EPRI JOURNAL

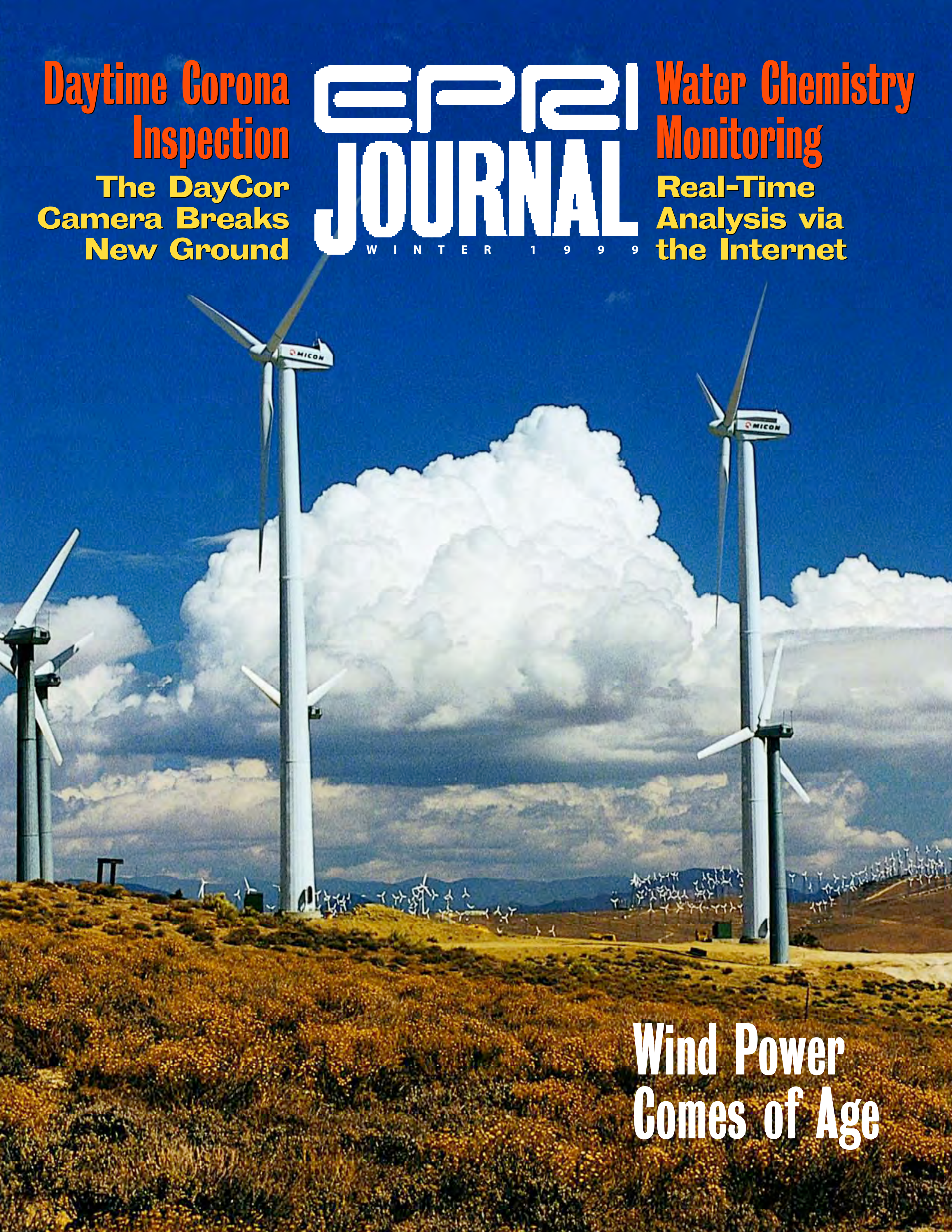
WINTER 1999

Daytime Corona Inspection

The DayCor Camera Breaks New Ground

Water Chemistry Monitoring

Real-Time Analysis via the Internet



Wind Power Comes of Age

About EPRI®

EPRI creates science and technology solutions for the global energy and energy services industry. U.S. electric utilities established the Electric Power Research Institute® in 1973 as a nonprofit research consortium for the benefit of utility members, their customers, and society. Now known simply as EPRI, the company provides a wide range of innovative products and services to more than 1000 energy-related organizations in 40 countries. EPRI's multidisciplinary team of scientists and engineers draws on a worldwide network of technical and business expertise to help solve today's toughest energy and environmental problems.

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COVER: Wind power, the world's fastest-growing source of energy over the past decade, now has an installed capacity of 10 GW around the globe. (Photo courtesy American Wind Energy Association)

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Editorial

Power Reliability at Risk

The Electricity Technology Roadmap, under development by EPRI and other electricity stakeholders for the past two years, has identified some extraordinary opportunities for the coming decades. From widespread electric transportation to waste-free industrial processes to the seamless provision of information, services, and products via smart energy networks and the Internet, we are poised to tap the full power of the electron for the benefit of society in the twenty-first century. However, the roadmap has also brought into clear focus a problem that could be a roadblock not only for society's future aspirations but for our current energy security as well.

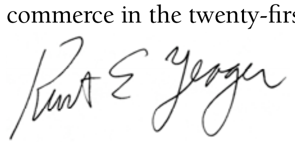
The problem is our power delivery infrastructure. The transmission lines that carry high-voltage power over long distances and the lower-voltage distribution lines that connect to businesses and homes are becoming noticeably fragile in the high-traffic, newly competitive electricity industry. The North American power grid—installed 50 years ago—was not designed to handle the volume of power trades we are seeing today. As a result, the potential for larger-scale and more frequent disruptions on this interconnected grid is considered higher now than at any time since the great Northeast blackout of 1965. It is myopic to consider the recent city- and regionwide power failures as just local anomalies in a basically secure national system. There is every reason to believe that such problems will increase if prudent steps to avoid them are not taken now.

The solution lies in creating and deploying innovative tools that will improve both power delivery capacity and control. Progress is being made on these fronts with the development of silicon-based power electronics devices that improve the speed and precision of power switching and with the successful testing of superconducting cables that can handle up to three times the capacity of today's lines. But as timely as these advances appear, it will require considerable work to ensure that they are brought to commercial readiness and deployed widely and effectively.

And lest we become overly comfortable with our progress, it must be remembered that we are dealing with a fast-moving target. During the development of the interstate highway system in the 1950s, designers were criticized for their insistence on four-lane, divided highways—obviously more roadway than we could ever possibly need! The growth of electronic traffic—carrying both power and information—is certain to be much more rapid with the rise of e-commerce and an increasingly digital economy. And capacity is not the only requirement for the digital age; the growing reliance on computerized control systems and sensitive, microprocessor-based end-use equipment will soon demand nothing less than perfect power quality.

Certainly the threat of widespread power reliability problems is real and requires immediate attention, but focusing only on the problem as it exists today will produce a short-lived security. We must go beyond fixing our aging power delivery infrastructure; we must *transform* it so that it can be integrated with tomorrow's technical and business paradigms, where energy and information converge. Advances like power electronics and high-temperature superconducting materials, which have been steadily advancing through the R&D pipeline, give us confidence that science and technology can provide the tools we need, but they should also remind us that the development of effective, enduring solutions takes time, commitment, and a carefully considered vision of what tomorrow's needs will actually be.

The prosperity and quality-of-life opportunities envisioned in the Electricity Technology Roadmap will require an extremely reliable, functionally flexible electronic delivery system that can satisfy the growing appetite for power quantity and quality in a digital economy. An intensified research, development, and demonstration effort will be needed as the foundation for accomplishing this. Our goal should be nothing less than to create the superhighway system for electronic commerce in the twenty-first century.



Kurt E. Yeager
President and Chief Executive Officer

Contributors

Wind Power: Gaining Momentum (page 8) was written by Taylor Moore, *Journal* senior feature writer, with assistance from two managers in EPRI's Science and Technology Development Division.

CHARLES MCGOWIN, manager for wind power and team leader of the Renewable Technology Options and Green Power Marketing Target, joined EPRI in 1976. Previously he was a senior research engineer in the chemical engineering department of Shell Development Company in Emeryville, California, and Houston, Texas. McGowin received a BA degree in applied science and a BS degree in chemical engineering, both from Lehigh University, and MSE and PhD degrees, also in chemical engineering, from the University of Pennsylvania.

TERRY PETERSON manages work in solar power and green power marketing. He joined EPRI in 1986 after eight years at Chevron Research Company, where he was involved in catalyst and solar cell research. Peterson holds a BS in physics from the University of California at San Diego and two graduate degrees from the University of California at Berkeley—an MA in physics and a PhD in materials science and engineering.

Viewing Corona in the Daytime (page 18) was written by Lee Harrison, technical writer at EPRI's Energy Delivery and Utilization Center in Lenox, Massachusetts, with assistance from the center's Andrew Phillips.

ANDREW PHILLIPS has worked as a research engineer at the Lenox center since 1997, first as an employee of J. A. Jones Power Delivery, which managed the center until 1998, and then as an EPRI employee. Before joining J. A. Jones, he worked at the University of the Witwatersrand in Johannesburg, South Africa, where he was involved in high-voltage research and consulting for the South African electric power industry—primarily for Eskom. Phillips received BS, MA, and PhD degrees in electrical engineering from the University of the Witwatersrand.

Water Chemistry Off-Site and On-Line (page 24) was written by Christopher R. Powicki, science writer, with assistance from two members of EPRI's new subsidiary, EPRIsolutions.

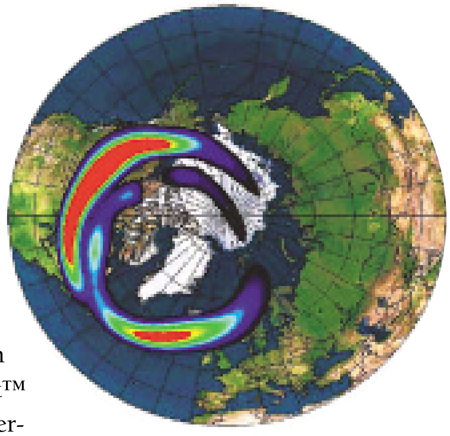
PETER MILLETT joined EPRI in 1991 as a project manager for steam generator chemistry research. Now on the EPRIsolutions staff, he is team leader for chemistry and steam generator technology. Before coming to EPRI, he worked for Northeast Utilities and GPU Nuclear and also as a consultant. Millett holds a BS in chemical engineering from Worcester Polytechnic Institute and MS and PhD degrees in the same field from the University of Connecticut.

TINA GAUDREAU, manager for chemistry and corrosion technology in EPRIsolutions, came to EPRI in 1997 as a program integrator for the Nuclear Power Group's asset management research. Before that, she worked for GEBCO Engineering and B&W Nuclear Technologies. Gaudreau began her career in nuclear power at Northeast Utilities after graduating from Tufts University with a BS in chemical engineering.

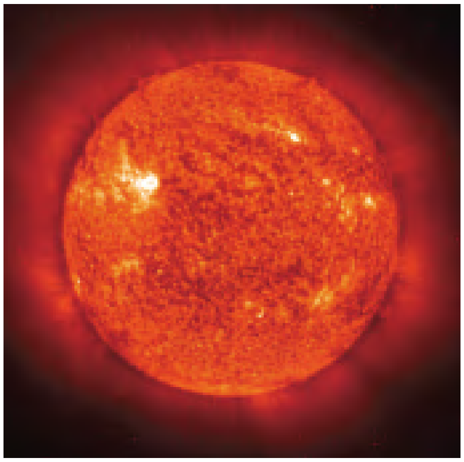
Products

Deliverables now available to EPRI members and customers

SUNBURST 2000



The peak period of geomagnetic disturbances from the current 11-year solar cycle is expected in the first quarter of 2000. Power companies in danger of impact from the solar storms' geomagnetically induced currents can now receive advance warning to protect their systems. In a collaborative effort with National Grid Company of Great Britain and two U.S. firms—Electric Research and Management of State College, Pennsylvania, and Metatech Applied Power Solutions of Duluth, Minnesota—EPRI has worked to combine its SUNBURST 2000 real-time monitoring equipment with Metatech's SpaceCast/PowerCast™ geomagnetic storm forecasting services. As the first client to use the new system, National Grid earlier this year received forecasts of transmission system impacts some 45 minutes before events—early enough for its operators to take precautionary actions. And since the second phase of installation has now been completed, the SUNBURST 2000 monitoring equipment can also provide National Grid with real-time observations of geomagnetic disturbances and their impacts.



COURTESY LOCKHEED MARTIN CORP.

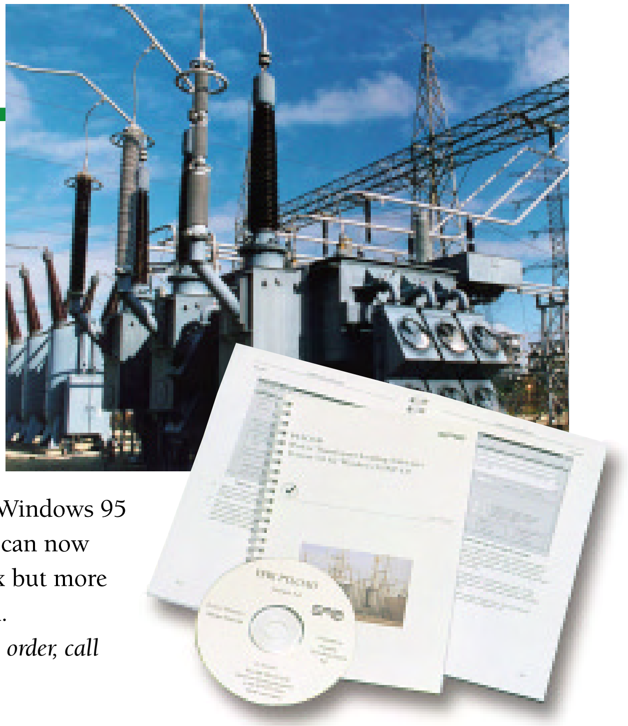
■ *For more information on participation in the solar storm monitoring and forecasting program, contact Ben Damsky, bdamsky@epri.com, 650-855-2385, or Ray Lings, lings@epri.com, 650-855-2177.*

Valve Application, Maintenance, and Repair Guide

This guide (TR-105852-V1), an expanded version of an earlier report, is a comprehensive reference on the installation, operation, and maintenance of various types of valves and actuators. Produced by the EPRI Nuclear Maintenance Applications Center, the guide covers gate, globe, butterfly, ball, plug, and diaphragm valves. It describes common problems with each type and discusses how to select valves on the basis of functional and system requirements. It also covers general maintenance requirements and diagnostics. Extensive illustrations and sample calculations make the guide useful to a wide range of personnel, including system designers, engineers, operators, and instructors. Although the information focuses on the use and maintenance of valves in power plant systems, the guide is also directly applicable to comparable systems in such industries as the chemical, petroleum, and marine industries.

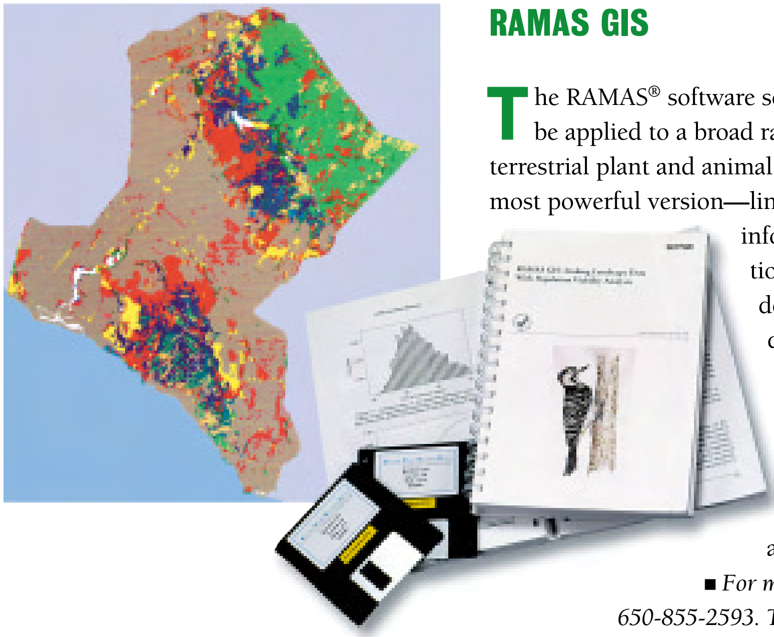
■ *For more information, contact Leonard Loflin, leloflin@epri.com, 704-547-6010. To order, call EPRI Customer Service, 800-313-3774.*

PTLOAD 5.0



Version 5 of the Power Transformer Loading (PTLOAD) software provides users with an accurate, flexible way of calculating substation transformer oil and winding temperatures, transformer loss of life, and the likelihood of gas bubble formation at high loads. The calculation methodology is based on the recently revised ANSI/IEEE C57.91-1995 standard and incorporates user-specified physical parameters for the transformer and user-specified load and air temperature. PTLOAD 5.0 (AP-111247)—an upgrade of the Windows 3.1 version released in 1993—includes a revamped user interface (for the Windows 95 and NT operating systems) and many other enhancements. For example, a user can now choose between the conventional top-oil rating algorithm and the more complex but more accurate bottom-oil rating algorithm described in Annex G of the IEEE standard.

■ *For more information, contact Steven Eckroad, seckroad@epri.com, 650-855-1066. To order, call EPRI Customer Service, 800-313-3774.*



RAMAS GIS

The RAMAS® software series for ecological risk assessment and management can be applied to a broad range of environmental issues relating to both aquatic and terrestrial plant and animal populations. RAMAS GIS 3.0 (AP-113031)—the latest and most powerful version—links landscape data generated by a company's geographic information system to a metapopulation model for extinction risk assessment, viability analysis, conservation reserve design, and wildlife management. Such issues as thermal discharge, impingement and entrainment, ecosystem management, endangered species, and right-of-way ecological impacts can be analyzed—for example, to develop site-dependent water quality criteria and discharge standards. Complementing the detailed user's guide for this version is a report (TR-111387) that gives examples of RAMAS applications.

■ *For more information, contact Robert Goldstein, rogoldst@epri.com, 650-855-2593. To order, call EPRI Customer Service, 800-313-3774.*

PISCES 3.0: Power Plant Chemical Assessment Model

EPRI's PISCES (Power Plant Integrated Systems: Chemical Emissions Studies) model provides key capabilities to help utilities report chemical releases covered by the U.S. Environmental Protection Agency's Toxics Release Inventory (TRI). As the only model for TRI emissions that is based on material balances, PISCES allows users to configure all common coal-, oil-, and gas-fired power plants and then estimate the distribution and fate of all gaseous, liquid, and solid chemical emissions. Enhancements in the most recent version (AP-112347) address specific TRI requirements, model usability and output, database modifications, and new configurations for water and solid waste management. In addition to the easy-to-install PISCES program, the software package includes an installation guide, user documentation, and a model tutorial.

■ *For more information, contact Paul Chu, pchu@epri.com, 650-855-2812. To order, call EPRI Customer Service, 800-313-3774.*

Project Startups

New ventures of importance to power and service providers

Cross-Border HVDC Link Planned

EPRI is working with Central and South West Corporation (CSW) and the Comisión Federal de Electricidad (CFE), Mexico's national electric utility, to install and test an asynchronous transmission tie using a new high-voltage direct-current (HVDC) technology. The tie will link the transmission system of Central Power and Light (CPL)—a CSW subsidiary—in Texas with CFE's transmission system; it is expected to be operational by June 2000.

