EPRI JOURNAL

SPRING 1999

Fast Charging for Lift Trucks

Field Demos Show Broad Benefits

Advances in Welding

New Techniques Reduce O&M Costs

Superconducting Cable Packs a Power Punch

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: Electrical tests of a prototype high-temperature superconducting cable in Milan, Italy, pave the way for the world's first HTS cable field demonstration on a power distribution system in downtown Detroit. (Photo courtesy Pirelli Cables and Systems)

Correction

The feature entitled "Charting Power System Security," which appeared in the Journal's September/October 1998 issue, included mention of the Voltage Security Assessment (VSA) software tool. The article should also have mentioned that VSA is owned by BC Hydro and is being developed by its subsidiary Powertech Labs Inc.

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A pioneering project at Detroit Edison will demonstrate supercon-ducting underground distribution cable as a twenty-first-century answer to upgrading urban power infrastructures.

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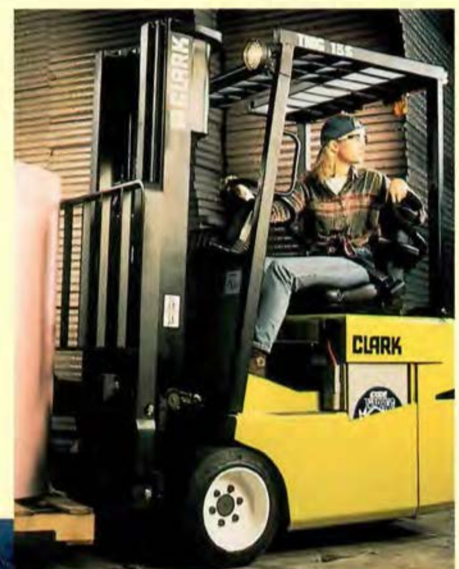

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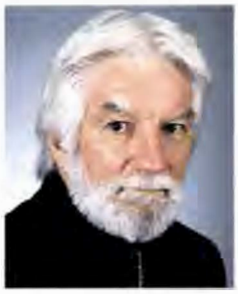


Editorial

Timing Is Everything

Timing is everything. This old maxim is heard repeatedly at social and business occasions alike—in dinner party palaver on such topics as love, politics, sports, and the stock market, as well as in boardroom deliberations. But the phrase can also apply to science and technology, especially to their practical application, with one important difference. With regard to technology and its use, the assertion becomes a question: "Is the time right yet?"

In our industry, the workhorse commodity is wire, wire based on good old aluminum and copper metal—not usually considered a high-tech arena. We sometimes forget that wire benefited from one of the first fruits of that early high technology called electrification: the 1886 invention of the Hall-Heroult process. As a result, aluminum, until then considered a precious metal, became cheap and plentiful and revolutionized transmission line wire. Twenty-five years later, in 1911—a relatively brief period in that slower-moving age—an event occurred that promised an even greater leap forward. This was the discovery of superconductivity, the almost magical ability of many metals to conduct electricity without resistive loss at sufficiently low temperatures. Almost immediately, dreamers envisioned the transport of massive amounts of electric power over long distances via superconducting transmission lines and cables.

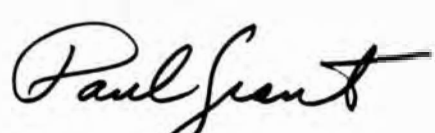
But the dream harbored a technical nightmare—actually two. First, the low temperatures required to operate the early superconductors (e.g., mercury and lead) were *really* low, just a few degrees above absolute zero, and could be attained only by immensely complex refrigeration systems for liquefying helium, then an extremely rare gas. Second, these early materials could carry only a few milliamperes of current—hardly the stuff of transmission lines—and lost their ability to superconduct in moderate magnetic fields, barely a few multiples of the earth's. The time was definitely not right yet.

It was not until midcentury that the discovery of a new class of superconducting materials, the niobium alloys, made possible wires that could carry currents of hundreds of amperes in magnetic fields many thousand times stronger than the earth's. Subsequently, several efforts were undertaken to develop superconducting cables. These succeeded technically, but the high cost and complexity of the requisite helium refrigeration posed a significant barrier to utility acceptance. Timing-wise it was close, but no cigar.

It is an axiom of superconductivity science that advances are governed by the empirical search for new materials; in other words, guided luck is a key ingredient. Twelve years ago, such a search struck pay dirt with the discovery of materials that become superconducting at temperatures well over 100 K above absolute zero. For these materials, liquid nitrogen—cheap and both user and environmentally friendly—could replace helium as the refrigerant. It was time to try again.

This issue's cover feature describes the upcoming demonstration of superconducting cables at a Detroit Edison substation—the industry's first field test of this new technology and the tremendous promise it holds for the future. Indeed, the EPRI Electricity Technology Roadmap points to the continued development of superconducting power applications as key to the robust, reliable T&D system required for the competitive power markets of the next century.

Will the Detroit Edison demonstration succeed? I'm confident it will, both technically and operationally. However, as noted NFL sports commentator John Madden likes to point out, if we really could predict the outcome of a contest, we wouldn't have to blow the starting whistle. For us, the stadium will be the backyard of the Frisbie substation, and the players will be not only scientists but—for the first time—utility engineers, supervisors, operators, and line workers as well. Perhaps the right time has at last arrived. Let the game begin.



Paul Grant
Science Fellow

Contributors

Powering Up Superconducting Cable (page 8) was written by Taylor Moore, *Journal* senior feature writer, with technical assistance from Paul Grant of Strategic Science and Technology and Donald Von Dollen of the Energy Delivery and Utilization Division.

PAUL GRANT, science fellow and lead technology forecaster, joined EPRI in 1993 as an executive scientist to manage programs in superconductivity and wide-bandgap semiconductors. He previously worked at IBM for 40 years, much of the time as a scientist at the Almaden Research Center in San Jose, California. Grant earned a BS degree in electrical engineering at Clarkson University and AM and PhD degrees in applied physics at Harvard University.

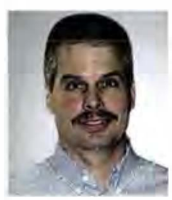
DONALD VON DOLLEN, business area manager for underground transmission, joined EPRI in 1991. Previously he spent three years at Pacific Gas and Electric Company as an engineer in the R&D and technical services programs. Von Dollen holds a BS in physics from California State University, Sacramento.

Fast Charging for Lift Trucks (page 16) was written by Leslie Lamarre, *Journal* senior feature writer, with technical assistance from Gary Purcell of the Energy Delivery and Utilization Division.

GARY PURCELL, until his retirement at the end of last year, was manager for electric vehicle systems technology, with a focus on infrastructure and vehicle interface research. He joined EPRI in 1977 after 15 years with Lockheed Missiles & Space Company, where he specialized in aerospace vehicle temperature controls, including work on the Apollo lunar scientific experiments. Purcell received a BS in mechanical engineering from Oklahoma State University and an MBA from Pepperdine University.

Welding Research Heats Up (page 22) was written by science writer Dawn Levy, with technical assistance from Vis Viswanathan of the Energy Conversion Division and David Gandy and Shane Findlan of the EPRI Repair and Replacement Applications Center (RRAC) in Charlotte, North Carolina.

VIS VISWANATHAN, technical fellow and manager for materials applications technology, came to EPRI in 1979. Before that, he spent 14 years at the Westinghouse R&D Center, where he worked in metallurgical applications and evaluations for nuclear and high-temperature systems. Viswanathan received a BS in chemistry from Madras University and holds three degrees in metallurgy—a BE from the Indian Institute of Science, an ME from the University of Florida, and a PhD from Carnegie Mellon University.



DAVID GANDY is RRAC manager for materials and fossil applications, overseeing research on the welding repair of steam turbine components, superalloys, and high-energy piping and headers. Gandy joined EPRI in 1996 after 12 years as a project manager with J. A. Jones Applied Research Company, which then performed welding research under contract to EPRI. He received a BS in materials science and engineering from North Carolina State University.

SHANE FINDLAN, manager of the RRAC's overall program, leads the group in the development of innovative materials and power plant repair technology. Before joining EPRI in 1996, he managed this effort as an employee of J. A. Jones Applied Research. Findlan joined J. A. Jones in support of EPRI in 1980 to develop repair solutions for BWR stress corrosion cracking problems. Previously he was involved in EPRI-supported research at Battelle Memorial Institute. He earned a BS in welding engineering from Ohio State University.

Products

Deliverables now available to EPRI members and customers

Power Quality Diagnostic System

Power quality disturbances cost electricity users significant losses in productivity each year. Driven by increasing competition, electric utilities are responding to customers' PQ concerns with new contracts and services, often working cooperatively with them to find economical answers to their problems. The process can be rigorous, time-consuming, and complex. That's why EPRI developed the Power Quality Diagnostic System—a complete set of tools to help engineers and technicians deal with PQ problems. It consists of four CD-ROM modules: a module that enables engineers to quickly identify PQ events; a module that facilitates the analysis of large quantities of PQ measurement data; a module that performs computer-based simulations to help solve typical PQ problems; and an economic assessment module that conducts cost-benefit analyses for various PQ improvement technologies.

■ *For more information, contact Sid Bhatt, sbhatt@epri.com, (650) 855-8751. To order, call the Electric Power Software Center, (800) 763-3772.*

Bundling Report

Given the dramatic changes occurring in the electric power industry due to deregulation and retail competition, power companies have a crucial need to develop offerings that will retain customers and promote future growth. This report, *Bundling of Products and Services in the Energy Services Industry* (TR-108983), describes how the bundling approach can help in meeting this need. It provides an overall framework for bundling as a key corporate strategy, discusses a variety of issues that should be considered in connection with a bundling effort, and presents examples from various industries.

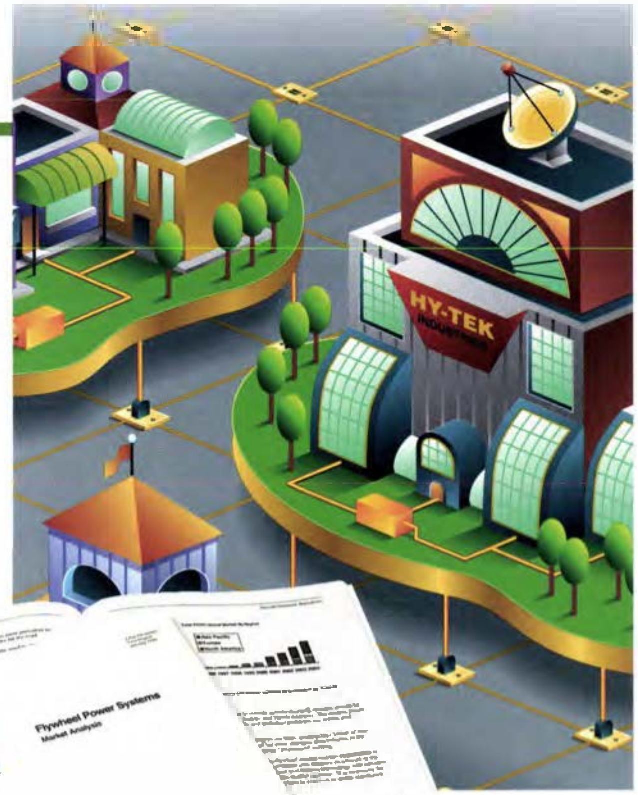
■ *For more information, contact Ahmad Faruqui, afaruqui@epri.com, (650) 855-2096. To order, call the EPRI Distribution Center, (925) 934-4212.*

SmartLoop 2000

EPRI and GC Controls of Greene, New York, have teamed up to introduce a low-cost digital controller that maximizes the performance and efficiency of water-loop heat pump (WLHP) systems. Known as SmartLoop 2000, this reliable microprocessor-based system is capable of controlling all aspects of WLHP system operation, including cooling tower and boiler staging, variable- and two-speed tower fan operation, loop pump lead and lag control, variable-speed loop pumping, and heat pump staging for setback recovery. An inexpensive addition to a WLHP system, SmartLoop 2000 provides substantial savings in energy use. Also, because it requires minimal control wiring, it is easily retrofitted to existing WLHP systems.

■ *For more information, contact Mukesh Khattar, mkhattar@epri.com, (650) 855-2699. To order, call GC Controls, (607) 656-4117.*

Flywheel Market Analysis



Process industries now routinely rely on electronic control and monitoring systems, and the trend is toward the increasing use of such systems. As a result, these industries are becoming more vulnerable to power quality disturbances on electricity distribution systems. Flywheel power systems offer an ideal solution, since they can store and deliver energy to an industrial load as needed. Flywheels have been used to store energy since ancient times, but modern composite fibers make it possible to greatly increase rotational speeds and stored energy. This report, *Flywheel Power Systems: Market Analysis* (TR-109911), evaluates the industrial market for flywheel power systems and identifies barriers to the technology's acceptance. It discusses commercialization timing, offers suggestions for entering the market, and presents specifications for selected flywheel products.

■ *For more information, contact Ben Banerjee, bbanerje@epri.com, (650) 855-7925. To order, call the EPRI Distribution Center, (925) 934-4212.*

Gas Turbine Overhauls

A complete overhaul of a combined-cycle power plant can take as long as 10–12 weeks. Proper planning for such an outage is critical in avoiding delays, cost overruns, and other complications. EPRI's GTOP (Gas Turbine Overhaul Plan) Combined Cycle software is an integrated maintenance management tool specifically designed to help optimize the planning and management of major overhauls of combined-cycle plants. Used in conjunction with the Microsoft Project scheduling program, GTOP Combined Cycle provides state-of-the-art techniques for resource planning, project status assessment, and cost-to-date and cost-to-completion calculations. Its database can easily be customized to meet specific plant or maintenance event requirements.

■ *For more information, contact John Scheibel, jscheibe@epri.com, (650) 855-2850. To order, call the Electric Power Software Center, (800) 763-3772.*

Discovery

Basic science and innovative engineering at the cutting edge

Power Electronics Milestone Reached

The world's first gallium nitride (GaN) MOSFET—metal-oxide semiconductor field effect transistor—has been fabricated in high-power electronics R&D work sponsored by EPRI and the U.S. Defense Department's Advanced Research Projects Agency (DARPA). This achievement is a significant step toward the development of ultrahigh-power inverters for unprecedented switching speed and control capabilities in high-voltage ac and dc power circuits.

Silicon-based MOSFETs are key components in today's fastest inverters. Switches based on wide-bandgap semiconductors like GaN promise to handle higher power levels and operating temperatures, resulting in wider applicability and better performance.

A consortium led by the University of Florida produced the GaN MOSFET, an early milestone in the three-year, $14 million EPRI-DARPA program to accelerate the development of high-power devices and circuits for electric power and defense applications. The consortium, one of six groups funded under the program, has also developed a process for producing GaN wafers with the smooth, well-defined sidewall required for device fabrication.

A new process can produce gallium nitride wafers with well-defined sidewalls (right).

■ *For further information, contact Jerry Melcher, jmelcher@epri.com, (650) 855-2299.*

New Firm for Membrane Technology

A startup company focused on the commercial development and application of an innovative liquid membrane purification technology has been formed by EPRI, SRI International, Spectrum Laboratories, and Edison Technology Solutions. Called FaciliMax, the new technology could greatly reduce the economic and environmental costs of separating gases and liquids and of removing contaminants from mixtures. It could be used for processing industrial gases, waste, and wastewater and for separating components in the chemical, food processing, agricultural, pharmaceutical, and biotechnology industries.

The new company, Facilichem, has been awarded a two-year, $2 million grant from a National Institute of Standards and Technology program that supports leading-edge technologies with economic and commercial promise.

Developed at SRI International, the FaciliMax process features a proprietary membrane configuration that holds the selective liquid membrane stable to effectively separate the components in the feed stream. This highly selective separating agent allows only purified material to pass through.

Historically, a key drawback of liquid membrane separation has been the short lifetime and insufficient endurance of the membranes for commercial-scale industrial use. To make the process economically feasible, the FaciliMax system provides unique access to the liquid membrane compartment, enabling constant replenishment of the separating agent.

Says Abhoyjit Bhown, who invented the technology while at SRI and who now heads Facilichem, "Despite 30 years of research, the structure for liquid membrane systems has not been sufficiently stable for widespread industrial use." The new company's goals, he goes on, are to investigate methods of stabilizing these membranes, then to make them thinner and more efficient, and finally to commercialize and market the technology for a broad range of industrial applications.

Ammi Amarnath, EPRI's manager for process industries, calls FaciliMax "a very clever, logical extension of the hollow fiber technology used in renal dialysis and water desalination." Through Facilichem, he says, EPRI is involved in an effort that will greatly enhance the efficient, value-added electrification of the industries that apply the new technology, while benefiting the community in several ways. FaciliMax could provide the first economical method of recovering heavy metals from wastewater and could significantly reduce processing costs in hydrocarbon separations.

Over the next two years, Facilichem will further develop, build, scale up, and demonstrate the FaciliMax system and seek partnerships with companies interested in specific commercial applications.

■ *For further information, contact Ammi Amarnath, aamarnat@epri.com, (650) 855-2548.*

Pulsed Laser Could Speed Communications

An ultrafast pulsed laser developed in an EPRI lightning diversion project shows significant promise for making fiber-optic communications lightning fast—three orders of magnitude faster than with current technology. EPRI is pursuing work on the technical challenges involved—work that, if successful, could enable wide commercialization of femtosecond (10^{-15}) laser pulse technology for data communication speeds approaching 10 THz.

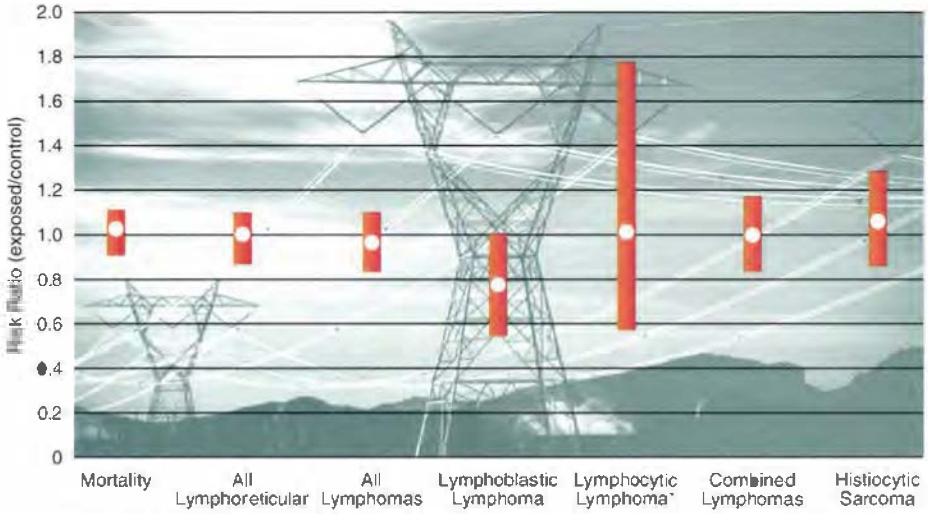
The concept of using femtosecond laser pulses with time multiplexing to increase communication speeds emerged in research on using an ultrafast laser to trigger lightning discharges and divert them from utility structures. Researchers recognized that the concept had great potential for communications applications in the power industry (for distribution automation, grid operation, and control center communications) and in such other markets as data transfer, the Internet, television, and facsimile.

Satellite and other advanced communications applications currently use wavelength multiplexing to increase transmission rates: 10 or 20 signals are broadcast simultaneously at neighboring wavelengths. This approach has two drawbacks: each channel's broadcast speed is determined by the electronics, and the number of channels is limited by the bandwidth of the emitting or amplifying laser medium.

The drawbacks can be overcome by time multiplexing in an optical system. Ultrashort laser pulses that code "words" as a particular time sequence of 100 femtosecond pulses within 5 or 10 picoseconds (10^{-12}) can be sent through the air without significant broadening. With a different word emitted every 10 picoseconds, a communications system working at a rate of 10 THz is achievable. Even higher rates may be possible if wavelength multiplexing can be added to time multiplexing. Time multiplexing with pulses on the order of 50 picoseconds may also be applicable to optical fibers.

