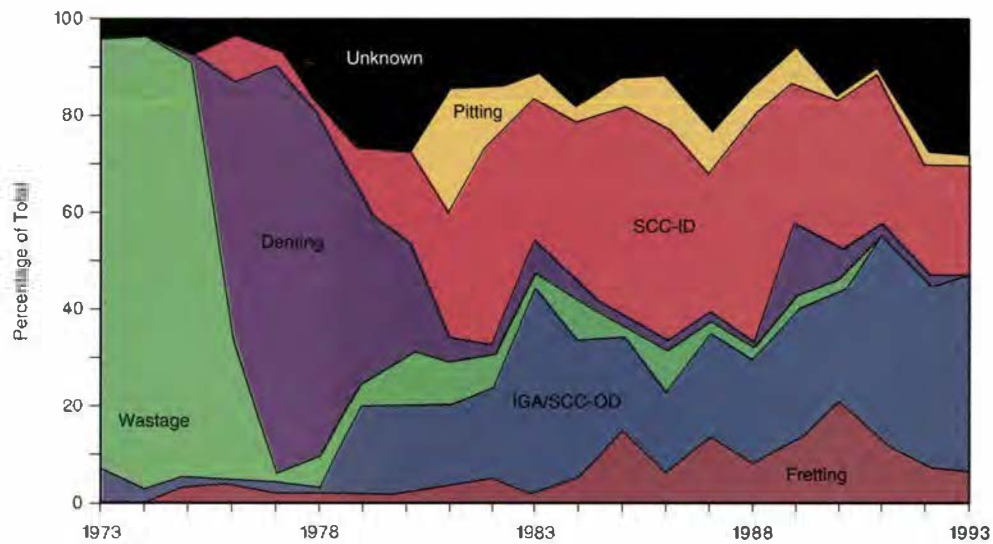
The amount of damage suffered by PWR steam generator tubes depends largely on three factors: the material from which they are made, the stresses in the material produced during fabrication and operation of the unit, and the environmental conditions during operation—particularly those related to temperature and water chemistry. The material used for tubes in early steam generators was Alloy 600, composed pri-



DEGRADATION FORMS AND LOCATIONS **Since they were first introduced, steam generators have experienced various forms of damage, most involving some kind of corrosion. Some of these problems have been virtually eliminated, others are being successfully managed, and a few have not yet been brought under control.**

marily of nickel, chromium, and iron. Initially, when those tubes were fabricated, they were softened by mill annealing (a treatment that involves relatively brief exposure to temperatures of 1700–1900°F) and then straightened and ground. They were then inserted through drilled (round) holes in carbon steel support plates, and their ends were expanded to fit snugly inside holes in the bottom tubesheet. Water treatment in early steam generators was based on conventional methods used in fossil plants.

This combination of factors quickly led to the premature deterioration of some first-generation utility steam generators. Tube degradation forced the replacement of steam generators at four nuclear plants in less than 10 years of commercial operation. Units at two other plants were replaced in less than 13 years. Alloy 600 tubing turned out to be more sensitive to several types of corrosion than anticipated. Sodium phosphate, employed in the conventional water treatment process, concentrated in crevices and other areas of localized boiling, leading to aggressive corrosion and wastage (generalized tube thinning) in those regions.



CAUSES OF STEAM GENERATOR PLUGGING When steam generators began having severe problems, around 20 years ago, the main causes were wastage and denting, which required tubes to be taken out of service by plugging. As water chemistry treatment was changed, these damage forms were replaced by stress corrosion cracking on the inside of tubes (SCC-ID) and most recently by intergranular attack and stress corrosion cracking on the outside of tubes (IGA/SCC-OD).

The wastage problem resulted in a move away from sodium phosphate water treatment to an all-volatile treatment (AVT) in which ammonia was added to water that had been highly purified. Using AVT, however, led to another problem—rapid corrosion of carbon steel support plates. As a result, corrosion products built up in the holes where tubes passed through the plates, eventually squeezing the tubes and denting them. And at some plants, impurities from external condensers leaked into the secondary water, contributing even more corrosive materials to sludge piles and leading to severe pitting in adjacent tubes. Eventually these problems were corrected by adjusting the AVT process and taking steps to prevent in-leakage of condenser cooling water or air.

Currently, the most pervasive type of tube degradation in PWR steam generators is intergranular corrosion, in which the chemical attack tends to follow grain boundaries in tube metal. In the absence of significant stress, the grain boundaries degrade more or less uniformly, beginning at the surface; the result is a form of deterioration called intergranular attack (IGA). If the metal has relatively higher stresses remaining from fabrication or generated by operation, cracks may propagate into the tube metal along grain boundaries, a phenomenon known as intergranular stress corrosion cracking (IGSCC).

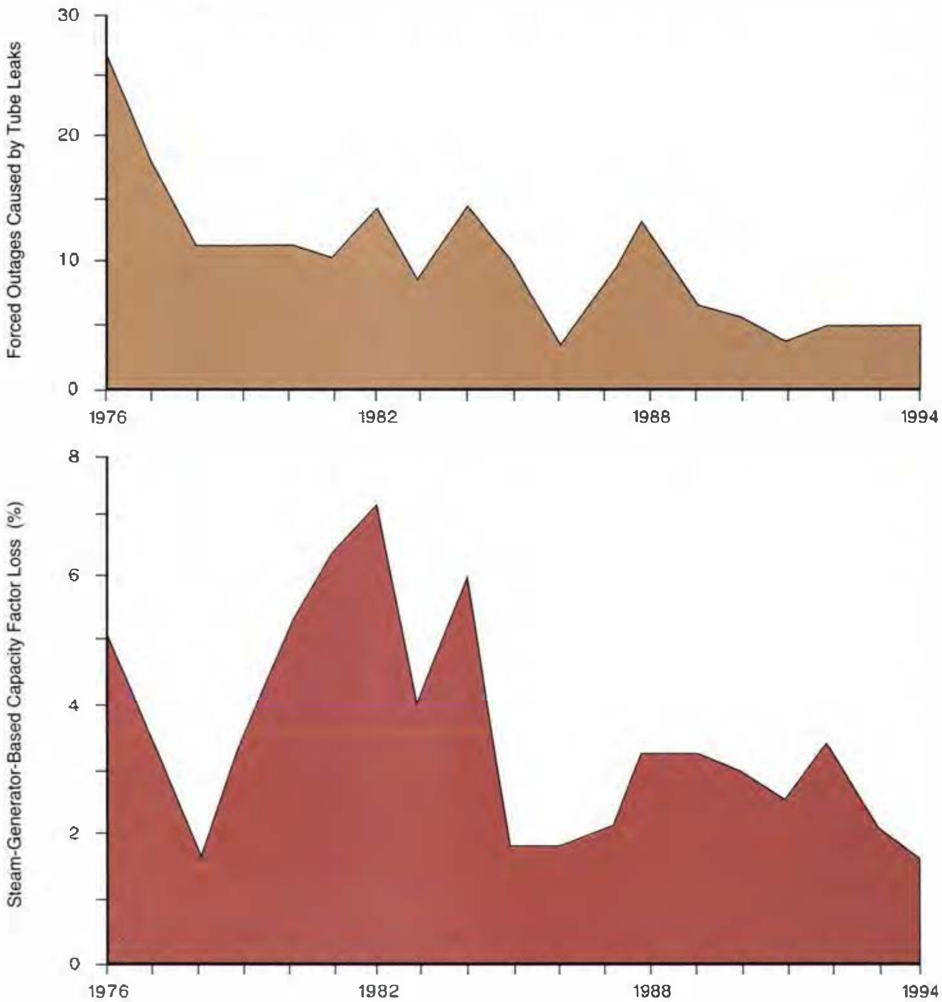
In the crevices between tubes and the tubesheet, where sludge piles tend to build up, IGA has been a major problem. At the top of the tubesheet—where tubes are expanded to achieve a tight seal—and in the U-bend region of tubes in recirculating steam generators, considerable fabrication stresses may remain and IGSCC has been common. (Once-through steam generators, which contain only straight tubes, have experienced generically similar types of problems but at different locations.)

Early successes

By 1976, a variety of steam generator tube problems—especially wastage and denting—had become widespread, causing more than 20 forced outages per year at PWR plants and an overall capacity factor loss of more than 5% per year. At the time, the causes of these and other problems were not well understood, and appropriate corrective actions had not been identified. Since the scope of these problems was beyond the capacity of any single vendor or utility to handle, SGOG was formed through EPRI. The work of this group was extended into a second phase in 1982 as IGA and pitting associated with sludge piles became more important, as did IGSCC in the U-bends of tubes.

Through the work of SGOG, all of these early degradation mechanisms have been reduced to insignificant levels. In particular, the group revolutionized chemistry control measures for plants that had replaced conventional (phosphate) water treatment with methods using only volatile organic compounds to maintain near-neutral pH. Ways were also found to reduce in-leakage of impurities from condensers. Crevice

PROBLEMS YIELD TO RESEARCH Water chemistry treatments and other preventive measures developed through EPRI research have sharply curtailed steam generator problems in the United States, including capacity factor loss and forced outages caused by tube leaks. The peak in capacity factor loss in the early 1980s reflects the rise of new degradation forms as old ones were being solved.



flushing was introduced to remove caustic materials. Materials with greater corrosion resistance were introduced for use in new steam generator tubes. Subjecting tubes to thermal treatment at lower temperatures and for longer periods of time than those involved in mill annealing—to improve the structure and reduce stresses—was found to reduce IGSCC in the U-bend region. Denting was virtually eliminated by making tube supports from more-corrosion-resistant material and using broached (as opposed to drilled) holes or an "egg crate" (grid-type) support geometry to allow free flow around the tubes and prevent buildup of corrosion products.

During the mid-1980s, however, new problems arose. IGSCC that originated inside tubes caused particular concern. Continued research, conducted through the Steam Generator Reliability Project, eventually identified the causes of these degradation mechanisms and enabled utilities to reduce them to modest levels. In particular, in situ peening of the inside surfaces of tubes in the tubesheet expansion region and thermal treatment of U-bends were found to reduce internally initiated IGSCC. As a result of this and previous work, the number of forced plant outages caused by tube leaks was reduced to three or four per year by the early 1990s, and the overall capacity factor loss caused by problems with steam generator tubes was 2.66% in 1992—about half the level experienced by U.S. utilities when SGOG was formed.

Strategic management

Recently, however, intergranular corrosion that originates on the outside of tubes, particularly at or near tube support plates in older steam generators, has become a leading concern. If not controlled soon, it is likely that this secondary-side IGA/IGSCC could limit the useful life of the steam generators involved to 20–25 years. At that age, the economic decision as to whether to install new steam generators becomes particularly difficult, since nuclear plants are licensed for 40 years and there may not be enough remaining life for some utilities to recover the additional investment.