The new technology will provide strong voltage support while significantly improving the reliability of power delivery service between the two grids. The 36-MW

COURTESY ABB POWER SYSTEMS

Computer-aided drawing of the planned voltage source converter at CPL's Eagle Pass substation

HVDC tie, a back-to-back voltage source converter, will be installed at CPL's Eagle Pass substation and will allow electricity to be exchanged across an existing 138-kV tie line between Piedras Negras, Mexico, and Eagle Pass. The existing line is currently used only in emergencies and requires a brief service interruption to customers in order to shift load from or to CFE. ABB Power Systems is developing the voltage source converter, using its HVDC Light technology, which extends the benefits of HVDC to low-power applications.

"Voltage source converters are a major thrust of EPRI's FACTS—Flexible AC Transmission System—program," notes Karl Stahlkopf, EPRI vice president for applications. "The technology-based FACTS program is designed to help the power industry improve transmission system performance and meet the demands of a rapidly changing business. EPRI is pleased to be working jointly with CSW, CFE, and ABB on a first-of-a-kind field demonstration of this technology."

With the HVDC link, "CPL and CFE will be able to provide emergency service to each other without first having to disrupt power," points out Abdel-Aty Edris, EPRI's manager for FACTS technology. CPL will operate the tie at Eagle Pass, but it will be available for use by other utilities through the ERCOT (Electric Reliability Council of Texas) Independent System Operator. Power exchanged over the tie will be provided on a nonfirm basis, subject to interruption for reliability needs in the area.

"We are excited about this new technology and the ways it will enhance our ability to maintain reliable service to CPL's customers in the Eagle Pass area," says Tom Shockley, CSW president and chief operating officer. "We look forward to continuing our long-standing relationship with CFE and developing other mutually beneficial projects in the future."

■ *For more information, contact Abdel-Aty Edris, aedris@epri.com, 650-855-2311.*

Pioneering a Premium Power Industrial Park

The first U.S. industrial park to feature premium power quality is being developed in Ohio by American Electric Power and Siemens Power Transmission & Distribution under a new EPRI contract. The two-year research and demonstration project will test new premium power technologies for cost-effectiveness in industrial customer applications. The Delaware Industrial Park, originally developed in the 1960s by an AEP subsidiary, will be retrofitted and converted into a premium power park designed to supply customers with high-quality electricity.

"Studies have shown that commercial and industrial customers want a higher quality of electric service than is currently available," says Larry Carmichael, EPRI technical manager for communications and automation in distribution system services. As computers and electronics become more and more essential in manufacturing and business applications, the voltage sags and spikes or sustained outages that can result in production downtime are of growing concern to these customers.

Premium power park technologies are designed to compensate for erratic power quality, protect sensitive electronic and electrical devices, and improve reliability. The park concept entails the integration of several state-of-the-art Custom Power devices into a utility distribution system—devices that previously have been deployed only as stand-alone equipment. According to Harry Vollkommer, AEP's project comanager, "What makes this project unique is that for the first time multiple power quality technologies—with a communications network between the devices—will be integrated into one plan and system. The project will also allow us to demonstrate that we can adapt existing systems with new technology."

Customers in the Delaware Industrial Park represent a variety of loads and a broad spectrum of power quality and reliability needs. The park is home to 11 industrial companies, representing manufacturing, warehousing, data processing, and assembly functions. Four of the park's customers, accounting for approximately 70% of its electrical load, have already agreed to participate in the project.

The AEP-Siemens research team will measure power quality and reliability at the park and assess the degree of customer satisfaction with the new system. The cost benefits of serving multiple customers' power quality and reliability needs will also be evaluated.

As the host utility and a project subcontractor, AEP will provide utility system expertise. Siemens is the system integrator and will be responsible for investigation, coordination, and analysis. AEP, Siemens, and EPRI have previously collaborated on demonstrations of new Custom Power technologies, including the Distribution Static Compensator and the Unified Power Flow Controller.

John Kessinger, vice president and general manager of Siemens Power T&D, says that "by demonstrating the ability to implement a park that provides both technical and financial satisfaction for the energy provider and the user, we hope to prove that the premium power park is more than just a concept."

■ *For more information, contact Larry Carmichael, lcarmich@epri.com, 508-358-4959.*

COURTESY ESKOM

Shown at the dedication ceremony of the African Center for Energy & Environment are (left to right) Victoria Evans, EPRI environment market segment leader; Steve Lennon, Eskom senior general manager for technology; and Wendy Poulton, Eskom corporate consultant, strategic environment.

Environmental Center Launched With Eskom

A center for environmental projects and training in Johannesburg, South Africa, is providing important education and technology transfer under a collaborative effort between EPRI and Eskom, South Africa's largest electric utility. Following the dedication last August of the African Center for Energy & Environment, more than 100 people attended the first four days of offered courses. The participants included representatives from several other African countries.

Eskom and EPRI, both of which have extensive experience in the environmental field, are jointly offering training and technology courses at the center to personnel from electric utilities and other industries in the region. Increased environmental awareness and new laws to protect the environment have resulted in a substantial need for such training in South Africa. The center's facilities and training will also be available to personnel from other developing countries and EPRI members. Joint EPRI-Eskom environmental projects managed through the center will include applications of new environmental technologies and some pilot projects.

The center's well-attended first training course focused on environmental excellence in power transmission and distribution, covering environmental management systems, life-cycle analysis, oil risk assessments, bioremediation options, herbicides and vegetation control, and animal interactions.

The African Center for Energy & Environment is the third technology center jointly established in South Africa by Eskom and EPRI. The others are the South African Power Systems Studies Institute and the South African Center for Essential Community Services.

"The vision for the new center is to improve environmental knowledge and facilitate technology transfer between EPRI and Eskom and other interested parties in South Africa and around the world," said Wendy Poulton, Eskom corporate consultant, strategic environment, at the center dedication. "Eskom and EPRI together have a formidable pool of expertise and network of specialist contacts," she continued. "At Eskom, we actively support the concept that environmental considerations form an integral part of our business planning processes and decision making."

Victoria Evans, EPRI's environment market segment leader, noted that "the mission of the Eskom-EPRI center is to provide an essential, quality, and cost-effective environmental training service and to facilitate joint or collaborative projects. EPRI's intention is to share with Eskom and benefit from our mutually rich base of knowledge, expertise, and experience. Our goal is to empower progress toward a sustainable culture, economy, and environment for the planet."

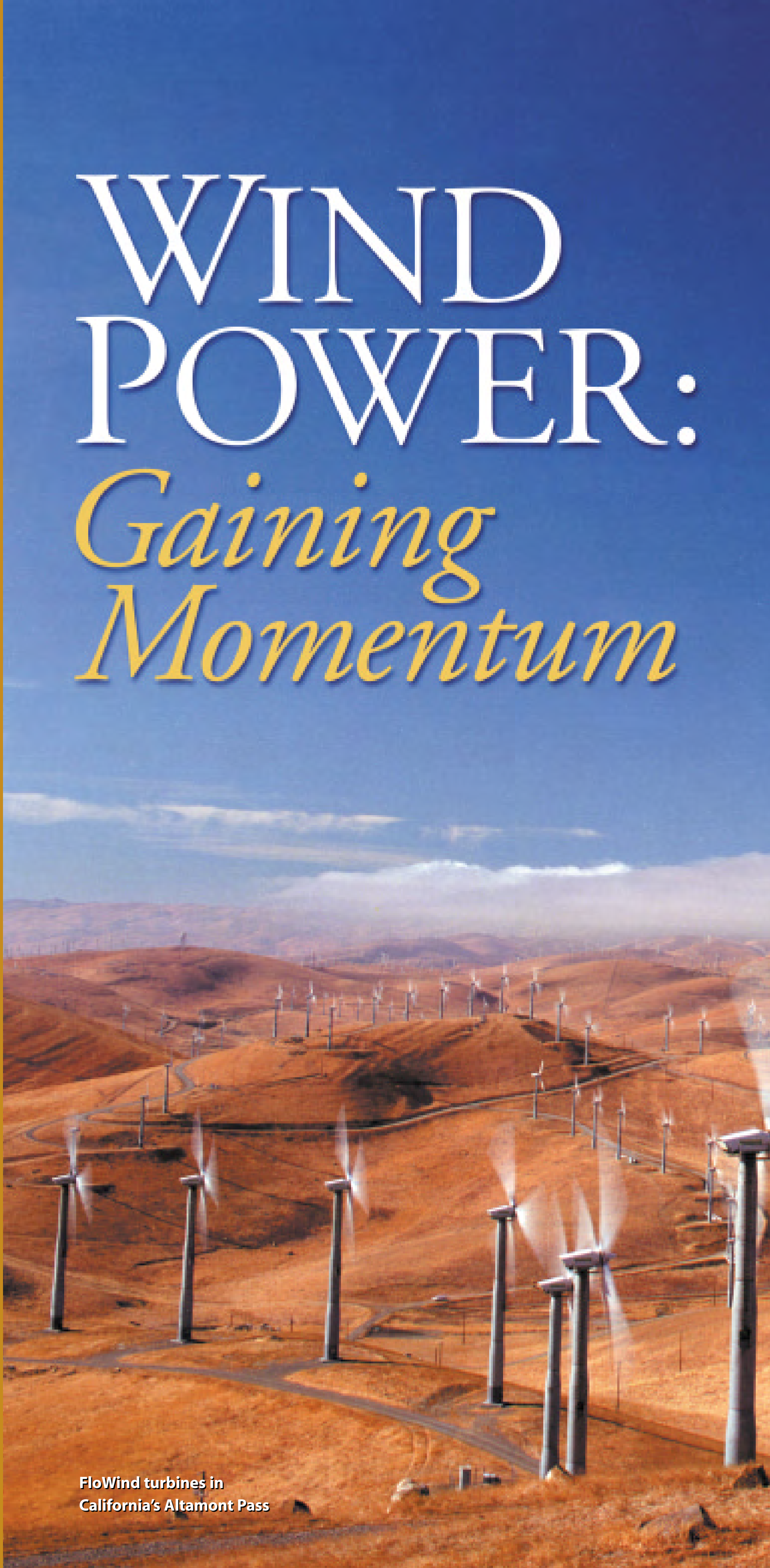
■ *For more information, contact Victoria Evans, vevans@epri.com, 650-855-2042.*

WIND POWER: *Gaining Momentum*

THE STORY IN BRIEF

In the past two decades, wind power has emerged as one of the most economically competitive and promising renewable energy technologies, giving rise to a thriving commercial industry with substantial global reach. Policymakers and energy planners around the world expect wind to supply an increasing share of electricity generation, thereby helping to limit atmospheric emissions of carbon dioxide. The cost of electricity from wind has declined dramatically with the maturing of the technology through several generations of turbines. But further cost reduction and technology breakthroughs are essential to the development of wind power's enormous potential and its integration into a competitive generation market.

BY TAYLOR MOORE



FloWind turbines in California's Altamont Pass

As the last decade of the century and the millennium draws to a close, a commercial, zero-emission renewable technology for electricity generation has achieved a sort of critical mass. Around the world, tens of thousands of wind turbines totaling 10 GW in capacity and representing more than $10 billion in investments are up and running, many supplying a growing utility and consumer market for environmentally preferred, or green, power.

Wind power is now a $2.5 billion to $3 billion a year global industry. Nearly a quarter (2500 MW) of its installed capacity is in the United States, where the development of modern turbines was pioneered in the late 1970s and 1980s with government support. For several years, however, Europe has led the world in wind power development. Installed capacity has increased rapidly in such countries as Denmark, Germany, and Spain, thanks to consistent, sustained government support and mandated higher prices for wind-generated electricity. In contrast to the United States—where installations typically are large, multiunit wind parks built by developers, independent power producers, and, in some cases, utilities—most wind turbine installations in Europe involve comparatively few units, and many are owned by small groups of individuals or local cooperatives.

Germany alone has more than 6800 wind turbines, totaling almost 3400 MW. Denmark, with more than 1500 MW of installed capacity, generates 10% of its electricity from wind, and Danish manufacturers have supplied more than half the new turbines recently installed around the world. Overall, European manufacturers account for 9 of every 10 turbines installed worldwide.

During the 1990s, global wind generating capacity expanded at an annual rate of more than 25%, doubling every three years. The cost of wind-generated electricity has declined with each doubling and with the increased economies of scale from the use of progressively larger turbines. (Many machines are now rated at more than 1 MW, and some in Europe are 2 MW.) According to the European and American wind energy trade associations, wind-generated electricity today costs one-sixth what it did in the early 1980s, and its cost is expected to decline by an additional 20–40% by 2005.

In the United States, the cost of wind-generated electricity has declined from 40¢/kWh in 1980 to 4–6¢/kWh. Emboldened by the progress achieved over the past two decades, the U.S. Department of Energy last June launched a national initiative called Wind Powering America. Its goal is to increase the contribution of wind power to the country's electricity supply by a factor of 50 (from its present 0.1% to at least 5%) by the year 2020. The DOE initiative is focusing on wind power's potential for rural economic development and includes a series of grants to projects in 10 states to support mainly smaller, distributed turbine installations.

"Wind energy has been the fastest-growing source of energy in the world during the past decade and now represents a major economic opportunity for the United States," said Energy Secretary Bill Richardson in announcing the initiative. He noted that greater use of wind power would "help combat global climate change by reducing carbon emissions" and that a significant increase in wind generation could lead "the charge in the transition to renewable energy." The wind initiative complements other initiatives in solar photovoltaics, biomass, and renewables-based economic development on Native American–owned lands.

A record amount of new and repowered wind turbine capacity was installed by developers in the United States in 1999, in part triggered by the June 30 expiration of a federal production tax credit of 1.5¢/kWh. The purpose of the credit was to make eligible wind-generated electricity (and electricity from some other renewable sources) more competitive with power from fossil fuels by partly compensating for the indirect subsidies long afforded to conventional fuels. An extension of the credit, which wind power advocates say is critical to the industry's transition to a competitive electricity market, was contained in recent tax legislation passed by Congress but vetoed by President Clinton because of other provisions. The wind industry and states with significant wind resources have been working hard to ensure that the extension is preserved in any subsequent compromise bill.

WARREN GRETZ, COURTESY NREL

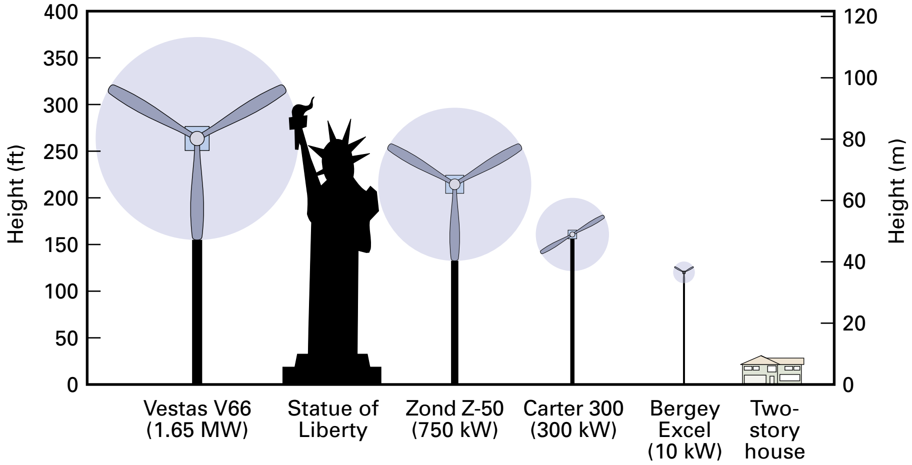
Wind farms have significant potential for economic development in rural areas because they require only small areas of land and have minimal impact on ranching and farming activities. The Zond turbines shown here are part of the 107-MW Lake Benton wind farm in Minnesota, which supplies electricity to Northern States Power.

PHOTO PAGES 8–9 BY WARREN GRETZ, COURTESY NATIONAL RENEWABLE ENERGY LABORATORY

Wind power in the heartland

According to the American Wind Energy Association (AWEA), the recent growth in wind power is also due to state policies encouraging or requiring the use of renewable resources and to growing consumer demand for green power. Thanks to these factors, U.S. growth markets for wind power have shifted in the past few years beyond California to the Midwest and the Southwest. The states of the upper and lower Great Plains—from North Dakota to Texas—offer the best wind resources in the country.

"More than half the new projects built



Wind turbines are typically sized to match regional energy needs and the landscape and wind resource of a particular site. Today's largest turbines, with generating capacities of 1–2 MW, stand taller than the Statue of Liberty. Under development are even taller and larger turbines that will be able to capture more of the wind's energy while operating at a lower blade rotation speed.

GRAPH BY KEN COX, ADAPTED FROM TXU ELECTRIC & GAS

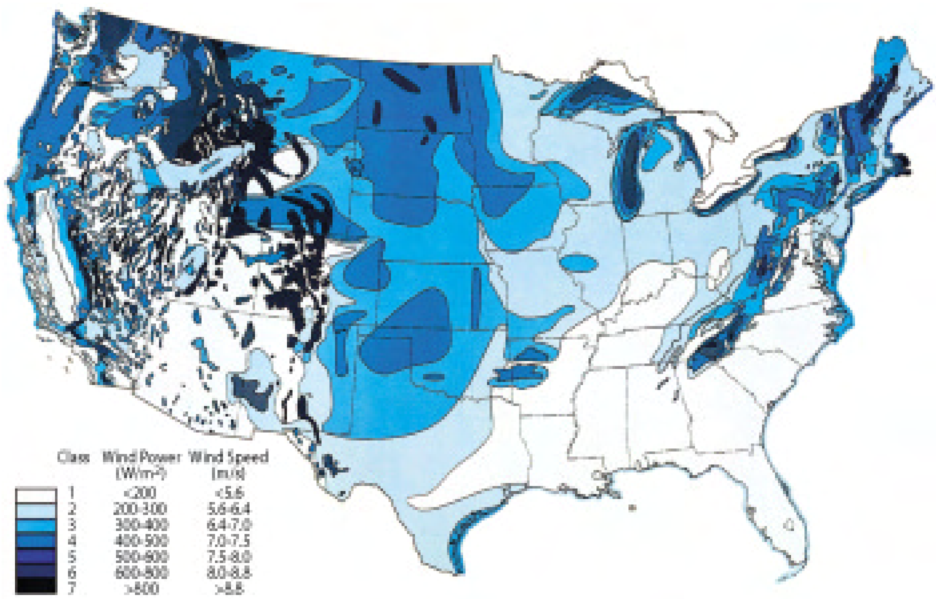
this year were developed in Iowa and Minnesota, where state laws passed several years ago have required that modest amounts of new generating capacity be based on renewable resources," says Randall Swisher, AWEA executive director. In Iowa, for example, utilities have invested significantly to obtain a portion of total electricity supply from renewable sources. "Wind is one of the most promising new energy sources to come along in many years. But we need continued strong leadership in Congress and the executive branch—and in the states, where new utility markets are being designed and implemented—for wind energy to realize its true potential to boost local economies and cut pollution," Swisher adds.

Iowa now boasts more than 250 MW of installed wind turbines, representing investments of some $300 million and a new source of income for hundreds of farmers and landowners. Turbines require only small amounts of land, and agricultural production is unimpeded. Over the past two years, several small wind projects were installed at various locations by municipal utilities and Alliant–IES Utilities. In just the past year, four larger, multiunit developments totaling more than 242 MW were completed by ventures whose participants included Alliant, Enron Wind Development (a subsidiary of Enron Wind Corporation), MidAmerican Industries, FPL Energy, NEG Micon USA, and Waverly Light and Power. Iowa's resource potential for wind power is conservatively estimated by Pacific Northwest National Laboratory at nearly 63 GW.

An overwhelming majority (more than 540) of the wind turbines installed in Iowa and Minnesota in the past couple of years, as well as several others elsewhere, are 750-kW variable-speed units produced by Zond Energy Systems, another subsidiary of Enron Wind.

Minnesota has approximately 270 MW of installed turbines, most of which were completed in the past year by ventures that sell the electricity to Northern States Power. The state legislature has required NSP to install 425 MW of wind capacity by 2002, followed by another 400 MW by 2013, in return for permission to continue the on-site storage of spent fuel at its nuclear power plants. Pacific Northwest National Laboratory's resource assessment puts Minnesota's wind power potential at 75 GW.