It is already possible to generate laser pulses as short as 10 femtoseconds. In order to realize the potential of femtosecond pulsed laser communications, technology must be developed to compress a nanosecond signal into a string of femtosecond pulses, to process 10 to 100 channels in parallel, and to decompress a string of femtosecond pulses back into nanosecond pulses.

■ *For further information, contact Ralph Bernstein, rbernste@epri.com, (650) 855-2023.*



*The wider confidence interval is due to the relatively low incidence of this disease type in the study.

Mouse Study Finds No EMF-Leukemia Link

A recently completed study of the effects of magnetic fields on the incidence of leukemia in nearly 2800 laboratory mice found no significant effects of such exposure. The study was the largest life-span animal study ever sponsored by EPRI and one of the largest rodent studies ever conducted. Because of its size and rigor, it gave researchers an excellent opportunity to evaluate the effects of chronic EMF exposure.

Mice were separated into eight treatment groups for the 30-month study. Beginning at four weeks of age, mice in four of the groups were exposed to 60-Hz, circularly polarized 1.4-µT (14-G) magnetic fields; mice in the other four groups were exposed only to the ambient average magnetic field of about 0.1 µT (1 mG). For each magnetic field exposure condition, mice were exposed to four levels of ionizing radiation: 0, 350, 475, and 600 R.

At death, tissues of all mice were microscopically evaluated for lymphoid cell neoplasms, and several types of leukemias were found. No significant effects of magnetic field exposure were found on the incidence of leukemia at the end of the study or on the rate of development of leukemia during the in-life portion. Because the treatment groups were so large, the investigators were also able to evaluate the magnitude of risk of particular types of lymphomas. The calculated risk ratio (the risk for exposed animals compared with that for control animals) for each type was approximately 1, indicating no effects from magnetic field exposure.

At all stages of the study, rigorous methods were used, including blind measurements and evaluations, conformance to the EPA's Good Laboratory Practices, and internal and external peer reviews.

Overall, the study found no evidence that magnetic field exposure either causes or promotes the development of leukemia in mice. This was true for each leukemia type, as well as for all types combined. The investigators concluded that "the results do not support any effect of magnetic field exposure on human risk of developing leukemia/lymphoma." Although definitive conclusions about human leukemia cannot be drawn from this research, the high-quality study is another piece of evidence in the continuing examination of the effects of magnetic fields.

■ *For further information, contact Charles Rafferty, craffert@epri.com, (650) 855-8908.*

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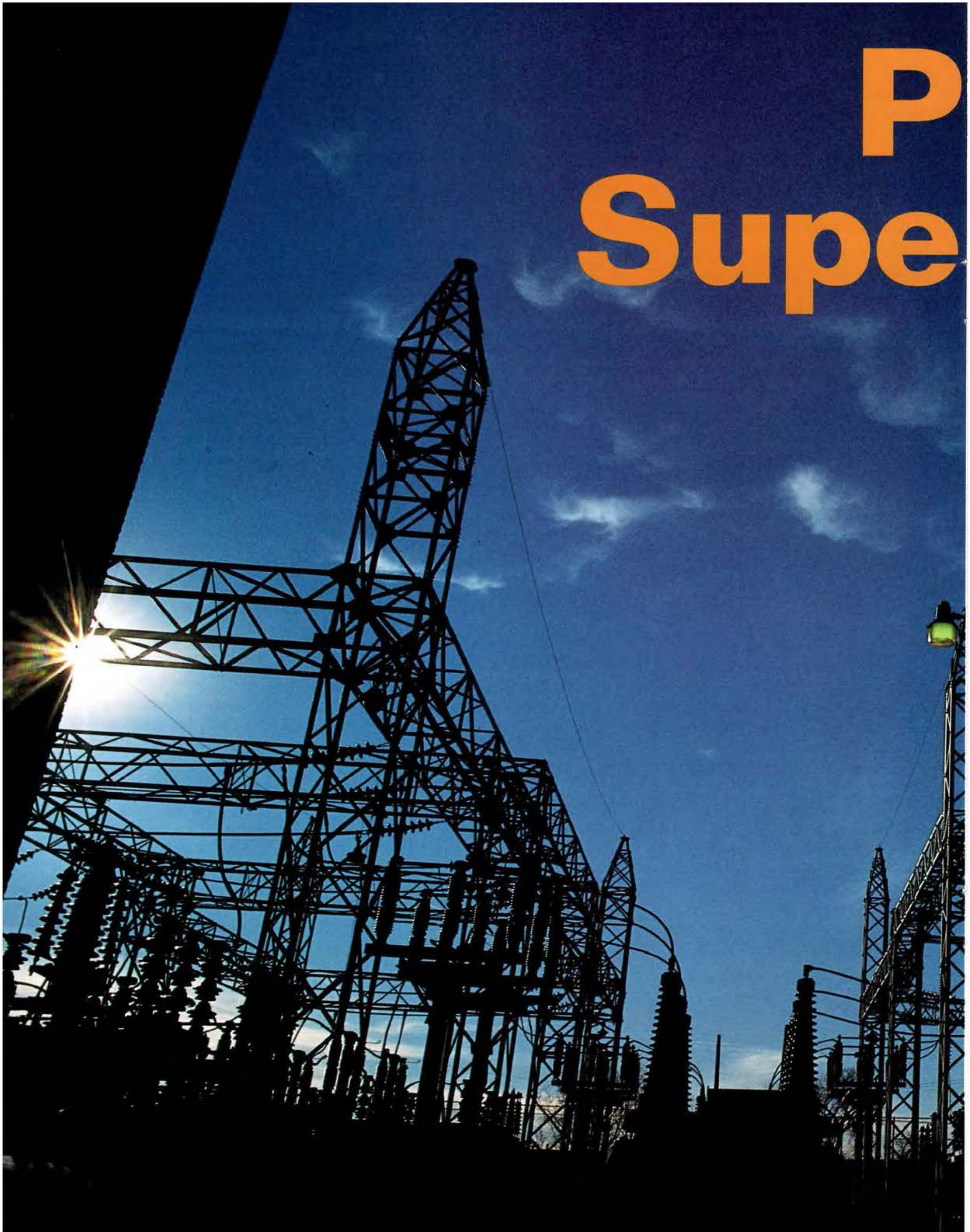
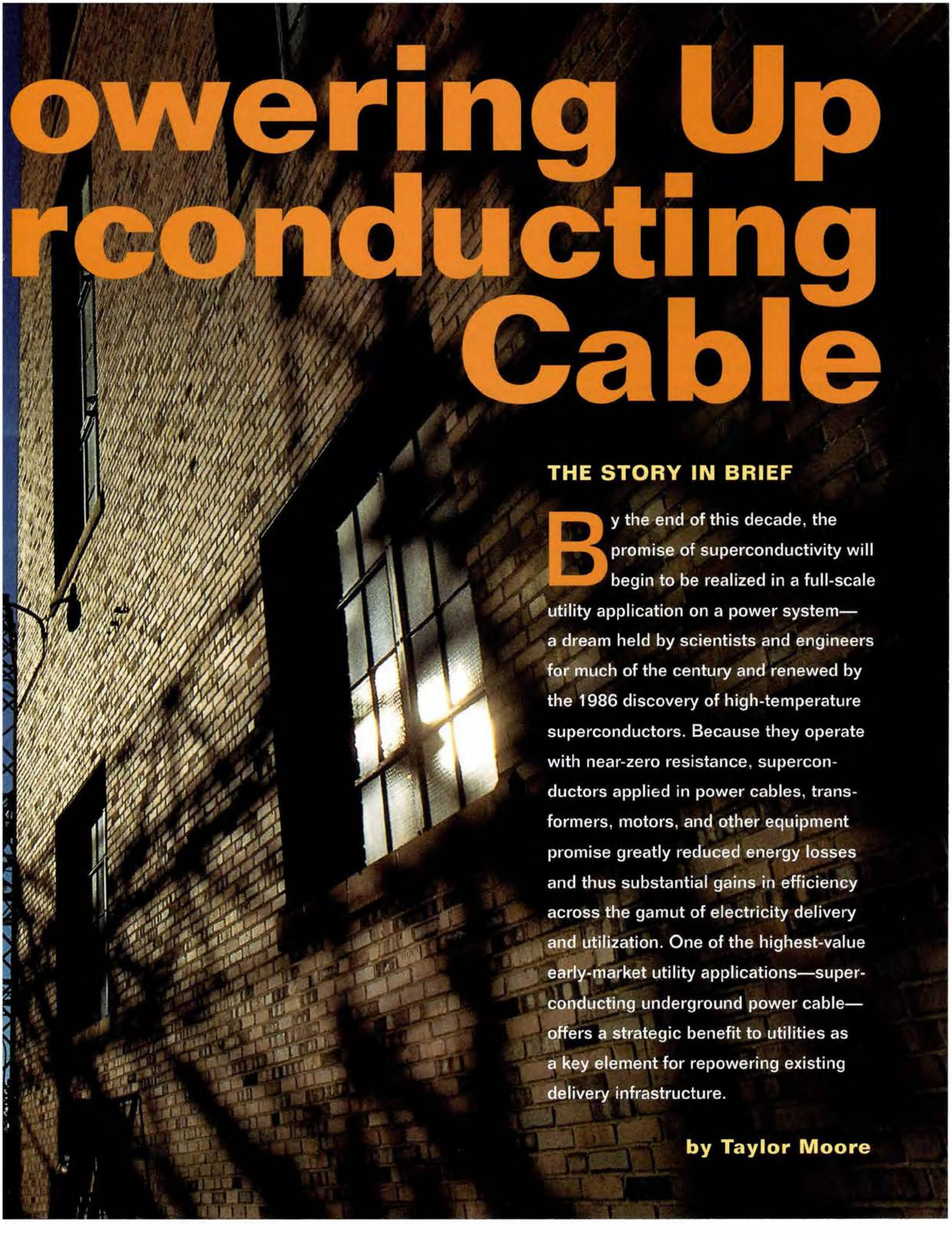




owering Up
rconducting
Cable

THE STORY IN BRIEF

By the end of this decade, the promise of superconductivity will begin to be realized in a full-scale utility application on a power system—a dream held by scientists and engineers for much of the century and renewed by the 1986 discovery of high-temperature superconductors. Because they operate with near-zero resistance, superconductors applied in power cables, transformers, motors, and other equipment promise greatly reduced energy losses and thus substantial gains in efficiency across the gamut of electricity delivery and utilization. One of the highest-value early-market utility applications—superconducting underground power cable—offers a strategic benefit to utilities as a key element for repowering existing delivery infrastructure.

by Taylor Moore

IN THE HEART OF THE RENOWNED industrial city of Detroit, part of an aging electricity delivery infrastructure is scheduled to be retrofitted with what could be one of the most important technologies of the twenty-first century. The installation and energizing of the world's first high-temperature superconducting (HTS) power cables in a utility network, set for the year 2000 at Detroit Edison's Frisbie substation, will be a pioneering demonstration of a likely early-market utility application of superconductivity. And for Detroit Edison, the principal operating subsidiary of DTE Energy, the project will test a strategy for upgrading its downtown underground distribution system.

VITO PALMISANO PHOTOGRAPHS

Detroit is experiencing a downtown revitalization, with major building projects under way or on the drawing board. Significant growth and shifts in the demand for electricity are anticipated over the next decade.

Three 400-foot (120-m) HTS cables, cooled to below 77 K (−196°C) by liquid nitrogen circulating in their cores, will each carry 2400 A ac at 24 kV—three times the current carried by a conventional copper cable. Installed in existing 4-inch-diameter (10-cm) ducts, the HTS cables together will replace nine conventional cables. The reduction in conductor mass will be dramatic: over 18,000 pounds (8200 kg) of copper will be replaced by less than 250 pounds (110 kg) of HTS conductor—helically wound, silver-sheathed wire tape made from a ceramic copper oxide compound (BSCCO) containing bismuth, strontium, calcium, and a small amount of lead.

The flexible HTS cables will be installed by personnel from Detroit Edison and Pirelli Cables and Systems. Originating at the lower-voltage terminals of a 120-kV/24-kV transformer in the substation yard, the cables will run in the underground ductwork through several 90-degree bends to the three-story substation building, where they will connect with switchgear on the top floor. The installation will provide a realistic learning experience for crews that may eventually perform similar jobs throughout the city's downtown area, where Detroit Edison has about 1000 miles (1600 km) of underground cables that are possible candidates for replacement.

Catalyzed by major funding from EPRI and the U.S. Department of Energy under its Superconductivity Partnership Initiative with private industry, the $5.5 million Detroit HTS cable project will culminate nearly a decade of collaborative science and technology R&D led by Pirelli, the world's largest manufacturer of power cables; American Superconductor Corporation (ASC), a leading producer of HTS wire and technologies for power applications; and EPRI. In addition, the project is expected to receive a critical technological contribution from the cryogenic experts of Lotepro Corporation, a subsidiary of the industrial gas technology company Linde.

"It's gratifying to see the results of R&D that EPRI began in 1989 finally come to fruition in a utility-scale demonstration on a power system," says Ralph Samm, the manager for underground distribution who initiated EPRI's early work on developing HTS power cables for utilities.

DOE and EPRI previously cosponsored the development of a 50-meter flexible HTS conductor assembly manufactured by Pirelli with wire made by ASC. In tests conducted in 1996, the conductor assembly carried 3300 A at 1 μV/cm dc and 77 K—a world record that still stands. Then, using the same conductor, Pirelli developed a 50-meter cable prototype for operation at 115 kV. This prototype, including terminal connections and a splice, was successfully tested last fall at the company's high-voltage laboratory in Milan, Italy. Energized at 69 kV, it carried 3300 A dc at 74 K and has since demonstrated an ability to carry 2000 A ac.

Last October, in announcing DOE's collaborative R&D award of $2.4 million to the Detroit cable demonstration, Energy Secretary Bill Richardson said the project would open "the gateway to the electricity superhighway of the future. The contract builds on the department's significant investment in developing HTS technology over the last decade and paves the way to commercialization of a technology that will transform the power delivery systems of the world." Richardson said the project "will help the United States build and increase its competitive position in the emerging world market for HTS electric power applications."

Superconducting cable technology has promise as a cost-effective means of at least tripling the current-carrying capacity of existing underground distribution or transmission circuits, and its availability in the next decade could fortuitously coincide with the emergence of competitive retail electricity markets that are likely to place greater power transfer demands on regional and urban networks. "High-capacity HTS cables will accelerate the growth and increase the value of an open and competitive marketplace for electricity," said Greg Yurek, ASC's president and chief executive officer, at the time of the DOE announcement. Yurek also emphasized the importance of the Detroit project in "the commencement of the growth of a significant commercial market for HTS products."

Added Walter Alessandrini, chief executive officer of Pirelli Cables and Systems North America, "The Detroit Edison cable project is the first of several we expect to undertake in the next few years as the market for high-capacity HTS cables starts to grow."

Key for urban infrastructure renewal

Detroit Edison believes that high-current HTS cables rated at subtransmission and distribution voltage levels could be a technology solution for meeting the growing demand for electricity in Detroit's urban core while avoiding the wholesale replacement of underground facilities and the resulting disruptions at street level. "The cables will be installed in downtown Detroit to support the revitalization of this older urban area in a nonintrusive, environmentally friendly way," says Robert Buckler, president and chief operating officer of DTE Energy Distribution.

Buckler notes that major downtown building and renovation projects under way or planned for the near future—including casinos, office and shopping complexes, a new baseball park, and a new football stadium—will bring significant load growth and load shifts for the utility's downtown distribution system over the next decade.

"Having the capability to triple the current-carrying capacity of existing conduits will allow us to avoid digging up and disrupting the infrastructure," he says. "Soon after the turn of the century, the city's revitalization will have progressed to the point that we will need more power in the downtown area, and superconducting underground cables could have a very significant impact in bringing this extra power in."

Like Detroit, most other large U.S. cities are experiencing building booms and expect double-digit—in several cases, even triple-digit—population growth over the next dozen years, according to survey information reported at a recent conference sponsored by the Fannie Mae Foundation and the Brookings Institution. Such growth will undoubtedly increase the demand for electricity. But as John Howe, ASC's vice president for electricity industry affairs, notes, "The siting of new transmission lines has become progressively more difficult and is virtually impossible in many areas with high real estate values. And with downtown underground distribution, often there is simply no more room in the ground for new cable conduits."

Bill Carter, Detroit Edison's director of transmission and subtransmission planning, says the traditional approach would be to install new 120-kV pipe-type or solid-dielectric cables to increase power capacity in the downtown service area. "But that's pretty expensive," he notes. "If we can use existing ductwork and take advantage of the much greater current-carrying capacity of superconducting 24-kV cables, we may be able to avoid installing new 120-kV cables, eliminate the two transformation steps—from 24 kV to 120 kV and back down—and simply transmit power into downtown at 24 kV."

Energy losses that result from resistance in conventional conductors are reduced at higher voltage levels of power transmission and distribution. But this traditional solution for delivering more power requires new transformers and other substation equipment. In contrast, superconductors are nearly resistance free and can

COURTESY DETROIT EDISON

DAVE BOGDEN

Three 400-foot (120-m) flexible HTS cables will be connected to a spare transformer (foreground, top photo) in the yard of Detroit Edison's Frisbie substation, then will turn underground and snake through several 90-degree bends to connect with switchgear inside the substation. After conventional 24-kV copper cables have been removed from nine ducts in a substation duct bank (right), the 24-kV HTS cables will be installed in three of the ducts. Because these three cables can carry the same amount of current as the nine copper ones they will replace, six cable ducts will be freed up for possible use in meeting future load growth.

operate at high current levels with much lower losses. Thus the need for voltage transformation steps is reduced.

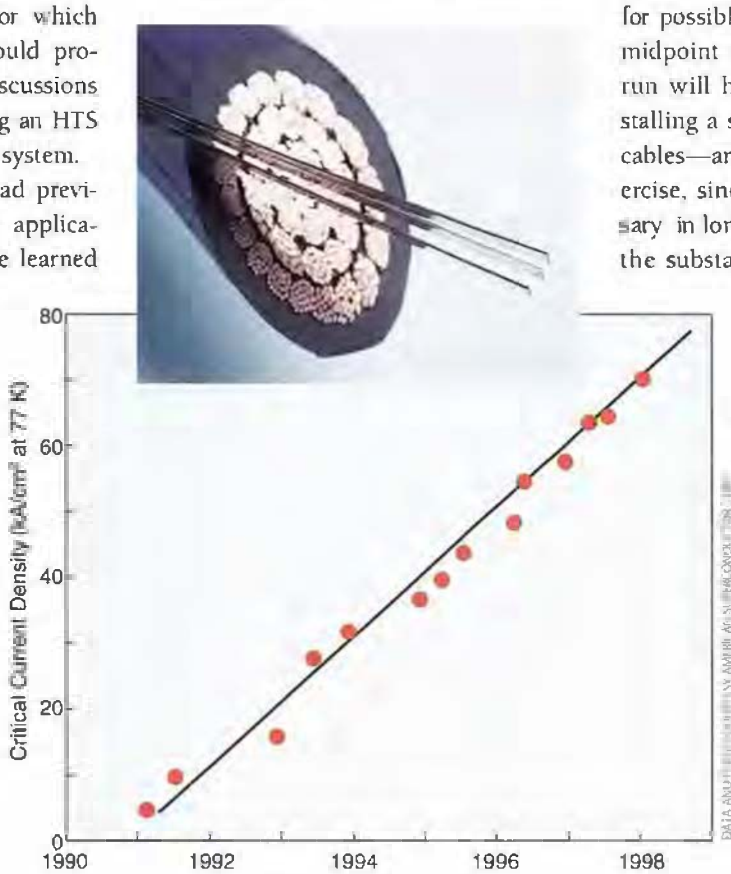
High-current HTS cables could help relieve transmission bottlenecks in existing corridors by eliminating the capacity limit posed by conventional underground cables (which can carry only about half as much current as overhead lines of the same voltage). Although more expensive than overhead lines, underground HTS cables could also serve as new circuits in existing overhead transmission rights-of-way where there is insufficient space for an additional overhead line.