EPRI's Steam Generator Strategic Management Project was formed to address this and other remaining problems through what Chuck Welty calls a balanced package of prevention, repair, and replacement options. In developing and promoting this technical package, the program has the specific goals of reducing industrywide capacity factor loss related to steam generators to less than 2.5% per year and reducing the number of forced outages due to tube leaks in U.S. reactors to nearly zero. In addition, the program aims to decrease the time necessary for steam generator replacement to less than 100 days. A secondary goal is to ensure that plants that do replace steam generators don't have to face this possibility again.

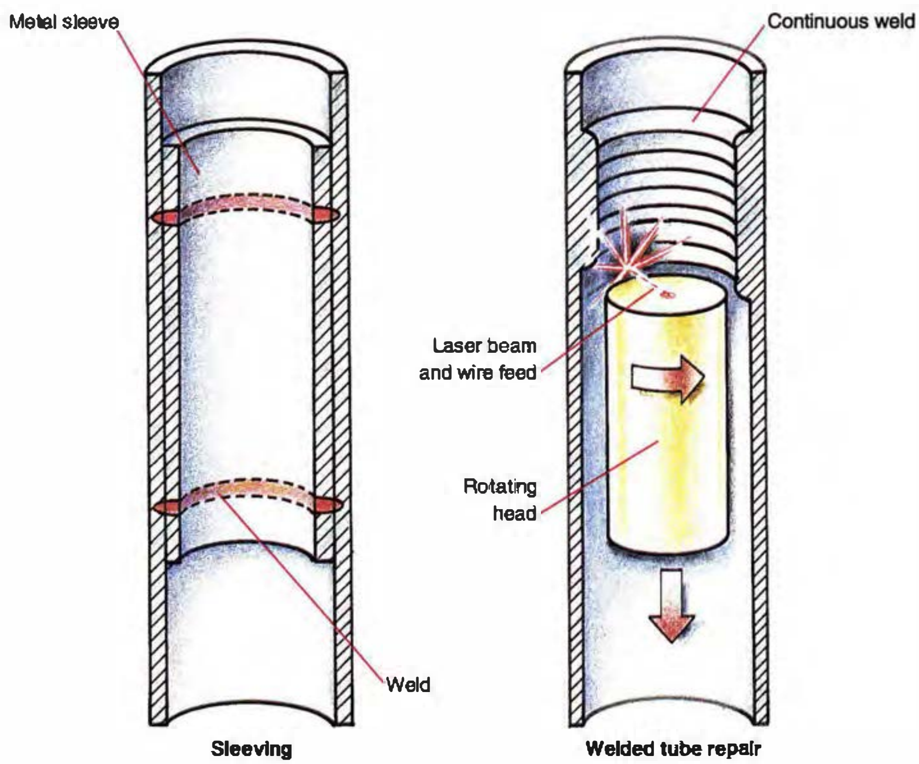
In terms of prevention, some progress has been reported in reducing secondary-side IGA/IGSCC through even more aggressive water treatment. One current focus of this effort is to control the ratio of negatively charged ions to positively charged ions, a ratio that can affect the pH balance in crevices. Organic amines are being used in the secondary water to reduce the transport of iron, which contributes to sludge buildup. Other additives, such as boric acid, are also being tested as chemical buffers that can help maintain neutral pH in crevices.

Another approach to damage prevention is the removal of corrosion products that can foul tube surfaces, contribute to sludge piles, and sometimes block the flow of secondary water through support-plate openings. Corrosion-product fouling in both types of steam generators (recirculating and once-through) has been identified as a major cause of reduced power generation in PWR plants, with the output at some plants being decreased to as little as 80% of full power. EPRI research has led to the development of a process and general guidelines—now widely used—for the chemical cleaning of sensitive areas in steam generators, particularly the surfaces of tubesheets and support plates. In addition, joint work with Consolidated Edison Company of New York and the Empire State Electric Energy Research Corporation has led to the development of a remotely operated robot, known as CECIL, that can reach between tubes and perform a variety of maintenance tasks. Equipped with a miniature video camera and fiber optics for illumination, CECIL can inspect tube exteriors directly, drill into sludge piles for samples, and direct a high-pressure water lance at hard-to-reach crevices.

Once tube degradation has occurred, the goal is defect management—that is, to ensure that damaged tubes that could leak or rupture during the next operating cycle are identified and are then either repaired or removed from service. In an inspection outage, a remote manipulator is used to insert a probe into selected tubes and find defects through nondestructive examination. The main nondestructive method is eddy-current testing, in which alternating current is delivered to small wire coils in the probe, creating magnetic fields around them. These fields, in turn, create electrical eddy currents in the surrounding tube, which affect the returning ac signal. When the probe passes by an irregularity in the tube, such as an area of wastage or pitting, the signal pattern changes in ways that allow identification of the type of flaw and its extent. To verify the initial results of eddy-current inspection, ultrasound probes are increasingly being used, since high-frequency sound is less attenuated by tube walls and can provide additional information about tube conditions.

If inspection reveals damage that threatens a tube's structural integrity, a utility has two choices. It can simply plug the

Stephanie Scarborough



WELDED TUBE REPAIR **Repair of damaged steam generator tubes currently requires inserting metal sleeves inside the tubes and sealing them at the top and bottom. This process is expensive and prevents subsequent repairs higher in a tube. EPRI's welded tube repair process, now under development, will use a laser beam to melt an alloy wire to create a uniform coat of material over the damaged area. A rapidly rotating head can lay down a 2–3-inch weld in a minute at a significantly lower cost than that of inserting a conventional sleeve. New welds can subsequently be created above the initial repair.**

ends of the tube, removing it from service, or it can cover the damaged area with a metallic sleeve that is mechanically expanded or welded into place. Plugging is substantially cheaper, but only about 10–20% of the tubes in a steam generator can be plugged before the unit must be derated. As for sleeving, high cost is not its only disadvantage. Once a sleeve is in place, another cannot be put above it in the tube. Moreover, some existing sleeve joints have begun to degrade, indicating that this technique may not be a permanent fix if the conditions that foster corrosion continue. (Changing views on what constitutes structural integrity and emerging options for tube repair are discussed below.)

The third element of strategic steam generator management is the development of long-range options for unit life extension or replacement. This effort includes the analysis of repair/replace decisions, the improved design of replacement units, and the development of more-expeditious methods for removing and reinserting steam generators through containment structures not designed to accommodate such exchange operations. Although the initial cost of replacement is high, the investment can often be recovered through a return to full-power operation and shorter subsequent plant outages. In more than 12 years of experience with replacement steam generators using improved materials and design features and advanced management techniques, no tubes have needed to be plugged for corrosion-related damage, and only minimal mechanical degradation has been reported.

New focus on tube repair

The regulations that govern the plugging or sleeving of steam generator tubes were developed early in the commercial nuclear program and reflect a concern for the types of structural damage observed at the time. For example, current Nuclear Regulatory Commission guidelines generally call for plugging a tube if inspection reveals a flaw that has penetrated 40% of the wall thickness. These criteria assume that structural damage in the vicinity of a flaw is relatively uniform—as in the case of wastage, thinning, and generalized IGA—and that further degradation would unacceptably increase the risk of tube rupture.

Research over the intervening years has shown, however, that such depth-based criteria are overly conservative when applied to some types of flaws—such as the cracks caused by secondary-side IGSCC near tube supports—that have come into prominence more recently. The chances of rupture from such flaws may depend not only on the depth of wall penetration but also on the length of a crack, its orientation, and the volume of material lost. EPRI has therefore undertaken the development of alternative plugging criteria as part of a steam generator degradation-specific management (SGDSM) initiative. This approach is similar to one now used extensively in France and other European countries.

At the heart of the SGDSM approach is the need to determine how specific degradation mechanisms are related to structural integrity and which inspection parameters are the best indicators of safety limits. For each type of problem, an allowable flaw size is determined by defining tube rupture and leakage correlations that describe the relationship between flaw size, tube dimensions and materials, tube burst or leakage behavior, and expected loading. For example, EPRI has developed revised repair criteria for secondary-side IGSCC on the basis of specific eddy-current test results. The NRC has now approved the use of these alternative criteria for this particular flaw mechanism for some plants. Applying the new criteria at one operating PWR plant resulted in estimated savings of $11 million to $18 million in the first two years. Discussions are under way with the NRC about applying the SGDSM approach to other types of flaws.

Technical advances are also beginning to change the way tube integrity is viewed. Laser welding technology, in particular, promises to revolutionize the repair of damaged areas in tube walls. Westinghouse Electric Corporation, for example, has developed a method of welding sleeves into place that uses a high-power neodymium-YAG laser and a fiber-optic delivery system. Compared with conventional welding, this new technique provides greater control, uses less energy, and reduces the amount of tube distortion and weld shrinkage. Since first implemented in 1992, laser-welded sleeving has built an impressive performance record: none of the sleeves installed has failed in service.

Westinghouse is now extending this basic idea to provide direct tube repair (DTR), which requires no sleeve. In DTR, the laser energy is used to produce controlled melting of the interior tube surface and thus cover the damaged area. An additional advantage of this technique is that it can be used in regions of tubing above existing sleeves.

EPRI is also developing a laser-based alternative to sleeving, called welded tube repair (WTR), which deposits a corrosion-resistant weld layer on the inside surface of a damaged tube. Rather than melting the tube material itself, as in the DTR approach, WTR uses a laser to melt an alloy wire and create a deposit of the alloy, which can restore the full structural integrity of the tube. The WTR process is expected to cost about one-third as much as conventional sleeving. Four major nuclear service vendors have seen demonstrations of the process and have expressed interest in licensing WTR.

"EPRI continues to work closely with utilities, vendors, and regulators to develop better ways to enhance steam generator performance," concludes Welty. "New units, which take advantage of technologies developed over the past two decades of EPRI research, have achieved an excellent service record. A utility can now be confident that if it replaces the steam generators at a PWR facility, they will last for the expected remaining life of the plant. For utilities that decide not to replace their steam generators, we hope that the application of degradation-specific management and new laser repair processes can help maintain the older units for several more years, even in the face of new degradation challenges." ■

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Lighting the Office Environment (page 22) was written by Leslie Lamarre, *Journal* senior feature writer, with information from **Karl Johnson,** commercial building systems manager in the Customer Systems Group. Johnson joined EPRI in 1977, following two years as coordinator of industrial and energy services for the Palo Alto, California, utilities department. Before that, he worked for eight years in energy management at Stanford University. ■

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Innovative HVAC

New All-Electric Wal-Mart to Save Energy

A futuristic heating, ventilating, and air conditioning system with water-source heat pumps and ozone-safe refrigerants is the centerpiece of an all-electric Wal-Mart "supercenter" under construction in Moore, Oklahoma. The HVAC system, which features more-comprehensive integration than conventional systems, will coordinate the store's space-conditioning, refrigeration, heat recovery, dehumidification, ventilation, and indoor air quality needs.