Meanwhile, in connection with utility industry deregulation and restructuring, some customers in nearly a dozen states have the option of purchasing green power from primarily renewable resources, often at a slight premium over a conventional generating mix of mainly fossil fuels and nuclear power. Wind, typically the lowest-cost renewable source of electricity after existing hydro capacity, is a primary source of much of this green power. According to AWEA, wind energy is a component of the green power programs of at least 36 utilities serving customers in Colorado, Idaho, Kansas, Michigan, Minnesota, Nebraska, New Mexico, Oregon, Texas, Washington, and Wisconsin. "A key driver for most of



The combined wind resources of a dozen states in the upper Midwest, Great Plains, Southwest, and Rocky Mountain regions have an energy potential that theoretically exceeds the country's total electricity consumption. (The data are for a turbine height of 50 meters.) Many of the windiest areas, however, are far from electrical load centers and have limited power transmission capacity. Six states (Connecticut, Maine, Massachusetts, Nevada, New Jersey, and Texas) have recently adopted a Renewables Portfolio Standard–based strategy, requiring that an increasing share of total electricity generation come from renewable resources like wind.

MAP BY PACIFIC NORTHWEST NATIONAL LABORATORY, COURTESY NREL the approximately 900 MW of new wind capacity installed in the past year has been the power industry's emerging awareness of customer interest in green power in California, Pennsylvania, and Colorado," says Terry Peterson, EPRI manager for green power marketing.

In Texas, the future of green power pricing pilot programs offered by TXU Electric & Gas and by Central and South West Corporation's utility subsidiaries is uncertain, given the legislature's adoption—and Governor George Bush's approval—of a market-based Renewables Portfolio Standard policy. The new policy requires electricity providers to add 2000 MW of renewables-based generation to the Texas power mix by 2009 as part of the state's electric utility restructuring plan, and it features a system of tradable, certified credits for renewable energy. Ranked second only to North Dakota in wind resource potential (136 GW), Texas has approximately 200 MW of installed wind turbines.

Among the major wind projects in Texas is the 107-unit, 75-MW Southwest Mesa project near McCamey. Sited on a 600-foot (180-m), 2200-acre (890-ha) mesa spanning two counties, the project is owned by an affiliate of FPL Energy, an unregulated subsidiary of FPL Group and the largest U.S. provider of wind energy, with an interest in 1000 MW of capacity in four states.

Elsewhere in Texas, eight of the largest wind turbines currently installed in the United States are part of the 41-MW Big Spring project, built by York Research Corporation. Electricity generated by these 1.65-MW, 370-foot (113-m) Vestas V66 machines, along with the output of 42 smaller turbines, is purchased by TXU Electric & Gas for distribution to customers in Waco who elect to participate in the company's pilot TU Renew customer choice program.

Houston-based Reliant Energy HL&P has added wind power to its supply mix by buying the initial 30 MW of the Delaware Mountain wind farm in rural Culberson County in western Texas. The farm—planned to eventually total 250 MW, which would make it the largest in the country—was built by American National Wind Power, part of National Wind Power (a subsidiary of National Power PLC and Britain's largest wind energy developer).

Wind power in a competitive market

The U.S. wind rush began in California in the 1980s, echoing the gold rush of nearly a century and a half earlier. Approximately 1600 MW of wind turbines are now operating in the state, primarily in three areas with extensive wind resources. These areas, along with tax incentives and a climate of regulatory and public acceptance, drew the first wind plant developers to California, even though it ranks only seventeenth among the states in terms of estimated wind power potential (6.8 GW). California's aggressive push to deregulate electricity generation carries important economic lessons for other states with greater wind resources.

COURTESY BERGEY WINDPOWER CO.

Small wind turbines of 50 kW or less have great potential both for distributed generation and for remote, off-grid applications at individual customer sites in rural areas. This 10-kW turbine was produced by Bergey Windpower; other U.S. manufacturers of small turbines include Atlantic Orient Corporation and Northern Power Systems.

Until recently, virtually all wind-generated electricity in California, like that in other states, was sold under contract to specific utilities. Many of the California wind energy contracts guarantee above-market wholesale prices under a 1978 federal law designed to encourage independent power generators. But with the advent of wholesale competition in electricity generation in California in 1998 and the evolution of a new market structure, wind energy is expected to eventually be sold in two basic markets.

The primary market is the California Power Exchange (CalPX), through which investor-owned utilities must buy all their load and sell power from any generating capacity that they own or that is under contract to them. CalPX offers the Green Power Exchange Service, which allows buyers and sellers to bilaterally exchange wholesale power and negotiate differences in green attributes.

Under the new market rules, power producers must sell into the market by bidding ahead—indicating how much power they will sell and at what time and price in the hour-ahead and day-ahead markets—and scheduling their deliveries with CalPX. The producers, particularly those using intermittent resources like wind, face the risk that they will generate more or less power than was offered and scheduled. The California Independent System Operator (ISO) has established a market to charge or pay participants market-based imbalance prices for the difference between the amount of power supplied to the grid and the amount scheduled.

An alternative to CalPX is the Automated Power Exchange (APX), a member of the Green-e certification standard organization. Wind-generated or other electricity sold through the APX Green Market qualifies for a 1.5¢/kWh incentive from the state. Under the APX Green Ticket trading program, generators receive a ticket for each megawatthour produced, differentiated by technology type, vintage, and other factors. Through the APX, wind generators can sell on the open market and collect a premium for each megawatthour generated, without having to forecast actual power production for the day and the next day.

Wind plant owners and developers in California have explored selling through the APX as an alternative to their existing high-priced contracts and for new wind power projects. But in an analysis for

COURTESY VESTAS WIND SYSTEMS

Wind power development in many parts of Europe is heading offshore both because available land is scarce and because larger turbines optimized for installation in shallow coastal areas can take advantage of the stronger winds there. These 1.65-MW Vestas V66 machines are deployed off Denmark.

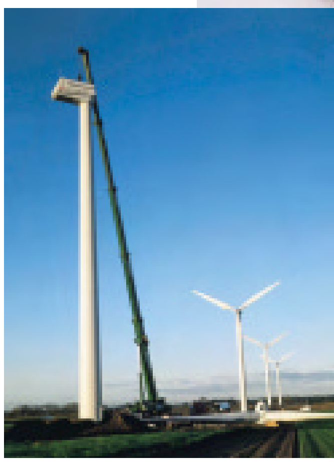
AWEA of California's competitive energy market and its first-year effects on the wind industry, renewable energy consultant and former wind company executive Robert Harmon notes that, as of June 1999, no wind energy had been sold on the APX. "The financial risk and management advantages of remaining in [existing] contracts are more attractive to wind facility owners than selling on the open market," Harmon writes. However, he adds, some developers plan to use the APX Green Market for new wind facilities that do not have bilateral contracts and may also use it for capacity that is renegotiated out of standard contract.

Harmon points out that state-mandated provisions in California for "must-run" plants and "must-take" power create an artificially smaller open market into which other generators can bid, causing excess capacity. That, in turn, lowers prices, making it more difficult for new renewable energy projects to compete. There is already a substantial amount of renewables-based electricity available in California, accounting for 25% of total capacity if hydro is included. "Many new wind projects will need to use forecasts of market prices as a backstop in their project financing. These artificially low prices make project financing much more difficult," says Harmon.

An intermittent resource

New generating projects based on intermittent resources like wind could face difficult challenges obtaining financing if their production is sold in markets with significant price volatility, such as the imbalance market. Harmon notes that high set penalties for imbalances, as are imposed in some regions outside California, would particularly threaten the competitiveness of wind energy facilities. Avoiding or minimizing such penalties would require the precise forecasting of wind speed in order to determine precise energy output. Unfortunately, however, wind speed forecasts can be imprecise and unreliable.

For a wind turbine operating in the medium wind speed range—between the speed at which it begins generating electricity and the speed at which it reaches full rated power—a change in speed of even 1 or 2 mph can alter the power output. Most wind facilities operate between cut-in and rated power up to 50% of the time, during which their output cannot be forecast precisely. Thus it is difficult to bid accurately even an hour ahead in forward markets. (One positive note is that aggregating the output of several wind turbines dampens the fluctuations of any single unit, and aggregating several wind plants can significantly reduce the variation further.) EPRI is collaborating with Central and South West Services, FPL Energy, and the California Energy Commission (CEC) to improve wind energy forecasting techniques, using both U.S. and Danish forecasting models.



"The uncertainty associated with the intermittent nature of wind energy, combined with high penalties from the ISO, could make wind noneconomic," says Harmon. As long as wind accounts for only a small share of California's electricity supply, differences between projected and delivered energy are not expected to result in major problems. But Harmon warns that high imbalance penalties, if adopted, could potentially force wind energy out of the market in the state.

Project finance groups view the uncertainties associated with operating in the imbalance market and with possible future set penalties for under- or overproduction as highly negative, adds Harmon, and buyers of wind energy are hesitant to buy a product when they do not know what it will cost. He calls this "a major challenge for the wind industry."

Many people in the industry, Harmon reports, believe that it is necessary to develop relationships with large power marketing groups or other generators that can help the industry shape the load, or create firm power. "Work is also being done to evaluate the actual (as opposed to perceived) financial risks associated with the intermittent nature of wind power," Harmon says.

PHOTOS COURTESY NEG MICON USA

Large wind turbines and their support towers are assembled on-site with the help of very tall and expensive cranes.

Wind power's future in the evolving, competitive California electricity market remains uncertain in light of the current price and supply environment, and it is not clear whether customer markets for green power will mature quickly enough to support demand for new wind generating capacity. But virtually all of the some 100,000 California residential customers that have switched electricity providers

A Bridge to Advanced Commercial Turbines

EPRI is a founding member, along with the U.S. Department of Energy, of the Utility Wind Interest Group (UWIG), which serves as an information exchange forum for utilities on wind turbine technology, project experience, and related issues. Formed in 1989, UWIG has 38 members, including investor-owned, public power, and rural cooperative utilities in 15 states and academic, government, and corporate organizations. Its activities are funded by a combination of member dues and support from DOE's National Renewable Energy Laboratory (NREL).

Many UWIG members are participants in the Wind Turbine Verification Program (TVP), which was initiated in 1992 by EPRI and DOE to evaluate prototype advanced turbines at several sites developed by U.S. electric utilities and to expand utility industry experience with wind power technology. The goal of the TVP is to provide a bridge from the current utility-grade wind turbine development programs to the commercial purchase of such advanced machines.

The technical data and performance results generated by the TVP help instill confidence that these machines will operate in various wind regimes and that new models of turbines can withstand the rigors of commercial operation. The program has been funded through contributions from DOE, the host utilities, and EPRI, which manages the program.

The first wind projects installed under the TVP were the 12-unit, 6-MW Fort Davis, Texas, project built by Central and South West Services in 1995 and the 11-unit, 6.1-MW project built by Green Mountain Power in 1996 in Searsburg, Vermont. Both feature fixed-speed Zond turbines that are predecessor models of today's variable-speed Zond turbine. "The support of EPRI and the early adopters among utilities interested in wind was critically important because the installations served as a test-bed for ironing out operational problems and proving the performance of new technology turbines," says NREL's Robert Thresher.

In 1997, DOE and EPRI began to support five utility projects that are evaluating distributed wind generation using smaller clusters of wind turbines connected directly to distribution systems. They include a two-unit, 1.5-MW project installed by the Nebraska Public Power District in 1998 in Springview, Nebraska, and a three-unit, 2.25-MW project installed by Cedar Falls Utilities in Algona, Iowa.

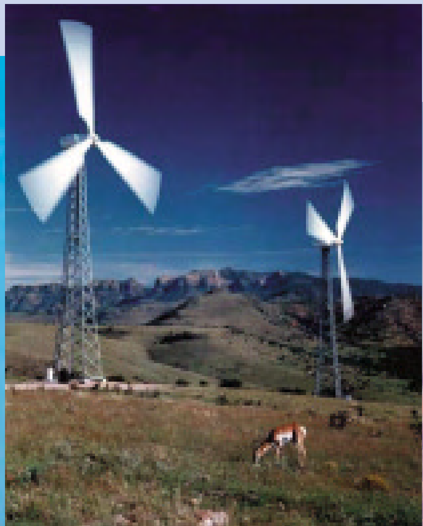
The 750-kW variable-speed Zond turbines installed in these projects provided critical early performance and engineering data that have benefited subsequent, larger wind plant installations in Iowa, Minnesota, and California. Because the machines' power electronics can lead or lag in power factor, adding reactive power if desired, they can help stabilize the voltage on distribution systems. Variable-speed operation also enables such turbines to convert more of the wind's energy to electricity, boosting production to at least 7% more than that of a comparable single-speed unit.

The EPRI-DOE Wind Turbine Verification Program—designed to evaluate prototype advanced turbines, foster utility experience, and obtain operating and maintenance data—currently has seven participating projects, shown here.

COURTESY NEBRASKA PUBLIC POWER DISTRICT

NPPD and Lincoln Electric: Springview, Nebraska; two 750-kW Zond Z-50 turbines

COURTESY CENTRAL AND SOUTH WEST CORP.



Central and South West: Fort Davis, Texas; twelve 500-kW Zond Z-40A turbines

COURTESY WISCONSIN PUBLIC SERVICE CORP.

Wisconsin Public Service: Glenmare, Wisconsin; two 600-kW Tacke TW 600e turbines

Before establishing the TVP, EPRI and NREL, through its National Wind Technology Center, contributed substantially to the development of power electronics–based variable-speed turbine technology at Kenetech/U.S. Windpower. Many of that company's assets, including its patented turbine design, were acquired by Zond Energy Systems in 1997.

"Our industry has managed to reduce the cost of wind energy to be competitive in many cases with other sources of generation, and the cost will come down further with the next generation of turbines," says Ken Hach, midwest regional manager for Enron Wind. "EPRI's and DOE's help through the TVP has been a big benefit to Enron Wind in our development across the country." Chuck McGowin, who manages EPRI's wind power work, says the field testing and feedback on early-model variable-speed Zond turbines in the TVP "directly satisfied one of the program's key objectives: to bridge the development of new turbine designs and the availability of commercial units."

Adds NREL's Thresher: "Zond has very successfully used the power electronics–based variable-speed technology developed by Kenetech and EPRI to increase energy capture, but even more important for small utilities is the power-conditioning capability to control harmonics and to provide reactive power, or whatever power factor is needed, at an affordable cost. The ability to strengthen distribution systems has been a major part of the value for the smaller public utilities that have bought these new machines."

Edgar DeMeo, who managed EPRI's wind and solar power programs for nearly 20 years and is now an independent consultant in renewables, helped foster, along with key managers at Kenetech/U.S. Windpower, the marriage of wind turbines and modern power electronics–based variable-speed technology. "As one who fought hard for the joint utility-manufacturer variable-speed development program and then watched the demise of Kenetech, I'm very pleased to see the technology live on as a critical contributor to the recent market success of the Zond machine," DeMeo says.

Three other wind power projects have joined the TVP as associates and receive limited technical and financial support for data collection and performance testing, but no financial support for project installation and operation. One is the 41-MW project in Big Spring, Texas, mentioned earlier in the article (p. 12). Another is a 1.2-MW project installed by Wisconsin Public Service and three other Wisconsin utilities in 1998 near Green Bay in a cost-shared tailored collaboration with EPRI. The project's two 600-kW turbines, specially designed for cold-weather operation and optimized for low wind speeds (which average 13.6 mph, or 22 km/h, at the site), were manufactured by Tacke Windenergie of Germany (recently acquired by Zond's parent company, Enron Wind Corporation).

Also a TVP associate is a three-unit, 198-kW project installed in 1997 by Kotzebue Electric Association in Alaska and featuring Atlantic Orient turbines. Kotzebue Electric has since installed seven additional turbines at the site, located 26 miles (42 km) north of the Arctic Circle. Together, the machines enable the small, isolated utility to replace costlier diesel fuel–generated electricity.

NREL's Thresher says the TVP's future will depend on the enthusiasm among utilities for project cost sharing with DOE and continued support for EPRI involvement. "The TVP has brought great value to the participants—DOE, EPRI, and, most of all, the host utilities and turbine manufacturers. DOE is prepared to consider additional TVP projects in which utilities and EPRI can contribute a fair share of the project costs." □

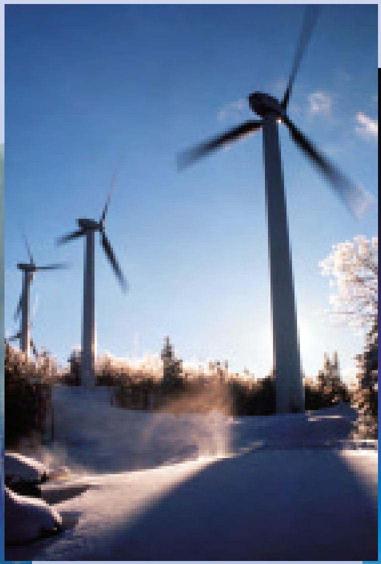
COURTESY CEDAR FALLS UTILITIES

Cedar Falls Utilities: Algona, Iowa; three 750-kW Zond Z-50 turbines

COURTESY KOTZEBUE ELECTRIC ASSOCIATION

Kotzebue Electric: Kotzebue, Alaska; three Atlantic Orient 66-kW AOC 1550 turbines

COURTESY GREEN MOUNTAIN POWER CORP.



Green Mountain Power: Searsburg, Vermont; eleven 550-kW Zond Z-40FS turbines

COURTESY TXU ELECTRIC & GAS

TXU Electric & Gas: Big Spring, Texas; forty-two 660-kW Vestas V47 turbines, eight 1.65-MW Vestas V66 turbines since early 1998 are now supplied by green power marketers.

And although no wind power is yet sold through the power exchanges, two new wind generating facilities specifically for California's green power market have recently been announced. Enron Wind installed 22 of its 750-kW Zond Z-50 turbines at a 16.5-MW project east of Palm Springs to supply green power marketers whose customers include municipal utilities, government agencies, and commercial companies (for example, the outdoor-clothing maker Patagonia). Meanwhile, three 700-kW NEG Micon turbines have been installed by SeaWest at San Gorgonio Pass near Palm Springs to supply wholesale power to serve Green Mountain Power's residential customers.

In contrast to the six states whose legislators or regulators have adopted the Renewables Portfolio Standard strategy, which specifies percentages of overall electricity supply that must come from renewable resources by a certain time, California is taking a different route to building a sustainable renewable energy industry. The 1996 legislation that deregulated the state's electricity market established a $540 million renewables trust fund (to be collected from 1998 to 2002 from the ratepayers of investor-owned utilities) for renewable energy projects and R&D.

Last July, the CEC completed a financial incentives auction that allocated $162 million to 55 new renewables-based development projects, including several involving wind energy. In the previous year, the CEC joined EPRI, funding seven target areas, including distributed generation. This year the CEC joined EPRI's renewable energy target through 2000. It also sponsors tailored collaboration with EPRI aimed specifically at benefiting California's wind energy industry (see sidebar below).

Forecasting to Improve Wind's Economics

The deregulation of the California wholesale electricity market is creating a challenge for wind plant owners and operators. The variability of wind speed and direction—and, in turn, electricity generation—exposes operators to risk when bidding to supply real-time and next-day wind energy and ancillary services. At times of high demand and power shortages, typically very hot days with little wind, the market imbalance price can soar and operators can incur large financial losses if they are unable to deliver on commitments.

Wind energy forecasting can reduce the risk of financial loss by predicting the hourly generation of a wind plant up to 48 hours in advance. Such predictions can, in turn, be used in determining the quantity of energy to be bid for each same-day and next-day hour. Wind power forecasts could also be of great value to power marketers and buyers, utility system dispatchers, and power pool operators, particularly where there is a high level (5–10%) of wind in an overall system generating mix.

