The Next Generation of Nuclear Plants

Also in this issue • System Visualization • Advanced Curing Techniques • MGP Site Remediation

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Cover: The control room of ABB Combustion Engineering's System 80+ reflects the simplicity, clarity, and user-friendliness that are the hallmark of advanced LWR power plant designs. The layout and integration of these controls are so efficient that they can be run by a single operator if necessary.

EPRI JOURNAL

Volume 19, Number 8 December 1994

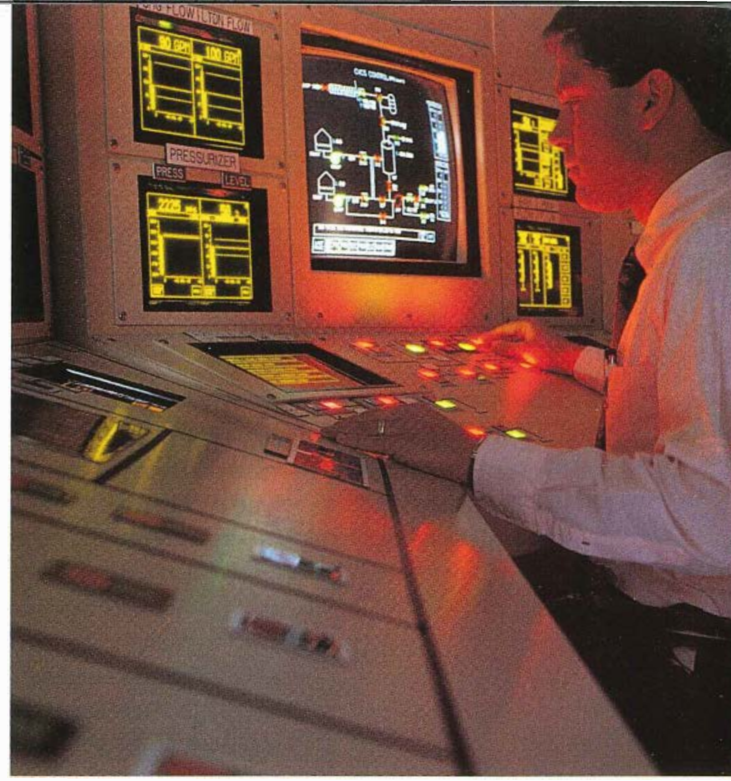
COVER STORY

FEATURES

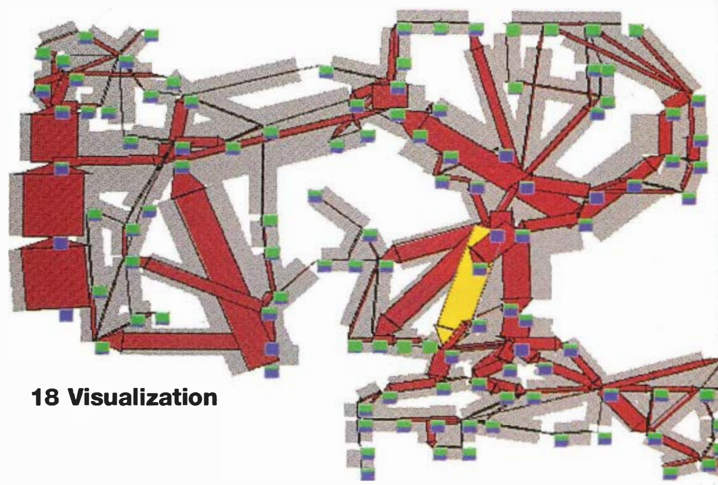
DEPARTMENTS

LISTINGS

RESEARCH UPDATES

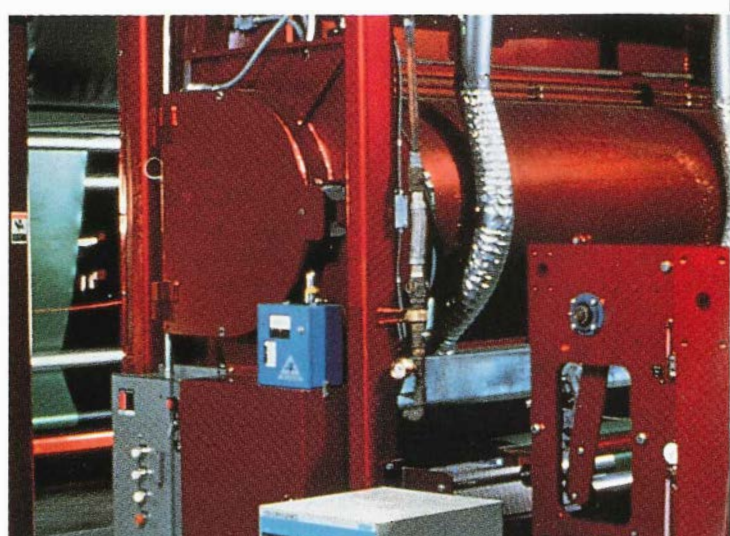


6 Advanced reactors



18 Visualization

24 Curing technologies



Videos for Preventing Blade Walk

Over the years, U.S. electric utilities have spent millions of dollars on combustion turbine compressor repairs necessitated by blade walk, a deterioration problem that can lead to turbine shutdowns. Additional money has gone toward purchasing power during shutdowns and training mechanics to perform the repairs. The two-part *Compressor Blade Walk* video set (VT-100578) is designed to help utilities reduce the significant costs associated with blade walk in Westinghouse's 501 gas turbine. Combustion turbine engineers, maintenance personnel, and supervisors alike will benefit from the videos, which show damaged compressor blades and offer guidelines for inspecting, repairing, and preventing blade walk.

For more information, contact Robert Frischmuth, (415) 855-2579. To order, call the EPRI Distribution Center, (510) 934-4212.

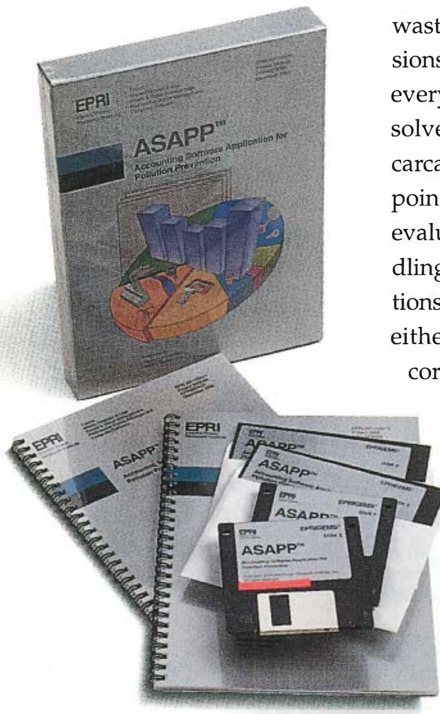
Premier Ground-Source Heat Pump

The EPRI-sponsored Premier AT series ground-source heat pumps offer exceptional comfort, the highest heating and cooling efficiencies available in a ground-source heat pump, and greater sizing flexibility to enable application in all climates. Specially constructed for residential use, these Premier series units by WaterFurnace employ advanced microprocessor controllers and multistage electronic thermostats to ensure maximum comfort. When the heat pump is operating in the space-cooling mode, an optional desuperheater can supply low-cost water heating. A variable-speed fan and a two-speed compressor contribute to the unit's quiet operation. WaterFurnace's latest model in the series, the Premier2, was released in the spring of 1994.