A press conference to announce the supercenter, a collaborative project of EPRI, Oklahoma Gas and Electric Company (OG&E), and Wal-Mart Stores, was held on February 15. Construction is already under way and will continue through the summer, with the grand opening expected this fall. A Wal-Mart spokesperson says that, given the cost of the combined electric and gas systems typically installed in Wal-Mart stores, the supercenter's annualized energy savings are estimated at $102,000. The bulk of the savings will be attributable to the efficiency of the HVAC system. Significant savings will also come from the store's efficient refrigeration system and from the use of skylights, which will provide daylight as a supplement to the store's interior artificial light.

The supercenter will include a full-scale grocery store and a general merchandise department store. The idea to make the building all-electric came about after OG&E brought Wal-Mart and EPRI together to review options for the store's mechanical system. EPRI, OG&E, and Wal-Mart worked together to find a system that would be cost-effective, efficient, and environmentally safe. Having analyzed several options, including both electricity- and gas-based systems, the team opted for a fully integrated mechanical system that includes such innovations as sophisticated ventilation and humidity controls and heat recovery from refrigeration through water-loop heat pumps. EPRI worked on equipment specification with Wal-Mart and its consultants. EPRI also secured agreements from manufacturers to design, develop, and produce the proposed equipment.

Not only will the new supercenter showcase energy-saving systems, but it will also include an environmental education center, automated lavatories, and countertops made from recycled paper bonded with soybean protein. Wal-Mart expects to use the store as a model for similar construction elsewhere.

Once construction is complete, EPRI will monitor the mechanical system's performance and make data available to utility members interested in pursuing similar projects with their own customers. "The results of this project will be applicable to a broad range of establishments," says Mukesh Khattar, EPRI's coordinator for the project. "We expect that retail stores, supermarkets, and variety stores are just some of the utility customers who could employ similar technologies."

■ *For more information, contact Mukesh Khattar, (415) 855-2699.*

Microwave Technology

EPRI and IBM Team Up to Reduce Volatile Solvents

EPRI and IBM Corporation are developing a microwave-based technology that, if successful, would virtually eliminate the use of volatile solvents in the manufacturing of many sheet-type materials. Currently, researchers are focusing on applying this technology in the production of prepreg, a resin-impregnated glass-fiber cloth that is the base material for printed circuit boards.

In the existing production process for prepreg, an epoxy dissolved in a volatile solvent is applied to a glass-fiber cloth. The solvent is then evaporated, leaving behind the desired epoxy coating on the cloth. The new technology under development by EPRI and IBM would rely on microwaves to cure the epoxy in a water-based process,

Current commercial machinery for prepreg production

eliminating the need for solvents. At this time, some 20 million pounds of solvents are used annually in the United States in the production of prepreg. The most common of these solvents, methyl ethyl ketone, is among the volatile organic compounds targeted by the Environmental Protection Agency for minimization.

Currently, the rate of heat transfer to resin and fiber is a significant limiting factor in the speed of the prepreg production process; hot jets are used to transfer heat to the material at an efficiency of just 1–2%. By contrast, the efficiency of microwave energy can be as high as 65%—primarily because microwaves are absorbed well by water, significantly improving heat transfer to the resin.

Although microwave technology has been used in manufacturing processes before, it has been applied only to batch processes involving thicker materials. Hence a major aim of this project is to develop microwave applicators and controls for continuous, thin-sheet processing.

Researchers at IBM's corporate laboratory in Yorktown Heights, New York, are designing several prototype microwave applicators and other equipment for the continuous process. By early next year, the prototype technologies will be ready for pilot-scale demonstration at IBM's production plant, also in New York. The researchers will also evaluate potential coating materials for the curing process.

Project manager Gene Eckhart notes that the potential for this technology extends far beyond the circuit board prepreg market into the manufacturing of other sheet materials, including rubber, photographic film, and paper. "Any kind of manufacturing process for sheet material that requires the use of energy either to dry the material or to cure a coating is a potential candidate for this technology," he says.

■ *For more information, contact Gene Eckhart, (202) 293-7517.*

Studying Frost

Researchers Aim to Improve Efficiency of Heat Pumps, Refrigeration

We know frost best as a substance that forms on our car windshields and inside our freezers. Its arrival is a sign that winter is coming, its departure a signal that spring is near. But while we've lived with it forever, we really don't know much about it. "It's surprising how little is known about frost," says Sekhar Kondepudi of EPRI, who is managing an in-depth investigation of frost growth. "It's such a simple material."

The problem is that the irregular nature of frost, which consists of a lattice of ice crystals, makes it difficult to estimate the temperature and density distribution of the material. As a result, the current scientific understanding of frost is based more on theory than on documented fact.

Frost develops when a humid airstream comes into contact with a cooled surface at a temperature below the dew and freezing points. Generally speaking, temperatures of about 32°F or less are conducive to frost growth. But we do not yet know precisely which combinations of temperature and humidity level trigger frost growth. We do know, however, that frost decreases the efficiency of heat pumps and refrigeration equipment an average of 25%, which is why EPRI researchers are determined to learn more about it.

Through a project at the University of Illinois at Urbana-Champaign, EPRI-sponsored researchers are studying the fundamentals of frost growth. The aim is to better understand the substance in order to develop effective antifrost techniques. Currently, the most common method of coping with frost is to employ defrosting mechanisms. Typically, as is the case in the "frost-free" freezers on the market today, this approach uses miniature heaters, which are activated when the temperature reaches a certain level somewhere in the freezing range. The obvious drawback of this technique is that it degrades the efficiency of the machine.

A scanning confocal microscope shows early frost growth.

The University of Illinois researchers are studying frost in its very early stages of growth, when it measures just one-tenth the thickness of a human hair. To do so, they are employing two high-resolution instruments used in medicine—a scanning confocal microscope and a magnetic resonance imaging machine. The researchers will also test the use of various materials, such as polymer-based coatings, to deter frost growth. (In a separate but parallel project at Texas A&M University, researchers are testing a variety of these coatings on heat exchangers and heat pumps.)

"Can we eliminate frost growth totally? Maybe not," says Kondepudi. "But perhaps we can deter it." For instance, some of the materials being tested may require a lower-temperature environment for frost growth. "Our goal is, first, to understand the threshold for frost under various conditions. Then we want to try to improve efficiency. If we can get only a fractional improvement, that's still significant, given all of the heat pumps and refrigeration equipment in use." The project is expected to be completed in the fall.

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

MGP Research Supports EEI Site Remediation Strategy

With EPRI's support, the Edison Electric Institute's subcommittee for manufactured gas plant (MGP) sites has developed a strategy that will allow utilities to continue the environmentally sound practice of coburning MGP site remediation wastes (such as coal tar and tar-contaminated soils) with coal in utility boilers.

Midwest Power Systems identified a need to coburn MGP remediation wastes and approached the Edison Electric Institute for help in developing a sound coburning approach. At the same time, the utility sought approval from the U.S. Environmental Protection Agency. The resulting strategy was the product of collaborative efforts that began in 1990 and involved EEI, EEI member companies, and EPRI.

As a result of utility litigation challenging the EPA's initial decision not to allow coburning, the EEI MGP subcommittee represented the utility industry in negotiations with the EPA. The negotiations led to the development of a strategy that is consistent with regulations implementing the Resource Conservation and Recovery Act (RCRA) and allows continued utility cofiring of MGP wastes without the need for a permit.

EPRI provided technical support to the EEI subcommittee in developing the strategy, which calls for remediation waste recovered during MGP site excavation to be blended with coal so as to render it nonhazardous for coburning in utility boilers. EPRI also developed a sampling approach that is consistent with EPA test methods for characterizing soils and developing blending ratios for treating soils but is quicker and less expensive than the EPA leaching procedure.

The site strategy ensures that only nonhazardous MGP wastes will be coburned in utility boilers, yet it avoids for utilities the burdens of the RCRA hazardous waste permit program and the high cost of commercial incineration. In a memo to EPA regional waste management division directors, Sylvia Lowrance, director of the agency's Office of Solid Waste, endorsed the utility industry strategy and encouraged regulatory cooperation with site owners to implement it. "I view the remediation strategy as another step in the direction of more risk-oriented and effective application of RCRA regulations to environmental cleanup activities," Lowrance said.

According to Joseph Shefchek, director of environmental affairs and research at Wisconsin Power & Light Company and past chairman of the EEI MGP subcommittee, "The MGP site remediation strategy will allow utilities to expedite flexible, cost-effective remediation at MGP sites. EPRI staff pro-

vided critical research data and were valuable members of the team that developed this strategy."

In tailored collaboration with three utility members—Rochester Gas & Electric Corporation, Illinois Power Company, and Northern Indiana Public Service Company—EPRI has completed coburning tests of MGP remediation waste. A fourth test series is scheduled this year with Duke Power Company.

■ *For more information, contact Ishwar Murarka, (415) 855-2150.*

Utilities Derive Multiple Benefits From MICAA Software at Fossil, Hydro Plants

EPRI's Machine Insulation Condition Assessment Advisor (MICAA) expert system software enables utilities to perform their own assessments of motors and generators for winding deterioration or impending failure, thus avoiding unnecessary maintenance and forced outages. Members of the MICAA users group expect 50 utilities to realize aggregate savings of $31 million over the next decade as a result of using the software.

A large percentage of power plant motor and generator outages are caused by rotor or stator winding failure. The most common problems involve breakdown of the groundwall or turn insulation. Aging stresses often gradually degrade the effectiveness of electrical insulation. Windings can deteriorate and eventually fail in over 40 different ways. Although numerous tests are available for evaluating the condition of windings, maintenance personnel still need specialized expertise to interpret the results.

The MICAA software incorporates information from EPRI's *Handbook to Assess the Insulation of Large Rotating Machines* (EL-5036, Vol. 16) and guides users through the process of assessing the condition of rotor and stator windings. Suitable for use with gas and steam turbine generators, hydrogenerators, and squirrel-cage induction motors, MICAA is applicable to machines rated 2300 V and above. Combining user-supplied information on specific machines with a knowledge base of technical information on insulation systems, MICAA deduces the most likely aging processes in the stator and rotor windings, recommends diagnostic tests, indicates what to look for in visual inspections, and interprets the results of 50 diagnostic tests and inspections.

Utilities have been using MICAA since 1992 to assess machine condition and determine whether windings are deteriorating or near failure. As a result, users have been able to delay or eliminate specialized testing; detect possible problems in advance of likely failure; identify machines needing special attention; and conveniently schedule corrective repairs, usually at a fraction of the cost for repairs and replacement power following an in-service failure.

Version 1.0 of MICAA is available to Fossil Power Plants Business Unit funders at no cost from the Electric Power Software Center, (800) 763-3772. Version 2.0 of MICAA is available from Iris Power Engineering, Mississauga, Ontario, Canada, (905) 564-4977.

■ *For more information, contact Jan Stein, (415) 855-2390.*

Dynamic Simulator Aids PSI's Wabash River Coal Gasification Repowering Project

PSI Energy, an Indiana utility that is part of CINergy Corporation, has repowered a 100-MW steam turbine at its Wabash River station, adding a 192-MW GE Frame 7FA gas turbine fired with coal-derived syngas. The syngas is produced at an adjacent plant that is owned and operated by Destec Energy, Inc. The Wabash River coal gasification repowering project represents several firsts for PSI. The plant is the utility's first combined-cycle plant. It is also the first plant of PSI to be totally controlled through a digital control system human-machine interface, the first to incorporate closed-process flow integration with a plant operated by a separate company, and the first to incorporate a highly complex water treatment system. PSI needed to be able to effectively train operators on the new systems and to debug and tune the control system for this unique plant before startup.