"The California Energy Commission identified wind energy forecasting as a high priority for research in its public interest R&D program for renewable energy," says Chuck McGowin, EPRI's manager for wind power. "At the CEC's request—and with supplemental funding from it that we are matching—EPRI is collaborating in a project to develop and test wind energy forecasting systems in California."

Michelle Pantoya, CEC wind R&D program manager, notes, "The primary reason the commission became a member of EPRI was to work collaboratively with it, DOE, and the wind industry to tailor wind forecasting models to California's wind parks. Advances in wind forecasting may make it possible to expand the functionality of wind parks to include control system logic that can automate the dispatching of turbines, thereby increasing the value and overall market competitiveness of wind power. We see wind forecasting as one of the most promising approaches for leveraging the economics of wind power into a range that is directly competitive with electricity generated with natural gas."

The CEC-EPRI project aims to develop within the next two years a forecasting system that will be operated at a single site and will produce two or more daily forecasts of hourly wind generation over the next 48 hours for each of the principal wind generation areas in the state. The forecasting model consists of a numerical wind simulation model, which predicts hourly wind speeds and directions at the reference point, and a wind plant power curve, which estimates wind energy production as a function of wind speed and direction. The automated system will be operated by a weather service provider, and forecasts will be sent by electronic mail to clients—wind facility owners and operators, the California Independent System Operator, the California Power Exchange, and the Automated Power Exchange. A computer graphic display of wind energy forecasts for major wind facilities or areas of the state may be possible.

Initially, the project will develop a forecasting model for a single California wind plant and will test it through comparisons with observed wind generation during a one-month period. Then three parallel wind energy forecasting systems will be developed and will undergo longer-term testing at four wind plants, one in each of the major wind areas. The models will be developed in parallel by Weather Services International (with technical assistance from Wind Economics & Technology, Inc.); Denmark's Risø National Laboratory; and TrueWind Solutions, a New York state partnership involving MESO, Inc., AWS Scientific, Inc., and Brower & Company.

Wind energy forecasts for the four wind plants will be scaled up to produce regional and statewide forecasts. The final phase of the CEC-EPRI project will entail selecting one of the three systems for application, adding more wind plants, refining the scale-up to regional forecasts, and releasing the system for commercial deployment after 2002. □

Technology breakthroughs essential

Wind energy advocates generally applaud the ambitious goals of DOE's Wind Powering America initiative. Targets along the road to wind power's meeting 5% of U.S. electricity needs by 2020 are to double the installed turbine capacity to 5 GW by 2005 and then to double it again to 10 GW by 2010. The initiative also seeks to increase the number of states with more than 20 MW of installed capacity from 8 to 16 by 2005 and then to 24 by 2010.

Experts widely agree that for wind power to reach these stretch goals, the cost of wind-generated electricity must be reduced to about 2.5¢/kWh within the next five years or so (or, alternatively, the perceived value of green electricity must be greater than it currently is). A turbine capable of generating electricity at this cost—and over a wide range of wind regimes and site conditions around the world—will have to be engineered to be much lighter, simpler, and cheaper to manufacture than today's turbines. It will also have to make extensive use of more-advanced power electronics. Turbines generating electricity at half the cost of today's machines "is no small challenge, but this administration is committed to making that goal a reality," Energy Secretary Richardson told an AWEA conference when he announced the federal initiative.

The next generation of lower-cost, advanced wind turbines is expected to become commercially available in the next two to three years as a result of technology R&D by turbine manufacturers sponsored by DOE's National Renewable Energy Laboratory (NREL) and the CEC. Advanced turbines are being designed that feature lighter, larger rotors and towers, variable-pitch airfoils, synchronous generators, low-speed direct drive, and power electronics–based variable-speed operation.

Zond Energy Systems and the Wind Turbine Company are each developing megawatt-scale turbines under the program. Zond's design features a three-bladed upwind rotor, while the Wind Turbine Company's design is for a somewhat more experimental two-bladed machine. The CEC is also supporting the latter company's nearer-term development of a prototype turbine capable of generating power at a cost of 3.5¢/kWh by 2001, as an intermediate step toward the ultimate next-generation machine.

"Manufacturing and assembly of individual turbines account for approximately 50% of installed capital costs for wind generating facilities, and these capital costs, in turn, account for approximately two-thirds of total project costs," notes Michelle Pantoya, who manages the CEC's wind R&D program. "Research, development, and demonstration efforts that yield lower-cost turbine manufacture and assembly can potentially reduce the cost of wind-generated electricity significantly."

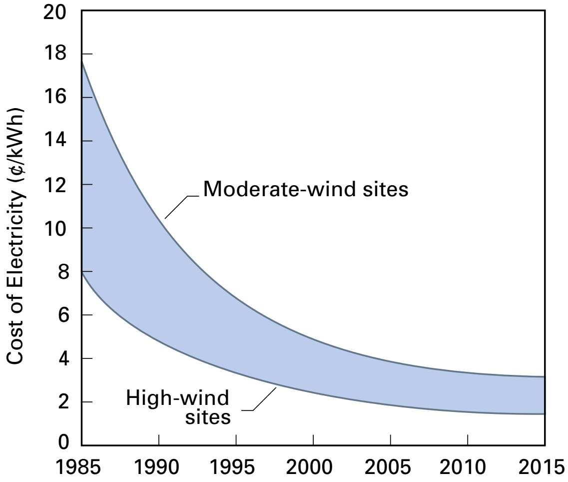
Robert Thresher, NREL's wind program director, notes that European turbine manufacturers are developing advanced designs for 5-MW machines with rotor diameters of 100–110 meters (330–360 ft), initially for offshore deployment in Europe, where onshore sites are scarce. "The wind environment in our Great Plains is even better than the offshore resource in Europe, so we could well see European turbines of that size deployed here in the next 10 years. But innovation, such as on-site manufacturing, will be needed to keep installation costs down," Thresher says.

"For folks in the U.S. wind and utility industries who want advanced technology developed and commercialized, now is the time to start thinking about how to get there," he continues. "Each time the manufacturers have scaled up to larger machines, the cost of electricity from wind has dropped, and European manufacturers have done it for three generations of technology. I expect costs will come down another notch with the next generation."

Halving the current cost of wind-generated electricity would make this power directly competitive, without subsidy, with electricity generated by new gas turbine combined-cycle plants, the most economical technology for new capacity available today. Achieving that goal, while difficult, is not unrealistic, given the progress that has been made over the past 20 years.

"Wind Powering America is our main focus now because wind technology has improved so dramatically over the past 20 years—the reliability has increased while the cost has decreased," says Dan Adamson, DOE's deputy assistant secretary for efficiency and renewable energy. "Although wind power is not yet competitive with wholesale power, it's getting close—so close that we believe the DOE initiative, combined with our ongoing activities like the Wind Turbine Verification Program with EPRI [see sidebar, p. 14], can help make a difference.

"Of all the renewable technologies, wind power is the closest to market competitiveness today. When you consider the improved technology, the opportunity for consumers to choose green power, and the concerns over climate change, it all adds up to a strong potential for wind to really take off over the next 20 years." ■



Improved technology, larger turbines, and economies of scale achieved in manufacturing and installation have reduced the average cost of wind-generated electricity in the United States to around 5¢/kWh. Experts say the cost must be reduced further, to about 2.5¢/kWh, for wind power to directly compete with the lowest-cost forms of fossil power and significantly expand its share of total generation. (The graph shows costs in constant 1996 dollars and assumes 100-turbine wind plants.)

GRAPH COURTESY U.S. DEPARTMENT OF ENERGY

Background information for this article was provided by Chuck McGowin (cmcgowin@epri.com) and Terry Peterson (tpeterso@epri.com), Science and Technology Development Division.

Viewing Corona

in the Daytime

The Story in Brief

The presence of corona activity is a good indication of trouble with nonceramic insulators and other transmission line equipment. But since corona radiates in the ultraviolet region of the light spectrum, it is invisible to the naked eye, and conventional corona cameras are ineffective in daylight because sunshine drowns out the corona's image. Responding to the need for better technology, EPRI researchers and engineers from Ofil Ltd. developed the DayCor daytime corona camera, which features bispectral imaging for effective use in daylight. This breakthrough camera, which has already been successfully field-tested on utility transmission systems, will enable utilities to perform comprehensive airborne inspections safely and economically.

• by Lee Harrison •

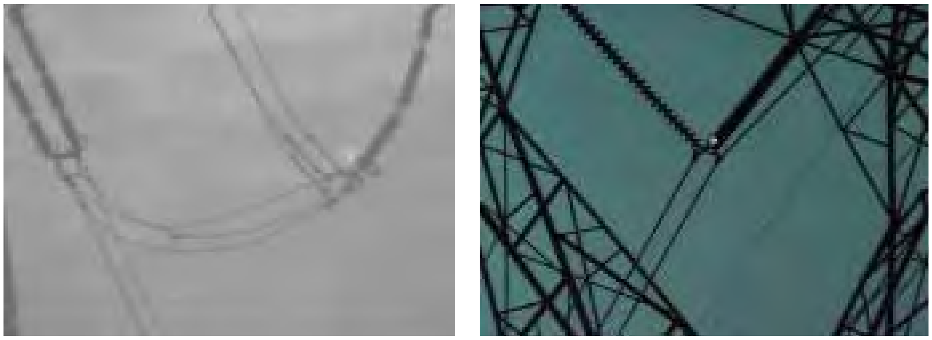
Corona from overhead transmission lines means trouble for utilities. In addition to causing noise and radio interference problems, these luminous discharges, which result from the ionization of air around an electrode, may indicate the presence of faulty transmission line and substation components. Thus, identifying sources of corona is high on most utilities' lists.

The problem is that corona is almost impossible to see during the daytime with currently available devices, and nighttime viewing—either from the ground or by helicopter—is often difficult, inefficient, and expensive. Other methods for detecting corona activity, including listening for audible noise and measuring radio interference, are affected by background noise and cannot be used to pinpoint the source of corona.

Because of these limitations, utilities have used corona inspection to identify defective components only sparingly, mostly to investigate customer complaints about audible noise or radio interference. Something better was needed, and Andrew Phillips, a senior research engineer at the EPRI Energy Delivery and Utilization Center in Lenox, Massachusetts, found it on the Internet. But more about that later.

Now, after nearly 12 months of R&D, Phillips and his development team have successfully tested—on the ground and from a helicopter—a prototype daytime corona camera that can spot corona anywhere on a transmission line or substation in full sunlight. By allowing utility maintenance personnel to look for corona activity during the daytime, this device—called the EPRI DayCor camera—will make it possible for them to inspect more structures in a day than ever before and to conduct airborne inspections of transmission lines. Such capabilities, says Phillips, will lower maintenance costs while increasing the reliability of electric service.

Engineers at the Tennessee Valley Authority agree. "This is a breakthrough technology," says Fisher Campbell, a TVA project manager who has worked with EPRI in the development of the DayCor prototype. "It allows daytime corona inspections that were not previously possible." TVA plans to use the camera in its substation predictive maintenance program and for inspections of nonceramic insulators (NCIs) and other transmission line hardware in suspected problem areas. "Ultimately," Campbell adds, "we would like to employ the DayCor camera in airborne inspections. That would allow us to inspect our 17,000 miles of transmission lines for corona and to work the camera into our routine line inspection program."



Ofil Ltd.'s early experiments with two cameras and a solar blind filter demonstrated that it is possible to photograph corona discharge, and to indicate its position, in the daytime. Refinements built into the DayCor camera prototype provide a significantly clearer image.

Surfing for a solution

In 1997 Phillips, who had come to EPRI the previous year from the University of the Witwatersrand in South Africa, began a study of techniques for evaluating NCIs in service—work that culminated in the publication of the *Application Guide for Transmission Line Nonceramic Insulators* (TR-111566). During that study, Phillips determined that the presence of corona activity is one of the best indicators of defective NCIs; unfortunately, the equipment to detect corona in daylight did not exist.

"We had evaluated all current corona inspection equipment, and nothing worked as well as we had hoped," he says, "so I was surfing the Internet to see what else might be available. This led me to Ofil Ltd., an Israeli company that makes something called solar blind UV filters for use by the Israeli military and for fire detection. I immediately knew this would change everything."

Located in the UV, or ultraviolet, range of the light spectrum, the solar blind band is of great interest, notes Phillips, because all the sun's radiation in this frequency band is absorbed by the ozone layer in the upper atmosphere; none actually reaches the earth. "Therefore, this spectral band is as 'dark' at noontime as it is at midnight," he says. "Because corona emits radiation in this band, it would be possible to detect corona even in bright sunlight—if you had the right equipment."

To develop that equipment, Phillips immediately contacted Ofil. "I told them I was interested in their technology but needed proof it could be used to view corona. They forwarded a measurement they had made—not even an image, just a spectral graph. While the graph supported the concept we were pursuing, it wasn't what we were looking for. We knew we should be able to observe corona discharges in daylight by viewing them through a solar blind bypass filter, but without the ability to overlay the corona image on an image of the structure under scrutiny, it would be impossible to determine the exact location of the activity. We needed to see an actual image of the corona.

"After some discussion, Ofil conducted tests with cameras hooked up in parallel and was able to capture an image of corona on a transmission line, and that really got me excited. We were finally able to view corona on actual structures during the daytime. We then turned to the task of developing a practical device that utilities could use; the DayCor MKI prototype was the first step in this process." Phillips confesses to being amazed at the speed of the camera's development from concept to prototype. "All our communication was via e-mail," he says. "The Internet made it all possible."

The DayCor MKI employs bispectral imaging to solve the image overlay problem; that is, it uses a UV beam splitter to create a duplicate of the incoming image. One image is sent through the solar blind filter, which eliminates solar radiation, then through an image intensifier and a charge-coupled device camera. The other image is sent through a standard video camera. The two images are then processed and combined in an image mixer, which produces an image of the corona exactly as it appears on the insulator, conductor, or other line component. This makes it possible for utility personnel to pinpoint the exact location of the corona and take corrective action.

Corona discharges emit UV radiation from 230 nm to 405 nm, but the DayCor camera is designed to detect the radiation in only the 240–280-nm range in order to stay within the UV solar blind band. Although the use of this narrowed range results in a somewhat weaker signal, the DayCor camera is equipped with an image intensifier and is able to provide high-quality, high-contrast images owing to the complete absence of background radiation.

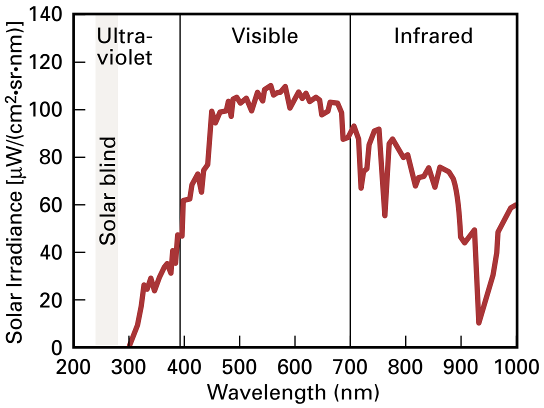
Testing the technology

Ofil delivered the prototype DayCor camera in the spring of 1999, and EPRI researchers immediately put the unit through a series of indoor and outdoor tests at the Lenox facility. "We were all very excited, but as with any new technology, nothing could be taken for granted," says Phillips. "We had to invent everything as we went along—how to hold the camera, how to keep it steady while it is operating, where to stand in order to get the best image, and so forth."

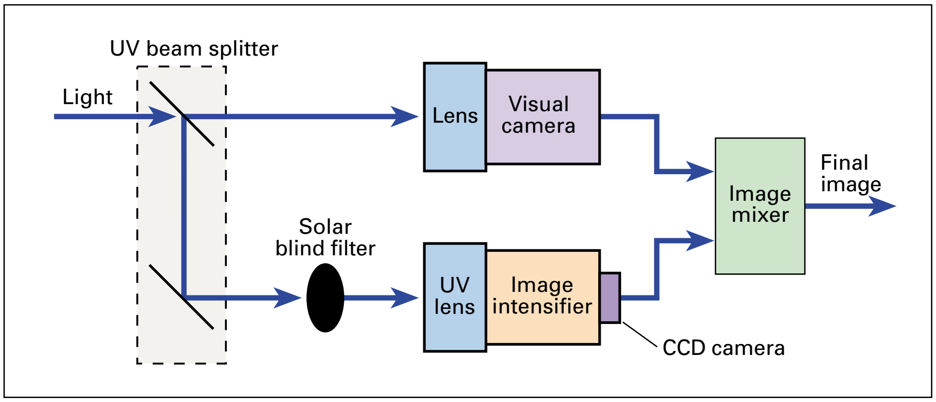
In the first tests at Lenox, the camera was focused on the end fittings of a 500-kV NCI that was installed without grading rings. Corona in such situations is common and not only results in customer complaints about audible noise and radio interference but also degrades the polymeric rubber material of the NCI, which in turn can cause premature failure of the insulation. "In the first test, the corona activity was audible but not visible to the naked eye," says Phillips. "Yet, as we had hoped, the DayCor camera was able to produce a good image of the corona, something that two nondaytime corona cameras could not do. This showed that we were on the right track."

The next series of tests involved a defective NCI that had been removed from the field after four years of service. To simulate in-service conditions and viewing positions, the researchers installed the NCI outdoors on a simulated tower at a height of 48 feet (15 m). After the tests were completed, the researchers compared results from the DayCor camera with those from two other inspection devices: a nondaytime corona camera and an infrared camera.

As before, the DayCor camera was able to observe significant discharge activity and hence identify the defective insulator. The nondaytime corona camera was unable to observe any discharge activity, even though the inspection was conducted on a heavily overcast day. This confirmed previous EPRI work indicating that sunlight renders nondaytime corona cameras unsuitable for daytime inspections. A small amount of heating was observed in the image from the



While the sun radiates light in ultraviolet, visible, and infrared frequencies, all of the radiation in the so-called solar blind band (part of the UV range) is absorbed by the ozone layer in the earth's upper atmosphere. As a result, no background solar radiation is detectable in this band day or night. Because corona discharge radiates in the solar blind band, corona can be detected clearly when all other solar frequencies are blocked out by means of a solar blind filter.



The DayCor camera uses bispectral imaging to superimpose the image of a corona discharge over the image of the faulty equipment producing it. The light entering the camera is split, and one copy of the image goes through a conventional camera that records what is visible in daylight. The other image passes through a solar blind filter, which blocks out all of the light spectrum except a narrow band of ultraviolet in which corona radiates. The corona image is picked up by a charge-coupled device (CCD) camera, and the two images are mixed for the superimposed output.

Images from comparative tests of (left to right) a nondaytime corona camera, an infrared camera, and the DayCor camera show that the DayCor is the only option practically suited for detecting corona discharge in daylight.

infrared camera, "but if it had not been an overcast day and the sun had been shining brightly, this increase in temperature would not have been discernible from background solar radiation," says Phillips. The DayCor camera clearly was the best method for identifying an NCI with this type of defect.

After the successful tests at Lenox, Phillips and his team took the DayCor camera on the road to test its capabilities on structures belonging to several utilities that were participating in the development project. Here, too, the camera identified numerous corona sources in broad daylight. During an in-service inspection of one utility's 500-kV steel lattice tower, the DayCor camera identified two principal sources of corona: broken wire strands on conductors about one-quarter span from the tower, and a possibly defective porcelain bell near the energized end of the vee-string configuration that supports the center phase. "The utility's line workers had reported a high level of audible noise coming from the tower, but they had not been able to identify the cause of the noise or its location," says Phillips.