EPRI project manager: Carl Hiller. To order, call WaterFurnace International, Inc., (219) 478-5667.

ASAPP for Effective Pollution Prevention

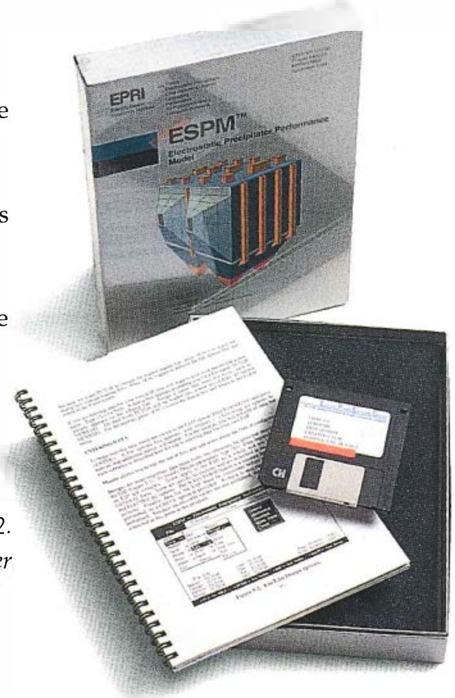
In financial accounting, revenues, operating expenses, and profits are tracked and evaluated with respect to a company's budget. In these days of increased interest in pollution prevention, why not do something similar for waste? In response to that question, EPRI researchers have come up with ASAPP—Accounting Software Application for Pollution Prevention. ASAPP is a waste-accounting data management system that facilitates cost-effective waste management decisions. Users can track everything from spent solvents to transformer carcasses, starting from the point of generation, and can evaluate the costs of handling these wastes. Evaluations can be performed at either the facility or the corporate level.



For more information, contact Mary McLearn, (415) 855-2487. To order, call the Electric Power Software Center, (800) 763-3772.

ESPM

The utility industry has come to depend on electrostatic precipitators as a reliable method of particulate control. Yet ESPs are complex devices, with physical configurations as widely varied as the properties of the ash they are designed to collect. EPRI's ESPM software for modeling ESP performance helps utilities get the most out of this equipment. Whether the need is for troubleshooting, an upgrade analysis, performance monitoring, or a fuel-switching study, ESPM offers swift and accurate performance predictions. Users can easily input and analyze existing operating data. When actual data are not available, the software will provide default values.

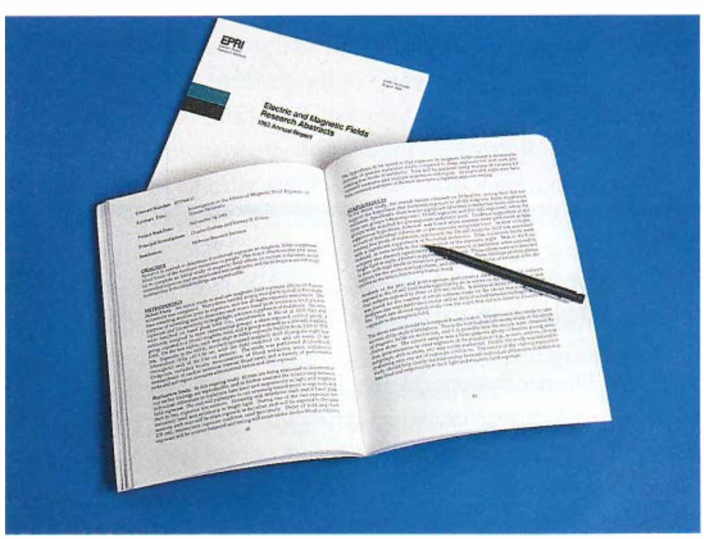


For more information, contact Ralph Altman, (615) 899-0072. To order, call the Electric Power Software Center, (800) 763-3772.

EMF Research Abstracts

EPRI's *Electric and Magnetic Fields Research Abstracts* (TR-104359) offers a comprehensive overview of the EMF research in progress at the Institute. The fifth annual report of its kind, the document covers all projects EPRI is conducting that pertain to EMF—for example, exposure assessments, magnetic field management, laboratory studies, and epidemiologic research. Each project is described in a one-page summary written by the researchers performing the work. Scientists, engineers, utility staff members, and others interested in the EMF issue will find this report a valuable resource. The information in the report is current as of late 1993.

For more information, contact Stan Sussman, (415) 855-2581. To order, call the EPRI Distribution Center, (510) 934-4212.