Recognizing that it was breaking new ground, PSI tapped EPRI's expertise in order to develop a real-time dynamic simulator for the repowering project. The simulator provides both hands-on operator training and control system checkout, verification, and tuning.

The training program increases operator responsiveness and familiarity during plant startup and operation, helping to minimize trips due to operator actions, decrease equipment wear, improve plant thermal performance, speed plant startups and recoveries to full load, improve water treatment operations, and reduce operator training costs. Early checkout of the control system will save weeks of initial startup time, allow full-load operation sooner, reduce annual outages, improve thermal performance, and minimize engineering and operating costs for control system troubleshooting. The simulator is also being used by PSI engineers to check component designs and ensure that the gasification and combined-cycle plant interfaces are correct.

PSI Energy projects that the use of the dynamic simulator for operator training and control system verification and improvement will yield net savings of over $9.4 million during the planned life of the Wabash River repowering project.

■ *For more information, contact Michael Epstein, (415) 855-2260.*

Global Climate Change

Greenhouse Gas Decision Tools

by Tom Wilson, Environmental & Health Sciences Business Unit

ABSTRACT *Global climate change is an environmental issue with important strategic ramifications for the electric utility industry. Although no mandatory greenhouse gas (GHG) emissions control programs now exist, many utilities have decided to participate in voluntary emissions reduction and reporting efforts under the Department of Energy's Climate Challenge program and the Energy Policy Act of 1992. Given uncertainty about possible future regulation and the potentially huge stakes of such regulation, utilities are increasingly taking GHG emissions into account in planning for the future. EPRI is developing a set of decision tools to help utilities in this effort. One of these products is a greenhouse gas accounting framework, scheduled for release this year.*

The potential for human activities to cause changes in global climate is a major environmental issue. Despite the substantial scientific uncertainty surrounding this issue, actions aimed at limiting greenhouse gas (GHG) emissions are receiving serious attention. The United Nations Framework Convention on Climate Change, the Energy Policy Act of 1992 (EPAct), the Clinton administration's Climate Change Action Plan, and state-level consideration of carbon dioxide emissions in such areas as integrated resource planning are all focusing attention on actions to limit GHG emissions.

The electric utility industry is a significant source of carbon dioxide, a major greenhouse gas. Thus utilities are likely to be affected by GHG policies and are becoming increasingly involved in GHG reduction and reporting activities. Principal examples of this involvement are participation in the U.S. Department of Energy's Climate Challenge program and reporting of emissions under Section 1605(b) of EPAct.

GHG reporting and reduction activities can involve virtually every aspect of electric utility operations, from integrated resource planning to demand-side management programs. To understand their future emissions, utilities must analyze the GHG implications of choices about fuels, generating-capacity additions, load dispatch, transmission and distribution system upgrades, power transactions, demand-side management, electrotechnology substitutions, and a host of other strategic and operational matters. As if that weren't a tall enough order, options for offsetting emissions—for example, through methane capture or tree planting—also may become part of the utility landscape. And the geographic sphere of influence of U.S. utilities may grow substantially with the advent of international emissions reduction opportunities (through what are called joint implementation projects).

Given all of the uncertainty and complexity inherent in the evolving situation, utility members have asked EPRI for help in the analysis and planning of their greenhouse strategies. As a result, EPRI has stepped up efforts to provide its members with tools to help identify cost-effective GHG strategies for use in short- and long-term planning.

In late 1994, EPRI published the draft report *Workbook for Screening Greenhouse Gas Reduction Options*. This workbook complements the *Climate Challenge Options Workbook*, which was developed by DOE and the electric utility industry (and is available through DOE or the Edison Electric Institute). The EPRI workbook is designed to help utility staff identify promising alternatives for more-detailed study. It describes basic methods and procedures for screening options and also presents cost, reduction potential, and other important information for a variety of both on-system and off-system options. The workbook comes with spreadsheet templates to help utility staff make reduction potential and cost calculations.

The principal focus in 1995 is on the development and delivery of a greenhouse gas accounting framework (GGAF). The GGAF is aimed at making it easier for utility staff to calculate and express emissions reductions in a consistent manner. Useful for strategic planning or reporting, the framework provides consistent methodologies for defining, tracking, and reporting GHG emissions over time, and it will be revised periodically to incorporate specific accounting guidelines—for example, those for EPAct Section 1605(b).

GGAF features

Regardless of the decisions an individual utility makes about voluntary participation in the Climate Challenge program or Section 1605(b) reporting, analysis of the GHG implications of corporate actions is a vital strategic issue with important long-term ramifications. It is also a complex and challenging endeavor. The challenges include assembling data from wide-ranging sources, establishing and maintaining consistency among data, meeting diverse analysis and reporting needs (historical, future, individual project, full system), sorting out numerous calculating and reporting options, and managing emissions data over time.

EPRI's GGAF (Figure 1) will help utility staff meet these challenges by assembling, verifying, updating, and tracking the data needed to calculate GHG emissions; estimating historical and future emissions under alternative scenarios or calculation methods; evaluating the implications of alternative emissions accounting and reporting rules or guidelines; clarifying the implications of planned or potential projects; and supporting internal and/or external reporting. In performing these data management, analysis, and reporting functions, the software system will provide guidance to the user and will allow considerable flexibility and some level of customization to meet unique user needs.

In the data management area, the GGAF will provide essential capabilities for organizing related data and analyses; using default data when appropriate; entering, transforming, and using data in different forms; and using alternative calculation methods. The framework also will provide advanced capabilities for checking data, identifying gaps or errors, and resolving inconsistencies; using structured forms and algorithms to carry out more-detailed analyses of specific classes of projects; and performing database searches, queries, and other data management functions.

The GGAF's analysis and evaluation component will enable utility staff to efficiently carry out a range of analyses:

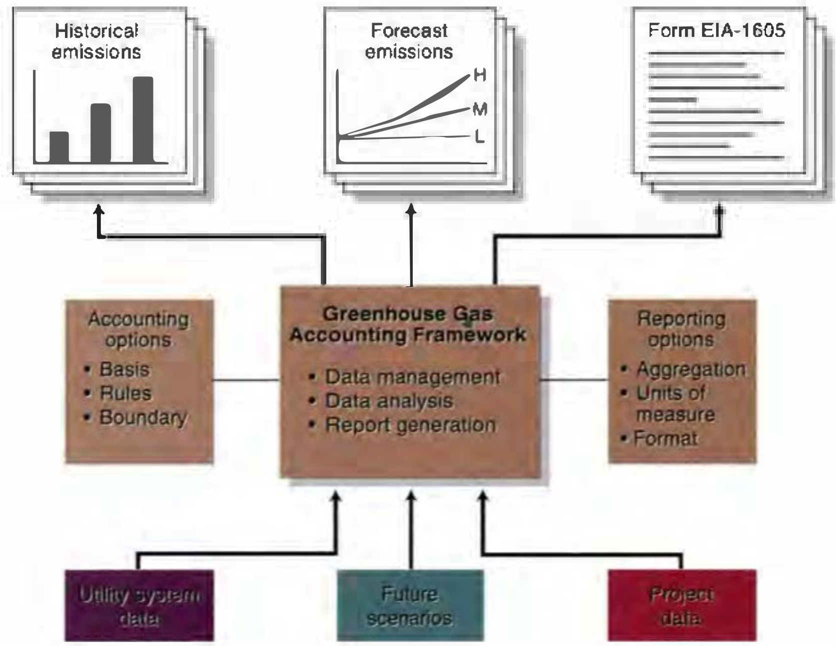
□ Evaluate various methods of calculating emissions

□ Compare historical and estimated future emissions

□ Identify trends in underlying data that explain emissions patterns

□ Break down emissions by plant, fuel, region, and so on

Figure 1 EPRI is developing a greenhouse gas accounting framework that will produce greenhouse gas emissions estimates on the basis of system and project-specific information and future scenarios. The software tool will provide guidance to users, as well as flexibility in calculation and accounting methods and reporting parameters.



□ Evaluate the implications of projects, system modifications, load growth assumptions, and the like

□ Clarify the implications of alternative reporting rules or guidelines (e.g., for bulk power transactions)

□ Estimate uncertainty ranges

For reporting, the GGAF will provide standard forms (including Form EIA-1605 for submissions under EPAct), as well as numerous default graphs, tables, and reports for internal or external use. It will also allow utilities to customize reports to meet their specific needs, with reporting organized by plant, region, scenario, or other attributes.

To give users flexibility in defining the scope and structure of analyses and the format of reports, the GGAF will offer a range of options in many areas, including the following:

□ Units of measure (tons, tonnes, tons/year, tonnes/kWh)

□ Target gases (all gases for EPAct reporting and any user-defined gases)

□ Boundary/aggregation (e.g., project, plant, system)

□ Reference case (basic, modified, or modeled for a specific system or project)

□ Time frame (e.g., years, quarters, multiyear periods)

□ Calculation methods and accounting rules

□ Reporting parameters (e.g., by project, by entity)

GGAF development

The EPRI project started in mid-1994 with an assessment of utility needs, development of the basic design concept for the product, and two utility case studies. The case studies provided a trial run to confirm what is necessary for estimating and accounting for GHG emissions under the various external programs and for meaningful internal use.

Several insights were gained during this prototype development with actual utility data. For instance, the amount of data required for complete accounting can be substantial and typically comes in various forms and formats. Although virtually all necessary data already exist at a utility, the information tends to be spread among several departments and is often based on inconsistent assumptions.

The prototype development work also demonstrated that uncertainties in emissions factors, heat rates, and other key conversion data used in calculations for baseload plants in a utility's system can have a larger impact on total reported emissions than the impact from entire projects aimed specifically at reducing greenhouse gases. Also, project-level reporting and system-level reporting are not easily reconciled, particularly in the case of projects with indirect emissions impacts. In addition, most past or current in-house efforts to address greenhouse gases have focused primarily on carbon dioxide, which is only part of the issue.

The work done to date suggests that carrying out what-if analyses based on multiple options is an important need at utilities both for internal decision making and for external reporting. The framework will allow utilities to show regulatory and legislative bodies that the issues surrounding GHG emissions are not clear-cut, even for simply calculating total system emissions. For example, calculated emissions reductions can be significantly affected by alternative assumptions about such parameters as load growth forecasts, future fuel prices, or past actions taken for other purposes but with GHG benefits.

An initial, limited-capability version of the GGAF will be available for use by the middle of 1995, and plans call for a full product for limited distribution by late 1995 and a version for general use in 1996.