EPRI and Pirelli originally envisioned 138-kV-class, pipe-type underground transmission cables as the most likely early-market entry for HTS cables. Indeed, many utilities still view high-voltage underground transmission as the most promising future application for HTS cables. But a more immediate need for which superconducting technology could provide a solution emerged in discussions with some utilities about hosting an HTS cable demonstration on a power system.

"Although EPRI and Pirelli had previously focused on transmission applications, from our joint studies we learned that several utilities were interested in high-current HTS cables as a means of doing things on their distribution networks that they had been unable to do before," says Don Von Dollen, EPRI's manager for underground transmission. "One of the utilities identified an application in which 13-kV HTS cables, carrying the same amount of power as conventional 69-kV cables, could eliminate a voltage transformation step in bringing power into its high-density-load downtown area. That, in turn, could eliminate some expensive substations and allow for more-compact substation designs."

Continues Von Dollen, "Another utility needed to tie several of its downtown substations together to enhance system reliability. Space constraints in the substations precluded using conventional 69-kV cables, and there was not adequate space in existing duct banks to install multiple 13-kV circuits. But 13-kV HTS cables could be installed in the banks to carry the additional current."

Given this utility feedback, it came as no great surprise when Detroit Edison's Carter described system operation challenges that called for high-current, 24-kV cables. "In some ways, our demonstration will be even more of a challenge for Pirelli than the 138-kV-class cable they have already designed, because now they have to fit a single-phase conductor into a 4-inch duct," says Carter. "For us, the greatest economic appeal is in maximizing the use of our existing infrastructure. The result will be reduced costs that ultimately will be reflected in lower rates for customers. If we can increase the distribution capacity downtown for less money largely by using existing assets, it will allow us to grow our system to meet customers' needs and better control our costs."



American Superconductor continues to increase the critical current density of multifilament HTS wire manufactured with the ceramic copper oxide compound Bi-2223. Shown here are the values achieved in short lengths of the superconductor material, with a high of 70,500 A/cm^2 being reported last year. This steady progress has led to kilometer-length HTS wire tape that can carry 130 A; three such tapes now carry as much current as a 400-A conventional copper cable (photo).

Realistic test environment

EPRI's Von Dollen says the Detroit Edison substation offers an almost ideal utility environment for demonstrating HTS power cable, including its installation, testing, routine operation, and maintenance. The three cables will be connected to a spare transformer that, when switched into the utility network, will expose them to surges and transients typical of a utility distribution system.

The substation's 60-year-old underground concrete duct banks are the same as those throughout the city. Replacing nine conventional cables with three HTS cables will leave six conduits available for possible future use. A manhole at the midpoint of the 400-foot (120-m) cable run will have just enough room for installing a splice on one of the three HTS cables—an invaluable demonstration exercise, since many splices will be necessary in longer, permanent installations. In the substation yard, there is room near the transformer at one end of the HTS cable run to install a liquid nitrogen refrigeration system, to be built by Lotepro Corporation.

Next year, under the supervision of Pirelli personnel, cable crews will install the HTS cables, and engineering personnel will develop operating and maintenance procedures that not only will be used for a two-year series of tests to determine cable reliability and O&M costs but also will serve as initial procedures for other utilities to follow. "This demonstration project is as real-world as it gets," says DTE Energy's Buckler. "It will encompass most of what we expect to encounter in the future if we decide to pursue a major HTS retrofit strategy.

Our people are excited at the prospect of learning how to do their work using the new, cutting-edge superconducting technology."

Adds Carter, "We will be one of the first utilities to get O&M experience with liquid nitrogen–cooled, HTS power technology—something we believe will be of significant value as HTS cables and other power products, such as fault current limiters and transformers, enter the commercial market. We've involved our O&M personnel from the outset in discussions with Pirelli and the project's other partners to address any safety concerns and procedures that must be worked out before the HTS cables are placed in service."

Notes Paul Grant, an HTS expert and science fellow in EPRI's Strategic Science and Technology group, "The most valuable, tangible results from the Detroit demonstration, in my opinion, will be the operating rules and insights that Detroit Edison will develop for using HTS cable technology. On the basis of prototype test results to date, I am confident that the technology itself not only will work but will be a slam dunk—with the possible exceptions of pulling the cable through the conduit bends and splicing a joint in the space previously used for conventional cables."

Cryogenic refrigeration technology based on cheap, environmentally benign liquid nitrogen is used in a wide variety of industrial and research applications. However, the utility industry's experience with the coolant has been limited primarily to its use for temporarily freezing dielectric oil in a cable to facilitate repair or splicing and as a spray for cleaning conductor insulators.

For the Detroit Edison HTS cable demonstration, Lotepro will engineer the refrigeration system to meet Pirelli specifications. The system will involve "well-proven and -tested components, although their arrangement in a system will be a first of a kind," says Hans Kistenmacher, president of Lotepro. In one likely configuration, he says, pressurized liquid nitrogen would be circulated in a loop and would be cooled at the refrigeration unit via heat exchange with pressurized helium. The helium would then be expanded in a high-speed turbine enclosed in a cryogenic coldbox before being returned to a compressor. The expansion turbine would run on frictionless gas bearings for highest reliability.

A guiding objective for a cable refrigeration system design is that it be economically optimal from the first unit's initial operation. "We want a system that will be practical for commercial operation, and so we are trying to achieve the optimal economic limit relative to the state of the art for copper cable in this application," says Kistenmacher.

COURTESY AMERICAN SUPERCONDUCTOR CORP.

American Superconductor's HTS tape is fabricated into a stranded conductor assembly by Pirelli Cables and Systems, using modified conventional-cable equipment. The machine on the right then wraps the conductor assembly with thermal insulation made of metallized polyester film.

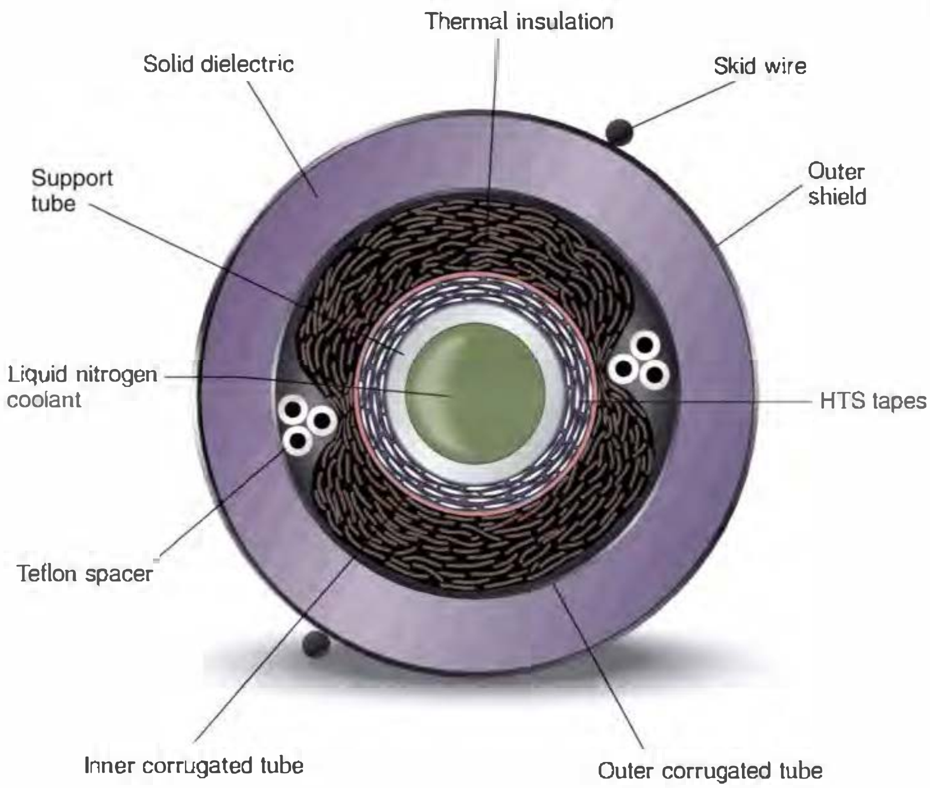
Dielectric: warm or cold

Pirelli, which has identified superconducting power cables and fiber-optic communications as strategic technologies for its future business, is developing two basic HTS cable designs in separate efforts.

The design planned for the Detroit Edison project, an extension of previous work sponsored by EPRI and DOE, features a warm dielectric. In this design, hollow-core conductors contain pressurized liquid nitrogen, but the dielectric that electrically insulates the conductors operates at external ambient temperature and thus can be made from such conventional materials as fluid-impregnated paper, paper-polypropylene-paper laminate, extruded ethylene-propylene rubber, and cross-linked polyethylene. The flexible cables can be installed in a steel pipe and surrounded by pressurized dielectric fluid or gas or, as is the case in Detroit, encased with extruded solid dielectric.

Also, under a 1997 agreement with Electricité de France (EdF), Pirelli is developing a 50-meter prototype of coaxial underground HTS cable in which the dielectric operates at cryogenic temperatures. In this design, one conductor is inside another; the two are separated by the dielectric, with liquid nitrogen circulating through the insulated pipe that contains the cable assembly. The neutral outside conductor creates a superconducting shield that repels the magnetic field from the primary conductor, meaning that electrical losses are even lower than with a warm-dielectric cable. Pirelli and EdF plan to test the cryogenic HTS cable prototype by late 2000. (In the United States, DOE is supporting a coaxial cable prototype development effort featuring HTS wire from Intermagnetics General. This effort is being led by Argonne and Oak Ridge National Laboratories and includes Southwire Corporation.)

Pirelli envisions offering the warm-dielectric design for applications of up to several hundred megavolt-amperes and the cryogenic-dielectric design for applications of 225 kV and up and current levels as high as 1 GVA (1000 MW of power). Candidate applications for both types of design exist in many utility markets, said Steve Norman, Pirelli's manager for the Detroit Edison demonstration, in an interview last November. "EdF has a particular application for dense, high-power urban penetration, so we are talking about a system at 225 kV carrying 1 GVA per circuit or, alternatively, one at 90 kV that probably would carry about 600 MVA." Norman added that, as a result of its 1998 acquisition of Siemens' power cable business, Pirelli is also developing a coaxial cold-dielectric HTS cable prototype in Berlin, Germany, for eventual demonstration there.



The 24-kV, 2400-A warm-dielectric HTS cables that Pirelli is planning to use in the Detroit Edison demonstration are based on an earlier design for a 115-kV solid-dielectric cable. Liquid nitrogen circulates through the hollow core of the HTS conductor assembly, and multilayer thermal insulation surrounds the conductor. The solid dielectric for the demonstration will be either extruded ethylene-propylene rubber or Pirelli tree-retardant cross-linked polyethylene.

Interviewed just after the first electrical tests of the warm-dielectric HTS cable prototype were conducted in Milan, Norman said that success in the laboratory had shifted the focus to proving HTS cable technology in a utility network. "We've done about all that we can in the laboratory. Now Detroit is going to be the proof of the pudding. We're going to put the cable in the field and demonstrate to users that it can be applied in their environment. Once we have installed the cable and then maintained the performance of the superconductors—which is no trivial issue—the emphasis will be on operation. A key issue undoubtedly will be the refrigeration plant and its reliability."

Goal is to meet or beat copper

Pirelli anticipates several field trials of HTS power cables with utility users, beginning with Detroit Edison, before the technology enters commercial markets (perhaps as soon as 2003). The early prototypes and demonstrations are not expected to have installed costs competitive with those of conventional cables, which have benefited from a century of manufacturing know-how. But owing to expectations that ASC's HTS wire will continue to improve in performance and that the demonstrations will give a clearer picture of total HTS cable costs, researchers are optimistic that in commercial installations the cables will have a cost-performance ratio equal to that of conventional cables.

"We must compare the total owning cost of the new superconducting cable—including losses as well as O&M costs for the refrigeration system and for the cable system overall—with that of conventional cable," says EPRI's Don Von Dollen. "The bottom line is that the cost of HTS cable has to be better than that of conventional cable."

The cost of superconducting wire dominates the cost of HTS power cables. According to EPRI's Paul Grant, there has been a general belief in the HTS community that to be cost-competitive in power applications, the basic manufacturing cost of HTS wire for operation at 77 K can be no more than $10 per kiloampere-meter (kA-m). Today's HTS wire, based on the BSCCO compound Bi-2223, costs several times that amount.

In a recent paper submitted for publication in a professional journal, Grant and colleague Thomas Sheahen of Science Applications International Corporation suggest that the cost-performance target of $10/kA-m "may be extremely difficult to realistically achieve for silver-sheathed BSCCO produced by the oxide-powder-in-tube [OPIT] technique." ASC, meanwhile, asserts that with full exploitation of large-scale production economies, including automation, the cost-performance target is attainable with current HTS wire technology.

"We suspect—in fact, we are convinced—there is no single cost-performance market-entry value whose realization would constitute a declaration of victory," say Grant and Sheahen. As an example, they conclude that in the case of high-current HTS power cables for retrofit installation, the potential value of urban real estate formerly occupied by intermediate-voltage step-down substations could justify a cost-performance ratio 100 times greater than $10/kA-m.

In a separate, parallel part of the EPRI-DOE cable demonstration project, Pirelli will make and test a 1-meter multistrand conductor featuring ASC wire that differs from BSCCO-OPIT wire both in HTS ma-

Pirelli successfully tested a 50-meter prototype HTS cable last November at its high-voltage laboratory in Milan, Italy. Designed for operation at 115 kV, the prototype system included terminal connections, a splice, and a pilot liquid nitrogen refrigeration unit. Energized at 69 kV, the cable carried 3300 A dc at 74 K and later 2000 A ac.

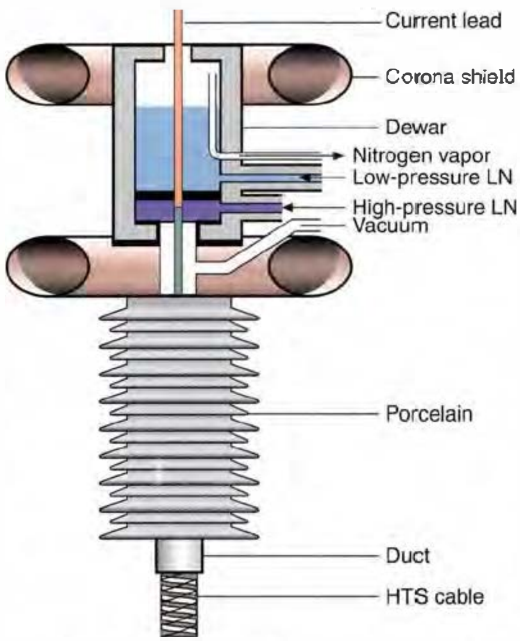
COURTESY PIRELLI CABLES AND SYSTEMS

terial and in fabrication method. The work will build on a large private effort undertaken by ASC and EPRI to commercialize this so-called second-generation HTS wire, made by growing thick (>1-μm) biaxial films of an yttrium barium copper oxide (YBCO) compound on flexible metallic tape. (The original HTS material, this compound was discovered by researchers in 1986 to be superconducting at liquid nitrogen temperature.) The ASC-EPRI effort benefited substantially from work at DOE's Oak Ridge and Los Alamos National Laboratories that demonstrated possible approaches to producing coated YBCO conductor.

According to Alex Malozemoff, ASC's vice president for technology, recent collaborative work by his company and the Massachusetts Institute of Technology—work sponsored under the alliance with EPRI—achieved low-cost deposition of YBCO films on single-crystal lanthanum aluminate. Films over 1 μm thick with a current density greater than 1 MA/cm² were produced. ASC has gone on to produce films 2 μm thick (carrying 1 MA/cm²) and 0.8 μm thick (carrying 2.2 MA/cm²).

"These results are important because they open up a new approach to achieving a truly low-cost manufacturing process for YBCO-coated conductor," Malozemoff and his colleagues reported at last year's Applied Superconductivity Conference. "Initial estimates indicate that at least a factor of two can be gained in cost-performance vis-à-vis BSCCO-OPIT. . . . YBCO-coated conductor technology lies further out in the development cycle but has the potential to open up a significant further increment in cost- or price-performance over BSCCO-OPIT, enabling a broader market for HTS wire in power and other applications."

The ASC scientists said that the different capabilities and characteristics of YBCO and BSCCO are likely to ensure an active market for both technologies in the future.



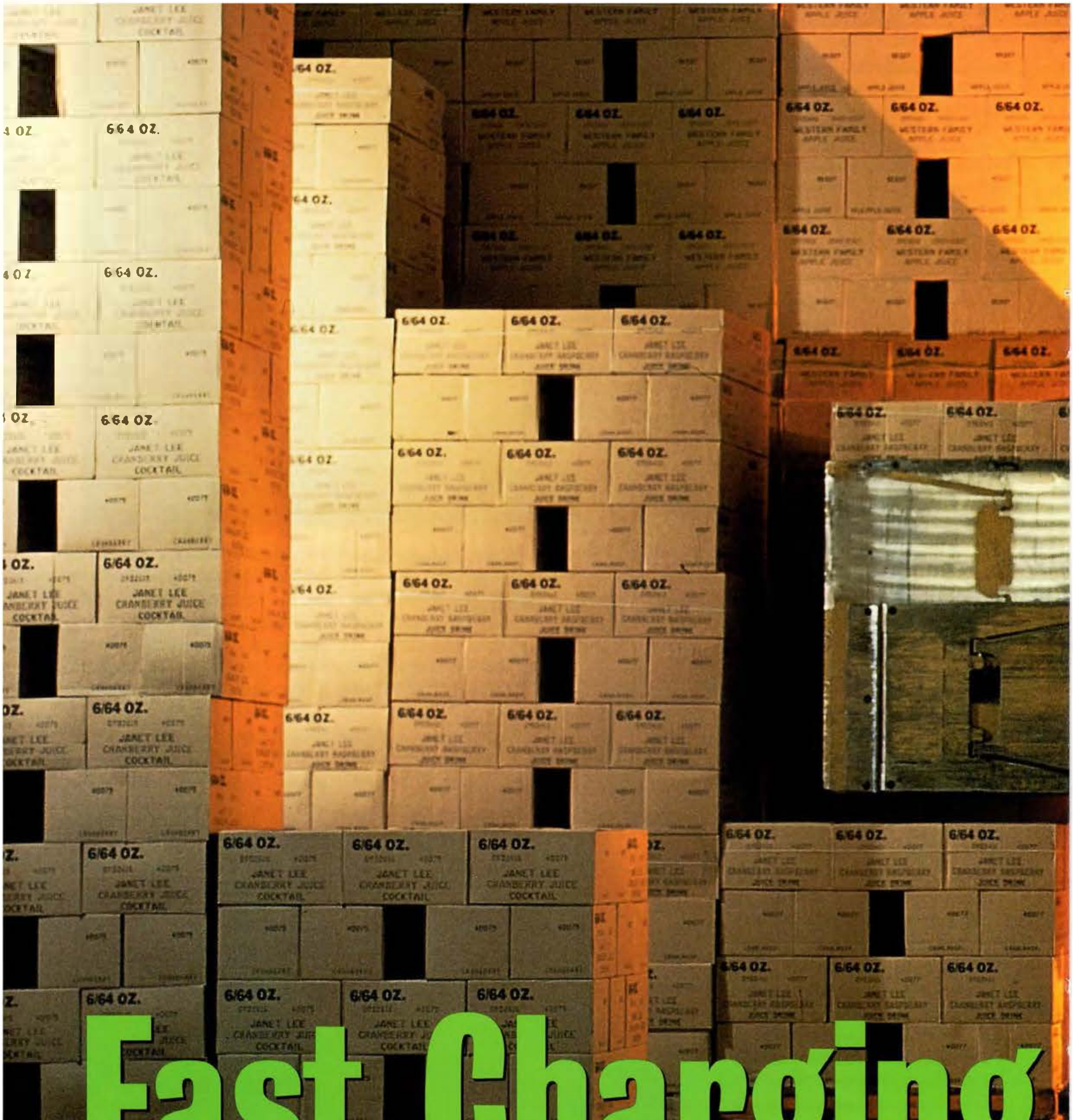
Pirelli has developed a basic termination design for HTS cables that channels the flow of high- and low-pressure liquid nitrogen (LN) and minimizes heat generation at the transition to conventional conductors.