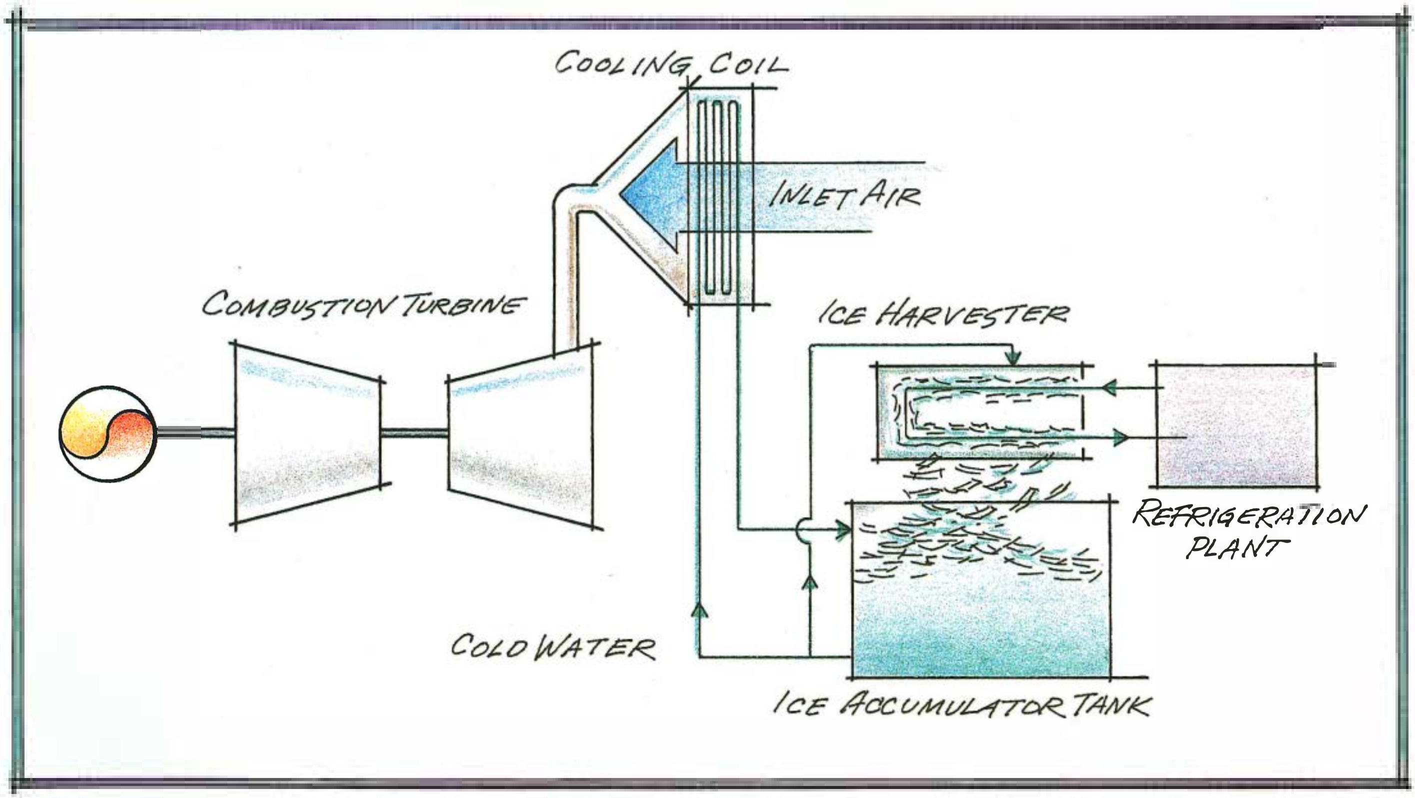


Ice Storage System Boosts Turbine Capacity

Utilities that use combustion turbines to meet demand peaks caused by air conditioning loads on hot summer days face a dilemma: as ambient air temperature rises, the effective capacity of the turbines decreases. The reason for this phenomenon is that combustion turbines ingest air at a nearly constant volume flow rate, but the amount of fuel they burn depends on the mass—not the volume—of the airflow. At higher temperatures air is less dense, so the throughput of air mass decreases just when it is needed the most. A turbine with a rated capacity of 57 MW at 80°F, for example, might have an actual capacity of less than 53 MW at 101°F.

Lincoln Electric System (LES) of Lincoln, Nebraska, faced just such a problem recently when it needed to increase peaking capacity to meet load growth. It found a novel solution—cooling the inlet air for its 57-MW GE Frame 7B turbine by means of ice storage. With preliminary design and engineering help from EPRI and cofunding from the American Public Power Association, LES added cooling coils and a high-flow guide vane to the air inlet of its turbine. Cold water for the cooling coils comes from a tank that receives ice produced by refrigeration during off-peak hours.

Startup and testing of the system began in 1991—less than a year after the beginning of detailed design work. The tests showed that on a day when temperatures reach 101°F, the modified turbine would have an output of 69 MW—some 30% above the expected level. The cost of this incremental capacity was under $200/kW, compared with $320/kW for adding capacity by installing a new turbine. Since startup, the cooling system has worked well, and the EPRI report on the project (TR-103464) concludes that "thermal storage for inlet air cooling is a practical option for increasing the capacity of combustion turbines."



■ *For more information, contact Robert Frischmuth, (415) 855-2579.*

Targeting Arsenic in Drinking Water

An electrotechnology originally developed to remove radioactive nucleotides and corrosion products from reactor cooling water is now being used to treat drinking water from wells contaminated with arsenic. The need for better treatment methods is critical, says EPRI's Myron Jones, because the U.S. Environmental Protection Agency is considering lowering the maximum contaminant level for arsenic in drinking water from 50 ppb to perhaps as low as 3–5 ppb, near the limits of detection. Chronic exposure to low levels of arsenic has been linked to a variety of adverse health effects, including several kinds of cancer.

The technology involved, called selective electrochemical ion exchange (SEIX), uses an electric field to attract heavy metal ions from flowing water toward the side of a reaction chamber, where they can be absorbed by an ion-exchange resin. A dopant on the surface of the resin selectively removes arsenic from the stream—allowing harmless ions, such as calcium, to pass without saturating the resin. Arsenic absorbed by the dopant-resin medium can be removed by reversing the polarity of the electric field. The SEIX process was developed by the UK Atomic Energy Authority laboratory at Harwell, England, and by Electrochemical Design Associates of Orinda, California.

An SEIX pilot plant for treating drinking water is now operating in Albuquerque, New Mexico; it uses water from wells where naturally occurring levels of arsenic average 30 ppb. The plant reduces the arsenic levels to about 5 ppb. This demonstration project is funded by EPRI, the American Water Works Association Research Foundation, Public Service Company of New Mexico, and the city of Albuquerque.

Operation of the first pilot unit has gone so well that a second unit is being considered that would feature continuous regeneration of the ion-exchange medium. Engineering design for a commercial prototype has also begun. And beyond this application, SEIX shows promise for the treatment of acid mine drainage, the removal of selenium and nitrates from groundwater, and the remediation of agricultural soils.

■ *For more information, contact Myron Jones, (415) 855-2993.*

Effects of DC Testing on Cable

Direct-current high-voltage testing of cable has been a widely employed method for detecting gross imperfections or deterioration. Such testing is used by the cable manufacturer after production (factory testing) and by the utility after installation (proof or acceptance testing) and during service (proof or maintenance testing). Traditionally employed with paper/oil cable, the practice of dc testing was carried over to extruded dielectric distribution cable many years ago. More recently, however, the influence of dc high-voltage testing on the life of cross-linked polyethylene (XLPE) cable has come under study because of a perception that the testing may be contributing to premature failures. An extensive test program sponsored by EPRI and coordinated by Detroit Edison Company has clarified the issue and led to a new understanding about how dc testing affects XLPE cable.