Tailored collaboration opportunity

There are many trade-offs involved in building a software system like the GGAF. One issue to be considered, for example, is the diversity of needs among utilities. Other trade-offs include flexibility versus simplicity of use; simplicity of use versus scope of data requirements; and calculation speed versus guidance or special features offered.

To better understand these trade-offs and to meet the near-term needs of member utilities, EPRI is establishing a tailored collaboration project. EPRI members participating in this project will have an opportunity to help specify implementation requirements for the basic GGAF and to obtain assistance in customizing the framework to their own systems and needs. This tailored collaboration experience will enable EPRI to refine calculations, enhance user interfaces and guides, and test the GGAF under realistic circumstances. The result will be a better final product for release to all members.

For more information on the GGAF, other GHG decision tools, or participation in the tailored collaboration project, member utilities are invited to contact the EPRI project manager, Tom Wilson, at (415) 855-7928.

Applied Science and Technology

New Guidelines for Evaluating Seam-Welded Piping

by Vis Viswanathan and Barry Dooley, Strategic R&D Business Unit, and Rich Tilley, Fossil Power Plants Business Unit

Seam-welded piping, fabricated from plate that has been rolled up and then welded longitudinally to form a pipe, is used in high-energy applications in many fossil power plants. Several hundred feet of it are found in a typical plant, usually as hot reheat (HRH) piping carrying steam at about 1000°F and 400–700 psig from the boiler to the intermediate-pressure turbine. Less-common applications include main steam header link pipes, outlet bends, and reducers. (Main steam pipes, which carry steam at much higher pressures—1800–3600 psig—are seamless, being of smaller diameter and thus more easily formed by extrusion.)

Catastrophic weld failures at Southern California Edison's Mohave plant in 1985 and Detroit Edison's Monroe plant in 1986 focused industry attention on the importance—from both a safety and an economic perspective—of ensuring the integrity of seam-welded piping (Figure 1). Cracks and ruptures occur almost exclusively along the welded seam, but failure mechanisms and contributing causes are not fully understood. The many possible factors include stress, temperature, heat treatment, fabrication defects and inclusions, weld geometry, creep strength mismatch between weld and base metals, and pipe curvature; failures are evidently attributable to unique combinations of factors.

EPRI evaluation procedures

Following the 1985–1986 failures, utilities and EPRI joined in an aggressive industry-wide effort aimed at reducing the risk of operating seam-welded piping in high-energy applications. To ensure a rapid response to this pressing concern, the analysis of already published data on materials properties served as the basis for the development of EPRI's 1987 *Guidelines for Evaluation of Seam-Welded Piping* (CS-4774). These limited data—very little was then known about geometry, inclusion, or materials effects on seam weldments, for example—suggested a scenario of gradual failure. That in turn led to the recommendation of a simple, crack-growth-based approach to setting inspection intervals for seam-welded piping. The guidelines also prescribed EPRI-developed nondestructive evaluation (NDE) and remaining-life assessment procedures—the only such procedures available for this type of piping.

The primary inspection procedure specified by the guidelines was high-sensitivity ultrasonic testing (UT), an in-service technique that in prior development work had been used on pipe-cracking problems in the nuclear industry. Supplementary NDE methods—such as magnetic particle testing, radiography, and surface replication and analysis—were also identified, but they are not as sensitive and, in most cases, are not even applicable.

As the only available engineering basis for inspection and maintenance decision making for seam-welded piping, the procedures detailed in the guidelines were quickly found by the industry to be valuable for piping serviceability evaluation. They have been used widely—in most cases, by utilities customizing them to fit into existing programs—and their application is thought to have identified a number of potential failures. Duke Power, for example, instituted a high-pressure pipe inspection program in 1986 and then in 1987 incorporated EPRI's procedures for assessing the integrity of seam-welded piping. To date, Duke has applied this program to piping at 30 units to identify early indicators of potential failure.

ABSTRACT *Recently EPRI issued new guidelines for evaluating the integrity of seam-welded high-energy piping in fossil plants, expanding on guidelines produced in 1987. The original guidelines, developed in response to two catastrophic weld ruptures in 1985 and 1986, had heightened industry awareness of the problem and alerted utilities to several potential failures. During the early 1990s, however, some incidents of leaking and cracking in previously inspected pipes prompted a comprehensive reexamination of damage detection in seam-welded piping. The review indicated that these incidents might have been prevented had EPRI evaluation procedures been strictly followed, and it confirmed the procedures' effectiveness in minimizing the risk of pipe failure and avoiding premature pipe replacement. The new guidelines incorporate these results and the additional understanding acquired since 1987.*

Weld failure reassessed

The effectiveness of the EPRI evaluation methods was questioned in the early 1990s, however, when several incidents of major cracking or leaking in recently inspected piping were reported. In response, EPRI launched a comprehensive program to reassess the failure of seam-welded piping in general and to reexamine the 1987 guidelines.

Information about known failures was reevaluated, additional failures were identified and characterized, NDE practices were examined, and materials properties data were consolidated and reviewed. These activities required minimal use of outside contractors because of the expertise of EPRI's Strategic R&D staff and of personnel at the Institute's Nondestructive Evaluation Center in Charlotte, North Carolina. Researchers at Failure Analysis Associates (Menlo Park, California) played a supporting role. The work was performed in close consultation with EPRI's Generation Group, which provided cofunding.

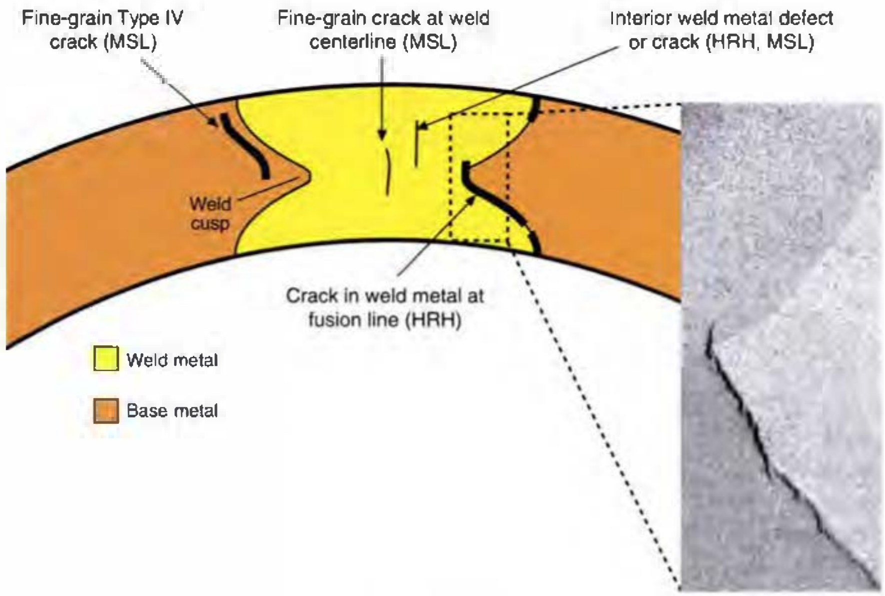
Failure analysis included the in-depth characterization of a major HRH pipe leak at the Sabine plant of Gulf States Utilities in 1992. Additionally, information on failure and cracking experiences with seam-welded pipes from 1979 to 1993 was consolidated and assessed. In all, 17 cases were studied, 12 involving thin-walled HRH pipes and 5 involving thicker main steam link pipes and fittings.

Figure 1 In power plants, the failure of seam-welded hot reheat piping, which carries steam at around 1000°F and 400–700 psig, is costly and potentially hazardous. Responding to catastrophic ruptures at two fossil plants in 1985 and 1986, EPRI developed the utility industry's only guidelines for evaluating the integrity and preventing the failure of such piping.

NDE approaches were examined in a survey of utility industry inspection practices, with particular emphasis on the EPRI-recommended procedures. The survey covered 162 units having some 47,000 feet (almost 9 miles) of seam-welded high-energy piping. In addition, the flaw detection and sizing capabilities of UT were evaluated in laboratory testing on ex-service material from the Sabine plant.

Extensive new materials properties data were collected and analyzed. Most had been generated in recent examinations of ex-service seam weldments, including HRH piping, clamshell elbows, tees, and

Figure 2 Typical crack locations in seam-welded piping. EPRI analysis indicates that in hot reheat (HRH) piping, damage begins almost exclusively near weld cusps and grows gradually as cracking along the weld fusion line (see photo). The high-sensitivity ultrasonic inspection techniques specified by EPRI can detect this type of damage years before major cracking, leaking, or rupture might occur. In main steam link (MSL) piping, which is thicker, damage occurs over a wider area, and cracking is thus much less predictable.



main steam pipe fittings. The analyses supplied key information required for serviceability evaluations—information on such properties as stress rupture, creep, and crack growth.

Enhanced understanding

For thin-walled, HRH-type seam-welded piping, the results of the review program confirm the fundamental appropriateness of a gradual-failure scenario, as well as the accuracy and effectiveness of EPRI's assessment procedures. The findings for main steam header link pipes are not as definitive. The evolution of weldment damage in this thicker piping is not yet adequately understood or predictable, and hence assessment procedures for it are less quantitative.

The examination of ex-service weldments and materials properties data indicates that for HRH piping, damage begins predominantly in a heterogeneous fashion and progresses in a time-dependent, evolutionary manner. Stress analysis reveals significant stress intensification at weld cusps, which suggests localized rather than uniform damage initiation (Figure 2). According to available metallographic evidence, there is a wide distribution of crack sizes and damage zones in a weldment at the time of failure, suggesting that cracking is progressive rather than instantaneous. And in the four cases in which oxides on crack surfaces were dated, it was determined that cracks had been exposed to steam for at least three years—a further indication that piping integrity can be managed by using an inspection-based approach.

Regarding inspection techniques, a detailed comparison of laboratory UT analyses and actual observations of corresponding metallographic samples from cracked and uncracked pipes demonstrates that the EPRI procedures can reliably detect and size cracks and creep-microcrack damage zones having through-wall depths of 0.05 inch or less. Conservative benchmarking of laboratory predictions against reported failures indicates that a period of at least five years is necessary for detectable damage to grow to a through-wall crack.

And concerning the early-1990s incidents, in which cracking or leaking occurred within one or two years of inspection, industry survey data indicate that the piping inspections had used procedures that were less sensitive than those specified by the 1987 guidelines and that could have missed critical flaws or incipient damage. Also, in other instances, evaluations thought to have adhered to the EPRI procedures were found to have involved incomplete or improper implementation, sometimes as a result of the nonstandardized NDE qualification of vendors.

New guidelines

The reassessment effort indicated that the inspection and evaluation procedures of the 1987 guidelines provide an effective means of ensuring the integrity of HRH piping, and EPRI has enhanced these procedures in a new draft guidebook—*Guidelines for the Evaluation of Seam-Welded High-Energy Piping* (TR-104631). Issued in 1994, the expanded guidelines incorporate the considerable experience, empirical data, and scientific understanding acquired since 1987, as well as practical insights contributed by Ohio Edison and South Carolina Electric & Gas. The updating effort was supported by the rigorous review of numerous utilities, including Boston Edison, Houston Lighting & Power, and Union Electric.