Demonstrating the fruits of R&D

Phenomenal success in advancing the performance of high-temperature superconductors—discovered by IBM research physicists only 13 years ago—continues to spark media headlines and public interest. Yet definitive engineering conclusions as to whether these complex and even mysterious materials will, in fact, fundamentally reshape the technology of electricity delivery in the next century critically depend on the results of full-scale demonstrations in key applications—including power cables, transformers, and motors—over the next few years. EPRI is continuing a long-term commitment to commercializing HTS technologies that offer the greatest, most immediate benefits to electric utilities.

"EPRI focused early on a retrofit strategy for HTS cables—replacing copper cables in urban settings with high-capacity HTS cables, much as fiber-optic cables have been replacing copper communications cables," says EPRI's president and chief executive officer, Kurt Yeager. "Detroit Edison's leadership in opening up the urban market will provide a valuable experience base for all EPRI members, thereby helping to accelerate the acceptance of this new technology." ■

Background information for this article was provided by Paul Grant (pgrant@epri.com), Strategic Science and Technology, and Don Von Dollen (dvondoll@epri.com) and Ralph Samm (rsamm@epri.com), Energy Development and Utilization Division.



Fast Charging

Quick battery charging is critical to increasing the use of electric lift trucks demonstrations have shown that fast-charging technologies not only offer speed

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A mid billowing clouds of white gypsum dust, the clamor of giant conveyors ejecting 70-pound (30-kg) sheets of wallboard, and the roar of propane-powered lift truck engines, a clean, quiet electric lift truck might seem somewhat out of place—like a ballet dancer at a boxers' gym. But an electric forklift has recently held its own in such an environment at a National Gypsum plant in Baltimore.

"There's basically no difference in performance," reports plant manager Dave Cureton, comparing the electric forklift with its noisy counterparts. "The guys have been grousing a bit about the fact that it's different to drive than the internal combustion engine trucks they're used to. But it does the work."

And that's no small feat. Vehicles like the plant's are the heavyweights of lift trucks, responsible for hauling stacks of up to 160 sheets of wallboard for distances equivalent to the length of a football field. Each one of these loads weighs anywhere from 8000 to 11,000 pounds (3600 to 5000 kg). And the trucks repeat these trips continually throughout the workday. First they deliver wallboard from the production line to the warehouse, where they stack

for Lift Trucks

and other electric vehicles in industrial and commercial applications. EPRI but also reduce space and maintenance requirements. by Leslie Lamarre it in piles as high as 15 feet (4.6 m). Then they move the product from the warehouse to dozens of flatbed trailer trucks waiting to deliver it to distributors and job sites in seven states in the mid-Atlantic region. As Cureton concedes, "It's a pretty rigorous workout."

Manufactured by Clark Material Handling, the 12,000-pound-capacity (5400-kg) vehicle at National Gypsum's Baltimore plant is the latest in a series of electric lift trucks EPRI has deployed over the past three years to demonstrate the technology's capabilities. Interestingly enough, though, muscle power is not the point of these demonstrations. (Indeed, even bigger electric lift trucks have been operating reliably in a variety of rugged industrial environments, such as metal fabrication plants, for more than half a century.) Rather, EPRI launched the projects to show the feasibility of using fast-charging technology with electric lift trucks. The ability to charge these vehicles quickly—reducing the usual 8-hour charging time to half an hour or less—is critical to increasing their use in industrial applications.

COURTESY CLARK MATERIAL HANDLING

COURTESY ELWELL-PARKER LTD.

Electric lift trucks have enjoyed long and widespread use (the Elwell-Parker model, left, dates from 1927), but further market growth is being limited by the slowness of battery charging. A large-capacity Clark electric lift truck like that shown above was used in one of several EPRI demonstrations of fast battery-charging systems—a technology that could open up new opportunities for electric vehicles.

Charged up

Among the many so-called nonroad electric vehicles—vehicles not intended for highway driving, including golf carts, sweepers, and scrubbers—forklifts represent the largest single electrical load for U.S. electric utilities. As of 1996, well over 50% of all lift trucks in use in this country were electric. (In western Europe, the figure is even higher—70%.) Contributing to the appeal of this technology are its lack of emissions, quiet performance, and—compared with internal combustion engine alternatives—reduced maintenance requirements and lower life-cycle costs.

The largest single barrier to increasing the technology's market share in the United States is its battery-charging requirements. A conventional 8-hour charging regime generally means that lift truck users must purchase spare batteries to maintain the trucks' productivity. "The typical practice at companies that have electric lift trucks is to have three batteries per vehicle: one in use, one being charged, and one cooling down," says Gary Purcell, who until his recent retirement managed EPRI's nonroad electric vehicle (EV) work. At $2400 each, the spare batteries significantly raise the capital cost of the electric option, and the changing process increases its labor requirements.

Adding to the expense is the very large amount of space—often thousands of square feet—needed to accommodate the battery-charging and -changing operations. At the auto plant where EPRI's first fast-charging demonstration was held, the battery-charging area was equivalent to a quarter of a football field. "It was such a big operation that they employed one person on each shift just to exchange batteries," says Purcell.

Fast charging, which can easily be accomplished during workers' breaks, lunch hours, and shift changes, eliminates the need for spare batteries. Not only does this amount to significant up-front savings, but it also greatly reduces the space requirement of the electric option. And rather than having to remove the battery from a vehicle for charging, users simply plug the vehicle into the charger, which means that less labor is devoted to the charging process.

The conventional charging practices for lead-acid batteries can lead to the release of hydrogen, or gassing, which also means water loss. This results in the need not only for ventilation to remove the gases from the room but also for battery watering. Both battery and charger operators and manufacturers are interested in determining the impacts of fast charging on batteries. The results from EPRI's lift truck field demonstrations have been mixed, but it appears that, in some cases, fast charging may reduce overall fleet watering and ventilation requirements—which in turn could have implications for both battery maintenance and charger siting. EPRI has launched several studies to examine this issue in depth. It is working with charger and battery manufacturers to analyze the batteries used in the field demonstrations for effects of fast charging.

Finally, there's evidence that fast charging may significantly increase battery life. In a study conducted by Cominco Ltd. and sponsored by the Advanced Lead-Acid Battery Consortium and the Ontario Ministry of Transportation's Strategic Vehicle Technology Office, fast charging increased the cycle life of the lead-acid batteries tested by 320%—from 250 conventional-charge cycles to 1050 rapid-charge cycles. That study ended in 1997. Now, EPRI and

Southern California Edison are collaborating on another study of the effects of fast charging on battery life. In this project, SCE's Electric Vehicle Technical Center is performing life-cycle analyses of lift truck batteries.

Fast-charging technology isn't exactly new. It's just taken a while to catch on. Purcell remembers when Norvik Traction Inc. of Ontario, a leader in the technology, first introduced EPRI to the concept in the late 1980s. "Our response was, we're not sure we believe you," Purcell recalls. A couple of years later, he came across a Japanese automaker's brochure that advertised the capability to "emergency charge" on-road EVs. "For me, that was the turning point," he says. "I began to think about Norvik and what they had told us."

Purcell worked to establish relationships between various automakers and charging companies to encourage their pursuit of the technology independently of EPRI. And in 1994, planning began for EPRI-funded demonstrations of the fast charging of lift trucks.

"Our feeling was that if the demonstrations could prove the feasibility of fast-charging technology for electric lift trucks," says Purcell, "they would help eliminate the only significant barrier to the wider use of these trucks in the United States." At the same time, successful demonstrations could open the door for the fast charging of other nonroad EVs (for example, sweepers, scrubbers, and airport baggage carriers and shuttle buses), as well as on-road vehicles.

In practice

The project at National Gypsum is the fourth in the series of EPRI-sponsored fast-charging demonstrations involving lift trucks. All of the others featured trucks with smaller capacities—in the range of 5000–7000 pounds (2300–3200 kg).

The first demonstration took place at a Ford Motor Company plant in Wixom, Michigan, over a six-month period in 1996. The results of this project, which are reported in EPRI TR-108255, showed that a fast-charged electric lift truck could be used continually in a high-demand, two-shift industrial environment. In fact, the need for spare battery packs and for battery changing was eliminated. Another benefit was that the battery-watering requirements were significantly reduced by fast charging. Ford has since expressed great interest in the technology, calling its advantages "too numerous to list on a single page," Purcell says.

For the second fast-charging demonstration, EPRI selected a Honda manufacturing plant in East Liberty, Ohio. This facility covers 1.4 million square feet (130,000 m^2), employs 2700 people, and produces about 240,000 cars per year, including the Civic sedan and the Acura coupe. Already an all-electric lift truck operation, the plant has a fleet of 40 such trucks for moving auto body parts around on its assembly lines. As was the case at the Ford plant, the Honda facility operated two long shifts per day during the six-month demonstration, which concluded in January 1998.

The plan at the Honda plant was to fast-charge one electric lift truck per shift, using the workers' half-hour lunch break and two 10-minute snack breaks, as well as the time between shifts. During the demonstration, however, the workers discovered that after driving the vehicle to the charging area, plugging it in, and going to the break room, they barely had time for a breather before having to return to pick up the vehicle; therefore, the two 10-minute charging sessions were eliminated. The result was a total charging time of about 75 minutes per shift, compared with the 8 hours plus cooldown time required for conventional charging.

"They were very impressed with the technology," says Don Caridas of American Electric Power, which worked with EPRI in overseeing the project. He points out that the plant currently devotes a significant amount of space to battery storage and charging—an area that would be greatly reduced with fast charging. Honda is now discussing with Norvik the possibility of converting to fast charging at this facility.

EPRI's third fast-charging demonstration, which concluded last September, involved an especially grueling, three-shift, seven-day-a-week environment: the Buffalo Rock Company's bottling plant in Birmingham, Alabama. The fast-charged lift truck used in this demonstration—one of eight electric lift trucks working the 190,000-square-foot (18,000-m^2) plant—hauled stacks of bottled Pepsi, Dr. Pepper, 7-Up, and other beverages from the production lines to the trucks that deliver them to distribution centers across the Southeast.

According to Purcell, the plant's lift trucks are operated an average of 61% of the time, whereas the more typical average for industrial applications is 35%. "The use of the lift truck was extremely high, compared with other operations we've dealt with," agrees Bob Bellenger, who managed the demonstration on behalf of Alabama Power and also participated in the other EPRI demonstrations. "This put an

As indicated in the lift truck demonstrations, these fast-charging systems from AeroVironment (left) and Norvik Traction can dramatically reduce the time required for battery charging, enabling it to be performed during workers' breaks and shift changes.

Because conventional technology requires batteries to be removed from lift trucks for lengthy charging, users typically must buy multiple spare batteries to avoid vehicle downtime and must devote considerable labor and space to the charging, changing, and storage operations. Quick, in-vehicle charging can free up both worker time and plant space.

extra burden on the truck's batteries and gave us a good test."

The fast charger used in this project, a 50-kW unit developed by AeroVironment of Monrovia, California, charged the batteries in about 1 hour, compared with the 7 hours typically required for conventionally charging the lift trucks at the plant. "I think the people at Buffalo Rock were a bit skeptical going in," recalls Bellenger, "but the sense I've gotten is that this might be something they're interested in as the chargers come down in price."

The conversion question

The most recent EPRI demonstration, at the National Gypsum plant in Baltimore, ran from September of last year through this January. The participating utility was Baltimore Gas and Electric, whose effort was managed by Larry Mattivi.

According to plant manager Dave Cureton, 40 minutes during each of two 8-hour shifts per day was all it took for workers to fast-charge the 12,000-pound-capacity (5400-kg) lift truck. (It was also plugged in to charge overnight, he notes.) The truck's strong performance has led to some serious consideration of converting the rest of the fleet at this site to electrics. "We've been talking about this for a long time," says Cureton, referring to the possibility of using electric technology. "We do use some small electrics in some of our accessory plants, but we've never tried an electric lift truck here because we didn't know there was one with this kind of load capacity."

Cureton likes the fact that electric lift trucks require less maintenance than the 23 propane-powered forklifts operated at the site. "Electric forklifts would have higher up-front costs than regular, engine-powered vehicles, but maintenance costs would be lower," he points out. Indeed, in a study by Florida Power Corporation that was cited in a November 1997 EPRI report (TR-109189), it was found that electric lift trucks have a total life-cycle cost 35% lower than that of their internal combustion engine equivalents.

The Baltimore facility is one of about 25 production plants owned by National Gypsum, the second leading supplier of wallboard in the country. Company officials are awaiting the final results of the study before making any firm commitments on the possibility of converting.

Many companies mulling over the conversion decision are holding out for the critical piece of missing information on fast charging: its economic feasibility. As Jimmy Wolfe, vice president of manufacturing and operations at Buffalo Rock, puts it, "It all boils down to economics. If it saves me money, I'm all for it. But if it doesn't save money, then we don't have any use for it." Admittedly, although fast charging has many advantages, it's also very expensive at this time. A conventional charger might cost about $4000, while a fast charger currently costs about $40,000. That's primarily because fast chargers are higher powered—typically larger than 50 kW, compared with less than 10 kW for conventional chargers.

This year, in a project involving Ford, Norvik, and Edison Source (a subsidiary of Edison International), EPRI plans to explore a technology advance that could overcome the cost hurdle—an advanced fast charger controller capable of charging more than a dozen vehicles simultaneously. The new fast-charger will be tested in a Wayne, Michigan, plant that produces Ford Escorts. The project is expected to last through the end of the year, and Ford

This Clark lift truck and AeroVironment charging unit were used in a bottling plant that has an especially grueling operating schedule of three shifts a day, seven days a week. With the 50-kW unit, battery-charging time was reduced from the typical 7 hours to about 1 hour.

is eagerly awaiting its outcome. Depending on the technology's economic feasibility, the company could possibly convert to fast-charged electric forklifts at its 110 manufacturing plants worldwide.

Clean and quiet

Any promising results from this study would be very timely, given recent regulatory action. On October 22 of last year, the California Air Resources Board (CARB), which often sets the pace in air quality regulation for the rest of the country, passed its first restrictions on emissions from a category of engines (over 25 horsepower) that includes those found in forklifts. Set to begin in 2001 for engines larger than 1 liter, the regulations limit the amount of hydrocarbons, nitrogen oxides, and carbon monoxide that vehicles with these engines can release. Manufacturers will have to meet the emissions requirements for 25% of such vehicles sold in 2001, 50% in 2002, 75% in 2003, and 100% in 2004. Engines 1 liter or smaller will be restricted starting in 2002.

Spark-ignited engines would probably not meet these regulations, says a spokesperson for CARB's off-road controls section. He notes that manufacturers will have to modify their engines to meet the new limits—a move that is likely to increase the cost of the vehicles. Moreover, much like the smog-control pollution standard for automobiles, the standard will have to be met not just at the time a vehicle is produced but rather over its useful life. The Environmental Protection Agency is expected to propose similar regulations (affecting forklifts) for implementation in 2004. According to the CARB spokesperson, the board worked closely with the EPA to develop a program that could be applied nationally.

These new regulations could boost the market for electric lift trucks, as have various regulations and standards in the past. And that's good news for electric power companies. Indeed, by 2005, the annual charging value of nonroad EVs could total $673 million.

EPRI members can realize some of that value with the help of EPRI's NREVA (Non-Road Electric Vehicle Applications) Life-Cycle Costs Model. Power companies can use this model to calculate annual life-cycle costs for 11 types of nonroad EVs, including lift trucks, and to generate cost comparisons for electric and internal combustion engine vehicles. According to Gloria Krein, who recently took over the management of EPRI's nonroad EV work, the model can be very useful to utility sales and marketing staff members who want tangible cost benefits to discuss with their customers. Other potential users include facility or fleet managers responsible for vehicle purchasing decisions and utility planners responsible for developing marketing strategies for electrotechnologies.

While EPRI believes that fast-charging technology holds the key to a far broader market potential for electric lift trucks, other advances are also being pursued that could make the technology more attractive. These include work on advanced batteries and brushless ac motors, which will offer improved performance over the existing dc technology and are also expected to be cheaper to manufacture.

"All of this work is important," says Purcell. "But we believe fast charging holds the greatest potential for increasing the electric lift truck market share." Moreover, he notes, if fast charging proves itself in the lift truck market, it could very well help jump-start the market for on-road EVs—overcoming the issue of limited mileage range between charges. In Purcell's words, "If we can ultimately fast-charge a vehicle in 15 minutes, it will go a long way toward resolving the range issue for on-road EVs." ■

Background information for this article was provided by Gary Purcell and Gloria Krein (gkrein@epri.com), Energy Delivery and Utilization Division.

One Conference Leads to Another

EPRI's first national conference on nonroad electric vehicles last summer drew more than 250 attendees. Held August 20–21 in Orlando, Florida, the conference, called "The Changing World of Industrial and Recreation Electric Vehicles," covered technologies ranging from lift trucks to bicycles.

The attendees came from a wide variety of firms, including electric power companies interested in supporting the technologies and companies (such as Costco Companies and American Airlines) that already use them in their operations. Leading manufacturers of nonroad EVs and charging devices, among other pioneers in technology development, were also on hand to share their knowledge and learn more about customer needs. Representatives from the regulatory arena addressed air quality issues that encourage the use of both nonroad and on-road EVs.

COURTESY ZAP POWER SYSTEMS

"We weren't certain how much interest there would be when this conference was in the planning stages," recalls Gary Purcell, formerly the manager of EPRI's nonroad EV research. "But before the first day was over, a number of firms approached us and said, 'You must do this again next year.'" As a result, plans are already well under way to hold the second national nonroad EV conference in Orlando this August 19–20. Says Gloria Krein, who now manages EPRI's nonroad EV work, "We expect this to be an annual event." For more information on this summer's conference, contact Michele Samoulides, (650) 855-2127. □

WELDING RESEARCH HEATS UP

BY DAWN LEVY

THE STORY IN BRIEF As power plants age, welds are the most common locations for failures in pipes and pressure vessels. While plant managers can deal with small problems during scheduled maintenance, big problems can cause long, expensive outages. EPRI has developed advanced weld repair technologies to extend the life of aging components by decades, as well as state-of-the-art repair guidelines to aid technology transfer. EPRI staff both in the Materials Performance program and at the Repair and Replacement Applications Center in Charlotte, North Carolina, have been instrumental in finding solutions to weld-related problems that plague older plants. These EPRI innovations have saved the industry billions of dollars—proving that an ounce of prevention really is worth a pound of cure.

CO[illegible] BY MARTH[illegible] LOVETTE

Weld failures are unavoidable and are a common cause of downtime in fossil and nuclear power plants. Even in the best-run facilities, splits happen. Day in and day out, metal parts are exposed to cycles of extreme temperatures and pressures, radiation, corrosion, and other factors that take their toll in the form of cracks, splits, ruptures, embrittlement, and pitting. And as the U.S. power industry nurses its aging facilities—nearly half of its fossil plants are over 25 years old, and more than half of its nuclear plants are over 15 years old—welding is going to become an even hotter topic.

Better welds can extend the lifetime of older components by decades and can save the industry billions of dollars. "A good weld extends plant life, enhances safety and reliability, and cuts down on operation and maintenance costs," says EPRI's Vis Viswanathan, technical fellow and senior manager for materials application technology. These benefits are especially important in nuclear plants, where a day of forced outage costs $300,000 to $750,000.

In today's competitive business environment, in which it may be cheaper to maintain an old plant than build a new one, welding is a crucial aspect of plant management. It represents 10% of new construction costs and 20% of maintenance costs. In some cases, it may provide the only economically viable approach for avoiding a permanent plant shutdown. EPRI has long recognized the importance of welding to plant management and has developed resources the industry can use to make the most of its weld repairs. The major resource is the EPRI Repair and Replacement Applications Center (RRAC) in Charlotte, North Carolina (see sidebar, p. 28).