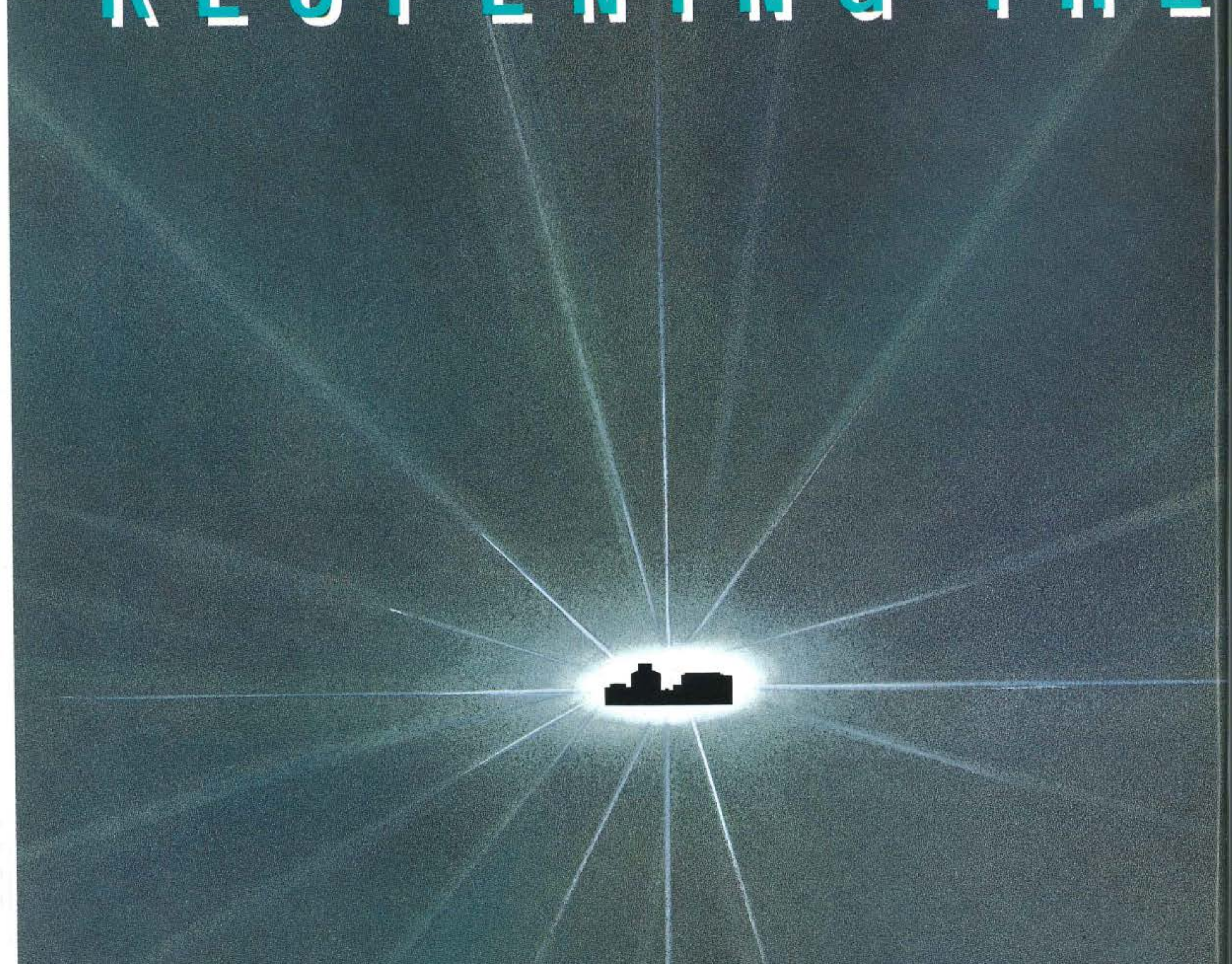
The study showed that a key consideration for determining the influence of dc testing is whether the cable has been aged. It was concluded that dc testing of new (unaged) cable in accordance with industry specifications does not harm the cable. However, maintenance testing was found to cause more-rapid loss of XLPE cable life. This reduction in life expectancy was especially noticeable in systems where an aged cable has been spliced to a new one.

A general conclusion that emerged from this research is that dc maintenance testing should be discontinued where feasible. Specifically, testing should not be performed on cables that have failed in service and have been spliced or on cables that show signs of heavy aging, such as "water trees" (tree-shaped imperfections on XLPE insulation that are caused by prolonged exposure to water and voltage stress). Testing under industry standards of all-new cables before energizing, however, remains an acceptable procedure.

As a result of the study, several utilities have stopped performing dc maintenance testing and have reported reduced failure rates.

■ *For more information, contact Bruce Bernstein, (202) 293-7511.*

REOPENING THE



NUCLEAR OPTION

After more than 10 years of intensive effort, EPRI's and the nuclear industry's program to develop the next generation of advanced light water reactors (ALWRs) is coming to fruition. These reactors embody advanced technical features that enhance their safety, performance, and economic competitiveness. Their development has been undertaken as part of a larger strategic plan (see sidebar, p. 11) that addresses broad institutional issues, such as public acceptance, financing, and regulatory reform; all of these elements are needed to revitalize the nuclear option in the United States.

The technical program has made substantial progress, and already versions of the first power plants based on the new designs are under construction abroad, where demand for electricity is growing at a faster pace than in the United States. By the time American utilities are expected to begin ordering new baseload plants again, around the year 2000, their options will include four standardized ALWR designs precertified by the Nuclear Regulatory Commission—plants that can be built with a high degree of confidence with respect to schedules and total costs.

"The ALWR effort has received broad support from utilities both here and abroad," says Joseph Santucci, the manager responsible for EPRI's advanced reactor development activities and the deputy executive director of the Advanced Reactor Corporation (ARC), a utility consortium set up to conduct the ALWR commercial design standardization program. "I believe the next generation of light water reactors will meet utility needs for power plants that are exceptionally safe, environmentally benign, acceptable to the public, and economically competitive."

The road to certification

The EPRI effort to develop a new generation of reactors began in 1983, when a survey of utility executives was conducted to determine their preferences and prerequisites for ordering new nuclear power plants. The results were clear: new plants must be safer and simpler and must have greater design margins—that is, they must be more "forgiving." The executives also supported making improvements to established light water reactor technology, rather than trying to develop radically new reactor concepts that would require prototype demonstrations. Finally, they wanted the option to build midsize nuclear plants—around 600 MWe—in addition to "evolutionary" plants of more than 1000 MWe. Such midsize plants could better match the demands of slower load growth, and they could better accommodate safety features that rely on natural forces as the primary means of providing emergency cooling for the reactor and its containment structure (sometimes called "passive safety" features), thereby greatly simplifying plant design and operation.

In response to these industry guidelines, EPRI launched the ALWR design effort in 1985, focusing initially on the development

by John Douglas

THE STORY IN BRIEF With new orders for baseload power plants stalled in this country, what would it take to rekindle utility interest in the nuclear option? EPRI asked the question, and utilities answered specifically: the plants must be simpler and have higher design margins and enhanced safety features; they must be economically competitive with other forms of generation; they must be standardized; and they must be prelicensed by the NRC. As tall as this order may seem, four advanced light water reactors (ALWRs)—all based on these utility requirements—are being designed by three major vendors, and a version of one of these plants is actually under construction in Japan. Just recently, the NRC issued final design approvals for two of the designs and also issued a favorable safety evaluation report on the EPRI Utility Requirements Document. Working closely with utilities, industry groups, and regulatory agencies, EPRI is making a key contribution to the reopening of the nuclear option.

of the Utility Requirements Document (URD), a comprehensive set of design specifications desired by utility users. In addition, the document was to address more than 700 regulatory issues that the NRC required to be resolved in any future designs. The first three volumes of the URD were completed in 1990 and contain more than 20,000 detailed requirements for ALWR designs.