The new guidelines outline HRH pipe evaluation procedures in an easy-to-use, stepwise format. This presentation facilitates strict adherence to EPRI's UT inspection methods, thereby avoiding the unreliability associated with either incomplete guideline implementation or the use of less-sensitive methods. Furthermore, the crack growth methodology described in the guidelines can be implemented by using a new, modified version of EPRI's BLESS (Boiler Life Evaluation Simulation System) code. This version, called BLESS-PIPES, was developed by Engineering Mechanics Technology (San Jose, California) in work funded by the Generation Group.

Supplementary chapters present case-specific details and extensive background on failures, UT procedures, and modifications of the evaluation procedures. Of particular value is an appendix listing complete bid specifications for the examination of seam-welded piping. The use of uniform bid specifications can help utilities overcome today's inconsistent standards for vendor qualification, improving the reliability of UT steam pipe examination.

EPRI is planning to introduce the new guidelines and the BLESS-PIPES code in a two-day industry workshop this spring at the NDE Center. Geared toward utility engineers, technicians, and plant managers, the workshop will feature discussions of inspection procedures and hands-on training in the use of BLESS-PIPES.

Looking ahead

The 1994 guidelines, like those issued in 1987, rely on empirical understanding of damage initiation and crack growth for seam weldments. Scientific knowledge in this area is growing, practical experience is increasing, and there is great potential for advances. For example, new inspection techniques, such as UT techniques using focused array transducers, may enable better detection and characterization of flaws and damage progression. Periodic and on-line monitoring capabilities based on acoustic emission technology show promise for increasing safety margins and decreasing inspection costs. And round-robin quantification of inspector variability could enhance examination reliability. Ultimately, increased knowledge should allow comprehensive, mechanism-based engineering analysis of seam-welded piping, facilitating stress evaluation as well as design and operational improvements with the potential to mitigate failure.

To deepen understanding, EPRI is planning new investigations as well as keeping abreast of related work elsewhere, such as an industry-sponsored research program managed by the Material Properties Council. Results from this program—for example, simplified stress analysis techniques, higher-sensitivity NDE procedures, and large-specimen rupture data—are expected to provide the basis for further refinement of the guidelines.

New Contracts

Project	*Funding/ Duration*	*Contractor/EPRI Project Manager*
Customer Systems		
Added Value in Marketing Electricity (WO2343-19)	$89,700 6 months	EEE Limited/*P. Sioshansi*
Automated CO_2- and Volatile-Organic-Compound-Based Control of Ventilation Systems (WO2830-18)	$400,000 25 months	Honeywell/*L. Carmichael*
Battery-Powered Bicycle Demonstration (WO2882-24)	$50,000 12 months	ZAP Power Systems/*J. Guy*
Energy-Efficient Office Technology Performance Evaluation (WO2890-23)	$100,000 11 months	Architectural Energy Corp./*K. Johnson*
Power Quality Diagnostic System Integration (WO2935-35)	$95,000 11 months	Practical Concepts/*M. Samotyj*
Infrared Heat Treating for Aluminum Castings (WO3244-4)	$95,000 12 months	Technomics/*E. Eckhart*
Strategic Analysis of Power Options for a Major Process Industry Facility (WO3245-25)	$60,000 10 months	SFA Pacific/*A. Amarnath*
The High-Efficiency Laundry Metering and Marketing Analysis (THELMA) Study (WO3872-3)	$559,900 17 months	HBRS/*J. Kesselring*
Electrotechnology for Environmentally Compatible Infrared Curing of Coatings on Diesel Engine Components (WO3899-2)	$233,600 12 months	Industrial Coating Services/*E. Eckhart*
Commercial Clothes Dryer Study: Customer Needs Definition and Market Description (WO4001-20)	$74,200 6 months	National Analysts/*T. Henneberger*
Energy Efficiency in Education Facilities (WO4809-1)	$200,000 21 months	Hawaiian Electric Co./*M. Khattar*
Silicon Technology Competitive Cooperative Program (WO4810-2)	$144,000 28 months	SCRA/*E. Eckhart*
Minimization of Electric Arc Furnace Dust (WO4810-3)	$467,100 27 months	Carnegie Mellon University/*E. Eckhart*
Baseline Costs and Performance of Fabric Drying/Curing Processes (WO4813-2)	$100,100 20 months	Olympic Laboratories/*A. Amarnath*

Project	*Funding/ Duration*	*Contractor/EPRI Project Manager*
Emissions From Wood-Drying Operations (WO4829-1)	$500,000 16 months	Institute of Paper Science & Technology/*A. Amarnath*
SAE-JEVA Conductive Coupler Development (WO4855-1)	$50,900 12 months	Hart, McMurphy & Parks/*G. Purcell*
Ground Fault Circuit Interrupter Protection—High Voltage (WO4857-1)	$67,100 12 months	Hart, McMurphy & Parks/*G. Purcell*
Communications for Small-Business Electrotechnologies (WO4876-1)	$50,000 16 months	Pacific Consulting Services/*W. Krill*
Environment		
EMF Database (WO2966-13)	$115,500 11 months	T. Dan Bracken/*R. Takemoto-Hambleton*
Application of CompMech Individual-Based Modeling Approach to the Issue of Global Warming (WO3316-9)	$150,000 24 months	Martin Marietta Energy Systems/*J. Mattice*
Issues in the Economics of Climate Policy (WO3441-21)	$50,000 10 months	Charles River Associates/*L. Williams*
Magnetic Field Management (WO3959-7)	$306,800 11 months	Enertech Consultants/*R. Lordan*
MOSES Enhancements (WO4132-1)	$99,900 10 months	Tetra Tech/*I. Murarka*
Industrial Ecology: Technological Trajectories, Technological Transitions, and Habitability (WO4133-1)	$120,000 12 months	Rockefeller University/*S. Peck*
Coal Tar Test Burn: Handling and Transport (WO9015-18)	$668,700 5 months	Northern Indiana Mechanical/*I. Murarka*
Coal Tar Test Burn: Mixing and Burning (WO9015-19)	$99,500 8 months	Gilbert/Commonwealth/*I. Murarka*
Utility Support for MANAGES Version 2 (WO9020-4)	$123,300 10 months	Science and Technology Management/*I. Murarka*
Southern Oxidant Study (WO9031-3)	$256,300 15 months	Tennessee Valley Authority/*A. Hansen*
Long-Term Effects of 60-Hz Electric vs Magnetic Fields on Interleukin-1 and Other Immune System Parameters in Sheep (WO9082-1)	$1,510,000 50 months	Oregon State University/*K. Ebi*

Generation

Project	Funding/ Duration	Contractor/EPRI Project Manager
Utilization of Coal Gasification Slags (WO1654-16)	$100,000 25 months	Praxis Engineers/ *M. Epstein*
Wind Turbine Performance Technical Review (WO3404-13)	$76,600 12 months	Electrotek Concepts/ *E. Davis*
Modification of the HEST Method for Mercury Speciation in Utility Flue Gas (WO3471-10)	$66,700 11 months	TRC Environmental Corp./ *B. Nott*
Gas Turbine Inlet Water Overspray System: Utility Demonstration (WO3534-6)	$367,000 25 months	Fern Engineering/ *R. Frischmuth*
Rotating Machinery Workstation (WO3693-3)	$90,600 24 months	Automation Technology/ *T. McCloskey*
Development of Chaos-Based Diagnostic Tools in Rotating Machinery (WO3693-4)	$900,000 36 months	Case Western Reserve University/*T. McCloskey*
Comparative Evaluation of Control Strategies (WO3891-2)	$215,000 27 months	PowerGen/*M. Perakis*
Repowering With Advanced Technologies: Strategic Alliance (WO3936-1)	$73,000 24 months	Sargent & Lundy/ *W. Weber*
Milliken Mist Eliminator Test Support (WO9017-3)	$368,400 14 months	New York State Electric & Gas Corp./*R. Rhudy*
Selective Noncatalytic Reduction for Coal/Gas-Fired Wet Bottom Utility Boilers (WO9029-1)	$871,600 23 months	Public Service Electric and Gas Co./*J. Stallings*
Development of Transient Thermography for Inspecting FGD Coatings (WO9056-1)	$450,600 27 months	PowerGen/*P. Radcliffe*
Low-NO_x Combustion Retrofit Demonstration (WO9062-1)	$770,000 9 months	Pacific Gas and Electric Co./*A. Facchiano*
NO_x Reduction Evaluation at Azienda Energetica Municipale's Cassano Unit 2 (WO9066-1)	$60,100 14 months	PowerGen/*A. Facchiano*
State-of-the-Art Cooling Water Treatment (WO9071-1)	$550,000 36 months	Puckorius & Associates/ *B. Nott*
Evaluation of LS-2 Wet Limestone FGD Process (WO9085-1)	$1,233,000 61 months	ABB Environmental Systems/*R. Moser*
Collaborative Advanced Gas Turbine Program (WOCAG2-5)	$83,000 7 months	Energy Options/ *C. Dohner*

Nuclear Power

Project	Funding/ Duration	Contractor/EPRI Project Manager
CORETRAN Depletion Capability (WO2853-37)	$224,000 12 months	S. Levy/*L. Agee*
Resolution of the Reactivity Insertion Accident Issue (WO2905-6)	$390,000 12 months	Anatech Research Corp./ *O. Ozer*
Analysis of a Dissolved-Oxygen Limit for PWRs (WO2977-15)	$50,100 8 months	Tetra Engineering Group/ *P. Millett*
Evaluation Procedure and Criteria for Risk-Based Inspection (WO3230-6)	$78,100 11 months	Sartrex Corp./*S. Gosselin*
Requirements Specification Methodology for Digital Upgrades (WO3332-6)	$164,500 11 months	Capri Technology/ *R. Torok*
BWR Integrated Control Algorithms (WO3332-7)	$55,500 9 months	Touch Base Computing/ *R. Torok*
Commercial Dedication for Digital Upgrades (WO3373-12)	$125,000 12 months	MPR Associates/*R. Torok*
Investigation of Ion-Exchange Resins for Filtering Iron Compounds (WO3388-15)	$118,200 24 months	San Jose State University Foundation/*P. Millett*
Compilation, Analysis, and Interpretation of Data From the Advanced Containment Experiments, Phase C (WO3425-1)	$225,100 12 months	Argonne National Laboratory/*M. Merilo*
Application Guide for Motor-Operated Valves (WO3814-15)	$150,000 9 months	Kalsi Engineering/ *V. Varma*
Charging-Pump Maintenance Guide (WO3814-16)	$102,500 11 months	Life Cycle Engineering/ *K. Barry*
CECIL Development for Combustion Engineering Steam Generators (WO3877-1)	$589,000 15 months	Foster-Miller/*R. Thomas*
Microstructural Characterization of Reactor Pressure Vessel Steels (WO3975-21)	$130,600 8 months	AEA O'Donnell/*R. Carter*
FatiguePro Upgrade (WO4021-2)	$160,000 11 months	Structural Integrity Associates/*S. Gosselin*
Battery Performance Monitoring by Impedance or Conductance Testing (WO4031-1)	$75,400 9 months	Edan Engineering Corp./ *N. Hirota*
Commercial Version of RAYTRACE and RAYNEW (WO4148-1)	$165,100 8 months	Karta Technology/*T. Taylor*
Electromagnetic Interference/Radio-Frequency Interference Measurements at Palo Verde Station (WO4409-2)	$82,400 14 months	Wyle Laboratories/ *R. James*
Analysis of Weld Residual Stresses in BWR Core Shrouds (WOB301-8)	$61,100 6 months	Dominion Engineering/ *R. Pathania*
Hatch 1 In-Reactor Stress Corrosion Monitoring Test Report (WOB401-1)	$58,300 4 months	General Electric Co./ *K. Ramp*
Neutron and Gamma Flux Distributions (WOB401-2)	$174,200 11 months	TransWare Enterprises/ *K. Ramp*
Development of EPRI chemWORKS (WOS521-5)	$199,800 10 months	GEBCO Engineering/ *P. Millett*
Relationship of Radiation-Induced Segregation and Microstructural Change to Irradiation-Assisted Stress Corrosion Cracking (WOX133-2)	$274,800 12 months	Battelle Memorial Institute/ *L. Nelson*