Through 1998, EPRI has spent $30 million to develop better welding technologies, according to RRAC manager Shane Findlan. The return on that investment would make any Wall Street analyst salivate: the industry has documented more than $2 billion in savings from the use of improved welding techniques. In one project, nine utilities applied EPRI-developed technology at 12 plants to improve pipe replacements, for total savings of $361 million. EPRI helped Niagara Mohawk Power Corporation speed piping repairs, which saved the utility $14 million. Carolina Power & Light saved $20 million by using EPRI technology to replace two reactor re-

COURTESY TENNESSEE VALLEY AUTHORITY

New techniques like the temperbead process make possible the on-site repair of thick-section components that once had to be transported to off-site welding shops, where postweld heat treatment could be used to relieve residual stresses. Tennessee Valley Authority engineers have already saved about $10 million by using the temperbead technique for on-site turbine casing repairs.

circulation pipes. And the biggest winner, Commonwealth Edison, saved $434 million when EPRI verified the effectiveness of a stress remedy for nuclear power plant piping.

The birth of consensus guidelines

EPRI can help utilities find solutions to thorny technical dilemmas through resources like the RRAC, but it has also done a great deal to help utilities help themselves. A major success in this area has been the development of repair guidelines.

Before 1996, few guidelines existed to identify the best weld repair technologies or to determine how long repairs were likely to extend a particular component's life. Original equipment manufacturers have little incentive to develop new repair technologies, and those that have done so guard their knowledge closely to maintain a competitive edge over other manufacturers and repair vendors and to recoup their technology development investment. Power companies, in contrast, are strongly motivated to repair rather than replace damaged equipment, both to minimize the length of forced outages and to extend component life. EPRI's efforts have already resulted in a seven-volume report (TR-103592) that presents guidelines for the weld repair of high-temperature and -pressure parts. Produced by Viswanathan and his colleagues, this report also documents worldwide industry practices.

When EPRI began compiling extensive guidelines to walk utilities through the repair process, it first surveyed the industry about its major concerns. The questions utilities wanted answers for included the following: What are my options if I find damage in a part? What caused the damage, and how do I avoid a recurrence? What's the best weld repair technique to use? How do I test the repair, inspect it, and service it in the future? What are the limitations of the repair? How do I select a repair vendor? Is the repaired part covered under warranty? What considerations must I address when planning an outage? "We're still going back to those questions to make sure we're staying on the right track with our answers," says David Gandy, the RRAC's manager for materials and fossil applications. The intent of the EPRI guidelines is not to provide utilities with the knowledge or tools for performing their own in-house repairs. Rather, it is to give them the precise information they need to make better decisions about their own equipment.

Downsizing and other factors are making guidelines even more important, says

Findlan. Perhaps a master welder has spent years performing repairs with great skill and precision. When that person leaves—whether as a result of promotion to another position, retirement, or downsizing—the welding expertise leaves too. Unfortunately, new welders are not entering the profession. "A shortage of skilled labor is a major problem," says Findlan. The fear is that the loss of such expertise could contribute to the slow decay of individual plants or could compromise safety.

Shouldn't every power plant have an expert welder capable of handling emergencies, just as a hospital emergency room has a surgeon on call? Perhaps, but in an age of cost cutting, it makes sense for utilities to at least have access to a centralized pool of industry experts. The RRAC provides a solution to this dilemma. Further, EPRI has helped develop weld technologies that do not require highly skilled welders. And finally, the new guidelines can help utilities address problems as the number of in-house experts shrinks.

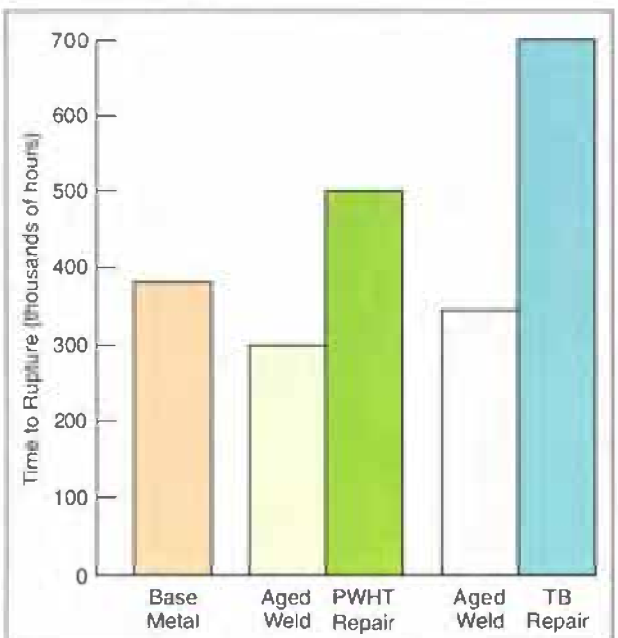
The guidelines describe state-of-the-art weld techniques for extending the life of components, says Viswanathan. But by how much? Will the repaired part be as good as new, lasting another 40 years, or will it last only 5? Knowing the answer is important when deciding whether to replace the part and how often to inspect it. One thing EPRI engineers have done is to examine damaged components to deduce what caused their failure. By studying weld failure experiences, they can characterize how certain types of repairs are likely to perform in the long run.

Typically, when the industry has used outdated repair methods instead of current practices, welds have failed in short order. Often, cracks have been found in the same places just a year later. Sometimes the repaired part has been operating outside its original design conditions. "And sometimes welders have performed repairs without removing prior damage properly," Viswanathan explains. "It's like somebody having cancer. If you perform surgery but don't get it all, the disease is not cured." Other times, the root causes of failure, such as external stresses, have not been eliminated. Viswanathan describes a formula for success: "If you eliminate the root cause of the problem and the extraneous out-of-design stresses and if you completely excavate the original damage and perform the right repairs, *then* you can get long life."

But nothing lasts forever. "After all, you're not repairing new components," says Viswanathan. "You may be repairing components that have been out there for 40 years and have generally aged. They've got creep damage. Microstructure changes have occurred. Eventually, you have to address the issue of repairability; you have to realize there's a point at which components are no longer repairable." Determining when that point has been reached is a big part of run-repair-replace decision making.

Advances at the melting edge

In the past, if a part was repairable, it was likely to be fixed by weld methods that used concentrated heat—typically from an arc created by an electrode—to melt and fuse surfaces at their point of contact. Recently, however, new welding technologies have yielded exciting results. Welds between dissimilar metals have improved. It's now possible to weld parts on-site rather than send them out for repair. Underwater welding is easier than ever. Lasers can repair damaged parts that once were considered hopeless. These and many other advances have paved the way for changes in the codes governing welds and for massive cost savings. And EPRI has spearheaded many of these improvements.



The remaining-life testing of a header with 35 years of high-temperature service has shown that temperbead (TB) repair matches or exceeds the capabilities of conventional weld repair with postweld heat treatment (PWHT). Repairs of the header's aged welds were made, and accelerated creep tests were performed to determine the time to failure. Repairs were effective with both methods, but the TB technique added nearly 30 more service years than PWHT.

Temperbead repair Consider the innovation that has made the biggest impact on the industry: temperbead repair. Traditionally, the codes that govern repairs—the National Board Inspection Code and the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code—have mandated postweld heat treatment (PWHT). This treatment softens, or tempers, the hardened material after a weld is performed and so relieves residual stresses. It also allows the diffusion of hydrogen, which is introduced into the metal during welding and can cause cracking. But PWHT is time-consuming and expensive, especially when the components involved are large or when many treatments are necessary. In nuclear plants, it can take up to 12 hours for a component to reach the desired temperature, 1 to 3 hours to perform the treatment, and another 8 to 12 hours for cooling. Sometimes PWHT may not even be possible because of the size or configuration of the flawed part. EPRI has spent a great deal of effort investigating alternatives to PWHT.

According to Gandy, temperbead welding performs the same function as conventional arc welding with PWHT, and its results are equal or superior. In this process, welding beads are deposited in precisely controlled patterns, and each successive bead provides heat tempering for the layer directly below it. The technique can be applied—without PWHT—to low-alloy steels to generate specific mechanical properties. It is an especially valuable technique for the in situ repair of large components, including pressure vessels and turbine casings, which have traditionally needed to be removed for repair offsite.

In addition to EPRI, many other organizations have sponsored temperbead research over the past decade: the Pressure Vessel Research Council, the University of Tennessee, the Edison Welding Institute, Chicago Bridge and Iron, Toshiba, and such utilities as Pacific Gas and Electric, Ontario Hydro, and the former Central Electricity Generating Board of England. During 1995 and 1996, EPRI and many utilities cosponsored work to develop temperbead welding guidelines. They found that the temperbead technique could produce welds that were tougher than conventional welds and could extend component life by at least 20 years. The temperbead repair guidelines—as well as a review of industry experience, the results of experimental studies on piping and casing steels, and a worldwide literature review—are included in the seven-volume report mentioned earlier.

Temperbead repairs save money. They saved Baltimore Gas and Electric $9 million and Yankee Atomic Electric $18 million. For the years 1996–2002, the Tennessee Valley Authority will save an estimated $18 million by performing casing repairs without PWHT, according to John Brooks, TVA project manager in the Technology Advancements Division. TVA's investment in this effort, including R&D, training, and implementation, is estimated to be $1.2 million—a benefit-to-cost ratio of 15, which TVA considers impressive. "Without the teamwork and close coordination between TVA and the EPRI researchers, this could not have been achieved," says Brooks. Since the problem of cracked casings is industrywide, the total savings resulting from this temperbead repair application alone are expected to reach hundreds of millions of dollars.

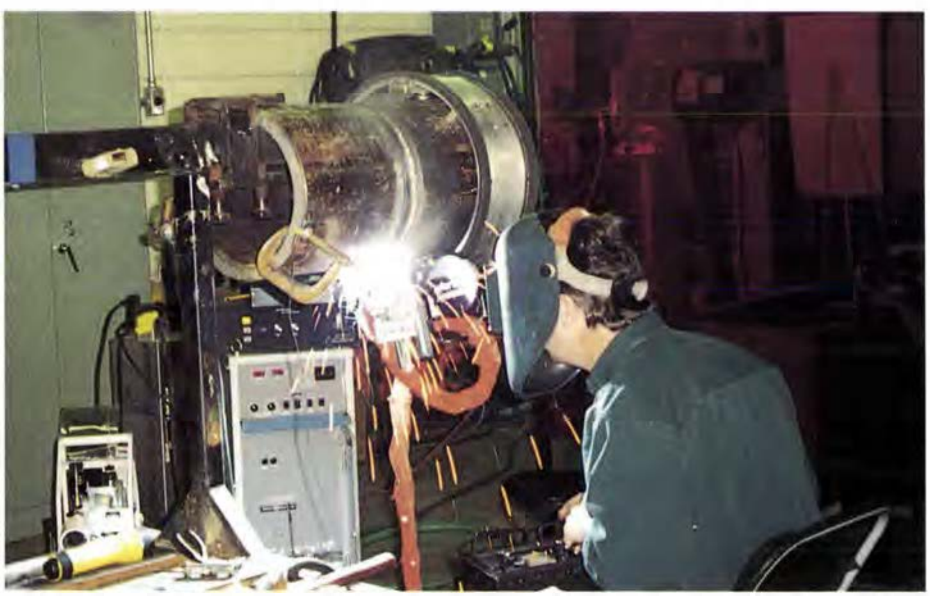
In 1995, the National Board Inspection Code incorporated a dramatic change that opened the door for the widespread use of temperbead repair: carbon steels and low-alloy steels can now be repaired without PWHT as long as the repair produces toughness properties comparable to those of the base metal. And beginning in 1999, ASME allows exemptions from PWHT in the case of certain piping with small diameters, thin walls, and low carbon content. Certain base materials are also now exempt from PWHT repair requirements.

Laser welding EPRI has also advanced the field of laser welding. In an industry survey, 9 out of 16 vendors would prefer to use laser welding over conventional welding for repairing combustion turbine blades. The reason is precision. "With normal welding, heating and cooling occur over a large area," explains Viswanathan. "Laser welding is more like a surgical repair, affecting a localized, narrow weld width." Lasers also permit greater flexibility in alloy compositions, allowing welders to concoct complex mixtures of metal powders appropriate for specific applications. And since workers have the option of defocusing the beam, lasers provide a means of in situ heat treatment: after a highly focused beam melts the metal and the weld repair is performed, a defocused beam, whose energy is spread out over a larger area, can be used to heat-treat the surface.

Laser welding is a noncontact, line-of-sight process. Compared with conventional methods, automated laser welding is faster and requires less finishing and machining. In preliminary trials, laser welding has been successfully applied in the repair of Inco 738 alloy combustion turbine blading to produce high-strength welds.

Underwater welding Underwater welding has been used in securing offshore oil rigs to the ocean floor. In the nuclear power industry, it has recently been employed in repairing boiling water reactors. "Although it's difficult for repair workers to go into a reactor because of radioactivity and access limitations," says Findlan, "it's done under certain circumstances." And it is safer for workers to perform such work underwater, he explains, "because water itself offers great protection from the radiation." If the vessel is drained, repair workers need extra shielding.

To avoid the problems associated with repair workers having to enter reactors, much underwater welding is automated. The RRAC has developed an automated underwater technology that has been applied by such utilities as Southern Nuclear and Pennsylvania Power & Light. It is mainly used to make repairs inside the lower two-thirds of a reactor pressure vessel, which is inaccessible and radioactive, and to repair fuel storage pools. This automated underwater method is based on fluxcored arc welding (FCAW), which uses a continuously fed wire made of metal



This automated flux-cored arc welding system developed by EPRI and Magnatech allows for superior repair of heavy-walled steam pipes. Depositing material three times faster than conventional methods, it combines an orbital tracking mechanism for welding in odd positions (including upside-down welding) and a power supply with real-time, "fuzzy logic" voltage and current control for improved arc stability.

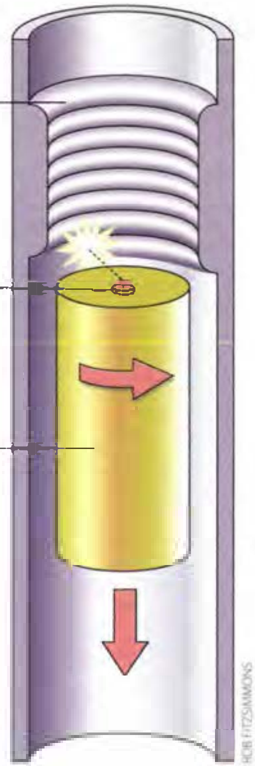
with flux and various alloying elements. (EPRI has also developed an underwater stick electrode divers can use for manual applications.)

As water depth increases, welding arcs become less stable. "What may work well when you're 20 feet [6 m] down may require changes in amperage and voltage when you're 50 to 90 feet [15–27 m] down," Findlan says. Currently, the automated FCAW technology allows welding at depths down to 50 feet. For testing welds at greater depths, the RRAC has a hyperbaric chamber that can simulate the pressures encountered down to 80 feet (24 m). The facility also features a 4-foot-deep (1.2-m) tank used to evaluate welding parameters and a 21-foot-deep (6.4-m) dive tank for training welders. EPRI research has resulted in better arc stability and splatter-free welding and has minimized the skill levels required to perform repairs.

EPRI also has created alloys with improved wet-weld characteristics. Alloy 625, for instance, is a mixture of chromium, nickel, and molybdenum that is resistant to stress corrosion cracking, crevice corrosion, and pitting. New nickel-alloy and stainless steel materials have contributed to high-quality welds, performing up to code at depths of 50 feet. EPRI has also developed and tested halogen-free filler materials, which are important because they minimize corrosion and the contamination of reactor water.

EPRI holds many patents for its underwater welding technologies, which are currently licensed to General Electric, Framatome Technologies, Siemens, and IHI, among other firms.

Automated orbital FCAW system In 1995, the power industry began looking for a way to improve the deposition rates of materials used to weld heavy-walled steam pipes found in both fossil and nuclear plants. Since conventional FCAW was ill-suited to weld pipes orbitally, EPRI and Magnatech partnered to develop a solution—an automated FCAW system that combines an orbital tracking mechanism for welding in odd positions (say, upside-down welding) and a power supply with real-time, "fuzzy logic" voltage and current control for improved arc stability. The system produces superior welds quickly, and deposition rates are three times higher than those achieved with conventional processes, says Gandy.



A state-of-the-art laser welding technique can permanently repair cracked steam generator tubes that ordinarily would be sleeved or plugged. This device, being marketed by ABB, employs an EPRI-patented rotating optical coupler—which allows the precise alignment of a laser beam—and a rotating weld head mounted at the end of a fiber-optic cable. Melting an alloy wire, the laser can create a uniform 2–3-inch (5–7.5-cm) weld over a damaged area in about a minute.

Steam generator repair A significant number of nuclear facilities have corroded or dented tubes in their original steam generators, says Findlan. Utilities are forced to plug such tubes or place welded sleeves over them—and efficiency drops. If efficiency falls too much, the entire steam generator may have to be replaced or the plant shut down. EPRI is helping develop alternatives to tube plugging and sleeving. One alternative, to be marketed by ABB starting this April, is a laser welding device that features an EPRI-patented rotating optical coupler. This coupler allows the precise optical alignment of a laser beam that travels to a rotating weld head mounted at the end of a fiber-optic cable. "Weld repair can maintain or even restore efficiency in steam generators," says Findlan, "and this is often a key determinant of a nuclear plant's overall cost equation." This state-of-the-art tube repair technology may also be useful for fixing heat exchanger tubing, control rod drive housings, and hardfacings.

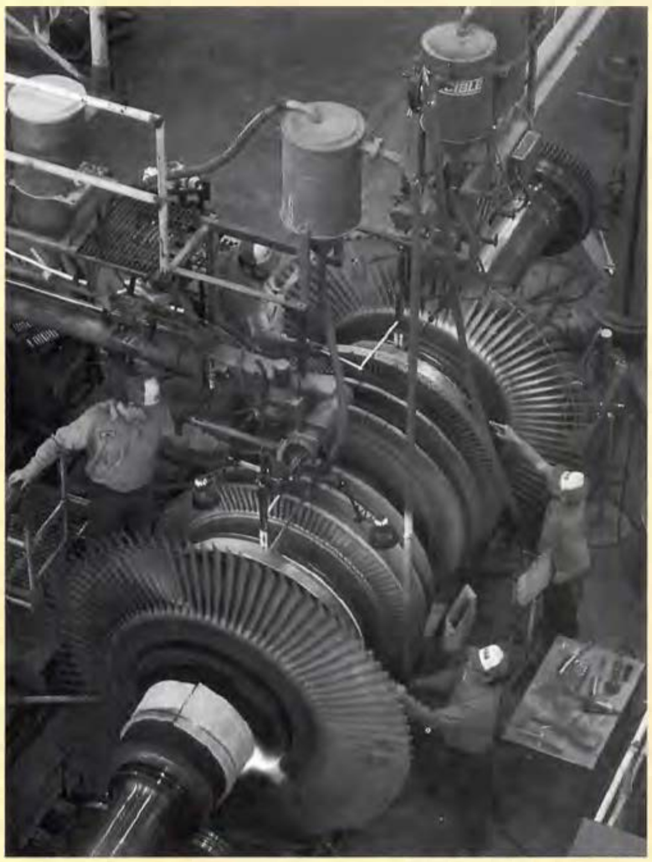
Repair of rotating components Components that rotate—turbine rotors, disks, and blades—present a special challenge for weld repair, since they are among the most critical and highly stressed components in nuclear and fossil power plants. Moreover, they are expensive. Combustion turbine blades, for instance, can cost as much as $30,000 each, or $3 million per row. Nearly 200 high- and intermediate-pressure steam turbines will be at the end of their design life before the year 2000, and hundreds of millions of dollars could be saved if their service could safely be extended by 10 to 20 years.

Recently, EPRI reviewed current repair technologies for rotating components and developed comprehensive repair guidelines for turbine rotors, disks, and blades. The

EPRI Repair and Replacement Applications Center

Imagine you're a power plant manager and a crucial component in your facility has developed a crack. It needs attention, but you aren't sure what's the best course of action. Do you continue to run the equipment? Force an outage to address the problem now, or wait until the plant's next scheduled maintenance? Retire the component? In each of the directions you could go, there is a path with dozens of different decisions to be made, and because of downsizing, your plant lacks the necessary in-house expertise to address the problem fully. What's your best resource for getting the answers you need?