Volume I describes the guiding design and operating philosophies and specifies overall requirements. A revision of this volume with an improved and updated definition of the economic competitiveness requirements will be issued in 1995. Volume II covers the design of evolutionary plants. This document received a safety evaluation report from the NRC in 1992. Volume III, covering midsize plants with passive safety features, received a safety evaluation report in the summer of 1994. The NRC review documents conclude that designs that meet the URD requirements are licensable designs. A coalition of domestic and international utilities (organized through EPRI), vendors, and the government is now working to develop and license ALWR designs that meet the URD requirements.

The work on the URD spawned several follow-on design programs, as well as the development of an integrated, industry-wide plan for and commitment to the resolution of technical and institutional challenges, which is a prerequisite to reopening the nuclear option. In addition to developing the URD, EPRI's direct responsibilities have focused on the development and certification of two midsize ALWRs, the post-certification engineering for two designs selected by utilities, and the resolution of siting issues and processes for the next generation of nuclear plants.

The two designs for evolutionary plants —General Electric's Advanced Boiling Water Reactor (ABWR) and ABB Combustion Engineering's System 80+ (a pressurized water reactor)—received final design approval from the NRC in the summer of 1994. A public review process will complete the certification of these designs in approximately one year, under the most recent provisions of the Code of Federal Regulations (10CFR52). By defining a three-step

FINDING OUT WHAT UTILITIES WANT **Before any design work on the next generation of light water reactors was undertaken, EPRI worked with domestic and international utility companies to define the characteristics that advanced plants should have in order to meet the companies' needs. The result was the Utility Requirements Document (URD), which specifies the technical and economic concepts for both a simplified, evolutionary plant and a midsize plant that incorporates passive safety features. All four of the designs now nearing commercialization conform to these requirements, some of which are listed below.**

Overall design philosophy: Simple, rugged, high design margin, based on proven technology, no plant prototype required

Plant size: 1200–1300 MWe (evolutionary design); 600 MWe (midsize design)

Plant design life: 60 years

Design availability: 87%

Refueling interval: 24-month capability

Unplanned automatic scrams: Fewer than one per year

Safety systems: Simplified active systems (evolutionary); primarily passive systems not requiring ac electric power (midsize)

Station power blackout coping time: 8 hours minimum (evolutionary); indefinite (midsize)

Occupational radiation exposure: Below 100 person-rem per year

Operational simplicity: Single operator able to control under normal conditions

Construction time: 54 months (evolutionary); 42 months (midsize)

Capital cost (1989 dollars): $1300/kWe (evolutionary); $1475/kWe (midsize)

URD

process (see sidebar, p. 12), these provisions greatly simplify the licensing process and reduce the risk to future licensees.

Following on the same path as the evolutionary plants are the midsize reactors, for which design work continues in earnest. The current focus is on completing extensive testing of the key passive safety features. The NRC's final design approval of the Westinghouse AP600 (a pressurized water reactor) is expected by late 1996, to be followed about a year later by approval of General Electric's Simplified Boiling Water Reactor (SBWR). Over $340 million has been committed to obtaining final design approval for the midsize reactors, with the funding provided by utilities (through EPRI), DOE, and design team cost sharing. Both midsize designs are responsive to the U.S. utility requirements and offer excellent potential for future implementation both domestically and abroad.

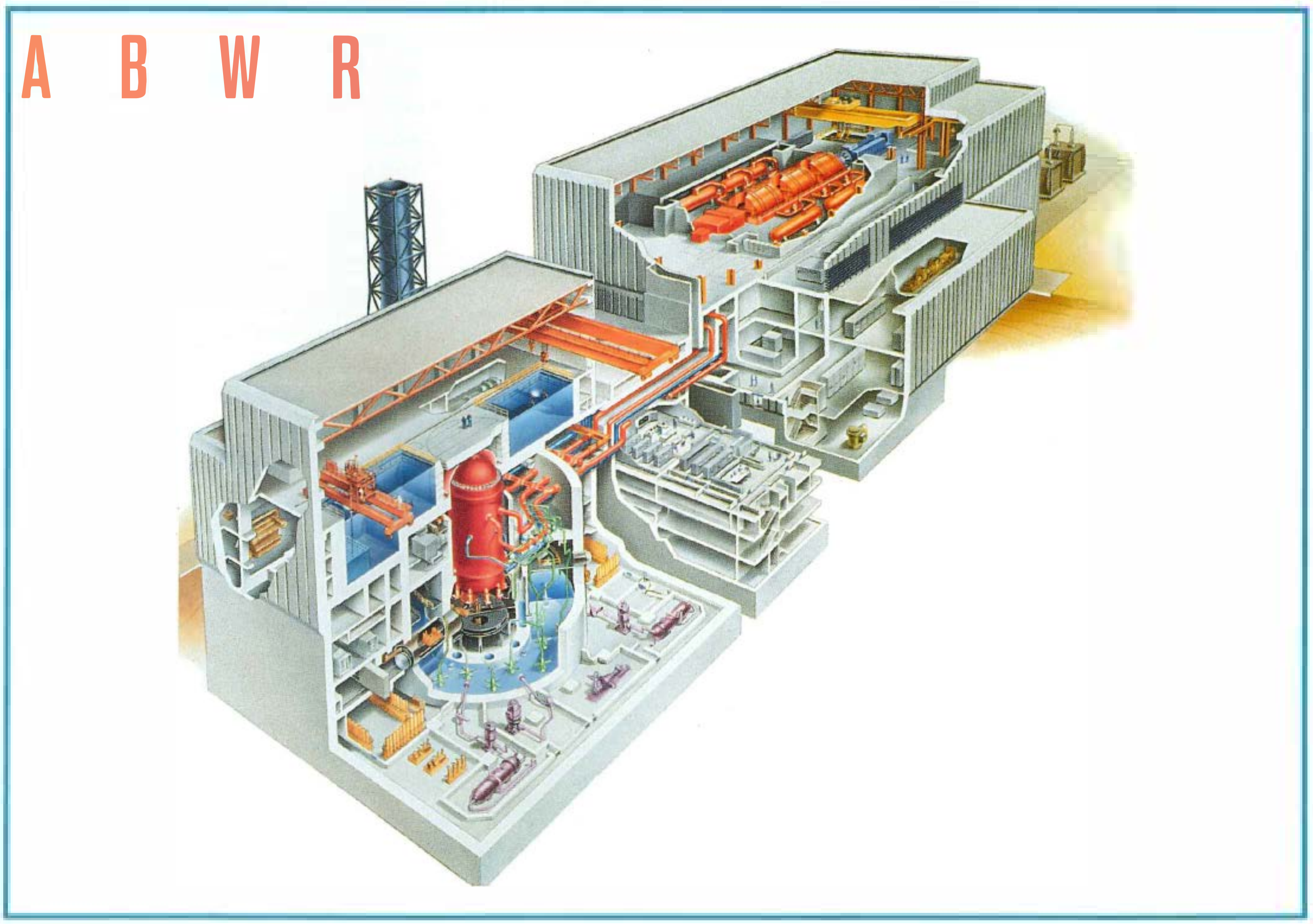
Safety, simplification, and standardization

"From the outset," Santucci explains, "key fundamental policies reflecting utility preferences formed the foundation of the URD. New reactors should have enhanced safety, simplification to the maximum extent possible, and comprehensive standardization. Together, these requirements will enable utilities to continue to rely on proven light water reactor technology while lowering costs, protecting their investment, and improving public acceptance of future nuclear power plants."