Power Delivery

Project	Funding/ Duration	Contractor/EPRI Project Manager
UCA Integrated Protection, Control, and Data Acquisition (WO3599-4)	$295,000 12 months	Aerospace Corp./ *J. Melcher*
UCA Integrated Protection and Control (WO3599-5)	$299,900 12 months	General Electric Co./ *J. Melcher*
Advanced Artificial Neural Net Short-Term Load Forecaster: Host Utility Testing, Support, and Enhancements (WO3692-2)	$182,000 24 months	Pattern Recognition Technologies/*D. Maratukulam*
Strategic Assessment of Distributed Investments (WO3733-6)	$275,000 9 months	Applied Decision Analysis/ *S. Chapel*
Nonconductive-Tower Evaluation (WO3748-6)	$83,300 10 months	J. A. Jones Power Delivery/ *A. Hirany*
Integrated Storage Planning Operations Workstation (WO3950-2)	$1,250,000 23 months	Decision Focus/ *R. Schainker*
Transmission Circuits Uprating Study (WO3957-1)	$471,400 27 months	Power Technologies/ *A. Edris*
Development of Integrated Resource Options Tools (WO4024-1)	$85,000 9 months	Applied Decision Analysis/ *R. Goldberg*
Development of Advanced Artificial Neural Net Short-Term Load Forecaster (WO4028-1)	$218,700 23 months	Pattern Recognition Technologies/*D. Maratukulam*

Strategic R&D

Project	Funding/ Duration	Contractor/EPRI Project Manager
Human/Neural Network Controller for Power System Security Enhancement (WO8016-7)	$440,300 40 months	Stanford University/ *D. Sobajic*
Investigations of CO_2 Hydrate Formation (WO8020-12)	$67,000 9 months	California Institute of Technology/*R. Moser*
Drawing Ecological Boundaries: Ecological Boundary Delineation Software (WO8020-13)	$63,300 11 months	Applied Biomathematics/ *L. Pitelka*
Fundamental Heat Transfer Mechanisms in Flooded Reactor Cavities (WO8034-11)	$65,000 12 months	University of California, Los Angeles/*M. Merilo*
Corrosion Prevention by Regenerative Biopolymers (WO8044-2)	$334,000 37 months	University of California, Irvine/*B. Syrett*
Micropipe Formation in Polytypes of Silicon Carbide (WO8064-1)	$208,900 36 months	University of Pittsburgh/ *P. Grant*
Wide-Bandgap Semiconductor Materials for the Fabrication of High-Power Solid-State Devices (WO8064-2)	$225,000 36 months	University of Wisconsin, Madison/*P. Grant*
Search for New High-Temperature Superconductors (WO8066-4)	$150,000 36 months	University of Houston/ *P. Grant*

New Technical Reports

Requests for copies of reports should be directed to the EPRI Distribution Center, 207 Coggins Drive, P.O. Box 23205, Pleasant Hill, California 94523; (510) 934-4212. EPRI members that fund the business unit issuing a report can receive the report free of charge (or, in the case of bulk orders, for a nominal price). Domestic organizations not eligible for EPRI membership pay the listed price. Others should contact the Distribution Center for further information.

CUSTOMER SYSTEMS

Customer Systems Group: Strategic Overview (Revision 3)
TR-100350-R3 Special Report (RP3557); $200
Business Units: All units in Customer Systems Group
EPRI Project Manager: I. Bran

Power Quality for Electrical Contractors: Applications Guide, Vols. 1 and 2
TR-101536-V1, TR-101536-V2 Final Report (RP2935-23, RP3810-1); $200
Contractor: Portland General Energy Systems
Business Unit: Power Quality & Information Technology
EPRI Project Manager: M. Samotyj

The EPRI Fryer Field Test Report
TR-102037 Final Report (RP2890-4); $200
Contractors: Penn State Facilities Engineering Institute; Hart, McMurphy & Parks
Business Unit: Residential & Small Commercial
EPRI Project Manager: K. Johnson

Proceedings: Third International Conference on Power Quality—Issues and Opportunities (PQA '93/PECON IV)
TR-104581 Final Report (RP2935-1); $200
Contractor: CK & Associates
Business Unit: Power Quality & Information Technology
EPRI Project Manager: M. Samotyj

Demand-Side Management Information Systems (DSMIS) Overview
TR-104707 Final Report (RP3269-24); $200
Contractor: Charles River Associates, Inc.
Business Unit: Marketing Tools & DSM
EPRI Project Manager: R. Evans

Development of the EPRI/Metcal Griddle
TR-104806 Final Report (RP2890-14); $200
Contractor: Metcal, Inc.
Business Unit: Residential & Small Commercial
EPRI Project Manager: K. Johnson

CSG Strategic R&D Workshop Proceedings
TR-104833 Proceedings (RP3557); $200
Contractor: D. J. Borstein & Associates
Business Units: All units in Customer Systems Group
EPRI Project Manager: P. Joyner

Performance Evaluation of the Hydronic Heat Pump System, Vol. 1: Heating Season
TR-104891-V1 Final Report (RP2892-27); $200
Contractor: GEOMET Technologies, Inc.
Business Unit: Residential & Small Commercial
EPRI Project Manager: J. Kesselring

ENVIRONMENT

Magnetic Field Management for Overhead Transmission Lines: A Primer—Definitions, Methods of Performing Calculations, Field Management Options, and Other Issues
TR-103328 Final Report (RP2472-6, RP3959-2); $200
Contractor: General Electric Co.
Business Units: Transmission; Environmental & Health Sciences
EPRI Project Manager: R. Lordan

Feasibility of Ground-Penetrating Radar for Use at Manufactured Gas Plant Sites
TR-104495 Final Report (RP9015-6); $200
Contractor: University of Kansas
Business Unit: Environmental & Health Sciences
EPRI Project Manager: I. Murarka

Survey Measurements and Experimental Studies of Residential Transient Magnetic Fields
TR-104532 Interim Report (RP3349-1); $200
Contractors: Enertech Consultants; High-Voltage Transmission Research Center
Business Unit: Environmental & Health Sciences
EPRI Project Manager: R. Kavet

A Field and Laboratory Study of Solute Release From Sluiced Fly Ash
TR-104585 Final Report (RP2485-8); $200
Contractor: Battelle Pacific Northwest Laboratories
Business Unit: Environmental & Health Sciences
EPRI Project Manager: I. Murarka

Association of Wire Code Configuration With Long-Term Average 60-Hz Magnetic Fields and Exposure, Vols. 1 and 2
TR-104656-V1, TR-104656-V2 Interim Report (RP3533-1); $200 for set
Contractor: T. Dan Bracken, Inc.
Business Unit: Environmental & Health Sciences
EPRI Project Manager: R. Kavet

Biology and Electric and Magnetic Fields: Biophysical Mechanisms of Interaction
TR-104800 Final Report (RP2965-28); $200
Contractor: Gradient Corp.
Business Unit: Environmental & Health Sciences
EPRI Project Manager: C. Rafferty

Technical Review of Externalities Issues
TR-104813 Final Report (RP3231); $200
Contractor: Science and Technology Management, Inc.
Business Unit: Environmental & Health Sciences
EPRI Project Manager: V. Niemeyer

Potential Effects of Climate Change on Electric Utilities
TR-105005 Final Report (RP2141-11); $200
Contractor: ICF Resources, Inc.
Business Unit: Environmental & Health Sciences
EPRI Project Managers: C. Clark, V. Niemeyer

GENERATION

TVA 160-MWe Atmospheric Fluidized-Bed Combustion Demonstration Project, Vol. 2: Test Program Results and Early Operating Experience
TR-100544-V2 Final Report (RP2543-1); $10,000
Contractor: Tennessee Valley Authority
Business Unit: Advanced Fossil Power Systems
EPRI Project Managers: J. Wheeldon, J. Fishbaugher

Environmental Performance of Atmospheric Fluidized-Bed Boilers
TR-102406 Final Report (RP3197-15); $200
Contractor: Combustion Systems, Inc.
Business Unit: Advanced Fossil Power Systems
EPRI Project Manager: R. Brown

Advanced Gas Turbine Guidelines: Rotating Blade Temperature Measurement System—Durability Surveillance at PEPCO's Station H
TR-103895 Final Report (RP3125-2); $60,000
Contractor: Fluor Daniel, Inc.
Business Unit: Fossil Power Plants
EPRI Project Managers: W. Piulle, G. Quentin

Advanced Gas Turbine Guidelines: Data Acquisition System and Baseline Data—Durability Surveillance at PEPCO's Station H
TR-103937 Final Report (RP3125-2); $60,000
Contractor: Fluor Daniel, Inc.
Business Unit: Fossil Power Plants
EPRI Project Managers: W. Piulle, G. Quentin

Advanced Gas Turbine Guidelines: Performance, Operation, and Maintenance Management System—Durability Surveillance at PEPCO's Station H
TR-104019 Final Report (RP3125-2); $60,000
Contractor: Fluor Daniel, Inc.
Business Unit: Fossil Power Plants
EPRI Project Managers: W. Piulle, G. Quentin

Advanced Gas Turbine Guidelines: Hot-Gas-Path Parts Condition and Remaining-Life Assessment—Durability Surveillance at PEPCO's Station H
TR-104101 Final Report (RP3125-2); $120,000
Contractor: Fluor Daniel, Inc.
Business Unit: Fossil Power Plants
EPRI Project Managers: W. Piulle, G. Quentin

Pollution Prevention Applications for Noncombustion Waste
TR-104111 Final Report (RP3006-6); $10,000
Contractor: Radian Corp.
Business Unit: Environmental Control
EPRI Project Manager: M. McLearn