Call EPRI's think tank and "expert bank" for all matters weldable—the Repair and Replacement Applications Center. Established in 1994 and based in Charlotte, North Carolina, the RRAC supports the development of advanced repair technologies for fossil and nuclear power plants. It provides products and information designed to meet industry needs in a rapid, cost-effective manner. Key areas of concern include the repair of in-vessel components, steam generator tube repair, in situ welding, the specification of welding filler materials, underwater weld repair, pump repair, and the repair of carbon steel pipe with erosion and/or corrosion damage.



Rotating parts—turbine rotors, disks, and blades—are among the most critical and highly stressed components in nuclear and fossil power plants. EPRI provides technical assistance and on-site troubleshooting for these and other components through its Repair and Replacement Applications Center.

The RRAC offers the diversified expertise of engineers, specialists, and technicians who can evaluate specific problems, find pragmatic solutions, and provide practical assistance, either at the center itself or at a utility site. To date, RRAC experts have helped utilities evaluate outage plans, perform technical reviews of in-house and contractors' procedures, evaluate bid specifications for the incorporation of cutting-edge technologies, evaluate equipment used for specific applications, and develop or adapt equipment for specific applications.

From troubleshooting to problem solving, the RRAC staff has a wealth of experience in areas ranging from pressure vessel manufacturing to the field installation of fossil and nuclear plant components. Do you have a technical dilemma related to corrosion, mechanics, metallurgy, or welding engineering? Need to measure and analyze residual stresses? Want advice about machining technology or inspections? EPRI members with fossil and nuclear power plants can access experts by subscribing to the RRAC's programs. And up to 25% of an RRAC member's dues can be used to address issues of specific interest to that member through the Subscriber-Requested Assistance (SRA) program. Custom-tailored attention is basic to this program. Typical SRA-provided services include expert consultations on an emergency basis, the development of new welding procedures, and the training of utility staff to apply advanced equipment and techniques.

Utilities have made broad use of the SRA program. Last year, for example, Duke Power used it to obtain support for its training of welders and to survey member utilities to learn how they tested welder performance. Also in 1998, the Tennessee Valley Authority received assistance for a technical review of alternative materials used in its Watts Bar nuclear plant and for a review of its software system for welding-program control; it also received support for the maintenance of ice condensers. Wolf Creek Nuclear Operating Company used the SRA program to review standard industry practices and code requirements for a specific weld repair and to evaluate the hardness of welds performed without postweld heat treatment. And Electricité de France received assistance in evaluating temperbead repair and addressing cracking, one of welding's biggest challenges.

Concludes the center's David Gandy, "Together, the considerable weld-related metallurgical expertise of EPRI's Palo Alto staff and the welding expertise at the RRAC ensure maximum value to our customers." □

guidelines detail repair decision methodology, repair techniques, damage mechanisms, specifications, life assessment, and insurance considerations. The goal is to help utilities make well-informed, cost-effective repair decisions. EPRI is also documenting the performance of previous repairs—examining case histories from utilities and repair vendors to see which repair techniques worked and which did not. Finally, EPRI is collecting information from utilities, industry experts, original equipment manufacturers, and repair vendors to develop a detailed methodology for making run-repair-replace decisions about rotating components.

EPRI innovations in underwater welding have resulted in better arc stability, splatter-free welds, and improved worker safety. Used for repairs at nuclear plants, underwater techniques are safer for welders, since the water provides a degree of radiation protection. And for repairs without divers, an automated underwater method based on flux-cored arc welding has been developed.

Getting the word out

Innovations in welding repair offer the power industry practical ways to improve safety and profits. At least a dozen EPRI-developed repair technologies, applying to areas as diverse as underwater welding, repair of rotating components, and novel alloys, have been patented and licensed. EPRI research has also been helpful to regulatory bodies in updating codes for the industry; at least nine new repair codes address topics ranging from laser welding of steam generator tubing to weld overlays in service-water piping. The technical advances spearheaded by EPRI will mean little, however, unless they are transferred, and effectively sharing knowledge is an ongoing challenge.

To facilitate the transfer of EPRI-developed weld repair technologies, the 20 to 25 utilities participating in the RRAC meet twice a year to talk about their progress in applying these new methods. The group also promotes the acceptance of innovative welding technologies to facilitate the updating of codes. Members attend a popular international conference on weld repair advances every two years, and they receive in-house training at the RRAC. "The center provides great value to customers," says Findlan. "Often we must show within the fiscal year that the direct savings from implementing a new technology justify the membership fee."

EPRI also conducts major international collaborations with other welding research organizations in order to identify optimal repair techniques and procedures. Key topics include the development of technologies for important power plant components—such as stationary components in fossil plants and rotating components in both fossil and nuclear plants—and technologies that eliminate the need for PWHT. Various utilities from around the world—including Electricité de France, ENEL of Italy, and Taiwan Electric Power—join with domestic utilities in cofunding these R&D efforts. EPRI initiated a collaboration in 1992, for example, involving 20 utilities from the United States and abroad.

EPRI's development of consensus guidelines has been a factor in helping the industry keep repair costs down. The seven-volume guideline report (TR-103592) documents worldwide industry practices and covers a broad range of other topics—for example, how to identify the best, most appropriate welding technologies for specific repair needs and how to determine the expected life extension for a repaired component.

Why is international collaboration so important? Industry standards and guidelines that result from such global teamwork are more likely to gain widespread acceptance and application. Consider the case of a nuclear power plant under construction just 180 miles (290 km) off the U.S. coast in Cienfuegos, Cuba. The Juragua nuclear complex there uses the same system employed at Chernobyl, and according to the Center for Policy Security, as many as 15% of the 5000 welds joining the pipes in the reactor's auxiliary plumbing system, containment dome, and spent-fuel cooling system are flawed. With 430 nuclear power plants in the world, global safety can only increase as the quality of welds improves throughout the international power industry. ■

Background information for this article was provided by Vis Viswanathan (rviswana@epri.com), Energy Conversion Division, and David Gandy (davgandy@epri.com) and Shane Findlan (sfindlan@epri.com), Repair and Replacement Applications Center.

In the Field

Demonstration and application of EPRI science and technology

Expert System Enables Near-Perfect Ice Storage

A new controller that improves the performance of ice storage systems could give building owners greater incentive to install new storage systems or update existing ones. The controller, called the NOC (for near-optimal controller), was developed by EPRI and Johnson Controls of Milwaukee. It predicts a building's daily cooling requirements, adapting to and limiting demand variations without operator intervention, and determines the best combination of direct mechanical cooling and storage to meet the instantaneous cooling load.

A new controller for optimizing ice storage systems was successfully tested at this Philadelphia arena.

"Commercially available controllers have been either too difficult to use or incapable of realizing the full benefit of storage," says Mukesh Khattar, EPRI's manager for HVAC and refrigeration. "This new product is easy to use and offers excellent control, making it possible to operate storage systems to maximum advantage for a given electricity rate."

The EPRI NOC is most suitable for application with internal-melt ice storage systems, but it can also be used with water storage systems. A real-time expert system, it incorporates rules—heuristics—learned by observing the common characteristics of control trajectories that minimize energy and demand costs over a monthly billing period.

For setup, the controller requires one-time inputs that include a building occupancy schedule, utility rates, and basic information about the mechanical cooling system. Once commissioned, the controller monitors the building's electrical load, cooling load, and ice inventory. A self-initializing algorithm predicts the daily cooling requirements and adapts to both seasonal variations and daily fluctuations in demand.

In addition to undergoing extensive laboratory and simulation tests, the EPRI NOC has been proved in field demonstrations. One was held at the CoreStates Center—recently renamed the First Union Center—in Philadelphia. The center, home of the 76ers of the National Basketball Association and the Flyers of the National Hockey League, can seat up to 21,000 spectators. When energy use during NOC operation was compared with computer-simulated energy use under the center's previous control strategy, the new controller was found to yield substantial energy cost savings.

In another trial, at a school administration building in Kenosha, Wisconsin, the NOC improved storage system reliability by reducing the frequency of out-of-ice conditions and by ensuring that the cooling plant would meet the load at all times. The NOC's rule-based control strategy proved to be robust, to be easily implemented, and to require only minimal computer memory or processor resources.

Johnson Controls is now preparing the EPRI NOC for commercial use.

■ *For product information, contact Michael Piotrowski, Michael.Piotrowski@jci.com, (414) 274-4118. For EPRI assistance, contact Mukesh Khattar, mkhattar@epri.com, (650) 855-2699.*

Flywheel Extends UPS Battery Life

The first installation of a flywheel energy storage device approved by Underwriters' Laboratories for use with an uninterruptible power supply (UPS) has been completed in a project sponsored by EPRI and Constellation Energy Source, a subsidiary of Baltimore Gas and Electric Company. "Our aim is to provide a cost-effective ride-through solution for voltage sag and momentary power supply interruptions," says Marek Samotyj, EPRI's product line leader for power quality.

The flywheel—Active Power's CleanSource CS 200—has been installed by Constellation for Comcast Corporation, the nation's fourth-largest domestic cable company. Comcast requires the highest level of power quality and reliability to protect its critical cable and Internet hub facility. The flywheel has been integrated into an existing Liebert UPS system to improve the system's overall reliability and extend the life of its battery set.

"The CleanSource flywheel is a reliable source of backup power that can protect the batteries from frequent discharges, which shorten their life," says Roger Lawrence, director of EPRI's Adjustable-Speed Drive Demonstration Office. Art Beasman, senior power quality representative for Constellation, explains that the natural gas engine–generator at the site has a longer-than-desired response time to load changes. The UPS system must switch to battery power while the generator output stabilizes after large load changes. But with the flywheel supporting the UPS load while the generator starts up and when large loads are cycled, battery power is conserved for use as emergency backup.

"Using the flywheel energy storage system to extend battery life in existing backup power applications is another example of how CleanSource can improve the reliability and performance of commercial UPS systems," says Joe Pinkerton, president of Active Power. "Our company is delivering proven energy storage technologies that will lower the overall energy production costs for any end users."

CleanSource flywheel products—which store energy in the form of a rotating steel wheel—are used to replace or supplement the lead-acid batteries in the UPS systems that help data-processing centers and industrial facilities ride through power outages. The company's energy storage solutions are designed to match the power ranges of typical UPS systems and can be paralleled to support even larger customer loads. Now approved by Underwriters' Laboratories, the product family is compatible with all popular three-phase UPS systems.

The EPRI-Constellation demonstration project at Comcast will quantify the flywheel system's costs and benefits.

■ *For more information, contact Marsha Grossman, mgrossma@epri.com, (650) 855-2899.*

ComEd Cuts Costs With Transformer Diagnostics

Unicom Corporation's Commonwealth Edison subsidiary has documented the potential to realize substantial savings on transformer maintenance, thanks to the effectiveness of an array of external diagnostic tests evaluated in a collaborative project with EPRI. The diagnostics will enable ComEd to reduce operating and maintenance costs and improve reliability by targeting for maintenance the transformers that need it most, such as those having loose windings.

In tests thus far, two transformers with loose windings have been identified. The Chicago-based utility expects to realize a net one-time avoided cost of slightly over $2 million by reclamping and refurbishing the units (and thus avoiding replacement). It also expects annual savings of $200,000 in deferred internal inspections.

Extrahigh-voltage autotransformers are critical to electricity transmission systems. After years of service, however, a transformer's internal coils may become loose, increasing its susceptibility to failure during system through-faults. Such failures have high costs in both money and time. A transformer can cost more than $1 million, and it can take weeks to replace one with a spare or months to a year to make repairs or build a new one.

Preventive maintenance is key to keeping these large transformers operating reliably. Periodic internal maintenance, the traditional practice, is a costly process that requires the removal of a transformer from service for several weeks. Alternatively, external diagnostics to test transformers for potential internal problems can help focus maintenance spending on the units that need intensive maintenance or refurbishment to restore coil strength and stability. The diagnostics evaluated by ComEd are based on proven EPRI techniques and data, including reliability-centered maintenance and integrated substation diagnostics.

ComEd applied frequency response analysis (FRA) and other diagnostic tests to seven of its 300-MVA autotransformers. FRA, used to set priorities for reclamping and refurbishment, was an important test because the transformers had been in service for 30 years and so were susceptible to through-fault failures. The FRA tests identified two potentially troublesome transformers that needed to be taken out of service for internal inspection. So far, ComEd has opened and inspected the unit indicated to be in worse condition. This inspection found that the transformer's coils did need to be retightened, thus demonstrating the effectiveness of external diagnostic testing techniques.

"The diagnostics used in our study with EPRI have proved to be good indicators of internal transformer condition. They will help us focus maintenance dollars on transformers with loose windings and other critical needs," says ComEd's Paul Myrda.

■ *For more information, contact Predrag Vujovic, pvujovic@epri.com, (650) 855-2991.*

Technical Reports & Software

To order reports, contact the EPRI Distribution Center, 207 Coggins Drive, P.O. Box 23205, Pleasant Hill, CA 94523; (925) 934-4212. To order software, contact the Electric Power Software Center, 11025 North Torrey Pines Road, La Jolla, CA 92037; (800) 763-3772.

Energy Conversion

Terry® Turbine Controls Maintenance Guide, Revision 1
TR-016909-R1
Target: Nuclear Power
EPRI Project Manager: J. Jenco

Survey on the Use of Configuration Risk and Safety Management Tools at Nuclear Power Plants
TR-102975
Target: Nuclear Power
EPRI Project Manager: J. Mitman

CHECWORKS™ Navigator User Guide
TR-103198-P6
Target: Nuclear Power
EPRI Project Manager: B. Chexal

CHECWORKS™ BWR Vessel and Internals Application: BWRVIP Component Database User Guide
TR-103198-P7
Target: Nuclear Power
EPRI Project Manager: H. T. Tang

Guidelines for Instrument Calibration Extension/Reduction, Revision 1: Statistical Analysis of Instrument Calibration Data
TR-103335-R1
Target: Nuclear Power
EPRI Project Manager: R. Shankar

Guidelines for Optimizing the Engineering Change Process for Nuclear Power Plants: October 1998 Revision
TR-103586-R1
Target: Nuclear Power
EPRI Project Manager: L. Loflin

On-Line Monitoring of Instrument Channel Performance
TR-104965
Target: Nuclear Power
EPRI Project Manager: R. Shankar

Development and Implementation of an Expert System for Vibration Monitoring and Diagnosis for Hydroelectric Pumped-Storage Units
TR-106034
Target: Hydro Performance Optimization and Asset Management
EPRI Project Manager: N. Hirota

Nuclear Plant Life-Cycle Management Implementation
TR-106109
Target: Nuclear Power
EPRI Project Managers: J. Carey, G. Sliter

Inhibition of IGA/SCC on Alloy 600 Surfaces Exposed to PWR Secondary Water, Vol. 3: Precracking Model Boiler Tests
TR-106212-V3
Target: Nuclear Power
EPRI Project Manager: T. Gaudreau

Application Guide for Motor-Operated Valves in Nuclear Power Plants, Vol. 2: Butterfly Valves
TR-106563-V2
Target: Nuclear Power
EPRI Project Manager: V. Varma

Feasibility of Analytical Techniques to Quantify Hot-Leg Streaming
TR-107325
Target: Nuclear Power
EPRI Project Manager: R. Shankar

Thermal Performance Engineering Handbook, Vol. 2: Advanced Concepts in Thermal Performance
TR-107422-V2
Target: Nuclear Power
EPRI Project Manager: T. Eckert

Oconee Electrical Component Integrated Plant Assessment and Time-Limited Aging Analyses for License Renewal: Parts 1 and 2
TR-107527
Target: Nuclear Power
EPRI Project Manager: J. Carey

An Improved Approach for Performing Simplified Elastic-Plastic Fatigue Analysis
TR-107533
Target: Nuclear Power
EPRI Project Manager: R. Carter

Cycling, Startup, Shutdown, and Layup Fossil Plant Cycle Chemistry Guidelines for Operators and Chemists
TR-107754
Target: Boiler and Turbine Steam and Cycle Chemistry
EPRI Project Manager: B. Dooley

Mixed-Waste Recycling Exemption
TR-107973
Target: Nuclear Power
EPRI Project Manager: C. Hornibrook

wasteWORKS™ '98: Solid Waste Manager User's Manual and Tutorial
CM-108098-V1
Target: Nuclear Power
EPRI Project Manager: C. Hornibrook

wasteWORKS™ '98 Wet: Liquid Processing User's Manual
CM-108098-V2
Target: Nuclear Power
EPRI Project Manager: C. Hornibrook

Development of Energy Trading Floors: Implications for Company Operations and Regional Energy Markets
TR-108477
Target: Fuel Supply Management
EPRI Project Manager: J. Platt

Study of Unsaturated-Zone Flow and Transport Models of Fractured Tuff
TR-108536
Target: Nuclear Power
EPRI Project Manager: J. Kessler

Cooperative IASCC Research Program: CIR-CD, Version 98.12
AP-108557-R2CD
Target: Nuclear Power
EPRI Project Manager: L. Nelson

Alternative Approaches to Assessing the Performance and Suitability of Yucca Mountain for Spent-Fuel Disposal
TR-108732
Target: Nuclear Power
EPRI Project Manager: J. Kessler

Development, Evaluation, and Analysis of the Initial CIR-IASCC Database
TR-108749
Target: Nuclear Power
EPRI Project Manager: L. Nelson

TMI-1 Cycle 10 Fuel Rod Failures: Vol. 1, Root Cause Failure Evaluations; Vol. 2, Hot Cell Examination
TR-108784-V1–V2
Target: Nuclear Power
EPRI Project Manager: B. Cheng

Fire Modeling Code Comparisons
TR-108875
Target: Nuclear Power
EPRI Project Manager: R. Kassawara

In-Vessel Core Debris Retention Experiments
TR-108876
Target: Nuclear Power
EPRI Project Manager: J. Chao

Guidelines for Reduced Seismic Loads to Assess Temporary Conditions in Nuclear Power Plants
TR-108904
Target: Nuclear Power
EPRI Project Manager: H. T. Tang

A Mobile High-Resolution Gamma Ray Spectrometry System for Radiological Surveys
TR-109035
Target: Nuclear Power
EPRI Project Manager: C. Wood

Evaluation of Radwaste Processing Options for High-Iron Liquids
TR-109442
Target: Nuclear Power
EPRI Project Manager: C. Hornibrook

Criteria and Methods for Estimating External Effective Dose Equivalent From Personnel Monitoring Results
TR-109446
Target: Nuclear Power
EPRI Project Manager: C. Hornibrook

Proceedings: Workshop on Condensate Polishing, September 1997
TR-109568
Target: Nuclear Power
EPRI Project Manager: P. Frattini

Guidelines for Preparing Risk-Informed, Graded Quality Assurance Program Implementation Request Submittals
TR-109646
Target: Nuclear Power
EPRI Project Manager: F. Rahn

Inventory Optimization in Support of the EPRI Work Control Process Module
TR-109648
Target: Nuclear Power
EPRI Project Manager: F. Rahn

COSTAR (Beta Version 3.0): Concrete Structures Aging Reference Manual for Nuclear Power Plants
TR-110025
Target: Nuclear Power
EPRI Project Manager: J. Carey

Effectiveness of Inhibitors on IGA/SCC of Alloy 600 Tubing
TR-110047
Target: Nuclear Power
EPRI Project Manager: T. Gaudreau

Interim Cycle Chemistry Guidelines for Combined-Cycle Heat Recovery Steam Generators
TR-110051
Target: Combustion Turbine and Combined-Cycle O&M
EPRI Project Manager: B. Dooley

User's Guide to RPVDATA: Reactor Vessel Materials Database, Version 1.4
TR-110122
Target: Nuclear Power
EPRI Project Manager: S. Rosinski

Use of Risk-Informed Inspection Methodology for BWR Class 1 Piping
TR-110701
Target: Nuclear Power
EPRI Project Managers: S. Gosselin, J. Mitman

ORAM-SENTINEL™ Demonstration at Diablo Canyon
TR-110739
Target: Nuclear Power
EPRI Project Manager: J. Mitman

Stress Intensification Factors and Flexibility Factors for Pad-Reinforced Branch Connections
TR-110755
Target: Nuclear Power
EPRI Project Manager: R. Carter