In another test, EPRI researchers used the DayCor unit to evaluate transmission line components on a number of 115-, 161-, 230-, 500-, and 765-kV line structures. "Some of the NCIs had been in service for more than 20 years, while others had been installed recently," notes Phillips. "In one case, the DayCor camera plainly showed that the grading ring attached to the insulator was inappropriate for the application." In other tests, the camera captured images of corona activity from a 765-kV substation bushing and from broken conductor strands on 230-, 500-, and 765-kV transmission lines.

While the field tests strongly validated the DayCor's potential value to utilities, they also revealed an important shortcoming of the camera prototype. "Insulators on the 765-kV structures were a considerable distance—about 90 feet [27 m]—from the ground," says Phillips. "This fact, along with the DayCor camera's relatively large field of view, made observations of corona activity difficult. We will be reducing the field of view of the final version of the DayCor, allowing closer, more effective inspections of such structures."

Helicopter inspections

In July 1999, EPRI and TVA staff conducted the first aerial inspections for corona activity with the DayCor camera. Until then, the use of a helicopter to perform visual inspections of long sections of transmission line for corona activity had been all but impossible: airborne inspections are practical only during the day, but corona could be viewed only at night. "We were confident that the DayCor camera could be used successfully from an airborne platform, and these tests confirmed it," says Phillips. "Inspections by helicopter will revolutionize the maintenance of transmission lines."

During such an inspection, the operator observes power lines or components in real time through the DayCor's viewfinder, and the images can be saved simultaneously on a videotape recorder. This has two benefits, Phillips notes. "It enables the operator to conduct an inspection quickly, which helps to reduce costs—a critical factor with airborne inspections—and it allows a detailed review of the results at a more convenient time and place." In the not-too-distant future, he goes on, "inspectors will be able to 're-fly' a transmission line and look for corona with a cup of coffee in one hand and a computer joystick in the other."

For the TVA helicopter inspections, the DayCor MKI prototype was mounted on the lap of an operator who sat in the rear seat and controlled the camera's viewing direction and settings. The "lap mount" for the camera consisted of a board strapped to the operator's legs. A three-axis tripod head was mounted on the board, allowing the operator to easily adjust the camera's viewing angle. A single-axis gyrostabilizer

The DayCor camera was used to pinpoint corona activity on a New York Power Authority transmission line suspected of causing interference with the broadcasts of a local radio station. The results ruled out corona from the line as the cause of the interference.

was installed between the tripod head and the camera to prevent unwanted vibrations from affecting the images—an enhancement that the researchers found unnecessary because of the camera's wide field of view. The need for a gyrostabilizer will be reassessed for later versions of the DayCor camera, which will have a narrower field of view.

The entire TVA inspection was recorded on 8-mm videotape, which clearly shows corona activity on 500-kV conductor bundles at several points on the TVA system. Subsequent helicopter inspections of NCIs on the Alabama Power and Georgia Power systems also identified problem insulators. "We're not yet sure what remediation might be required in these cases, but the utilities are happy that we were able to pinpoint potential problems before they created serious difficulties for them and their customers," says Phillips.

Real-world problem solver

The six months of laboratory and field testing have strongly convinced investigators of the corona camera's capabilities. But the DayCor's success is not limited to tests. One utility has already used the camera to resolve a potentially serious problem. When a local radio station in upstate New York began to experience radio interference, the problem was thought to be corona from a nearby New York Power Authority 765-kV transmission line. To resolve the issue quickly, NYPA asked Phillips to use the prototype DayCor camera to identify the source of the problem.

The device found a number of sources of corona activity on the 20-year-old transmission line, but none of these sources were in the beam pattern of the radio station's antenna. Says NYPA's Pete Muench, "The technology for daytime corona viewing developed by EPRI allowed us to prove that our line was not the source of radio interference." The utility avoided a lengthy investigation of its transmission line, which could have resulted in additional expenditures or line repair.

Other utilities involved in the development of DayCor technology are just as enthusiastic. "This device works," says Rick Stearns, a project manager at the Bonneville Power Administration. "I'm very excited about the promise it holds for use as a routine maintenance inspection tool. The early detection of corona discharge on high-voltage apparatus will allow us to replace defective components before catastrophic failure." In turn, Stearns continues, "this will help to improve system reliability and greatly reduce the financial risks that are associated with costly line dropping, tower and hardware damage, and unplanned outages."

Daytime corona inspection from a helicopter is a valuable, previously unavailable capability for transmission line maintenance. In airborne field tests on the Tennessee Valley Authority system, Andrew Phillips manipulated the camera with a three-axis tripod head mounted on a lapboard that was strapped to his legs. The inspection was recorded on 8-mm videotape.

Paul A. Dolloff, an engineer with East Kentucky Power Cooperative, shares these sentiments. "The DayCor camera will allow us to routinely check the integrity of NCIs in the field, thereby avoiding a systemwide change-out program."

Future developments

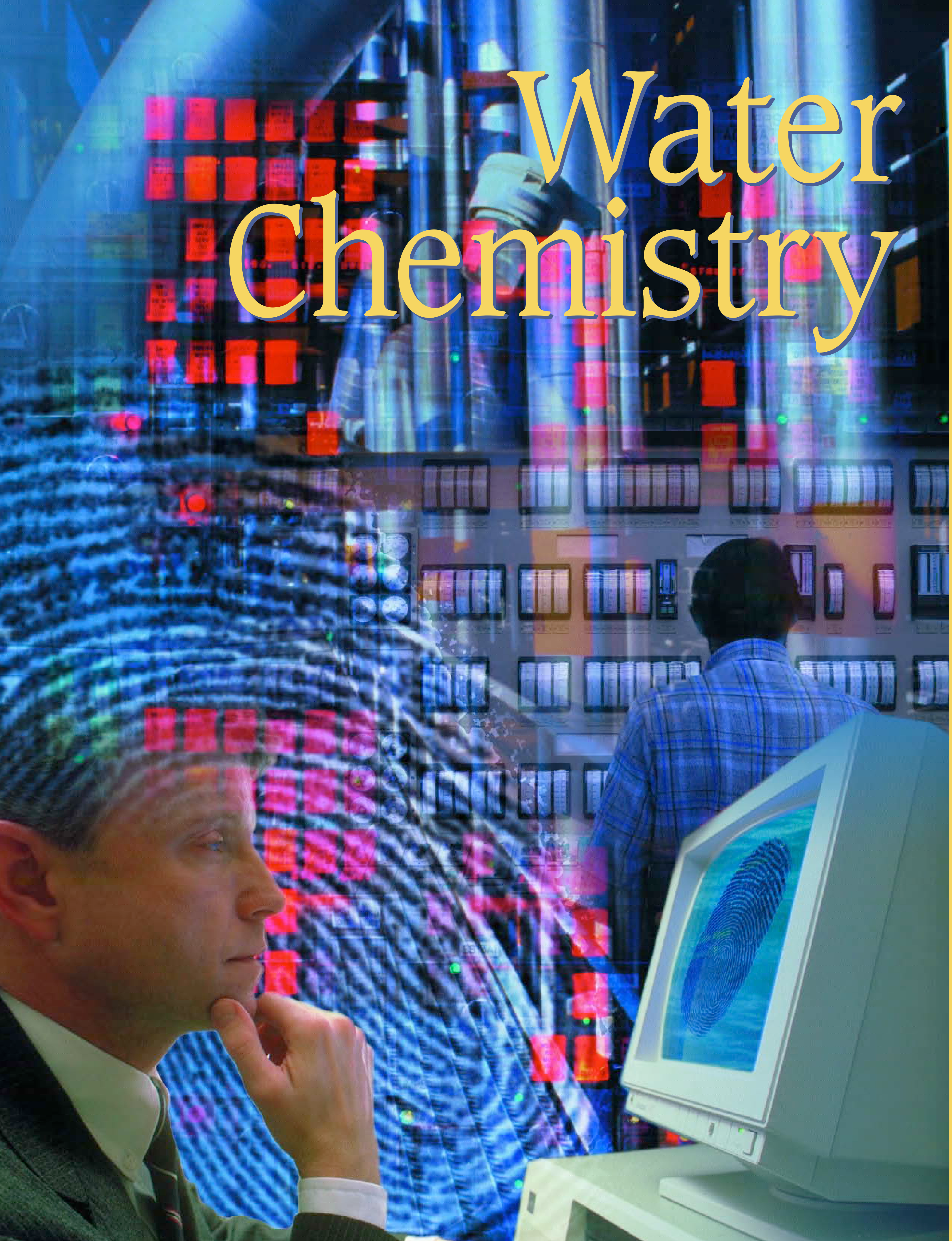
Even though the technology has met every goal so far, Phillips and his utility partners in the DayCor project are already working to improve the camera. The unit's weight and size will be reduced, and the ergonomics improved, for easier handling in the field. Technical refinements will include increasing the optical magnification and sensitivity, reducing spurious noise, and developing the capability to capture individual image frames for record-keeping purposes.

Next year EPRI will begin work on a DayCor camera application guide—in effect, a user's manual for utilities. Publication is slated for 2001. "The guide will not only discuss what you can see with the camera but also explain how to interpret the results," notes Phillips. "It will present detailed instructions on how to hold, mount, and use the camera, as well as specify appropriate viewing distances and other parameters for obtaining maximum benefit from this new technology."

Preproduction prototypes of the improved DayCor MKII will be supplied to some of the utilities that have partnered in the camera's development, including TVA, NYPA, Alabama Power, Allegheny Power, East Kentucky Power Cooperative, and Central Hudson Gas & Electric. And there are still opportunities for funding development and for investigating further applications. DayCor units are expected to be available on the open market by the end of the year 2000.

"The DayCor technology has the ability to fundamentally change the way utilities deal with corona problems," says Phillips. "Laboratory and field test results have already exceeded our expectations. With further improvements, which are under way, we believe this device will prove indispensable for the inspection of transmission line and substation components." Not a bad result from a little Net surfing. ■

Background information for this article was provided by Andrew Phillips (aphillip@epri.com), EPRI Energy Delivery and Utilization Center, Lenox, Massachusetts.


Water Chemistry

Off-Site *and* On-Line

THE STORY IN BRIEF

A new approach to nuclear plant water chemistry monitoring, SMART chemWORKS uses secure, high-speed Internet connections to deliver a remote, turnkey solution for real-time evaluation and diagnostics. The analysis software, located at EPRI's headquarters in northern California, receives raw data from customer facilities throughout the United States on a near-continuous basis. Integrating site-specific process models with an artificial intelligence engine, SMART chemWORKS compares current conditions to an internal library of "data fingerprints" representing individual operating scenarios. Customers receive valuable, real-time information on the current operating state and, if off-normal conditions are detected, on the problems that may be occurring.

KEN COX

Entergy's Waterford 3 pressurized water reactor plant sits on the banks of the Mississippi River just outside New Orleans. Yet some of the monitoring and diagnosis of the plant's water-steam chemistry is done in real time some 2000 miles away—in building 5 of EPRI's Palo Alto, California, headquarters. Entergy and other companies around the country are finding that this unlikely setup not only makes sense but is the smart way to go to improve monitoring capabilities while reducing costs.

Taking advantage of the Internet's real-time communications capability, the remote monitoring system—known as SMART chemWORKS™—integrates a plant's existing data management system with a customized intelligence engine and EPRI's industry-standard family of codes for chemistry analysis and optimization. From the 1165-MW Waterford 3 unit, for example, new data on more than 30 parameters are sent every 5 minutes via the Internet to EPRI's on-line monitoring server; there the data are automatically evaluated for consistency, and questionable or bad sensor readings are flagged. The system's analysis codes then simulate the chemistry throughout the water-steam cycle, evaluate the chemical state of the plant, and diagnose actual or potential problems, all on a near-continuous basis.

The SMART chemWORKS output data, analyses, and advice can be reviewed from anywhere by Entergy staff with access to a dedicated, secure Internet connection: by chemistry personnel on-site at Waterford; by Bill Burke, corporate chemist, from his office in Jackson, Mississippi; by Ron Stanley, technical specialist in charge of secondary-side chemistry at Waterford, from his home in Bayou Gauche, Louisiana; or by Gary Dolese, technical specialist in charge of primary chemistry at Waterford, from his next vacation destination.

Dedicated EPRI application engineers monitor the on-line system's performance and output all day, every day, and provide round-the-clock technical support. This independent monitoring offers Entergy an additional perspective in managing and optimizing the plant's water chemistry during normal conditions and off-normal events. If an incipient problem or upset condition is detected, SMART chemWORKS triggers alarms, paging or e-mailing Entergy's chemistry personnel and EPRI's specialists wherever they are.

"SMART chemWORKS takes a little getting used to," admits Peter Millett, team leader for chemistry and steam generator technology in EPRI's new service-oriented subsidiary, EPRIsolutions℠ (see Inside EPRI, this issue, p. 34). "It's off-site, out-

by Christopher R. Powicki

sourced, Internet-based, and driven by an artificial intelligence engine. These characteristics mark a pretty significant departure from the traditional way companies perform on-line monitoring of critical operations, but they underlie the system's economic efficiencies. The software's advantages are somewhat counterintuitive: its intelligence reduces sampling and manpower requirements, but chemistry control is actually improved."

Genesis

Water chemistry plays an important role in corrosion and other materials degradation mechanisms in nuclear plants. Chemistry-related problems can cause component failures, decrease energy conversion efficiency, and contribute to personnel radiation exposures. Understanding and managing water chemistry are thus critical to maximizing the availability, profitability, and safety of nuclear plants. For aging units, effective chemistry control may be the key to continued economic operation.

Worldwide, most nuclear plants employ one or more modules from EPRI's chemWORKS family of computer codes for optimizing water chemistry programs. The two most powerful modules simulate the secondary cycle of pressurized water reactors (PWRs) and the steam cycle of boiling water reactors (BWRs). Other codes focus on specific parameters (e.g., pH), chemicals (e.g., amine additives), damage mechanisms (e.g., crevice corrosion), and operational procedures or problems (e.g., plant shutdown or hideout return).

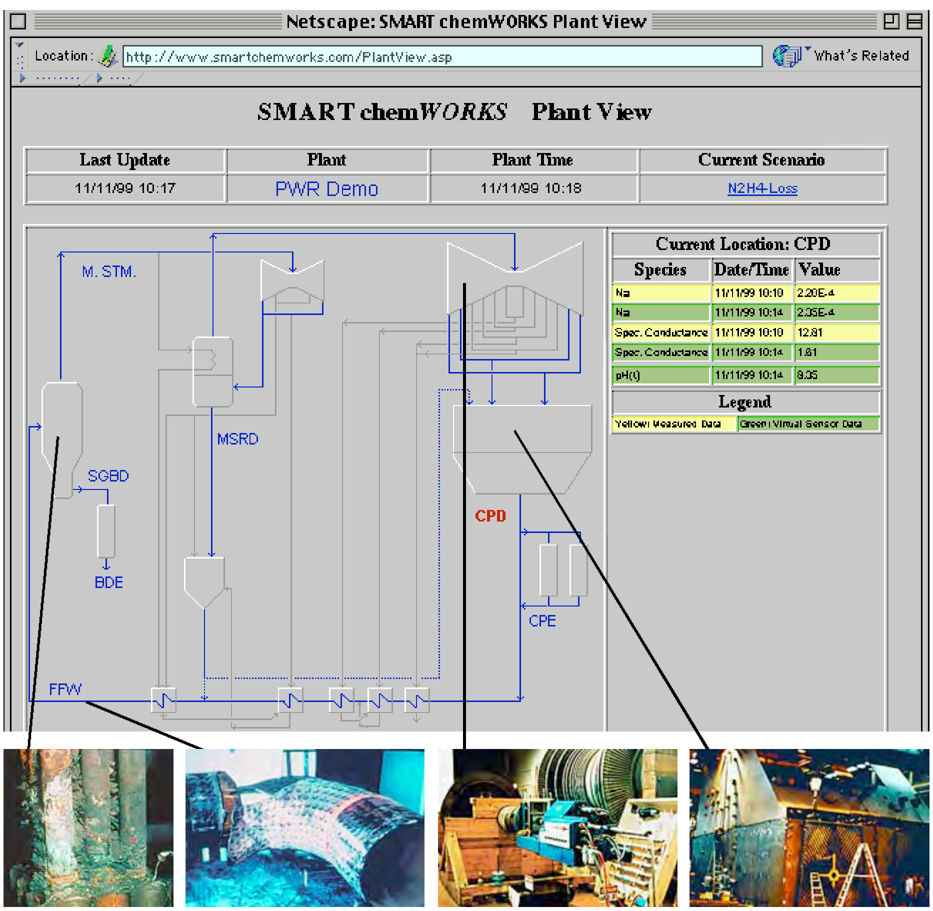
"The chemWORKS codes have been enthusiastically received by the industry, producing millions of dollars in savings by helping reduce corrosion problems, failures, availability losses, and O&M costs," says Tina Gaudreau, EPRIsolutions manager for chemistry and corrosion technology. "But while these codes are technically state of the art, they do have some operational limitations: they can be used only off-line, they offer limited predictive capacity, and they require in-house expertise and manpower for fully exploiting their complex capabilities on a unit-specific basis." Typically, EPRI assists users by providing technical support during implementation and off-normal events, as well as during routine maintenance and upgrading of the software.

The idea behind SMART chemWORKS was to build on the success of chemWORKS by improving its ease of use and addressing the increasingly intense cost pressures faced by nuclear power producers. "Chemistry departments are being challenged to do more with less—to simultaneously minimize operational impacts and personnel costs," says Gaudreau. "We envisioned SMART chemWORKS as an off-site, turnkey solution for providing real-time monitoring and diagnostic capabilities, delivering valuable information, and minimizing the need for chemistry personnel to learn the nuts and bolts of the software."

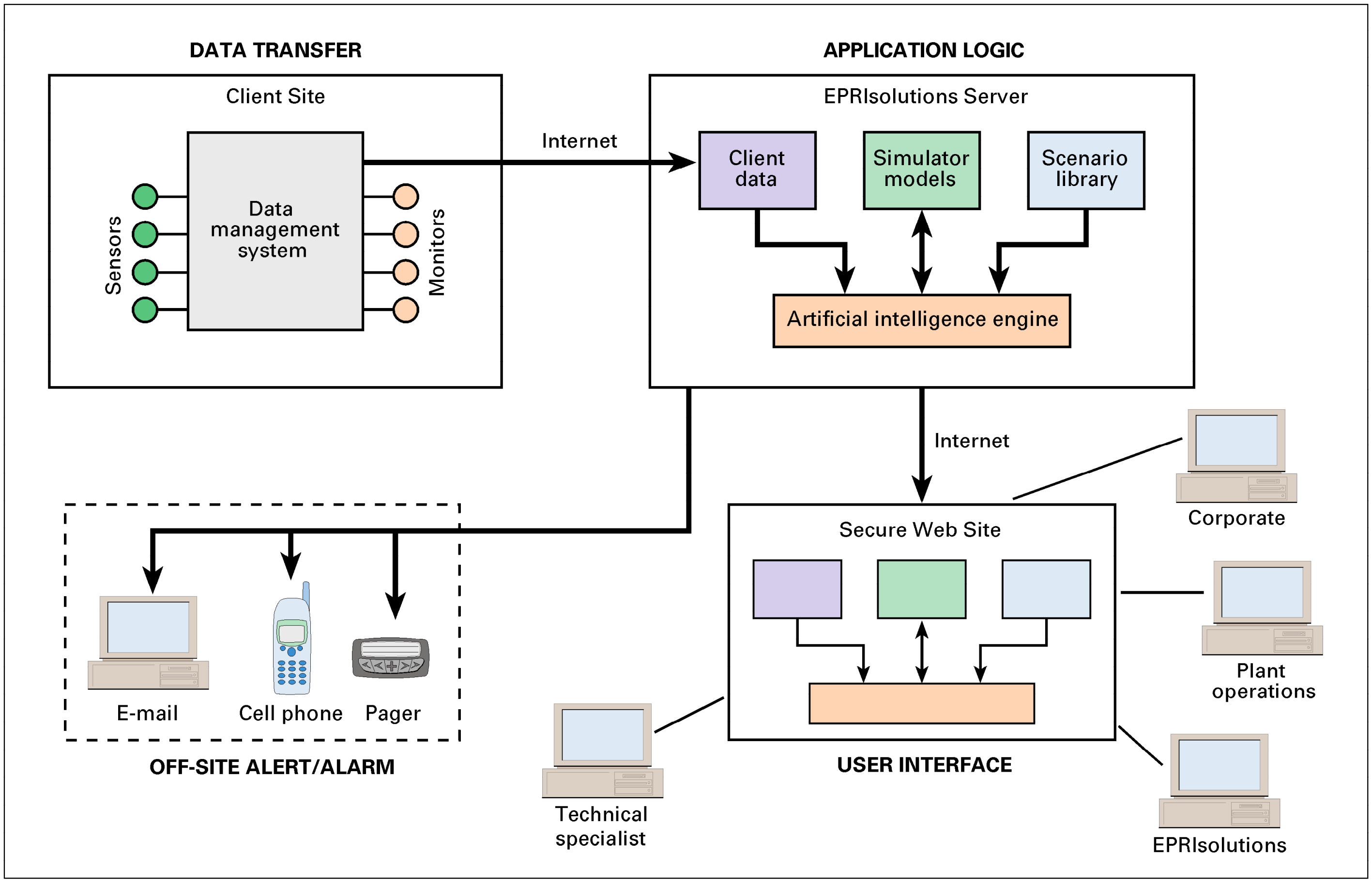
Real-time tools require access to real-time data, however, and many plants lack an on-line chemistry data management system (CDMS) or have only recently begun to implement one. Chemist Bill Burke recalls Entergy's comprehensive evaluation of chemistry-related operations and functions for its nuclear units in 1995. "Our data entry and reporting capabilities were inconsistent as well as antiquated," he says. "In one instance, the same data points were being recorded seven different times, on paper."