Coal Ash Disposal Manual: Third Edition
TR-104137 Final Report (RP3176-7); $10,000
Contractor: GAI Consultants, Inc.
Business Unit: Environmental Control
EPRI Project Manager: D. Golden

Developing Utility Pollution Prevention Plans: Workbook and Generic Plan
TR-104377 Final Report (RP3610-1); $10,000
Contractor: Radian Corp.
Business Unit: Environmental Control
EPRI Project Manager: M. McLearn

High-Efficiency Flue Gas Desulfurization Guidelines
TR-104597 Final Report (RP1031-9); $20,000
Contractor: Radian Corp.
Business Unit: Environmental Control
EPRI Project Managers: R. Moser, D. Owens

Pressure and Temperature Effects in Dilution Extractive Continuous Emission Monitoring Systems
TR-104700 Final Report (RP1961); $200
Contractor: Source Technology Associates
Business Unit: Environmental Control
EPRI Project Manager: G. Maybach

The Performance of the EPRI Large-Scale Hot Gas Filter During the Grimethorpe Topping Cycle Experiment
TR-104825 Final Report (RP1336-8); $200
Contractor: British Coal Corp.
Business Unit: Advanced Fossil Power Systems
EPRI Project Manager: R. Brown

Proceedings: Cooling Tower and Advanced Cooling Systems Conference
TR-104867 Proceedings (RP2113-9); $1000
Contractor: Yankee Scientific, Inc.
Business Unit: Fossil Power Plants
EPRI Project Manager: J. Tsou

NUCLEAR POWER

Shelf Life of Elastomeric Components
NP-6608 Final Report (RPQ101-15); $200
Contractor: Washington Public Power Supply System
Business Unit: Nuclear Power
EPRI Project Manager: T. Mulford

Infrared Thermography Guide (Revision 2)
NP-6973-R2 Final Report (RP2814-18, RP3232-1); $15,000
Contractors: American Risk Management Corp.; Honeyhill Technical
Business Unit: Nuclear Power
EPRI Project Managers: G. Allen, A. Wise, P. Zayicek

Underwater Maintenance Guide (Revision 2): A Guide to Diving and Remotely Operated Vehicle Operations for Nuclear Maintenance Personnel
NP-7088-R2 Final Report (RP2814-24); $10,000
Business Unit: Nuclear Power
EPRI Project Manager: J. Jenco

UPS Maintenance and Application Guide
TR-100491 Final Report (RP2814-77); $7000
Contractor: MOS, Inc.
Business Unit: Nuclear Power
EPRI Project Manager: W. Johnson

Earthquakes of Stable Continental Regions: Assessment of Large Earthquake Potential
TR-102261-V1-V5 Final Report (RP2556-12; RP2356-56, -59); Vol. 1, $100; Vols 2-5, $400 for set
Contractors: University of Memphis; Geomatrix Consultants; CAC, Inc.
Business Unit: Nuclear Power
EPRI Project Managers: J. Schneider, H. Tang

Development of a Main Coolant Pump Seal Decision Support System (MCPDSS), Vol. 1: Functional Requirements (Joint EPRI-CRIEPI Human Factors Studies)
TR-102938-V1 Final Report (RP3111-6); license required
Contractors: Anacapa Sciences, Inc.; MPR Associates, Inc.
Business Unit: Nuclear Power
EPRI Project Managers: J. Ketchel, L. Hanes

Handbook for Verification and Validation of Digital Systems, Vols. 1-3
TR-103291-V1-V3 Final Report (RP3352); $25,000
Contractor: S. Levy Inc.
Business Unit: Nuclear Power
EPRI Project Manager: S. Bhatt

Experimental Characterization of Fluid Film Effects in Various Steam Generator Tube Support Geometries
TR-103504 Final Report (RPS410-4); $200
Contractor: Combustion Engineering, Inc.
Business Unit: Nuclear Power
EPRI Project Manager: D. Steininger

A Proposed Public Health and Safety Standard for Yucca Mountain: Presentation and Supporting Analysis
TR-104012 Final Report (RP3055, RP3294); $200
Contractors: Risk Engineering, Inc.; Del Mar Consulting; Polestar Applied Technology, Inc
Business Unit: Nuclear Power
EPRI Project Managers: J. Kessler, R. Yang

Utility Experience With Major Radiation Monitoring System Upgrades
TR-104081 Final Report (RP2409-24); $200
Contractors: Louisiana LaissezFaire, Inc.; TARAwest Technologies
Business Unit: Nuclear Power
EPRI Project Manager: R. James

Mixed Waste Storage and Treatment: Regulatory Compliance Manual
TR-104223 Final Report (RP3800-18); $200
Contractor: Piper & Marbury
Business Unit: Nuclear Power
EPRI Project Manager: C. Hornibrook

Maintenance Job Cards (Joint EPRI-CRIEPI Human Factors Studies)
TR-104602 Final Report (RP3111-5); license required
Contractor: Anacapa Sciences, Inc
Business Unit: Nuclear Power
EPRI Project Manager: L. Hanes

Determination of Enthalpy of Ionization of Water From 250 to 350°C
TR-104668 Final Report (RP3500-9); $200
Contractor: Brigham Young University
Business Unit: Nuclear Power
EPRI Project Manager: P. Paine

PWR Molar Ratio Control Application Guidelines, Vol. 1: Summary
TR-104811-V1 Final Report (RPS520); $10,000
Contractor: Molar Ratio Control Guidelines Committee
Business Unit: Nuclear Power
EPRI Project Manager: P. Millett

POWER DELIVERY

Magnetic Field Management for Overhead Transmission Lines: A Primer—Definitions, Methods of Performing Calculations, Field Management Options, and Other Issues
TR-103328 Final Report (RP2472-6, RP3959-2); $200
Contractor: General Electric Co.
Business Units: Transmission; Environmental & Health Sciences
EPRI Project Manager: R. Lordan

Investigation of Cable Jacket and Shield Materials Capable of Mitigating Ingress of Ionic Impurities
TR-104247 Final Report (RP2986-2); $20,000
Contractor: University of Connecticut
Business Unit: Distribution
EPRI Project Manager: B. Bernstein

Prototypes for Gas-Insulated-Substation Infrared Monitoring
TR-104453 Final Report (RP1360-13); $5000
Contractor: Compix, Inc.
Business Unit: Substations, System Operations & Storage
EPRI Project Managers: S. Nilsson, M. Wilhelm

Option Pricing for Project Evaluation: An Introduction
TR-104755 Final Report (RP1920-5); $200
Contractor: Incentives Research, Inc
Business Unit: Utility Resource Planning & Management
EPRI Project Managers: S. Chapel, R. Goldberg

STRATEGIC R&D

Cycle Chemistry Guidelines for Fossil Plants: Phosphate Treatment for Drum Units
TR-103665 Final Report (RP9003-2, -7); $10,000
Business Unit: Strategic R&D
EPRI Project Manager: B. Dooley

Sodium Hydroxide for Conditioning the Boiler Water of Drum-Type Boilers
TR-104007 Final Report (RP9000-20); $1000
Contractor: M. Ball, Chartered Chemist
Business Unit: Strategic R&D
EPRI Project Manager: B. Dooley

Characterization of Surface-Modified Austenitic Alloys
TR-104181 Final Report (RP8042-1); $200
Contractor: Gary S. Was Consulting
Business Unit: Strategic R&D
EPRI Project Manager: H. Ocken

Proceedings: Fourth International Conference on Fossil Plant Cycle Chemistry
TR-104502 Proceedings (RP9003); $200
Business Unit: Strategic R&D
EPRI Project Manager: B. Dooley

Positioning for Competition: The Changing Role of Utility Fuels Management
TR-104550 Final Report (RP2369-12); $1000
Contractors: Resource Dynamics Corp.; J. T. Doudiet Associates, Inc.
Business Unit: Strategic R&D
EPRI Project Manager: J. Platt

EPRI Events

JULY

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

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

13
ASAPP: Accounting Software Application for Pollution Prevention
Austin, Texas
Contact: Mary McLearn, (415) 855-2487

13–14
Providing Quality Power to Steel Producers
Chicago, Illinois
Contact: Susan Bisetti, (415) 855-7919

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

19–20
5th Annual NDE Issues Meeting
Charlotte, North Carolina
Contact: Susan Otto, (704) 547-6072

20–21
Optical Sensors for Utility T&D Applications
Portland, Oregon
Contact: Pam Turner, (415) 855-2010

26–28
EPRI chemWORKS and Secondary Chemistry Training Workshop
Newport Beach, California
Contact: Barbara James, (707) 823-5237

AUGUST

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

15–18
EPRI/DOE International Conference on Managing Hazardous and Particulate Air Pollutants
Toronto, Canada
Contact: Lori Adams, (415) 855-8763

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

23–24
Nuclear Plant Performance Improvement Seminar
Albuquerque, New Mexico
Contact: Susan Otto, (704) 547-6072

28–30
Polymer Technology Workshop
Palo Alto, California
Contact: Bruce Bernstein, (202) 293-7511

29–31
Distributed Resources Conference
Kansas City, Missouri
Contact: Lori Adams, (415) 855-8763

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

SEPTEMBER

11–13
Reliability-Centered Maintenance
Newport Beach, California
Contact: Denise O'Toole, (415) 855-2259

14–15
Measurement of Power System Magnetic Fields
Lenox, Massachusetts
Contact: Gary Johnson, (413) 499-5712

19–21
International Conference on Remediation of Contaminated Sites
Prague, Czech Republic
Contact: Ishwar Murarka, (415) 855-2150

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

27–28
EPRI/DOE Wind Turbine Verification Program
Fort Davis, Texas
Contact: Earl Davis, (415) 855-2256

27–28
Feedwater Heater Technology Symposium
Kansas City, Missouri
Contact: Linda Nelson, (415) 855-2127

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

28–29
Strategic Asset Management for a Competitive Utility Environment
Denver, Colorado
Contact: Mikie Alves, (415) 854-9000

28–29
12th Annual Operational Reactor Safety Engineering and Review Groups Workshop
Baltimore, Maryland
Contact: Susan Bisetti, (415) 855-7919

OCTOBER

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

10–12
Achieving Success in Restructuring Electricity Markets
Atlanta, Georgia
Contact: Susan Bisetti, (415) 855-7919

18–20
Magnetic Field Management
Lenox, Massachusetts
Contact: Gary Johnson, (413) 499-5712

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

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

NOVEMBER

1–3
PWR Plant Chemists Meeting
Orlando, Florida
Contact: Barbara James, (707) 823-5237

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

2–3
Executive Forum on Retail Competition
Chicago, Illinois
Contact: Pam Turner, (415) 855-2010

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

6–9
6th Conference on Decision Analysis for Utility Planning and Management
San Diego, California
Contact: Charlie Clark, (415) 855-2994

7–9
Distributed Control Systems Retrofit Workshop
Knoxville, Tennessee
Contact: Susan Bisetti, (415) 855-7919

28–30
1995 EPRI International Clean Water Conference
La Jolla, California
Contact: Lori Adams, (415) 855-8763

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

EPRI JOURNAL

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