Assessing Air Pollution Control Options at the Hudson Station of Public Service Electric and Gas
TR-110867
Target: Air Toxics Control
EPRI Project Manager: R. Chang

Guideline for Computer-Based Training (CBT) Development, Vol. 1: Instructional System Design Process
TR-110965-V1
Target: Simulators, Training, and Production Automation
EPRI Project Manager: M. Perakis

Oconee Nuclear Station Application for Renewed Operating Licenses
TR-111030-CD
Target: Nuclear Power
EPRI Project Manager: J. Carey

Correlation of Flow-Accelerated Corrosion of Steam Generator Internals With Plant Water Chemistry
TR-111113
Target: Nuclear Power
EPRI Project Managers: P. Millett, A. McIlree

Effect of Iron Sulfide on Furnace Wall Corrosion
TR-111152
Target: Coal-Fired Boiler Performance Optimization and Combustion NO_x Control
EPRI Project Manager: W. Bakker

Waterwall Wastage in Low-NO_x Boilers: Root Causes and Remedies
TR-111155
Target: Coal-Fired Boiler Performance Optimization and Combustion NO_x Control
EPRI Project Manager: W. Bakker

Preventing Leakage in Water-Cooled Stator Windings: Phase 2
TR-111180
Target: Steam Turbines, Generators, and Balance of Plant
EPRI Project Managers: B. Syrett, J. Stein, J. Gaertner

ORAM-SENTINEL™ Development and ORAM Integration at Oconee
TR-111207
Target: Nuclear Power
EPRI Project Manager: J. Mitman

Productivity Improvement Handbook for Fossil Steam Power Plants
TR-111217
Targets: Various Energy Conversion and EPRIGEN targets
EPRI Project Manager: T. Armor

Evaluation of 2% CrMoWv HP/LP Rotor Forging for Single-Cylinder Steam Turbine Use
TR-111219
Target: Steam Turbines, Generators, and Balance of Plant
EPRI Project Manager: V. Viswanathan

EPRI Dam Safety Workshop Summary
TR-111285
Target: Hydro Performance Optimization and Asset Management
EPRI Project Manager: T. O'Shea

NIST's Ultrasonic Technology Assessment Program to Improve Flow Measurement
TR-111311
Target: Instrumentation and Control
EPRI Project Manager: R. Shankar

An Empirical Model of UO_2 Thermal Conductivity Based on Laser Flash Measurements of Thermal Diffusivity
TR-111347
Target: Nuclear Power
EPRI Project Manager: S. Yagnik

Guidelines for the Evaluation of Seam-Welded High-Energy Piping: Executive Summary of Current Approaches
TR-111380
Target: Boiler Life and Availability Improvement
EPRI Project Manager: V. Viswanathan

Relationship of RIS Phenomena to IASCC (NFIR-III)
TR-111385
Target: Nuclear Power
EPRI Project Manager: L. Nelson

Compliance Assurance Monitoring Protocol Development
TR-111478
Target: Continuous and Predictive Emissions Monitoring
EPRI Project Manager: C. Dene

Opportunity Fuels Guidebook
TR-111487
Target: Coal-Fired Boiler Performance Optimization and Combustion NO_x Control
EPRI Project Manager: E. Hughes

Streamlined Reliability-Centered Maintenance (SRCM) Program for Hydroelectric Power Plants
TR-111488
Target: Hydro Performance Optimization and Asset Management
EPRI Project Manager: C. Sullivan

Integration of Distributed Resources in Electric Utility Systems: Current Interconnection Practice and Unified Approach
TR-111489
Target: Distributed Resources for Energy Services and Delivery Enhancement
EPRI Project Manager: F. Goodman

Review of Downstream Fish Passage and Protection Technology Evaluations and Effectiveness
TR-111517
Target: Hydro Performance Optimization and Asset Management
EPRI Project Manager: C. Sullivan

Blade Life Management System for GE Frame 7FA/9FA Gas Turbine: 1998 Interim Report
TR-111548
Target: Combustion Turbine and Combined-Cycle O&M
EPRI Project Manager: R. Frischmuth

Catalog of Available Materials for IASCC Testing
TR-111603
Target: Nuclear Power
EPRI Project Manager: L. Nelson

Addendum to Guidelines for Fireside Testing
TR-111663
Target: Coal-Fired Boiler Performance Optimization and Combustion NO_x Control
EPRI Project Managers: E. Hughes, A. Mehta

Hydro Operational Restrictions Forum: Licensee and Stakeholder Workshop Summary
TR-111750
Target: Hydro Performance Optimization and Asset Management
EPRI Project Manager: T. O'Shea

Advanced Biomass: Technology Characteristics, Status, and Lessons Learned
TR-111882
Target: Renewables and Green Power Marketing
EPRI Project Manager: E. Hughes

Role of Renewables in Greenhouse Gas Reduction
TR-111883
Target: Renewables and Green Power Marketing
EPRI Project Manager: E. Hughes

Renewable Power Industry Status Overview
TR-111893
Target: Renewables and Green Power Marketing
EPRI Project Manager: E. DeMeo

ChemExpert
Version 1.0 (Windows)
Target: Boiler and Turbine Steam and Cycle Chemistry
EPRI Project Manager: B. Dooley

chemWORKS™: Primary to Secondary Leak Calculator
Version 1.0 (Windows 3.1)
Target: Nuclear Power
EPRI Project Manager: T. Gaudreau

DRWS: Distributed Resources Workstation
Version 1.0 (Windows 95, 98)
Target: Distributed Resources Information and Tools for Business Strategy Development
EPRI Project Manager: D. Herman

EQMS: Environmental Quality Management System
Version 1.0 (Windows 95, 98, NT)
Target: Nuclear Power
EPRI Project Manager: J. Hutchinson

MAAP4: Modular Accident Analysis Program for LWR Power Plants
Version 4.03 (Various)
Target: Nuclear Power
EPRI Project Manager: J. Chao

P-T (Pressure-Temperature) Calculator
Version 3.0 (Windows)
Target: Nuclear Power
EPRI Project Manager: S. Rosinski

Turbo-X: Turbine Outage Extension System
Version 1.0a (Windows 95, NT)
Target: Steam Turbines, Generators, and Balance of Plant
EPRI Project Manager: T. McCloskey

Energy Delivery and Utilization

Airport Electrotechnology Resource Guide
TR-108050-R1
Target: Airport Solutions
EPRI Project Manager: L. Sandell

Predicting Customer Choices Among Electricity Pricing Options, Vol. 1: Wholesale Markets
TR-108864-V1
Targets: Producing Successful Product and Service Portfolios; Power Markets and Resource Management
EPRI Project Managers: P. Meagher, A. Faruqui, V. Niemeyer

Disaster Planning and Mitigation Technologies: Interim Technology Inventory Report
TR-108972-V3
Target: Disaster Planning and Mitigation Technologies
EPRI Project Manager: J. Oggerino

Power Quality Diagnostic System: Simulation Module Final Production Version 1.0
CD-109126
Target: Power Quality
EPRI Project Manager: S. Bhatt

UCA™ Demonstration Project at Oglethorpe Power Corporation
TR-109479
Target: Distribution Systems
EPRI Project Manager: W. Blair

Energy Cost System Applying UCA™/DAIS™ Concepts
TR-109481
Target: Distribution Systems
EPRI Project Manager: W. Blair

Water Treatment Systems for Utilities, Phase 1: Technology Assessment
TR-109753
Target: Underground Distribution Infrastructure
EPRI Project Manager: R. Bernstein

Water Treatment System for Utilities, Phase 1a: Technology Assessment Update
TR-110220
Target: Underground Distribution Infrastructure
EPRI Project Manager: R. Bernstein

Effects of Flue Gas Contamination on Ceramic Insulator Performance in Freezing Conditions
TR-110296
Target: Substations
EPRI Project Manager: P. Dessureau

Cooling Plant Optimization Guide
TR-110404
Target: Commercial Building Chillers
EPRI Project Manager: B. Lindsay

Proceedings: Eleventh Forecasting Symposium—Forecasting in a Competitive Electricity Market
TR-110424
Targets: Producing Successful Product and Service Portfolios; Grid Operations and Planning
EPRI Project Managers: P. Meagher, D. Maratukulam

Increasing the Yield of Real-Time Pricing: Kansas City Power & Light's Real-Time Pricing Innovations
TR-110747
Target: Power Markets and Resource Management
EPRI Project Manager: A. Faruqui

High-Temperature Superconductivity: Joint Feasibility Study for a Power Application With HTS Cable by South Carolina Electric & Gas
TR-110891
Target: Underground Transmission
EPRI Project Manager: D. Von Dollen

High-Temperature Superconductivity: Joint Feasibility Study for a Power Application With HTS Cable by PECO Energy
TR-110892
Target: Underground Transmission
EPRI Project Manager: D. Von Dollen

Electric Bus Compendium
TR-111123
Target: Public Transportation Systems
EPRI Project Manager: L. Sandell

Field Evaluation of a Prototype Mobile Water Management System for Subsurface Vaults in the Electric Utility Industry
TR-111173 (see listing under Environment)

A Gas Monitor for Underground Electric Utility Manholes and Vaults
TR-111246
Target: Underground Distribution Infrastructure
EPRI Project Manager: R. Bernstein

Behavior of Paper-Polypropylene-Paper Laminate Under Thermal and Electrical Stresses
TR-111321
Target: Underground Transmission
EPRI Project Manager: T. Rodenbaugh

Dissolved Gas Analysis by EPRI Disposable Oil Sampling System
TR-111322
Target: Underground Transmission
EPRI Project Manager: T. Rodenbaugh

Measurement and Mitigation of Corrosion on Self-Contained Fluid-Filled Submarine Circuits for New York Power Authority, Vols. 1 and 2
AP-111323-V1-V2
Target: Underground Transmission
EPRI Project Manager: T. Rodenbaugh

Electric Compressor Guidebook
TR-111368
Target: Natural Gas, Petroleum, and Chemicals Industries
EPRI Project Manager: A. Amarnath

UCA™/DAIS™ Demonstration Project by Kansas City Power & Light
TR-111418
Target: Distribution Systems
EPRI Project Manager: W. Blair

Systems Integration at Kansas City Power & Light Using API and ICCP
TR-111443
Target: Grid Operations and Planning
EPRI Project Manager: D. Becker

Estimating Customer Preferences for New Pricing Products
TR-111483
Target: Power Markets and Resource Management
EPRI Project Manager: A. Faruqui

Accelerated Aging of Distribution Non-Ceramic Insulators
TR-111515-V2
Target: Distribution Systems
EPRI Project Manager: B. Bernstein

Application Guide for Transmission Line Non-Ceramic Insulators
TR-111566
Target: Overhead Transmission
EPRI Project Manager: A. Phillips

Commercial Green Energy
TR-111601
Target: Enhancing the Success of New Customer Technologies
EPRI Project Manager: B. Kalweit

National EV Infrastructure Working Council: Committee Meeting Minutes 98-2
TR-111641
Target: Infrastructure Deployment and EV Benefits
EPRI Project Manager: L. Sandell

Installation Costs of Electric Vehicle Charging Infrastructure
TR-111655
Target: Infrastructure Deployment and EV Benefits
EPRI Project Manager: L. Sandell

Multifamily Housing: Technologies and Trends
TR-111659
Target: Multifamily Housing
EPRI Project Manager: A. Saleh

Advanced Electric Lift Trucks: Power Train Prototype
TR-111698
Targets: Non-Road Electric Vehicles; End-Use Power Quality Mitigation Systems
EPRI Project Manager: B. Banerjee

DC Drive Ride-Through Technology Alternatives and Development
TR-111759
Target: End-Use Power Quality Mitigation Systems
EPRI Project Manager: B. Banerjee

Flywheel Energy Storage for End-Use Power Quality
TR-111831
Target: End-Use Power Quality Mitigation Systems
EPRI Project Manager: B. Banerjee

Impact of Customer Churn on Profitability
TR-111855
Target: Producing Successful Product and Service Portfolios
EPRI Project Managers: A. Faruqui, B. Kalweit

Projecting Market Share for Energy-Related Offerings
TR-111856
Target: Producing Successful Product and Service Portfolios
EPRI Project Manager: A. Faruqui

Rhode Island Disaster Recovery Business Alliance: CEO and Business Needs Assessment Workshops
TR-111862-V1
Target: Disaster Planning and Mitigation Technologies
EPRI Project Manager: J. Oggerino

Ice Storm '98: Characteristics and Effects
TR-111864
Target: Overhead Transmission
EPRI Project Manager: M. Ostendorp

High-Ampacity, Thin-Wall Novel Polymer Cable
TR-111888
Target: Underground Distribution Infrastructure
EPRI Project Manager: B. Bernstein

Integration of Information and Data From the EPRI Distribution System Power Quality Monitoring Project, Disk 1: PQ Database Reference Information
TR-111902-V1-CD
Target: Power Quality
EPRI Project Manager: A. Sundaram

Integration of Information and Data From the EPRI Distribution System PQ Monitoring Project, Disk 2: RMS Variation Disturbance Database
TR-111902-V2-CD
Target: Power Quality
EPRI Project Manager: A. Sundaram

Integration of Information and Data From the EPRI Distribution System PQ Monitoring Project, Disk 3: Steady-State Measurement Database
TR-111902-V3-CD
Target: Power Quality
EPRI Project Manager: A. Sundaram

Integration of Information and Data From the EPRI Distribution System PQ Monitoring Project, Disk 4: Harmonic Distortion Measurement Database
TR-111902-V4-CD
Target: Power Quality
EPRI Project Manager: A. Sundaram

Hybrid Active Filter Test Report
TR-111920
Target: End-Use Power Quality Mitigation Systems
EPRI Project Manager: B. Banerjee

Lineworkers' Insulating Gloves and Sleeves: Injection Molding Demonstration Project
TR-111947
Target: Distribution Systems
EPRI Project Manager: B. Bernstein

Energy Consumption and Load Profiling at Major Airports
TR-111951
Target: Airport Solutions
EPRI Project Manager: L. Sandell

DESK BOOK™: Residential End-Use Technologies
Version 2.5 (Windows 3.1)
Target: All targets in Residential area
EPRI Project Manager: J. Kesselring

EGEAS
Version 9.01 (Windows 95, NT)
Target: Grid Operations and Planning
EPRI Project Manager: N. Abi-Samra

MMW: Maintenance Management Workstation
Version 1.0 (Windows 95, NT)
Target: Substation Operation and Maintenance
EPRI Project Manager: P. Vujovic

ROPES: Real and Reactive Optimization for Planning and Scheduling
Version 2.0 (Windows 95)
Target: Grid Operations and Planning
EPRI Project Manager: D. Maratukulam

UTWorkstation: CCRIDER
Version 3.0 (Windows)
Target: Underground Transmission
EPRI Project Manager: T. Rodenbaugh

UTWorkstation: CONMAN
Version 3.0 (Windows)
Target: Underground Transmission
EPRI Project Manager: T. Rodenbaugh

Environment

Use of Automatic Wire Coding to Evaluate Control Selection Bias in the Savitz et al. Study
TR-108044
Target: Electric and Magnetic Fields Health Assessment
EPRI Project Manager: K. Ebi

Field Evaluation of the Comanagement of Utility Low-Volume Wastes With High-Volume Coal Combustion By-Products: SX Site
TR-108409
Target: Combustion Wastes and Groundwater Protection
EPRI Project Manager: A. Quinn

PISCES Water Characterization Field Study: Vol. 1, Site D Report; Vol. 2, Site D Appendix
TR-108892-V1-V2
Target: Plant Multimedia Toxics Characterization (PISCES)
EPRI Project Manager: P. Chu

Orimulsion Combustion By-Products: Chemical Composition and Leaching Characteristics
TR-109020
Target: Combustion Wastes and Groundwater Protection
EPRI Project Manager: A. Quinn

Life-Cycle Decision Making: Vol. 1, Getting Started; Vol. 2, Learning the Methods; Vol. 3, Using the Software
AP-110676
Target: Environmental Assets Management
EPRI Project Manager: M. McLearn

Flow in Water-Intake Pump Bays: A Guide for Utility Engineers
TR-110948
Target: Power Plant Water Management
EPRI Project Manager: J. Tsou

Southeastern Aerosol and Visibility Study (SEAVS): Concentration and Composition of Atmospheric Aerosols at Look Rock, Tennessee, July–August 1995
TR-111063
Target: Atmospheric Particulates and Precursors
EPRI Project Managers: M. A. Allan, P. Saxena

Field Evaluation of a Prototype Mobile Water Management System for Subsurface Vaults in the Electric Utility Industry
TR-111173
Targets: Transmission and Distribution Soil and Water Issues; Underground Distribution Infrastructure
EPRI Project Manager: M. McLearn

Business Practices for Environmental Excellence: Guidelines (Based on Case Studies of Other Industries)
TR-111244
Target: Environmental Assets Management
EPRI Project Managers: M. McLearn, D. Golden

EPRI EMF Exposure Database: University of North Carolina Electrical Utility Worker Data Set
TR-111315
Target: Electric and Magnetic Fields Health Assessment
EPRI Project Manager: R. Takemoto-Hambleton

Pilot-Scale Studies of Solvent Extraction Treatment of PCB- and PAH-Contaminated Soil and Sediment
TR-111317
Target: Transmission and Distribution Soil and Water Issues
EPRI Project Manager: A. Quinn

Coal Ash Utilization for Soil Amendment to Enhance Water Relations and Turf Growth
TR-111318
Target: Combustion Wastes and Groundwater Protection
EPRI Project Manager: J. Goodrich-Mahoney

Measurement of Condensable Particulate Matter: A Review of Alternatives to EPA Method 202
TR-111327
Target: Plant Multimedia Toxics Characterization (PISCES)
EPRI Project Manager: B. Nott

Long-Term Effects of 60-Hz Electric Versus Magnetic Fields on IL-1 and Other Immune Parameters in Sheep: Phase 4 Study
TR-111342
Target: Electric and Magnetic Fields Health Assessment
EPRI Project Manager: K. Ebi

Long-Term Effects of 60-Hz Electric Versus Magnetic Fields on IL-1 and Other Immune Parameters in Sheep: Phase 5 Study
TR-111343
Target: Electric and Magnetic Fields Health Assessment
EPRI Project Manager: K. Ebi

Environmental Performance Measurement: Design, Implementation, and Review Guidance for the Utility Industry
TR-111354
Target: Environmental Assets Management
EPRI Project Manager: M. McLearn

The Springdale Project: Applying Constructed Wetland Treatment to Coal Combustion By-Product Leachate
TR-111473
Target: Power Plant Water Management
EPRI Project Manager: J. Goodrich-Mahoney

Evaluation of Occupational Magnetic Field Exposure Guidelines
TR-111501
Target: Electric and Magnetic Fields Health Assessment
EPRI Project Manager: R. Kavet

An Evaluation of Electric Field Exposure Measurements Using the Positron Meter
TR-111555
Target: Electric and Magnetic Fields Health Assessment
EPRI Project Manager: R. Takemoto-Hambleton

Aquatic Life Criteria Guidelines: An Overview of the Criteria Development Process and Identification of Priority Research Needs to Update the Guidelines
TR-111608
Target: Water Toxics Assessment
EPRI Project Manager: J. Goodrich-Mahoney

Toxicology of Coal Tars (A Complex Mixture of Polycyclic Aromatic Hydrocarbons)
TR-111658
Target: MGP Site Remediation and Health Risk
EPRI Project Manager: L. Goldstein

Association of Wire Code Configuration With Long-Term-Average 60-Hz Magnetic Fields and Exposure
TR-111767
Target: Electric and Magnetic Fields Health Assessment
EPRI Project Manager: R. Kavet

Validation of Computational Methods for Evaluation of Electric Fields and Currents Induced in Humans Exposed to Electric and Magnetic Fields
TR-111768
Target: Electric and Magnetic Fields Health Assessment
EPRI Project Manager: R. Kavet

Leaching of Inorganic Constituents From Coal Combustion By-Products Under Field and Laboratory Conditions, Vol. 1
TR-111773-V1
Target: Combustion Wastes and Groundwater Protection
EPRI Project Manager: A. Quinn

Utility Brownfields Resource Guide
TR-111784
Target: Community Economic Development Solutions
EPRI Project Manager: P. Radcliffe