To optimize data entry, evaluation, and reporting practices, Burke and his Entergy colleagues provided a vendor with detailed specifications for designing a CDMS. During the design process, Burke learned about EPRI's plans for SMART chemWORKS. "The concept was immediately attractive to Entergy as a way to exploit CDMS capabilities," he says. "Normally, it is necessary to dedicate staff to deploying, operating, and maintaining complex software, but that is very difficult to justify in today's business environment. As a remote, outsourced application, SMART chemWORKS appeared to be an opportunity to get a solid handle on real-time conditions while resolving the resource dilemma."

Entergy's system, known as WinCDMS,



Corrosion is a problem in nuclear plant steam generators, feedwater piping, turbines, and condensers. Optimizing water chemistry for these components is important in order to avoid equipment failures and maintain unit conversion efficiency and capacity factor.



EPRI's on-line monitoring server for SMART chemWORKS analyzes the client's water chemistry information by means of state-of-the-art simulator models, a library of operating scenarios, and an artificial intelligence engine. Output data, analyses, and advice can be viewed on a password-protected Web site, and abnormal-condition alerts are automatically sent to client experts via e-mail, cell phone, or pager. This service architecture can be used for many other remote functions by substituting different application logic modules.

was installed in 1997. WinCDMS receives on-line monitoring data from instrumentation installed in the water-steam cycle at the Waterford PWR. In addition, some chemistry data are manually input to the system following laboratory analyses of grab samples taken at the unit on an as-needed basis. WinCDMS was selected by EPRI as an appropriate interface for the initial field demonstration of the SMART chemWORKS concept.

Fundamental elements

SMART chemWORKS has four components: a chemistry data interface, simulator models, an artificial intelligence (AI) engine, and a Web-based output interface. For every real-world application, each component must be customized with plant-specific information to "teach" SMART chemWORKS the unit's idiosyncrasies.

The data interface can be any CDMS. EPRI has created interfaces for WinCDMS and the LAB-PROF CDMS developed by Duke Power. It has also prepared detailed specifications that can be used to modify any plant's CDMS to communicate, via a secure connection, with the SMART chemWORKS server at EPRI's headquarters. Beyond data communications protocols, another interface issue is that the terminology for specific systems, sampling points, and chemical parameters varies from plant to plant. A pairing table is used to match a plant's nomenclature with the data requirements of SMART chemWORKS. This ensures that appropriate raw data from on-line instrumentation and grab samples are delivered automatically to EPRI at a specified frequency and in an understandable way. "A CDMS and SMART chemWORKS must speak the same language," says Millett. "The pairing table provides a front-end solution for translating a plant's unique dialect into the generic terminology used to simulate real-time conditions."

The software's simulator models expand on the complex PWR and BWR chemistry codes in chemWORKS to simulate plant chemistry on the basis of dynamic as well as fixed input data. Fixed inputs include a detailed description of a plant's fluid flow and thermal conditions in piping components and in major interconnections between piping systems. Real-time CDMS data are analyzed by using deterministic models that take into account material balance constraints, multicomponent equilibrium considerations, and chemical kinetic information.

To ensure that model predictions accurately reflect plant conditions, the simulators are customized on the basis of a combination of current and historical chemistry data. At Waterford 3, for example, a decomposition model was developed for hydrazine and ethanolamine additives, which are used to reduce corrosion throughout the plant's secondary system. Hideout rates for impurities in the steam generators were calculated during cooldown evolutions. And models for the demineralization of blowdown and condensate were devised. Once tuned, the simulators calculate the chemical speciation throughout the water-steam cycle, as well as pH and specific and cation conductivities.

The simulators can also act as "virtual sensors," providing information on chemical conditions at locations where no instrumentation exists. "It's critical to maintain pH control throughout the two-phase regions of a plant, which are highly susceptible to flow-assisted corrosion," says EPRI's Millett, "but high-temperature pH monitoring is costly and not very reliable. Virtual sensors allow plant personnel to infer and track conditions in locations that cannot be instrumented or can be monitored only very expensively."

The AI engine diagnoses the overall chemical state of the water-steam cycle by analyzing both the real-time measurements and the predictions from the deterministic models. The numerous process measurements represent known quantities, even though some degree of uncertainty is associated with each data point. The models predict chemical conditions on the basis of plant-specific phenomena and a small number of unknown quantities. Taken together, the number of knowns far exceeds the number of unknowns; the end result is that plant chemistry is "overspecified."

Overspecification allows the AI engine to produce a best-fit description of system chemistry by using the most certain model predictions to qualify the least certain measurements and vice versa. Bad, old, or unreliable data are flagged and may be removed from consideration. For example, the instrumentation that has operated the longest since its last calibration might produce the least reliable data. Similarly, older data are likely to be less indicative of the system's chemical state than recent readings. And changes in measured or predicted parameters might signify failing instrumentation or actual variations in system chemistry.

Using pattern recognition techniques, the AI engine continuously compares incoming data and overall system chemistry to a library of "fingerprints" that define normal, baseline operating conditions and known upset scenarios at an individual plant. "Just as the ridges and whorls at the tips of one's fingers establish identity, unique combinations of parameter values at specific locations define individual operating scenarios," explains Millett. "Of course, chemistry conditions are dynamic; SMART chemWORKS delivers value-added fingerprinting by analyzing current and historical data to identify where the system is headed."

At Waterford 3, scenario fingerprints

Internet-Based Services for Total Business Solutions

SMART chemWORKS is breaking new ground for both EPRI and its customers, extending the Internet-based application service provider (ASP) model to the real-time monitoring, diagnosis, and control of energy and other systems.

ASPs give companies the opportunity to outsource key business processes. Telecommunications, finance, and transportation are among the industries using ASPs for a growing number of enterprise-wide functions like electronic messaging, payroll, purchasing, order processing, and resource management. And major players and startups in the software, hardware, and consulting industries are racing to exploit the burgeoning ASP market.

"ASPs are rapidly penetrating many industries because they offer an effective way to manage assets in extremely fast paced environments," says Russ Burbank, vice president for power production and special projects at EPRIsolutions, EPRI's new service-oriented subsidiary. "In the energy sector, particularly in power generation, the business tempo is becoming much quicker as the focus shifts from recovering costs to maximizing return on assets. Real-time information makes possible this switch to a more aggressive mode of operation. By integrating the ASP model with our specialized knowledge, EPRI provides the energy marketplace with turnkey solutions for analyzing and optimizing operations in real time."

Under the ASP model, software applications are built for deployment over the Internet. The ASP hosts the application at a remotely located data and hardware center and provides comprehensive support for every customer: customized installation, management, and maintenance, as well as application consulting and training services. The center, networked to individual facilities by fast, secure two-way Internet connections, transforms incoming raw data into high-value information. For a flat monthly fee, customers receive not only real-time information but also access to support 24 hours a day, 7 days a week.

"For many data-centric applications, outsourced, Internet-managed, 'think-wrapped' solutions represent a more cost-effective approach than on-site installations of conventional shrink-wrapped software," says

EPRI's Internet-based ASP architecture promises to enhance analytical efficiency in a wide variety of applications, including steam plant turbine monitoring, silicon wafer manufacturing, and chemical processing.

consist of chemical species concentrations, pH, and conductivities at eight locations in the PWR secondary cycle. Comparing the incoming data with examples in the fingerprint library yields a series of values, each one indicating how well current conditions match a particular scenario; the closest match identifies the scenario most likely to be occurring in the plant. Over time, the fingerprinting process reveals trends in scenario fits—information that can be used to determine what to expect from incipient changes in plant chemistry. For example, as the correlation to one or more upset scenarios becomes stronger and SMART chemWORKS makes predictions with growing confidence, chemistry staff and other plant personnel can focus on these contingencies and attempt to mitigate operational impacts.

For each plant, the software's output interface is a password-protected Web site, accessible on either the Internet or an intranet. Web pages automatically display tables and graphs illustrating incoming data, current conditions throughout the cycle, virtual-sensor data, and scenario fit trends. Data can also be imported to a unit's CDMS for analysis, trending, and storage.

Output also comes in the form of automatic, instant notification via e-mail and pager. The alert function can be configured to notify personnel if significant changes in system chemistry occur (for example, when a measurement goes outside a specified range), if upset conditions are detected, or if the operation of SMART chemWORKS is for some reason interrupted.

Operational advantages

Since becoming fully operational at Waterford 3 on June 6, 1998, SMART chemWORKS has successfully performed routine monitoring functions. It has accurately analyzed changing chemistry conditions in real time, predicted off-normal events, and provided valuable diagnostic information. It has helped identify bad sensors and guided instrument maintenance and calibration efforts.

Plant chemistry personnel are gaining confidence in the software. "SMART chemWORKS has been up for a while, more or less running in the background as we've gone about our business," says Entergy's Gary Dolese. "Initially, it was hard to see the value in an off-site approach, but I'm finding the software's real-time snapshot of chemistry conditions to be increasingly useful. Because we are very busy and not always on-site, it's helpful to have a second set of 'eyes' looking—24 hours a day, 7 days a week—for potentially significant changes in chemistry conditions."

On September 9, 1998, for example, the plant's chemistry was normal as it powered up after an outage; incoming data to SMART

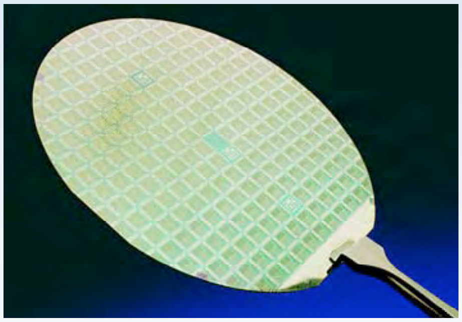
Peter Millett, EPRIsolutions team leader for chemistry and steam generator technology. "There are several benefits for customers: site-specific solutions can be implemented faster; the customers don't have to learn the intricacies of the system or install, maintain, and upgrade the associated information technology infrastructure; and hardware, software, and technical support costs are leveraged by other users."

For EPRI, it is less expensive to develop and deploy Internet-managed applications than conventional software applications. No elaborate interfaces are needed to enable less-sophisticated users to employ complex software. Customer-proofing is unnecessary, and training and technical support requirements are greatly reduced.

Other ASP opportunities, such as real-time monitoring and diagnostics for power transformers and semiconductor manufacturing processes, are being evaluated. "We're cutting our teeth on building and running a round-the-clock ASP operation with SMART chemWORKS," notes Millett. "The key to software development today is reusability. The SMART chemWORKS architecture is highly adaptable, allowing EPRI to easily plug in the business or engineering logic for just about any operation, inside or outside the energy industry. Any large or complex system that requires regular monitoring is a candidate for ASP solutions."

Already, the SMART chemWORKS infrastructure has been used in rapidly and cost-effectively developing a pilot demonstration of on-line turbine monitoring for fossil plants. "In less than six months, we were able to build and implement a tool that monitors Reliant Energy's Cedar Bayou unit 2 steam turbine, validates plant measurements, and trends performance data," says EPRI's Norris Hirota, area manager for fossil and hydro. "The broad deployment of Internet-based applications increases the value of collaboration, enabling EPRI and its members to mine a centralized database of real-time information to develop better solutions to problems and identify R&D needs and emerging issues."

EPRI is building its ASP capabilities within EPRIsolutions. "The ASP model represents a promising approach for achieving our mission, which is to unlock the value of science and technology for our customers," says Karl Stahlkopf, an EPRI vice president and the CEO of EPRIsolutions. "ASPs deliver advanced technical capabilities as a service, providing a cost-effective alternative to training existing personnel in areas outside their expertise or even beyond their skill level. This approach frees up customers to focus on what they do best—using real-time information to manage their business." □



chemWORKS most closely matched the fingerprint for the baseline scenario. Just before 10 p.m., however, the plant began to downpower. Within an hour, the software detected an increase in sodium and started to predict a condenser leak with increasing confidence. By 2 a.m., the match between real-time data and the condenser leak fingerprint was strong, and e-mail alerts were issued to chemistry staff. The alert came 40 minutes before plant personnel actually detected a leak.

Plant control room

Grab sample analysis

SMART chemWORKS server

Because of its advanced chemistry modeling and virtual-sensing capabilities, SMART chemWORKS can increase control efficiency and reduce the need for frequent grab sample analysis. Application engineers staffing the system server at EPRI headquarters monitor its output continuously and provide the customer with round-the-clock technical support.

Chemistry staff reduced hydrazine addition and secured a leaking waterbox, and the software indicated that normal operation was being restored. Soon after, however, it predicted a second condenser leak; the leak was detected at 9:20 a.m., and another waterbox was secured. Yet SMART chemWORKS continued to detect indications of condenser leakage. It was not until after plant personnel initiated cleanup of the secondary system using blowdown and condensate polishers that the software inferred a return to baseline conditions.

"The software sensed the changing conditions, notified me before the leak was detected, and tracked the chemistry pretty closely throughout a rapid progression of events," recalls Ron Stanley. "Because this was a start-up event, we had anticipated some problems and had good on-site staff coverage. In other situations, the software has called upset conditions to the attention of on-site or remotely located staff, prompting confirmatory analyses and actions."

In light of the successful demonstration at the Waterford unit, Entergy is installing SMART chemWORKS at all its other nuclear plants—both PWR and BWR units. "Our immediate objective is to improve front-end analysis of current conditions and recent trends in order to detect potential chemistry problems early and implement effective responses," says Bill Burke. "Reducing chemistry's impact on plant operation and availability offers the greatest return on our investment in the software. We also see real opportunities for near- and longer-term cost reductions."

In particular, SMART chemWORKS is expected to significantly reduce the staff time required for grab sampling and laboratory analysis and the direct costs associated with chemistry monitoring. "The software's modeling and virtual-sensing capabilities minimize the amount of data required to properly account for the chemical state of a water-steam cycle," says Burke. "Redundant sampling points and on-line monitors can be eliminated, and some of the locations at which we now take daily grab samples may need to be examined only once a week. Similarly, to verify the accuracy of our instrumentation, portable on-line monitors or grab sampling might need to be used only monthly rather than weekly."

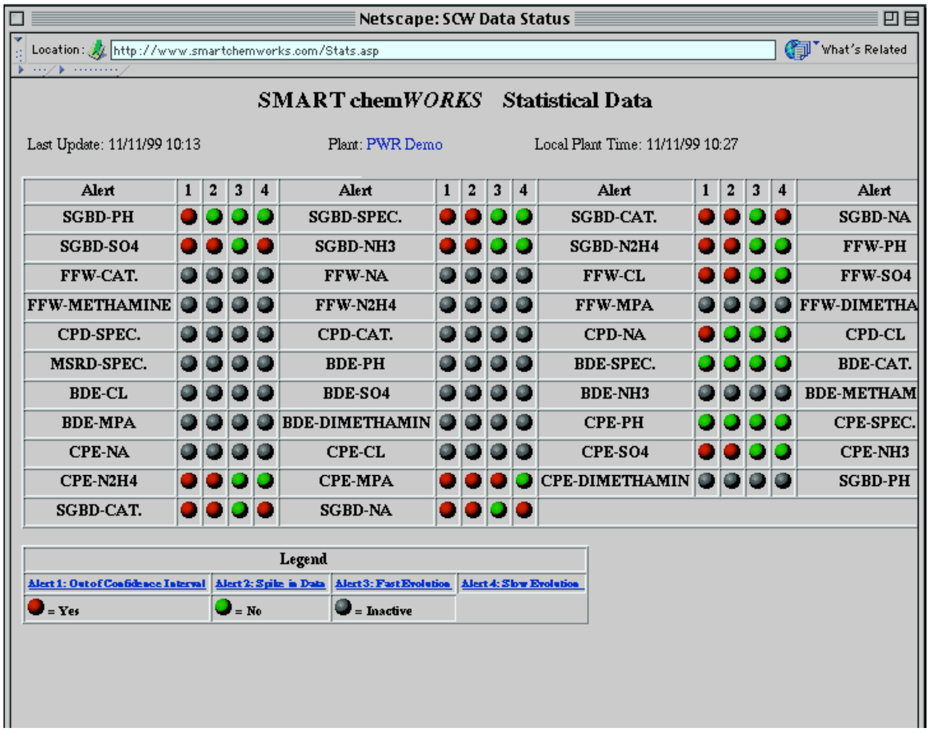
Burke also anticipates that the software will be used to optimize certain maintenance practices, such as condensate polisher regeneration. Typically, regeneration is scheduled on the basis of gallons of throughput or days of operation. By continuously monitoring key parameters upstream and downstream of the polishing unit, SMART chemWORKS will track its efficacy, alert maintenance personnel if early regeneration is necessary, or recommend an extension of the regeneration interval.