The ALWR safety design goal is realized through an integrated approach that features three overlapping levels of protection. The first level, accident resistance, requires minimizing the frequency and severity of events that could lead to an accident. This is achieved through increased design margins, greater system simplicity, and improved controllability. The second level of defense involves the development of systems that would prevent an initiating event from damaging the core. The third level, accident mitigation, involves the addition of systems that, in the event of core damage, would contain any fission products that might be released from the core and prevent them from leaving the plant.

On the basis of this integrated approach to protection, ALWR safety goals have been established to limit core damage frequency

GENERAL ELECTRIC'S ABWR
The first ALWR to be deployed commercially, this evolutionary 1350-MW boiling water reactor features simplified active safety systems, a completely internal recirculation system, and improved controls. The ABWR received final design approval from the NRC last summer.



JAPAN GOES FIRST The world's first advanced light water reactors—based on General Electric's ABWR design—are now under construction at Tokyo Electric Power Company's Kashiwazaki-Kariwa site. The first of two 1356-MW units is expected to begin operation in 1996, less than five years after groundbreaking. Already licensed for use in Japan, the ABWR is being constructed under a joint venture agreement between GE, Hitachi, and Toshiba.

to less than one event in 10^5 years and to limit the chance that someone outside the plant boundary would receive a 25-rem whole-body dose of radiation (not a fatal dose) to less than one occurrence in 10^6 years. As part of the design certification process, the validity of these goals is being demonstrated by probabilistic risk assessment for each type of ALWR plant. Accomplishment of these goals means that the chance of harm to the public would be less than 1% of that from other major industrial activities.

Since unnecessary complexity has been blamed for a wide range of expensive problems in existing nuclear plants, the ALWR program emphasizes simplicity in all aspects of plant design, construction, and operation. Specifically, the URD calls for minimizing the number of valves, pumps, and instruments; providing a control room that better reflects operator needs; and designing the arrangement of equipment in a way that facilitates maintenance. With systems in place to achieve these goals, a station blackout of at least 8 hours could be tolerated without causing cooling problems for the core in an evolutionary plant, and an indefinite blackout could be tolerated in a midsize plant with passive safety systems.

Control and instrumentation systems for ALWRs feature state-of-the-art digital technology, including a large graphic display that depicts overall plant operation at a glance. Because of the use of these advanced systems, the size of the control room is smaller and the layout more streamlined than in conventional nuclear plants. The use of fiber optics to carry control and instrumentation signals throughout the plant significantly reduces the need for expensive copper cabling, lowering materials costs and reducing construction time. The design of fault-tolerant digital control systems is based on experience gained with systems of this sort in the process and defense industries and will improve both the operability and the availability of ALWRs.

The construction of ALWRs will be substantially simpler and more streamlined than that of conventional reactors. In a modular approach, the basic reactor and balance-of-plant components would be fabricated in a factory, then shipped by rail or barge to the construction site for assembly. This technique, long used in the petrochemical and shipbuilding industries, makes it possible to perform many major tasks in parallel and promotes efficient tooling and materials handling. In addition, the use of a stable, well-trained factory workforce to manufacture the modules improves security, quality assurance, training, and productivity—reducing both construction time and overall capital cost.

In the midsize reactors, additional simplification is possible. The use of natural phenomena (such as the flow of water under the force of gravity, convection, or gas pressure) for emergency cooling provides great opportunities for simplification by eliminating the need for motor-driven pumps and valves.

The design work on the midsize ALWRs is further aimed at reducing maintenance and fuel costs. The great simplification in the basic designs means that there are far fewer components to maintain; in addition, the plants are being laid out for easier maintenance. Analyses project over 90% availability for the midsize plants, which would result in a capacity factor greater than 85%. The cores of these reactors also have a lower power density than conventional reactors and would thus require approximately 20% less uranium—leading to projected net fuel-cycle cost savings greater than 10%.

The driving motivation for greater reactor standardization is economy; indeed, the economic viability of the ALWR program strongly depends on its success in achieving standardization from the earliest stages of plant design through the rest of a plant's life cycle. This principle was reinforced by a position paper on standardization approved by the chief executive officers of all U.S. nuclear utilities and published in 1991. In addition to the requirements of the URD and the NRC design certification process, the position paper called for "commercial standardization" of the design and "life-cycle standardization" in operation and maintenance.

The effect of these efforts on plant costs promises to be dramatic. An average nuclear plant today has a staff of 400–600 people, more in many cases. It is conceivable that, through simplification and standardization, a midsize ALWR could require as small an on-site staff as 90–110 people. The standardization of design and operating features allows the sharing of many services among reactors in a "family" of plants. Services that could be centrally organized include engineering, licensing, training, quality assurance, procurement, and support of maintenance activities. Refueling crews, for example, could be shared among several plants, thus eliminating the need to retrain staff at every outage to handle this specialized job.

Pat McDonald, executive director of ARC and former chairman and CEO of the Southern Nuclear Operating Company, under-

Strategic Plan for the Next Generation of Reactors

The technical activities associated with planning, designing, and siting ALWRs represent only one subset of an industrywide program to prepare the way for the next generation of nuclear reactors. The goal of the overall program is spelled out in the *Strategic Plan for Building New Nuclear Power Plants*, published by the Nuclear Energy Institute (NEI) Executive Committee: to resolve the full spectrum of issues, technical and institutional, in an integrated and coordinated way. The *Strategic Plan* was first published in 1990 and has been updated annually. EPRI and the Advanced Reactor Corporation have the primary responsibility for guiding the technical work; other industry organizations are leading the effort to overcome outstanding regulatory and institutional hurdles.

In the industry plan, NEI has the primary responsibility for programs that help enhance public acceptance of nuclear power, establish a stable regulatory process, clarify questions of ownership and financing, and encourage government support for the ALWR. The Institute of Nuclear Power Operations (INPO) is responsible for life-cycle standardization for the ALWR—for example, by carrying out activities that help preserve standardization beyond the design stage. Reactor suppliers are responsible for the design-specific activities.

The performance of the current fleet of operating reactors is key to public and investor confidence in new designs. The latest update of the *Strategic Plan* reports that significant progress has already been made in several important areas. From 1989 to 1993, the total nuclear generation in the United States increased by about 15%. The operating capacity factors of existing nuclear plants increased on average from 66% to 75%, while electricity production costs dropped from 2.64¢/kWh to 2.15¢/kWh. Reflecting these excellent improvements in performance, two opinion polls conducted in 1993 show that a large majority of the public (69%) and an even larger majority of opinion makers (72%) say that nuclear energy should play an important role in meeting the nation's future energy needs.