SmartPlaces E Series User Manual
TR-111788
Target: Community Economic Development Solutions
EPRI Project Manager: P. Radcliffe

COOLADD: Database of Power Plant Cooling Water System and Generic Chemical Additives Usage
Version 1.0 (Windows)
Target: Facilities Water Management
EPRI Project Manager: K. Zammit

Decision Analysis for Transmission Line EMF Management
Version 1.0 (Windows)
Target: Electric and Magnetic Fields Health Assessment
EPRI Project Manager: G. Hester

LCDM: Life-Cycle Cost Decision Making
Version 2.0 (Windows 95)
Target: Environmental Assets Management
EPRI Project Manager: M. McLearn

MYGRT: Migration of Organic and Inorganic Chemicals in Groundwater
Version 3.0 (Windows 95, NT)
Target: Groundwater and Combustion By-Products Management
EPRI Project Manager: A. Quinn

WinSEQUIL
Version 2.0 (Windows 3.1)
Target: Facilities Water Management
EPRI Project Manager: K. Zammit

EPRICSG

Automated CO_2 and VOC-Based Control of Ventilation Systems Under Real-Time Pricing
TR-109117
Target: Information and Energy Management Services for C&I Customers
EPRI Project Managers: L. Carmichael, A. Kader

Small Commercial Customer Energy Management System Demonstration Project
TR-110183
Target: Information and Energy Management Services for C&I Customers
EPRI Project Managers: L. Carmichael, A. Kader

Electric Utility Marketing Guide to Foodservice
TR-110775
Target: Commercial Foodservice Facilities
EPRI Project Manager: W. Krill

The LiveWire Project
TR-111059
Target: Information and Energy Management Services for Mass Markets
EPRI Project Manager: S. Drenker

Supermarket Simulation Tool, Version 1.1
CM-111112-R1
Target: Retail/Supermarket Establishment Solutions
EPRI Project Manager: M. Khattar

Development and Demonstration of Energy Management Control Strategies for Automated Real-Time Pricing
TR-111365
Target: Information and Energy Management Services for C&I Customers
EPRI Project Managers: L. Carmichael, A. Kader

Technology as a Strategic Lever in Competitive Electricity Markets
TR-111711
Target: Technology Innovation and 21st Century Strategy
EPRI Project Manager: T. Henneberger

AC Drive System Efficiency Evaluation
TR-111879
Target: Power Electronics
EPRI Project Manager: B. Banerjee

Using Segmentation Insights to Sell Energy Products to the Mass Market
TR-111895
Target: Promoting Energy Products for Mass Markets
EPRI Project Managers: J. Kesselring, B. Kalweit

PQDS: Integrated Power Quality Diagnostic System (for PC Workstation)
Version 1.0 (Windows)
Target: Power Quality Software, Services, and Support
EPRI Project Manager: S. Bhatt

SST: Supermarket Simulation Tool
Version 2.0 (Windows 95)
Target: Retail/Supermarket Establishment Solutions
EPRI Project Manager: M. Khattar

EPRIGEN

EPRI Maintenance and Diagnostic Center Course Catalog, Revision 1
TR-109511-R1
Target: Plant Maintenance Optimization
EPRI Project Manager: R. Pflasterer

CMMS (Computerized Maintenance Management System) Selection at Cinergy
TR-109728
Target: Plant Maintenance Optimization
EPRI Project Manager: R. Pflasterer

Computerized Maintenance Management System Best Practices Guideline
TR-111464
Target: Plant Maintenance Optimization
EPRI Project Manager: R. Pflasterer

Strategic Science and Technology

Development and Evaluation of Low-Cost Sorbents for Removal of Mercury Emissions From Coal Combustion Flue Gas
TR-110532
Program: Strategic Science and Technology
EPRI Project Manager: R. Chang

Loading Margin Methods for Avoiding Voltage Collapse
TR-111275
Program: Strategic Science and Technology
EPRI Project Managers: N. Abi-Samra, M. Wildberger, T. Schneider, D. Sobajic

Stability, Damping Nonlinear Dynamics, and SSR in Thyristor Switching Circuits
TR-111276
Program: Strategic Science and Technology
EPRI Project Managers: N. Abi-Samra, M. Wildberger, T. Schneider, D. Sobajic

Mercury Flux Measurements: An Intercomparison and Assessment (Nevada Mercury Emissions Project)
TR-111346
Program: Strategic Science and Technology
EPRI Project Manager: M. A. Allan

Heart Rate Variability in Ambient Magnetic Fields
TR-111496
Program: Strategic Science and Technology
EPRI Project Manager: R. Kavet

Electroozonation: Experimental Development Program
TR-111681
Program: Strategic Science and Technology
EPRI Project Manager: A. Amarnath

Condensation of R-410A in a Horizontal Rectangular Channel
TR-111754
Program: Strategic Science and Technology
EPRI Project Manager: A. Saleh

Temperbead Welding of P-Nos. 4 and 5 Materials
TR-111757
Program: Strategic Science and Technology
EPRI Project Managers: V. Viswanathan, D. Gandy, S. Findlan

Advances in Communication Using Femtosecond Laser Technology
TR-111786
Program: Strategic Science and Technology
EPRI Project Manager: R. Bernstein

High-Voltage Laboratory Testing of Femtosecond Laser Lightning Diversion
TR-111787
Program: Strategic Science and Technology
EPRI Project Manager: R. Bernstein

A High-Speed PM Disk Motor for Compressor Drives
TR-111903
Program: Strategic Science and Technology
EPRI Project Manager: B. Banerjee

Heat Pumps for Ventilation Air Conditioning: State-of-the-Art Technology Review
TR-112021
Program: Strategic Science and Technology
EPRI Project Manager: M. Khattar

EPRI Events

April

12–14
Transmission Inspection and Maintenance (TIM) System Regional Training
Las Vegas, Nevada
Contact: Gayle Robertson, (817) 439-5900

12–15
Conference on Power Plant Impacts on Aquatic Resources
Atlanta, Georgia
Contact: Cindy Layman, (650) 855-8763

12–16
NDE for Engineers
Charlotte, North Carolina
Contact: Sherryl Stogner, (704) 547-6174

12–16
Simulator Instructor Station Operations
Kansas City, Missouri
Contact: Sarah Malinowski, (816) 235-5623

13–14
Power Quality for the Semiconductor Fabrication Industry
Tempe, Arizona
Contact: Megan Boyd, (650) 855-7919

13–14
12th Annual Forecasting Symposium
Denver, Colorado
Contact: Michele Samoulides, (650) 855-2127

13–16
Machinery Alignment
Eddystone, Pennsylvania
Contact: Melanie Moore, (610) 490-3216

14
PISCES Model 3.01 (TRI Version) Training
Dallas, Texas
Contact: Paul Chu, (650) 855-2812

14–15
Utility Strategic Marketing Conference
Orlando, Florida
Contact: June Appel, (610) 667-0351

15–16
TIM System Users Group
Las Vegas, Nevada
Contact: Gayle Robertson, (817) 439-5900

19–23
Infrared Thermography: Level 1
Eddystone, Pennsylvania
Contact: Melanie Moore, (610) 490-3216

20–21
Power Quality Interest Group
Baltimore, Maryland
Contact: Teri De Breau, (650) 855-2833

20–23
Structured On-the-Job Training Program Design, Development, and Implementation
Kansas City, Missouri
Contact: Sarah Vanberg, (816) 235-5623

25
Smart Tools for Sustainable Communities
Seattle, Washington
Contact: Paul Radcliffe, (650) 855-2720

26–28
China-U.S. Energy Development Conference
Washington, D.C.
Contact: Brent Lancaster, (704) 547-6017

26–30
Y2K Embedded-Systems Workshop
San Antonio, Texas
Contact: Paige Polishook, (650) 855-2010

27–29
Preserving Equipment Qualification
Charlotte, North Carolina
Contact: Sherryl Stogner, (704) 547-6174

27–30
Basic Vibration Testing and Analysis
Eddystone, Pennsylvania
Contact: Melanie Moore, (610) 490-3216

29–30
Dynamic Security Assessment Workshop
Minneapolis, Minnesota
Contact: Peter Hirsch, (650) 855-2206

May

3–5
GIS/GPS Workshop: Applications and Developments for Electric Utilities
Dallas, Texas
Contact: Gayle Robertson, (817) 439-5900

3–7
Steam Plant Operations for Utility Engineers
Kansas City, Missouri
Contact: Sarah Malinowski, (816) 235-5623

4–5
EPRI Healthcare Initiative Power Quality Council
Dallas, Texas
Contact: Kelly Ciprian, (614) 855-1390

4–7
Motor Monitoring and Diagnostics
Eddystone, Pennsylvania
Contact: Melanie Moore, (610) 490-3216

10–11
Continuous Emissions Monitoring (CEM) Preconference Tutorial
Cincinnati, Ohio
Contact: Michele Samoulides, (650) 855-2127

10–13
Industrial Energy Technology Conference
Houston, Texas
Contact: Sam Woinsky, (713) 963-9336

10–14
Combined-Cycle Operations for Utility Engineers
Kansas City, Missouri
Contact: Sarah Malinowski, (816) 235-5623

10–21
Ultrasonic Examination Technology: Level 2
Charlotte, North Carolina
Contact: Sherryl Stogner, (704) 547-6174

12–14
1999 CEM Users Group
Cincinnati, Ohio
Contact: Michele Samoulides, (650) 855-2127

17–19
License Renewal Training Workshop
Charlotte, North Carolina
Contact: Brent Lancaster, (704) 547-6017

17–21
Drum Boiler Unit Operations
Kansas City, Missouri
Contact: Sarah Malinowski, (816) 235-5623

18–20
Condition-Based Maintenance Automation and the Internet
Eddystone, Pennsylvania
Contact: Melanie Moore, (610) 490-3216

19–21
Transformer Reliability: Management of Static Electrification
Monterey, California
Contact: Paige Polishook, (650) 855-2010

20–21
Gas-Electric Partnership Workshop
Houston, Texas
Contact: Sam Woinsky, (713) 963-9336

23–27
5th International Conference on Mercury as a Global Pollutant
Rio de Janeiro, Brazil
Contact: Ron Wyzga, (650) 855-2577

24–27
PQA '99: North America
Charlotte, North Carolina
Contact: Megan Boyd, (650) 855-7919

24–28
Supercritical Boiler Unit Operations
Kansas City, Missouri
Contact: Sarah Malinowski, (816) 235-5623

26
Petrochemical Industry Overview
Salt Lake City, Utah
Contact: Sam Woinsky, (713) 963-9336

26–28
Valve Symposium
Lake Tahoe, Nevada
Contact: Linda Parrish, (704) 547-6061

31–June 4
Cyclone Boiler Unit Operations
Kansas City, Missouri
Contact: Sarah Malinowski, (816) 235-5623

June

1
Fundamentals of Corrosion
St. Pete Beach, Florida
Contact: Brent Lancaster, (704) 547-6017

2–3
Containment Inspection: Visual Examination Training, Level 2
Charlotte, North Carolina
Contact: Sherryl Stogner, (704) 547-6174

2–4
Corrosion and Degradation Conference
St. Pete Beach, Florida
Contact: Brent Lancaster, (704) 547-6017

7–11
Visual Examination Technology: Level 2
Charlotte, North Carolina
Contact: Sherryl Stogner, (704) 547-6174

10–11
Electromagnetic Interference Qualification of Digital Equipment
Charlotte, North Carolina
Contact: Sherryl Stogner, (704) 547-6174

14–18
ABB Circuit Breaker Users Group
Charlotte, North Carolina
Contact: Linda Parrish, (704) 547-6061

14–18
Joint ISA POWID/EPRI Controls and Instrumentation Conference
St. Petersburg, Florida
Contact: Paige Polishook, (650) 855-2010

14–18
Service Water Heat Exchanger Testing
Charlotte, North Carolina
Contact: Sherryl Stogner, (704) 547-6174

14–23
Ultrasonic-Testing Operator Training for the Detection of IGSCC
Charlotte, North Carolina
Contact: Sherryl Stogner, (704) 547-6174

15–17
3d Annual In-Service Inspection and Nondestructive Evaluation Workshop
Minneapolis, Minnesota
Contact: Sherryl Stogner, (704) 547-6174

15–18
American Council for an Energy-Efficient Economy
Saratoga Springs, New York
Contact: Rebecca Lunetta, (202) 429-8873

16–18
Healthcare Initiative Conference
Seattle, Washington
Contact: Kelly Ciprian, (614) 855-1390

17–18
CHUG Meeting
Portland, Maine
Contact: Lynn Stone, (972) 556-6529

20–24
Bioelectromagnetics Society Meeting
Long Beach, California
Contact: Chuck Rafferty, (650) 855-8908

21–22
Meeting of the American Society of Healthcare Engineers
Philadelphia, Pennsylvania
Contact: Kelly Ciprian, (614) 855-1390

21–23
Plant Maintenance Conference
Atlanta, Georgia
Contact: Cindy Layman, (650) 855-8763

22–24
Machinery Balancing Short Course
Eddystone, Pennsylvania
Contact: Melanie Moore, (610) 490-3216

22–25
Steam Chemistry: Interaction of Chemical Species
Freiburg, Germany
Contact: Barry Dooley, (650) 855-2458

23–25
5th Piping and Bolting NDE Conference
San Antonio, Texas
Contact: Susan Otto-Rodgers, (704) 547-6072

27–30
Technology Management Workshop
San Francisco, California
Contact: Megan Boyd, (650) 855-7919

28
Water and Energy Conference
Vancouver, Canada
Contact: Kim Shilling, (314) 935-8590

29–30
Municipal Water and Wastewater Program Meeting
Vancouver, Canada
Contact: Kim Shilling, (314) 935-8590

29–July 1
Predictive Maintenance Program: Development and Implementation
Eddystone, Pennsylvania
Contact: Melanie Moore, (610) 490-3216

July

6
EPRI's Hydropower Research Program
Las Vegas, Nevada
Contact: Paige Polishook, (650) 855-2010

6–9
WAPA Waterpower '99 Conference
Las Vegas, Nevada
Contact: Paige Polishook, (650) 855-2010

9
EPRI/WAPA Symposium/Workshop: Hydroelectric Sediment Management and Project Decommissioning Issues
Las Vegas, Nevada
Contact: Paige Polishook, (650) 855-2010

12–14
International Low-Level-Waste Conference and Exhibit
McAfee, New Jersey
Contact: Michele Samoulides, (650) 855-2127

12–15
Advanced Structural Analysis and Design Methods for Electric Power Line Upgrading
Dallas, Texas
Contact: Gayle Robertson, (817) 439-5900

12–16
Combined-Cycle Operations for Utility Engineers
Castine, Maine
Contact: Sarah Malinowski, (816) 235-5623

12–16
Ultrasonic Examination Technology: Level 3
Charlotte, North Carolina
Contact: Sherryl Stogner, (704) 547-6174

13–15
Turbine-Generator Troubleshooting Short Course
Eddystone, Pennsylvania
Contact: Melanie Moore, (610) 490-3216

14–16
ASME/EPRI Radwaste Workshop
McAfee, New Jersey
Contact: Michele Samoulides, (650) 855-2127

19–23
NDE Technical Skills Training: Level 3 Basic
Charlotte, North Carolina
Contact: Sherryl Stogner, (704) 547-6174

19–23
Steam Plant Operations for Utility Engineers
Castine, Maine
Contact: Sarah Malinowski, (816) 235-5623

20–21
On-Line Condition Assessment of Generators, Motors, and Plant Electrical Auxiliaries Using Electromagnetic Interference Analysis
Annapolis, Maryland
Contact: Megan Boyd, (650) 855-7919

20–22
Nuclear Utility Procurement
Charlotte, North Carolina
Contact: Sherryl Stogner, (704) 547-6174

20–22
Valve Packing Configuration, Implementation, and Program Development
Eddystone, Pennsylvania
Contact: Melanie Moore, (610) 490-3216

20–23
Infrared Users Group
Toledo, Ohio
Contact: Paul Zayicek, (704) 547-6154

26–28
International Joint Power Generation Conference
San Francisco, California
Contact: Patricia Irving, (800) 843-2763

26–30
Infrared Thermography: Level 2
Eddystone, Pennsylvania
Contact: Melanie Moore, (610) 490-3216

26–30
Terry Turbine Users Group
Sanibel, Florida
Contact: Linda Parrish, (704) 547-6061

26–30
Visual Examination Technology: Level 3
Charlotte, North Carolina
Contact: Sherryl Stogner, (704) 547-6174

27
9th Annual NDE Issues Meeting
Sunset Beach, North Carolina
Contact: Susan Otto-Rodgers, (704) 547-6072

29–30
In-Service Inspection/In-Service Testing Regional Workshop
Sunset Beach, North Carolina
Contact: Susan Otto-Rodgers, (704) 547-6072

August

2–6
Ultrasonic-Testing Operator Training for Weld Overlay Examination
Charlotte, North Carolina
Contact: Sherryl Stogner, (704) 547-6174

4–6
Radiation Field Seminar
Seattle, Washington
Contact: Paige Polishook, (650) 855-2010

11–13
Service Water Engineer Training
Charlotte, North Carolina
Contact: Sherryl Stogner, (704) 547-6174

16–19
Microbiologically Influenced Corrosion
Charlotte, North Carolina
Contact: Sherryl Stogner, (704) 547-6174

16–20
Mega Symposium: Combined NO_x, SO_2, Particulates, and Air Toxics
Atlanta, Georgia
Contact: Cindy Layman, (650) 855-8763

16–20
NDE Instructor Training
Charlotte, North Carolina
Contact: Sherryl Stogner, (704) 547-6174

17–19
Application of Reliability- and Risk-Centered Concepts to Maintenance
Charlotte, North Carolina
Contact: Sherryl Stogner, (704) 547-6174

17–20
6th Steam Turbine–Generator Workshop
St. Louis, Missouri
Contact: Paul Sabourin, (704) 547-6155

19–20
Non-Road Electric Vehicle Conference
Orlando, Florida
Contact: Michele Samoulides, (650) 855-2127

23–27
Westinghouse Circuit Breaker Users Group
Pittsburgh, Pennsylvania
Contact: Linda Parrish, (704) 547-6061

24–26
Charging-Pump Users Group
Charlotte, North Carolina
Contact: Linda Parrish, (704) 547-6061

25–27
Air-Operated Valve Workshop
Indian Lakes, Illinois
Contact: Linda Parrish, (704) 547-6061

30–September 3
Condenser Technology Seminar and Conference
Charleston, South Carolina
Contact: Brent Lancaster, (704) 547-6017

September

6–10
Integrated Global Water Management
Prague, Czech Republic
Contact: Robert Brocksen, (303) 840-7389

8–10
Rotating Electrical Machinery Colloquium
Orlando, Florida
Contact: Michele Samoulides, (650) 855-2127

13–17
NDE of High-Energy Piping
Charlotte, North Carolina
Contact: Sherryl Stogner, (704) 547-6174

14–15
Distribution Engineering Workstation Users Group
Kansas City, Missouri
Contact: Harry Ng, (650) 855-2973

20–October 1
Ultrasonic Examination Technology: Level 1
Charlotte, North Carolina
Contact: Sherryl Stogner, (704) 547-6174

23–24
3d Gas-Electric Partnership Symposium
Houston, Texas
Contact: Sam Woinsky, (713) 963-9336

27–29
RCM Users Group
Las Vegas, Nevada
Contact: Lora Cocco, (650) 855-2620

October

1
Industry Overview Courses: Inorganic Chemicals, Petrochemicals, Petroleum Production and Refining, Pharmaceuticals
TBA
Contact: Sam Woinsky, (713) 963-9336

4–5
Containment Inspection: Visual Examination Training, Level 2
Charlotte, North Carolina
Contact: Sherryl Stogner, (704) 547-6174

6–8
ASME Section XI Flaw Evaluation
Charlotte, North Carolina
Contact: Sherryl Stogner, (704) 547-6174

13–15
Healthcare Initiative Conference
Charleston, South Carolina
Contact: Kelly Ciprian, (614) 855-1390

17–20
Gasification Technologies Conference
San Francisco, California
Contact: Michele Samoulides, (650) 855-2127

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