Accelerating deployment

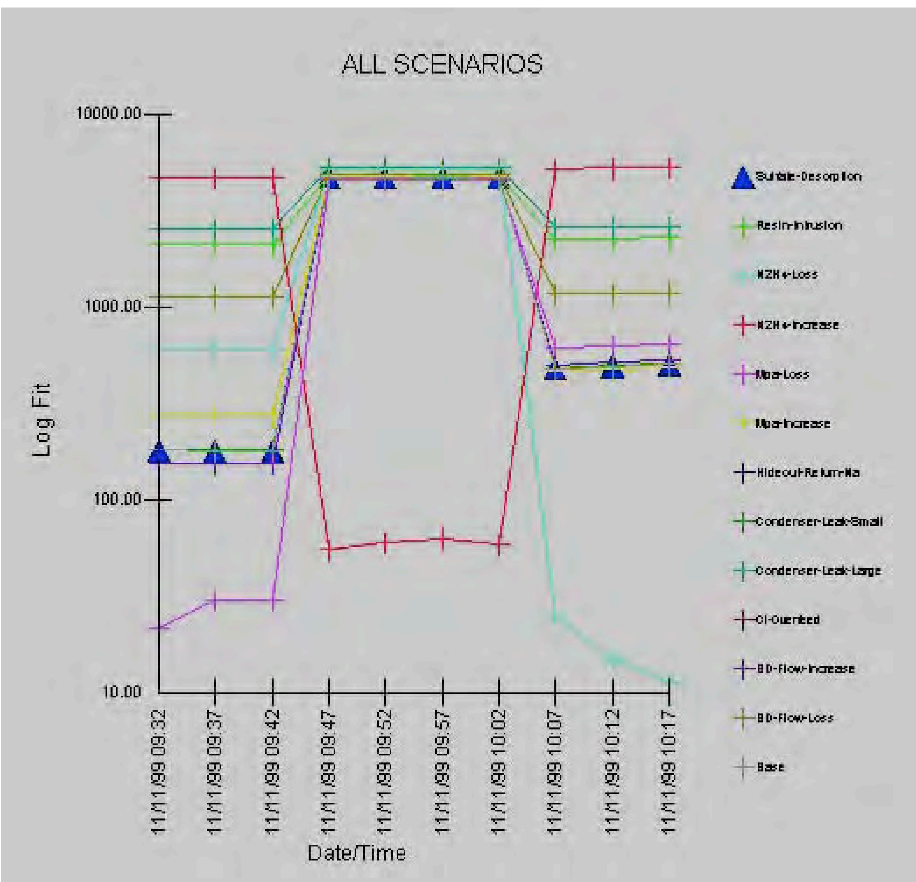
By the end of 1999, a total of 18 U.S. nuclear plants will be employing SMART chemWORKS to various degrees. Applications at European and Japanese nuclear units are expected in 2000, and there are plans to extend EPRI's turnkey services for real-time chemistry monitoring and diagnostics to fossil power plants and to other industries (see sidebar, p. 28).

"At most existing installations, we are in the confidence-building stage," notes Gaudreau. "It takes time for users to understand the software's capabilities, to trust its output, and to develop a rapport with off-site application engineers."

But an informal survey indicates that interest is high. "We've had a limited ability to monitor conditions throughout the cycle, but not at the level of detail afforded by SMART chemWORKS and certainly not in real time," says Pete Deckmann, adjunct chemistry instructor for GPU Nuclear. "That's where the immediate value lies. In time, chemistry staff should be able to turn over some trending responsibilities



Data output from the SMART chemWORKS system features easily recognizable alerts for off-normal readings. By providing this kind of early warning and tracking trends in the data, the system helps plant operators respond more effectively to developing problems.



Using pattern recognition techniques, the monitoring system's artificial intelligence engine continuously compares incoming plant data to a fingerprint library of scenarios for normal and off-normal operation. Finding a good fit with one of the scenarios can help pinpoint a problem to a particular plant function or component.

and other tasks to the software, getting some relief from heavy workloads."

Jeff Goldstein, supervisory nuclear chemical engineer for the New York Power Authority, is focused on front-end diagnostics. "The ability of SMART chemWORKS to look forward in time should enable us to anticipate off-normal events or detect them early. If on-site technicians can begin their analyses sooner than they normally could, response times should be accelerated, and, depending on the event, operational impacts reduced."

Some users also expect that as confidence in SMART chemWORKS grows and new functions are added, the software will help nuclear power producers cope with the loss of experienced personnel, increase the comfort level of new chemistry staff, decrease reliance on consultants, and meet future staff restrictions. In the near term, automated real-time advisory capabilities are being incorporated into the system; if certain chemical conditions are predicted or detected, the software will identify the short- and long-term implications associated with a failure to take corrective action within a specified time frame. For example, if conditions are conducive to crack growth, the software would predict the rate of growth and its potential consequences for the reliability and lifetime of susceptible components.

"The intelligence captured during software development, site-specific customization, and routine operation will augment the capabilities of chemistry departments during normal work hours," says Millett. "And on the backshift, the technical expertise offered by SMART chemWORKS could deliver as much or more value, particularly when upsets occur. We expect that some companies may be able to use the technology to deal with inevitable staff reductions dictated by economic pressures—without compromising chemistry control. Undoubtedly, over time every plant that implements SMART chemWORKS will decrease chemistry-related availability losses and realize substantial O&M cost savings." ■

Background information for this article was provided by Peter Millett (pmillett@epri.com) and Tina Gaudreau (tigaudre@epri.com), EPRIsolutions.

In the Field

Demonstration and application of EPRI science and technology

Predictive Maintenance Helps LG&E Avoid Motor Failures

Electric motor predictive maintenance (EMPM) tools and techniques developed by EPRI enable energy companies to consistently assess the type and extent of maintenance required, reducing operating and maintenance (O&M) costs and forced-outage rates. Louisville Gas and Electric (LG&E), for example, estimates

that by detecting and repairing electric motor faults in incipient stages, it has saved some $1.2 million in avoided costs over a three-year period.

Motor failure is a major source of fossil power plant downtime. With as many as 30 critical motors in a power plant, keeping them operating reliably is a challenge. Repair intervals for motors historically have been determined on the basis of time in service. But the unpredictability of motor failure makes this method costly. While time-based maintenance may be unnecessary on some motors, other machines not scheduled for maintenance may fail unexpectedly. This unpredictability calls for monitoring techniques that accurately set condition-based maintenance intervals for individual motors.

LG&E turned to EPRI for help with predictive maintenance for motors. EPRI's Maintenance and Diagnostics Center initiated a program to develop, apply, and validate techniques and tools for implementing EMPM. With the help of LG&E and six other original host utilities, EPRI created a condition-based EMPM program that includes data collection, storage, evaluation, and communication. LG&E was instrumental in delivering cost benefits and other accumulated data that were critical to the development of the new EMPM program and database, as well as motor predictive maintenance guidelines (TR-108773).

The program uses such methods as infrared thermography, current monitoring, lube oil monitoring, electrical tests, and vibration analysis to assess motor condition and identify potential problems early. Detected problems are noted, and specific information is recorded and used to determine the benefits of maintenance.

Using these methods, LG&E has developed the expertise to apply predictive maintenance monitoring and diagnostic techniques to other plant equipment—a wide-ranging, ongoing benefit. To date, a dozen participants in LG&E's EMPM program at various facilities report total avoided costs equal to a 250% return on the company's investment. "We've avoided a significant number of forced outages by implementing EPRI's EMPM program," notes LG&E's Don Gamble.

EPRI plans to extend the predictive maintenance program to include such new technologies and techniques as on-line partial discharge monitoring, electromagnetic interference analysis, and turn-to-turn failure monitoring. One goal is the development of software to automate the process of evaluating overall motor condition. The software will include expert system capabilities to automatically assess the maintenance required to preserve equipment life and reduce O&M costs.

EMPM is part of a larger EPRI effort to develop predictive maintenance methods for a variety of power plant components, including substation equipment.

■ *For more information, contact Jan Stein, jstein@epri.com, 650-855-2390.*

TVA Uses PISCES Model to Estimate TRI Releases

EPRI's PISCES model for power plant trace element analysis has helped the Tennessee Valley Authority to confidently estimate its releases of chemicals covered by the U.S. Environmental Protection Agency's Toxics Release Inventory (TRI). The estimates enabled TVA to avoid twice-monthly sampling and analyses with a projected five-year value of more than $800,000.

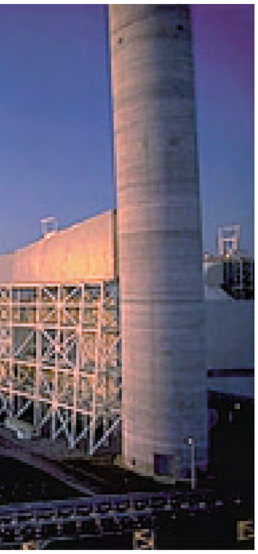
In response to a 1997 EPA rule adding electric generating plants to the list of industrial facilities required to estimate their annual toxics emissions, TVA formed an internal team to address the complex challenge of estimating releases of the TRI-listed chemicals relevant to power plants. (The chemicals are primarily trace elements occurring naturally in coal.) The team quickly identified the need for a

simple, comprehensive method that would conserve staff time and resources yet provide reliable estimates.

TVA's membership in EPRI gave it alternatives to conducting an extensive literature review and field test program and relying on published EPA air emissions factors. EPRI offered the new TRI-enhanced version of the PISCES model (see Products, this issue, p. 5), which draws from an extensive library of coal data to estimate discharges to each environmental medium (air, water, land). The model results could be used in conjunction with TVA's own water data and limited coal sampling data for trace elements.

TVA spent about $10,000 for a one-time elemental analysis of coal samples for use with the PISCES model. Without the model, the utility would have had to analyze each of 20 coals every two weeks in order to obtain statistically meaningful estimates of TRI trace elements—at an annual cost of approximately $150,000. It also would have had to spend about $100,000 to build a spreadsheet for managing the coal data and calculating the emissions estimates. The estimated current value of benefits to TVA over five years exceeds $800,000.

"EPRI's PISCES model helped us define a relatively simple method to estimate our combustion-related TRI discharges. It allows us to avoid the high cost of sampling and analyzing our many different coals for trace elements on a regular basis," says Thomas Burnett, TVA program manager for technology advancements.



■ *For more information, contact Barbara Toole-O'Neil, btooleo@epri.com, 650-855-1005.*

NYPA Demonstrates Advanced Lens for Infrared Thermography

At many fossil power plants, emissions of nitrogen oxides (NO_x) are reduced by recirculating flue gas to the plant's boilers. Higher levels of recirculation, however, reduce temperatures in the boiler's radiant section, which consequently absorbs less heat than before. As a result, the upper section of the furnace is subject to increased gas and metal temperatures that, over prolonged periods, can lead to creep failure in boiler tubes.

The boiler at the New York Power Authority's Charles Poletti plant experienced a rise in platen superheater tube failures due to long-term overheating that resulted from increased flue gas recirculation. NYPA sought a way to measure tube metal temperatures rapidly and accurately as a basis for balancing the combustion controls and thereby minimizing temperatures.

Traditionally, utilities have not been able to use infrared thermography in boiler applications because the high temperatures can damage the heat-sensing electronic imaging systems. But EPRI has developed a high-temperature lens that NYPA used with infrared thermography techniques to measure the Poletti plant's tube metal temperatures while firing the boiler with oil and natural gas under a variety of load conditions. One foot (0.3 m) long, the lens was inserted through a boiler port, providing a 40° viewing angle for two cameras mounted on the outside of the boiler for monitoring interior metal temperatures during various operating conditions. Using the temperature measurements, operators could adjust conditions to minimize long-term tube damage. Applied across the full 91-foot (28-m) cross section of the boiler, these adjustments included variations in the amount of combustion air, recirculated flue gas, overfire flue gas, and gas recirculation.

The high-temperature lens for infrared thermography provided NYPA with information for implementing several changes in boiler operation. In one such change, operators reduced overfire air from 20% to 10%, thereby decreasing metal tube temperatures by approximately 100°F (56°C) at the surface of the platen superheater. This was achieved with no significant increase in NO_x emissions.

As a result of the various changes in boiler operation, NYPA estimates savings of $1.6 million in avoided repairs and replacement power over a 10-year period. The program's success has led NYPA to require infrared thermography for testing plant improvements, such as a new burner tip design to lower NO_x.

■ *For more information, contact Russ Pflasterer, rpflaste@epri.com, 650-855-2541, or Bob Hammaker, hammakeb@compsys.com, 610-490-3242.*

Inside EPRI

News and information highlighting EPRI staff and operations

EPRIsolutions Delivers Integrated Services

To increase customer satisfaction by making its products easier to use, EPRI has created a new service-oriented subsidiary called EPRIsolutions℠. The for-profit subsidiary, which will begin operations on January 1, is part of EPRI's efforts to adjust to industry restructuring by offering new services to its members while reaching out to additional markets.

"Over the past several years, surveys of EPRI members have found the largest gap between expectations and performance to be in the area of technology application," says Karl Stahlkopf, an EPRI vice president and the CEO of EPRIsolutions. "Our goal is to enhance the value of EPRI technology by helping customers adapt our products for their specific needs and by training their staff in how to use the products more effectively. In addition, EPRIsolutions will provide confidential consulting services that will help individual customers meet the challenges of a more competitive environment."

EPRIsolutions is being formed through the merger of two existing subsidiaries—EPRICSG and EPRIGEN. Those organizations were created to allow EPRI to conduct proprietary R&D on behalf of individual funders, who would retain rights to the intellectual property involved. In addition to continuing this activity, EPRIsolutions will provide customized technology application and consulting services. Such private-benefit work lies beyond the scope of EPRI's tax-exempt mission and requires the use of an arm's-length taxable subsidiary.

"Our focus is on providing integrated service packages—that is, *solutions* to everyday business problems—rather than isolated services," Stahlkopf emphasizes. "In this way, we can help current members use our technology more effectively to lower costs and improve asset management, and we can open up new sources of revenue for EPRI by attracting new customers, such as independent power producers."

An example of this kind of integrated service offering involves ANNSTLF, a software package that uses an artificial neural network to improve the accuracy and reliability of short-term load forecasting. Depending on a customer's needs, EPRIsolutions could help adapt and install the sophisticated software, provide on-site training, and offer continuing support. Or, for customers who do not want to perform their own calculations, EPRIsolutions would run ANNSTLF as an application service, using customer-supplied data and providing proprietary results.

In the nuclear area, EPRIsolutions is carrying this type of service one step further: with SMART chemWORKS™, it is performing real-time monitoring and diagnosis of water-steam chemistry for 18 U.S. nuclear power units via the Internet (see "Water Chemistry Off-Site and On-Line," this issue, p. 24). Such an application service provider model represents a major business opportunity for EPRIsolutions, for it allows companies to outsource many data-heavy operations rather than tie up staff and computers for the task. The SMART chemWORKS service architecture is currently being adapted to provide real-time monitoring and diagnostics for critical operation and maintenance issues in fossil power plants and other types of industrial processes.

Many of the services offered by EPRIsolutions will be performed by staff members of EPRI's technology application centers. The Energy Delivery and Utilization Centers in Lenox, Massachusetts, and Haslet, Texas, for example, are operated for EPRI by EPRIsolutions, as are the Maintenance and Diagnostics (M&D) Center in Eddystone, Pennsylvania, and the Simulator and Training Center in Charlotte, North Carolina. EPRIsolutions owns and operates EPRI PEAC Corporation (formerly the Power Electronics Applications Center) in Knoxville, Tennessee, and the Retail Market Assistance Center in Dallas, Texas.

An example of a major new type of service offered by EPRIsolutions through the technology application centers is the power delivery performance audit, designed to identify weaknesses in transmission and distribution systems before they lead to major outages. A related service entails the investigation of actual system failures in order to prevent recurrences. Such an investigation was recently performed for Commonwealth Edison after outages virtually shut down Chicago's central business district.

Similarly, in the power generation area, experts from the M&D Center are helping customers make plant maintenance improvements that can result in cost savings of up to 15%. This integrated service package includes installation of EPRI's O&M Workstation, support for infrared thermography inspection of equipment, and implementation of a predictive maintenance program.

For EPRI members, many of the services provided by EPRIsolutions will be coordinated through the planning activities of EPRI staff assigned to ensure member satisfaction with their R&D investment. Conversely, when EPRIsolutions engages nonmembers as customers, funds may be used to tap the expertise of EPRI staff on a contract basis.

"The creation of the new subsidiary gives EPRI greater flexibility in helping its customers, both members and nonmembers, meet the demands of a restructured industry," Stahlkopf concludes. "EPRI has an excellent reputation for its scientific objectivity and technological innovation. EPRIsolutions will help extend that reputation to the provision of services."

EPRI Software Ready for the Year 2000

EPRI has done substantial work over the past several years to help the power industry prepare for potential year 2000 computer problems. But EPRI itself offers its customers a portfolio of more than 300 diverse software products. To ensure that these products maintain high functional integrity into the next millennium, software quality manager Bob Lara established a team in early 1998 to evaluate all EPRI software for Y2K readiness.

The technical team members—Ramtin Mahini, Peter Hirsch, Randall Takemoto-Hambleton, Marilyn Valentino, and Mary McKenna—found few problems with the software during the comprehensive review. EPRI's Business Operations and Support Group worked closely with the technical team to facilitate a prompt and open exchange with software licensees.

"Most of the EPRI software is used for analysis, planning, and scenario generation rather than for the control of real-time operations or the handling of business transactions," says Lara. "The vast majority of software codes contained no errors or performed no calculations involving dates. The dates that did have functions usually played limited roles, such as generating preventive maintenance schedules or projecting environmental chemical concentrations."

Some software products contained cosmetic errors only and were not changed. Products with calculation errors involving dates were returned to the developers for repair, although some old codes were removed from distribution because the level of customer interest did not warrant repair expenditures. Now, all new soft-

ware is tested to ensure Y2K readiness before release. Customers can view the results of the Y2K testing on EPRI's Web site (www.epri.com) via the link labeled EPRI software.

■ *For more information, contact Bob Lara, rlara@epri.com, 650-855-8977.*

EPRI Fellowship Program Receives Fishery Award

At its annual meeting in August in Charlotte, North Carolina, the American Fisheries Society (AFS) presented its President's Fishery Conservation Award to EPRI. Founded in 1870, AFS is the oldest and largest professional society representing fisheries scientists. The award was given in recognition of EPRI's Compensatory Mechanisms in Fish Populations (CompMech) Fellowship Program, which funded training in fish population studies for 75 graduate students. EPRI dedicated more than $3 million in funding for this program.

William W. Taylor, past AFS president, presented the award to EPRI's Doug Dixon, manager for aquatic protection, and Jim Lang, director for power production in the Science and Technology Development Division. "We are pleased to recognize the important contributions to fisheries conservation that EPRI supported, and we hope to encourage similar fellowship programs that facilitate research and communication for fisheries conservation," said Taylor.

In addition to studying fish population dynamics, graduate students pursued research in fish behavior, biochemistry, ecological genetics, biostatistics, ecological modeling, immunology, and health. EPRI fellows participated in workshops and conferences around the world and contributed to the literature through dissertations and theses.

"The research has resulted in the development of new techniques and extensive new information about the reproduction, growth, feeding, and natural mortality of various fish species," said Lang. "EPRI is particularly proud of having supported 75 graduate students in achieving those results."

Initiated in 1987, the fellowship program was driven by two goals: to develop information on the life histories and population dynamics of fish species known to experience impacts at steam and hydroelectric power stations; and to improve communication between the power industry, academic institutions, and state and federal resource management agencies on matters related to environmental quality.

EPRI launched this effort with representatives from Oak Ridge National Laboratory and the Sport Fishing Institute. Jack Mattice developed the fellowship program and managed it until he left EPRI in 1997. Dixon then managed the program until it ended in 1998. "Although the CompMech Fellowship Program has ended, I hope to develop and implement a new fellowship program that will continue to provide information and tools to better understand and prevent the impacts of power production on aquatic communities," said Dixon.

Technical Reports & Software

To place an order, call EPRI Customer Service at 800-313-3774 or 650-855-2121, and press 1 for software or 2 for technical reports. Target funders can download an Acrobat PDF file of a technical report by searching for the report number on EPRI's Web site (www.epri.com).