The *Strategic Plan* identifies as another prerequisite to new nuclear plant construction the resolution of issues related to the disposal of nuclear waste. Progress on this front has also been encouraging. Scientific studies related to the establishment of a permanent repository for high-level radioactive wastes were accelerated during 1993, and more than 30 electric utilities have signed an agreement with the Mescalero Apaches of New Mexico to develop a private storage facility for spent reactor fuel. □

OUTLINE OF STRATEGIC PLAN

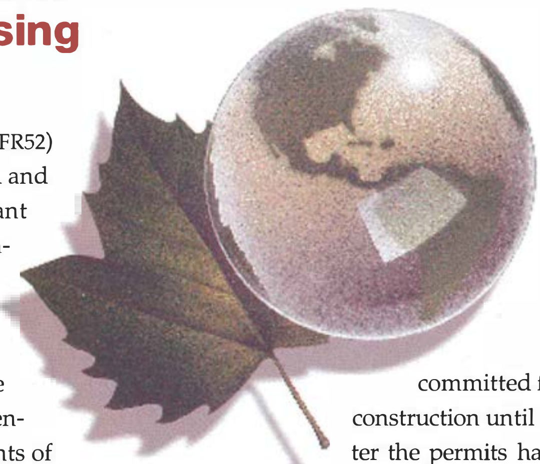
Prerequisites From Ongoing Programs
- Current plant performance
- High-level-waste management
- Low-level-waste management
- Fuel supply

Safety, Regulatory, and Industry Standards
- Predictable licensing and stable regulation
- ALWR utility requirements

Institutional Issues
- Enhanced public acceptance
- Ownership and financing issues
- State economic regulatory issues
- Enhanced governmental support

Project-Specific Activities
- NRC design certification
- Siting
- Commercial standardization
- Life-cycle standardization

A New Nuclear Plant Licensing Process



Recent new laws (10CFR52) have greatly simplified and streamlined the nuclear plant licensing process, thereby improving clarity and reducing risks to future plant owners, the public, and the government. Essentially, the process involves three sequential steps. First, those elements of the plant design that are significant to safety are reviewed by the NRC for approval, and after a public review process, certification is granted. Once adjudicated, these matters are considered closed. The circumstances under which previously adjudicated issues can be reopened are very limited. At this point, the certified design becomes available to the new plant owner as an off-the-shelf item, without the need for further NRC or public review.

After certification, a design may be used on any site that meets a certain envelope of physical site parameters. Under 10CFR52, a plant owner can obtain prelicensing of a specific site (an early site permit, or ESP) and maintain the site approval for many years. This greatly simplifies the process of planning electricity generation capacity and substantially reduces the financial risk, since the permitting and construction processes are decoupled (that is, no money is committed for construction until after the permits have been issued).

Further, the ESP envelope can apply for any of the four ALWR designs, so flexibility is maximized: the size and type of reactor can be selected "at the last minute" to best match planned generating capacity to load growth. The siting process is subject to public review and final adjudication in addition to NRC approval. As with design certification, siting matters are considered closed once they have been adjudicated.

In the last step in the process, when the utility is ready to build the plant, it applies for a combined construction and operating license, or COL. The COL references the selected preapproved certified design and the preapproved site. The licensing and financial risks beyond this stage are greatly reduced, and the applicant can proceed with a high degree of confidence on matters of schedule and costs. □

lines the importance of this element of standardization: "Maintaining the standardization designed and built into a family of plants for their full life cycle is the key to realizing the true rewards of standardization."

It is expected that many of the reductions in staffing requirements will be a direct result of implementing better tools for managing plant information. Advanced information management systems for the new plants offer the potential for a widespread simplification of all the activities normally associated with plant construction and operations. Accelerated and well-controlled construction schedules may depend on the availability of such tools. Plant operations will similarly benefit. For example, studies show that plant engineers now spend as much as a third of their time on information retrieval and documentation. The use of improved computerized information management systems, and the electronic capture of all plant design, construction, and operation data, could reduce this burden drastically.

Other efforts will address the thousands of required operating procedures that currently burden the typical nuclear facility, directing almost every staff action and response. This situation must be simplified to improve the attractiveness of the nuclear option to future plant owners. Santucci says that he expects this burden to be significantly reduced for ALWRs because of a combination of factors: simplifications in the design that lead directly to simplification in operations; simplification and streamlining in the licensing requirements; simplification and streamlining in the internal work and management processes for new plants; a capable information management system architecture; and standardization and sharing of resources among plants in a family.

First-of-a-kind engineering

The design certification process, focusing primarily on safety issues, covers only a fraction of the engineering details needed to build an ALWR. The first-of-a-kind engineering (FOAKE) work brings the level of design detail up to about 65% completion —enough to define firm cost estimates, support commercial standardization, and pave the way for plant construction in the American utility market. Since only about 15–20% of the total design scope that defines a plant has to be customized for site-specific needs, eventually about 80–85% of the engineering design of a plant will be part of a standardized, off-the-shelf plant package.

The FOAKE program for ALWRs has been under way since 1992. A consortium of utilities, working through EPRI in a tailored collaboration arrangement, established ARC as a vehicle to merge, under utility management, government and utility funds to support FOAKE on selected designs. Funding of the FOAKE effort is provided through matching contributions from DOE and private industry. ARC has already completed two phases of work on the FOAKE program—the definition of engineering scope and design evaluation criteria, and the selection of two ALWR alternatives for full FOAKE design. Phase 3 design work began in 1993 on the two plants selected: the ABWR and the AP600. For the ABWR, FOAKE is expected to be completed in 1996; for the AP600, in 1997. Over $275 million has been committed for this work.