Energy Delivery

Application of FACTS Technology to the Polish Power Grid
TR-112965
Target: Grid Planning and Development
EPRI Project Manager: R. Adapa

Longitudinal Load and Cascading Failure Risk Assessment (CASE): Interconexión Eléctrica SA's 500-kV San Carlos–San Marcos Transmission Line
TR-113056
Target: Overhead Transmission
EPRI Project Manager: M. Ostendorp

Substation Arrester Monitor Feasibility Study: Interim Report
TR-113197
Target: Substation Operation and Maintenance
EPRI Project Manager: K. Loynes

A Static Electrification Monitor for Large Power Transformers: The Smart Manhole Cover
TR-113381
Target: Substation Operation and Maintenance
EPRI Project Manager: S. Lindgren

CIM Data Views for Bulk Power Systems
TR-113384
Target: Grid Operations and Management
EPRI Project Manager: P. Hirsch

Power Transformer Insulation Behavior During Overload, Phase 1: Dynamic Behavior of Moisture
TR-113390
Target: Substation Operation and Maintenance
EPRI Project Manager: S. Lindgren

Development and Field Application of EPRI Dynamic Thermal Circuit Rating Technology
TR-113391
Target: Substation Assets Utilization
EPRI Project Manager: A. Edris

Research on Chronological Cost Simulation of Demand-Side Programs
TR-113393
Target: Grid Planning and Development
EPRI Project Managers: N. Abi-Samra, R. Adapa

An Analysis of Short-Term Risk in Power System Pricing
TR-113394
Target: Grid Planning and Development
EPRI Project Manager: N. Abi-Samra

Electrokinetic Effects in Power Transformers
TR-113441
Target: Substation Operation and Maintenance
EPRI Project Manager: S. Lindgren

Initial Laboratory and Field Evaluation of Daytime Corona Viewing Technology
TR-113459
Target: Overhead Transmission
EPRI Project Manager: A. Phillips

Proceedings: Substation Equipment Diagnostics, Conference VII
TR-113481
Target: Substation Operation and Maintenance
EPRI Project Manager: S. Lindgren

UCA Substation Communication Initiative Interoperability Demonstration
TR-113518
Target: Substation Operation and Maintenance
EPRI Project Manager: J. Melcher

AWESOME: Substation Operation and Maintenance Manual
Version 1.0 (Windows 95, 98, NT); AP-113691-CD
Target: Substation Operation and Maintenance
EPRI Project Manager: B. Damsky

PowerSimulator
Version 1.05.012 (Windows NT); AP-113712-CD
Target: Substation Operation and Maintenance
EPRI Project Manager: P. Hirsch

TIM: Transmission Inspection and Maintenance System
Version 2.4 (Windows 95, NT); AP-108090-R2DK
Target: Overhead Transmission
EPRI Project Manager: P. Lyons

Energy Utilization

Power Quality for Electrical Contractors, Application Guide, Vol. 2: Recommended Practices (Revision 1)
TR-111762-V2R1
Targets: Power Quality for Satisfied Commercial and Residential Customers; Power Quality for Improved Industrial Operations; Power Quality Basics (EPRICSG)
EPRI Project Managers: W. Moncrief, M. Grossman

Consumer Perceptions of the Channel They Use: Characteristics, Features, and Attributes
TR-112095
Target: Understanding Energy Markets (EPRICSG)
EPRI Project Manager: R. Gillman

The Multifamily Market: Size, Characteristics, and Decision Making
TR-112096
Target: Understanding Energy Markets (EPRICSG)
EPRI Project Manager: R. Gillman

Small and Medium Businesses: Early Insights, Vols. 1–4—Switching, Purchases, Attitudes, and Channels
TR-112126-V1–V4
Target: Understanding Energy Markets (EPRICSG)
EPRI Project Manager: R. Gillman

Performance Measurement and Enterprise Strategy: Lessons From EPRI's Workshops
TR-112483
Target: Producing Successful Retail Products and Services
EPRI Project Managers: B. Kalweit, P. Meagher

Lighting and Sustained Performance: Sustained Task Performance Under Three Lighting Installations
TR-112693
Target: Commercial Building Lighting
EPRI Project Manager: J. Kesselring

Waveform Characteristics of Voltage Sags: Definition and Algorithm Development
TR-113044
Target: Power Quality for Improved Energy Delivery
EPRI Project Manager: A. Sundaram

Contract Evaluator
Version 1.0 (Windows 95, 98, NT); AP-113198-P2
Target: Power Markets and Risk Management
EPRI Project Manager: A. Altman

Generation Asset Evaluator
Version 1.0 (Windows 95, 98, NT); AP-113198-P3
Target: Generation Asset Management and Valuation (EPRIGEN)
EPRI Project Manager: A. Altman

Project Evaluator
Version 1.0 (Windows 95, 98, NT); AP-113198-P4
Target: Generation Asset Management and Valuation (EPRIGEN)
EPRI Project Manager: A. Altman

Risk Manager
Version 1.0 (Windows 95, 98, NT); AP-113198-P1
Target: Power Markets and Risk Management
EPRI Project Manager: A. Altman

RSC Guide: Residential Space-Conditioning System Selection Guide
Version 1.0 (Windows 95, NT); AP-112995
Target: Promoting Energy Products for Mass Markets (EPRICSG)
EPRI Project Manager: J. Kesselring

Environment

Guidance for Comanagement of Mill Rejects at Coal-Fired Power Plants
TR-108994
Target: Groundwater and Combustion By-Products Management
EPRI Project Manager: K. Ladwig

Leukemia/Lymphoma in Mice Exposed to 60-Hz Magnetic Fields: Results of the Chronic Exposure Study (2nd Edition)
TR-110338-R1
Target: Electric and Magnetic Fields Health Assessment
EPRI Project Manager: C. Rafferty

Catalog of Assessment Methods for Evaluating the Effects of Power Plant Operations on Aquatic Communities
TR-112013
Target: 316 (a) and (b) Fish Protection Issues
EPRI Project Manager: D. Dixon

Life-Cycle Management of Chemicals: Conceptual Design for Information Management
TR-112438
Target: Environmental Assets Management
EPRI Project Manager: M. McLearn

Evaluation of an Ecolotree™ CAP for Closure of Coal Ash Disposal Sites
TR-112442
Target: Groundwater and Combustion By-Products Management
EPRI Project Manager: D. Golden

Multivariate Ozone Response Surface (MORS) Approach for Estimating Emission Weights for Contributions to Ozone Formation
TR-113049
Target: Tropospheric Ozone and Precursors
EPRI Project Manager: G. Hester

Environmental Distribution of Petroleum Hydrocarbons at a Utility Service Center
TR-113074
Target: Groundwater and Combustion By-Products Management
EPRI Project Manager: A. Quinn

SCICHEM: A New-Generation Plume-in-Grid Model
TR-113097
Target: Tropospheric Ozone and Precursors
EPRI Project Manager: A. Hansen

Review and Assessment of Air Quality Management
TR-113098
Target: Tropospheric Ozone and Precursors
EPRI Project Manager: A. Hansen

Characterization of PCBs in Groundwater Using a Drive Point Sampler
TR-113372
Target: Transmission and Distribution Soil and Water Issues
EPRI Project Manager: A. Quinn

ASAPP2: Accounting Software Application for Pollution Prevention
Version 2.00 (Windows 95, NT); AP-113711
Target: Environmental Assets Management
EPRI Project Manager: M. McLearn

EEF: Estuary Eutrophication Framework, Chesapeake Bay Version
Version 1.0 (Windows 95, NT); AP-113317
Targets: Tropospheric Ozone and Precursors; Watershed, Ecosystem, and TMDL Issues
EPRI Project Manager: R. Goldstein

EMF Modeler
Version 1.0 (Windows 95, 98, NT); AP-113725
Target: Electric and Magnetic Fields Management
EPRI Project Manager: R. Takemoto-Hambleton

3-D BurnVision
Version 1.0 (Windows 95, 98, NT); AP-113361
Target: Occupational Safety and Health
EPRI Project Manager: J. Yager

Fossil and Renewable Generation

Electric Motor Predictive Maintenance Program
TR-108773-V2
Targets: Steam Turbines, Generators, and Balance of Plant; Fossil Balance-of-Plant O&M Guidelines
EPRI Project Manager: J. Stein

Approach to Assessing Fuel Flexibility for Improved Generating Plant Profitability
TR-111563
Target: Fuel and Power Supply
EPRI Project Manager: D. O'Connor

Fuel Industry Response to Power Industry Environmental Pressures: Analysis of Risk and Investment in the Coal Supply Chain and Natural Gas Industry
TR-111565
Target: Fuel and Power Supply
EPRI Project Manager: J. Platt

Kingsnorth Pulverized-Fuel Flow Meter Demonstration Trials
TR-113033
Target: Coal Boiler Performance/Combustion NO_x Control
EPRI Project Manager: R. Brown

EPRI-DOE-EPA Combined Utility Air Pollution Control Symposium: The MEGA Symposium
AP-113187
Targets: All NO_x, SO_2, particulate, and air toxics control targets
EPRI Project Manager: G. Offen

Evaluation of LS-2 Advanced Wet Flue Gas Desulfurization Technology
TR-113473
Target: SO_2 and Nonparticulate Opacity Control
EPRI Project Manager: R. Rhudy

Nuclear Generation

Application of Master Curve Fracture Toughness Methodology for Ferritic Steels: PWR Materials Reliability Project
TR-108390-R1
Target: Nuclear Power
EPRI Project Manager: S. Rosinski

Compilation and Evaluation of NOREM™ Test Results: Implications for Valve Applications (Generic Background Information for 10 CFR 50.59 Evaluations)
TR-109343
Target: Nuclear Power
EPRI Project Manager: H. Ocken

A Processing Decision Matrix for Liquid Radioactive Waste
AP-109447
Target: Nuclear Power
EPRI Project Manager: C. Hornibrook

Guideline for the Management of Adverse Localized Equipment Environments
TR-109619
Target: Nuclear Power
EPRI Project Manager: J. Hutchinson

CORETRAN Validation: A Summary of Steady-State Physics Applications
TR-109621-CD
Target: Nuclear Power
EPRI Project Manager: L. Agee

Strategies for Optimizing Engineering Effectiveness in Corrective Action Programs
TR-109626
Target: Nuclear Power
EPRI Project Manager: L. Loflin

Calvert Cliffs License Renewal Aging Management Review Reports
TR-110163-CD
Target: Nuclear Power
EPRI Project Manager: J. Carey

Measuring Fatigue Damage in Materials, Phase 2
TR-110251
Target: Nuclear Power
EPRI Project Manager: S. Rosinski

Nonlinear Vibroacoustic Screening System for Detecting Cracks in Pipe Socket Welds
TR-110427
Target: Nuclear Power
EPRI Project Managers: K. Krzywosz, S. Walker

CPM-3 Validation: A Summary of Version 1.0 Benchmark and Assessment
TR-111149-CD
Target: Nuclear Power
EPRI Project Manager: J. Chao

Advanced O&M Cost Management Pilot Study
TR-111412
Target: Nuclear Power
EPRI Project Manager: J. Jenco

Lube Oil System Leakage Mitigation
TR-111413
Target: Nuclear Power
EPRI Project Manager: J. Jenco

Determination of the Accuracy of Utility Spent-Fuel Burnup Records
TR-112054
Target: Nuclear Power
EPRI Project Manager: J. Yedidia

Nuclear Feedwater Flow Measurement Applications Guide
TR-112118
Target: Nuclear Power
EPRI Project Manager: R. Shankar

PWR Materials Reliability Project: Analysis of Baffle Former Bolt Cracking in EDF CPO Plants
TR-112209
Target: Nuclear Power
EPRI Project Manager: L. Nelson

Decontamination Handbook
TR-112352
Target: Nuclear Power
EPRI Project Manager: H. Ocken

Proceedings: 1998 ASME-EPRI Radwaste Workshop
TR-112659
Target: Nuclear Power
EPRI Project Manager: C. Hornibrook

Proceedings: 1998 EPRI International Low-Level-Waste Conference
TR-112660
Target: Nuclear Power
EPRI Project Manager: C. Hornibrook

1998 Repair & Replacement Applications Center: Product Report
TR-112720
Target: Nuclear Power
EPRI Project Manager: S. Findlan

Reduced Control Voltage Testing of Low- and Medium-Voltage Circuit Breakers
TR-112814
Target: Nuclear Power
EPRI Project Manager: J. Sharkey

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TR-113005-CD
Target: Nuclear Power
EPRI Project Manager: L. Agee

Development of Shutdown Probabilistic Safety Analysis/Shutdown Equipment out of Service (EOOS) for River Bend Station
TR-113084
Target: Nuclear Power
EPRI Project Manager: F. Rahn

The Fork+ Developmental Measurement Campaign at Maine Yankee
TR-113169
Target: Nuclear Power
EPRI Project Manager: J. Yedidia

Proceedings: 1999 Workshop on Condensate Polishing
TR-113281
Target: Nuclear Power
EPRI Project Manager: N. Torigoe

Requalification of Low Crosslinked Resin
TR-113368
Target: Nuclear Power
EPRI Project Managers: N. Torigoe, P. Frattini

chemWORKS™: AminMOD
Version 4.0 (Windows 95); AP-109560-P6
Target: Nuclear Power
EPRI Project Manager: T. Gaudreau

chemWORKS™: BWRSIM
Version 2.0 (Windows 95); AP-109560-P7
Target: Nuclear Power
EPRI Project Manager: T. Gaudreau

chemWORKS™: Hideout Return Spreadsheet
Version 2.0 (Windows 95); AP-109560-P8
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EPRI Project Manager: T. Gaudreau

chemWORKS™: Mixed-Bed Ion Exchange
Version 1.0 (Windows 95); AP-109560-P9
Target: Nuclear Power
EPRI Project Manager: T. Gaudreau

chemWORKS™: PWR Plant and Chemistry Database
Version 2.0 (Windows); AP-109560-P10
Target: Nuclear Power
EPRI Project Manager: T. Gaudreau

chemWORKS™: PWR Secondary Chemistry Simulator
Version 2.0 (Windows 95); AP-109560-P11
Target: Nuclear Power
EPRI Project Manager: T. Gaudreau

CORETRAN-01
Version 1.47 (HP-UX; Solaris); SW-113409-CD
Target: Nuclear Power
EPRI Project Manager: L. Agee

CPM-3: Core Physics Module
Version 1.00 (Unix); CD-109645
Target: Nuclear Power
EPRI Project Manager: J. Chao

GOTHIC: Generation of Thermal-Hydraulic Information in Containments
Version 6.1 (Unix; Windows 95, NT); AP-111018-R1CD
Target: Nuclear Power
EPRI Project Manager: A. Singh

ICMP: Instrument Calibration Monitoring Program
Version 1.0 (Windows 95, NT); AP-106822
Target: Nuclear Power
EPRI Project Manager: R. Shankar

IPASS: Instrument Performance Analysis Software System
Version 2.03 (Windows 95, 98, NT); AP-106752-R2
Target: Nuclear Power
EPRI Project Manager: R. Shankar

MAAP4: Modular Accident Analysis Program for LWR Power Plants
Version 4.04 (Windows 95, NT); AP-108795-R1
Target: Nuclear Power
EPRI Project Manager: J. Chao

ORAM-SENTINEL: All Modes Maintenance and Safety Function Advisor
Version 3.3 (Windows 95); AP-112894
Target: Nuclear Power
EPRI Project Manager: J. Mitman

RETRAN-3D MOD 2PHY
Version 2PHY (Sun OS 2.6); AP-107599-R1CD
Target: Nuclear Power
EPRI Project Manager: L. Agee

Strategic Science and Technology

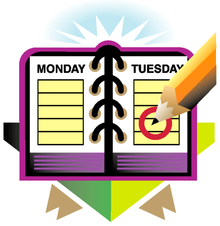
Advanced Heat-Resistant Steels for Power Generation
TR-111571
Program: Strategic Science and Technology
EPRI Project Manager: V. Viswanathan

On-Line Corrosion Monitoring Using Electrochemical Frequency Modulation
TR-112786
Program: Strategic Science and Technology
EPRI Project Manager: B. Syrett

Organic Aerosol Partition Module Documentation
TR-113095
Program: Strategic Science and Technology
EPRI Project Managers: A. Hansen, N. Kumar

Risk-Based Security Assessment
TR-113276
Program: Strategic Science and Technology
EPRI Project Managers: N. Abi-Samra, D. Sobajic

Methods for Computer-Aided Control Synthesis in Power Systems
TR-113314
Program: Strategic Science and Technology
EPRI Project Managers: D. Sobajic, D. Maratukulam



EPRI Events

January 2000

10–12
Simulator Acceptance Test Procurement Workshop
Charlotte, North Carolina
Contact: Dave Larson, 704-547-6029

10–14
CHUG Meeting
San Diego, California
Contact: Barbara McCarthy, 650-855-2127

12–14
Generator Operation, Troubleshooting, and Maintenance Course
San Clemente, California
Contact: Jan Stein, 650-855-2390

18–20
Modifying and Maintaining Structures and Conductors in Transmission Line Uprating
Haslet, Texas
Contact: Gayle Robertson, 817-439-5900

24–28
International Fossil Simulation and Training Meeting
San Diego, California
Contact: Cassie Maslowski, 816-235-5623

25–28
PM 2000: Particulate Matter and Health
Charleston, South Carolina
Contact: Ron Wyzga, 650-855-2577

26–28
Optical Sensors Conference
Atlanta, Georgia
Contact: Barbara Freel, 650-855-2253

26–28
Pressure Relief Devices Users Group
Orlando, Florida
Contact: Linda Parrish, 704-547-6061

February

20–23
Substation Equipment Diagnostics Conference VIII
New Orleans, Louisiana
Contact: Barbara Freel, 650-855-2253

March

6–10
Advanced Structural Analysis and Design Methods for Electric Power Lines
Haslet, Texas
Contact: Gayle Robertson, 817-439-5900

April

2–8
Joint Meeting of the Raptor Research Foundation and the World Working Group for Birds of Prey
Eilat, Israel
Contact: Rick Carlton, 650-855-2115

10–13
Boilers and Boiler Controls/Burner Management Systems
Kingston, Tennessee
Contact: Sherryl Stogner, 704-547-6174

May

1–3
Agriculture and Food Technology Alliance Spring Meeting
Denver, Colorado
Contact: Charles Sopher, 703-373-0401

15–18
PQA 2000 North America Conference and Exhibition
Memphis, Tennessee
Contact: Paige Polishook, 650-855-2010

24–26
2nd International Conference on NDE in Relation to Structural Integrity for Nuclear and Pressurized Components
New Orleans, Louisiana
Contact: Susan Otto-Rodgers, 704-547-6072

June

7–9
4th International Conference on Welding and Repair Technology for Power Plants
Marco Island, Florida
Contact: Brent Lancaster, 704-547-6017

9–16
22nd Annual Meeting of the Bioelectromagnetics Society
Munich, Germany
Contact: Leeka Kheifets, 650-855-8976

12–15
Aging Workforce and Educational Infrastructure Conference
Charlotte, North Carolina
Contact: Brent Lancaster, 704-547-6017

18–22
4th International Conference on Arsenic Exposure and Health Effects
San Diego, California
Contact: Janice Yager, 650-855-2724

19–21
6th Annual Conference on Balance-of-Plant Heat Exchanger NDE
Scottsdale, Arizona
Contact: Kenji Krzywosz, 704-547-6096

19–21
Steam Turbine–Generator Customer Service Seminar
Saratoga Springs, New York
Contact: Paul Sabourin, 704-547-6155

20–21
Joint EPRI-DOE Workshop on Carbon Dioxide
Pittsburgh, Pennsylvania
Contact: Mike Miller, 650-855-2455

26–28
Condensate Polishing Workshop
Annapolis, Maryland
Contact: Barbara James, 707-829-3500

27–29
6th International Conference on Cycle Chemistry in Fossil Plants
Columbus, Ohio
Contact: EPRI Conferences, 650-855-2522

July

17
ASME-EPRI Radwaste Workshop
San Antonio, Texas
Contact: Cindy Layman, 650-855-8763

17–21
Advanced Structural Analysis and Design Methods for Electric Power Lines
Haslet, Texas
Contact: Gayle Robertson, 817-439-5900

19–21
International Low-Level-Waste Conference
San Antonio, Texas
Contact: Cindy Layman, 650-855-8763

September

9–13
7th International Symposium on Environmental Concerns in Rights-of-Way Management
Calgary, Canada
Contact: John Goodrich-Mahoney, 202-293-7516

November

6–10
Advanced Structural Analysis and Design Methods for Electric Power Lines
Haslet, Texas
Contact: Gayle Robertson, 817-439-5900

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