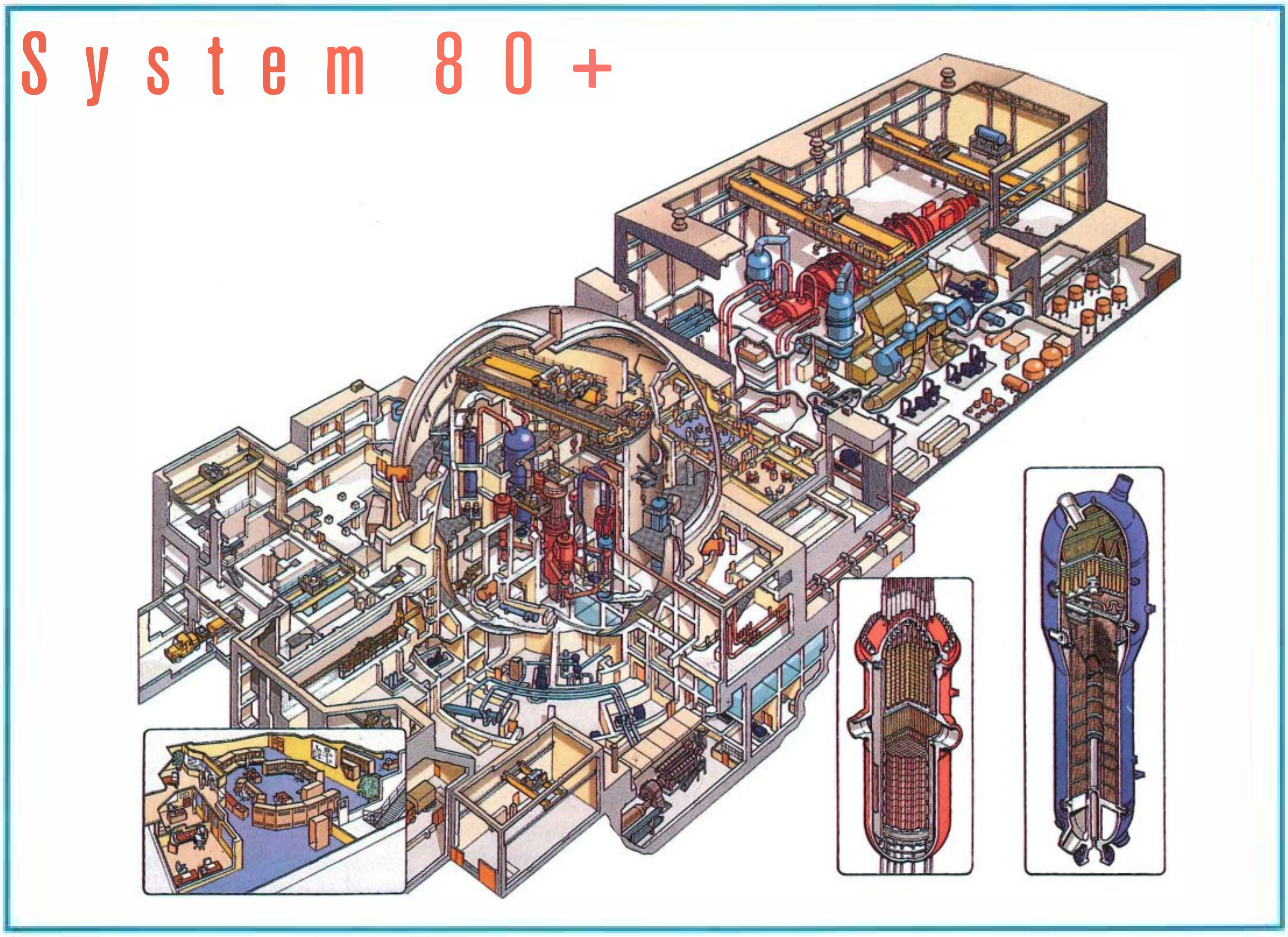
General Electric's ABWR is characterized by several advanced design features. In the FOAKE design, control blades are operated with electric motors capable of fine-motion control during startup and power maneuvering. The use of such motors will reduce the maintenance requirements and occupational exposure associated with equivalent controls in current plants. The flow of coolant through the core is accomplished by 10 internal pumps, thus eliminating external recirculation piping and all large-vessel nozzles below the core. This arrangement results in a 50% reduction in the number of welds for the primary system pressure boundary and also reduces the need for in-service inspections. In addition, no equipment inside the primary containment structure requires routine surveillance and maintenance during plant operation.

Several passive safety features have also been incorporated into the evolutionary ABWR design. In the unlikely event of an extreme accident, high temperatures in the drywell directly below the reactor vessel would automatically initiate flooding from the large suppression pool that surrounds the vessel. Such flooding would prevent the generation of noncondensable gases from a reaction of core debris with concrete at the bottom of the drywell. Water in the suppression pool would also serve to trap most fission products so that they could not be released to the environment, even if the containment structure should become overpressurized.

Modularity and passive safety

FOAKE work on the Westinghouse AP600 concentrates on taking the philosophy of

ABB COMBUSTION ENGINEERING'S SYSTEM 80+ An evolutionary unit, the 1350-MW System 80+ is a pressurized water reactor offering greater design margins, more redundancy and diversity, higher safety levels, and better operability and maintainability than conventional reactors. It received final design approval in 1994.



standardization and simplification one step further—toward modular construction and a primarily passive safety system. Compared with conventional reactors, the AP600 in its final design is expected to have 50% fewer valves, 80% less safety-grade piping, 35% fewer pumps, and 70% less control cable. Construction time could be reduced to three years or less, from groundbreaking to fuel loading.

The proposed schedule for modular construction of the AP600 would begin with the pouring of the first concrete, followed by the installation of the reactor coolant compartment as a single module in the fourth month. The reactor vessel and steam generators would be installed in the eighteenth month. The assembly of the containment vessel would be completed around the two-year mark, and the balance of plant would be completed by the end of the third year.

Passive safety features dominate both the emergency core cooling system and the containment cooling system of the AP600. To handle small leaks that may occur during normal operation, water from the core makeup tank would flow into the reactor by the force of gravity. In the event of a loss-of-coolant accident (LOCA), additional water could be injected by gas pressure from the accumulator tank. The contents of an even larger refueling water storage tank would also be available, if needed, to cope with a LOCA. Air-operated valves are designed to send makeup water to the core automatically if they lose either pressure or their control signal. This design eliminates the need for a separate emergency feedwater system, and no operator action would be needed to ensure a safe response to either a small leak or a major LOCA.

The passive containment cooling system of the AP600 uses convective airflow and evaporative cooling in much the same way a conventional cooling tower does. The steel containment vessel is separated from the surrounding concrete shield building by an airflow baffle. Natural convective forces cause air to flow upward between the baffle and the surface of the containment vessel—an effect that would be enhanced if the temperature of the vessel suddenly increased. If additional cooling was needed, water stored in 350,000-gallon tanks at the top of the shield building could be released to flow over the surface of the containment vessel, pulled by gravity. Again, no operator action would be required, since any increase in temperature or pressure in the containment vessel would automatically trigger the passive containment cooling system.

Other advanced plants

In addition to the two designs selected for the present FOAKE work, two other plants are also being developed aggressively. ABB Combustion Engineering has designed an evolutionary plant based on its three operating nuclear units at the Palo Verde plant in Arizona and four plants under construction in Korea. Called the System 80+, the new design is a 1350-MWe pressurized water reactor that embodies design features for enhanced safety, increased operating margins, improved operability and maintainability, and simplification for reduced costs. The System 80+ received final design approval from the NRC in the summer of 1994.

One of the key features of the plant design is an improved, state-of-the-art advanced control room design. Human factors engineering considerations have been treated explicitly in this design, as have considerations for simplified operations and maintenance aspects. The first unit of the advanced System 80+ design is expected to be built in Taiwan.

In addition to supporting the development of the AP600, EPRI and DOE are also supporting the development of General Electric's SBWR, which employs natural circulation for power generation. This design offers levels of simplicity unprecedented in a commercial nuclear power plant of this size. Natural forces are the primary means of providing emergency cooling in the unlikely event of an accident. Emergency core cooling capability is provided through a suppression pool elevated above the reactor core and driven by gravity. The suppression pool also provides a heat sink to reduce containment building temperatures and pressures in the event of a severe accident.

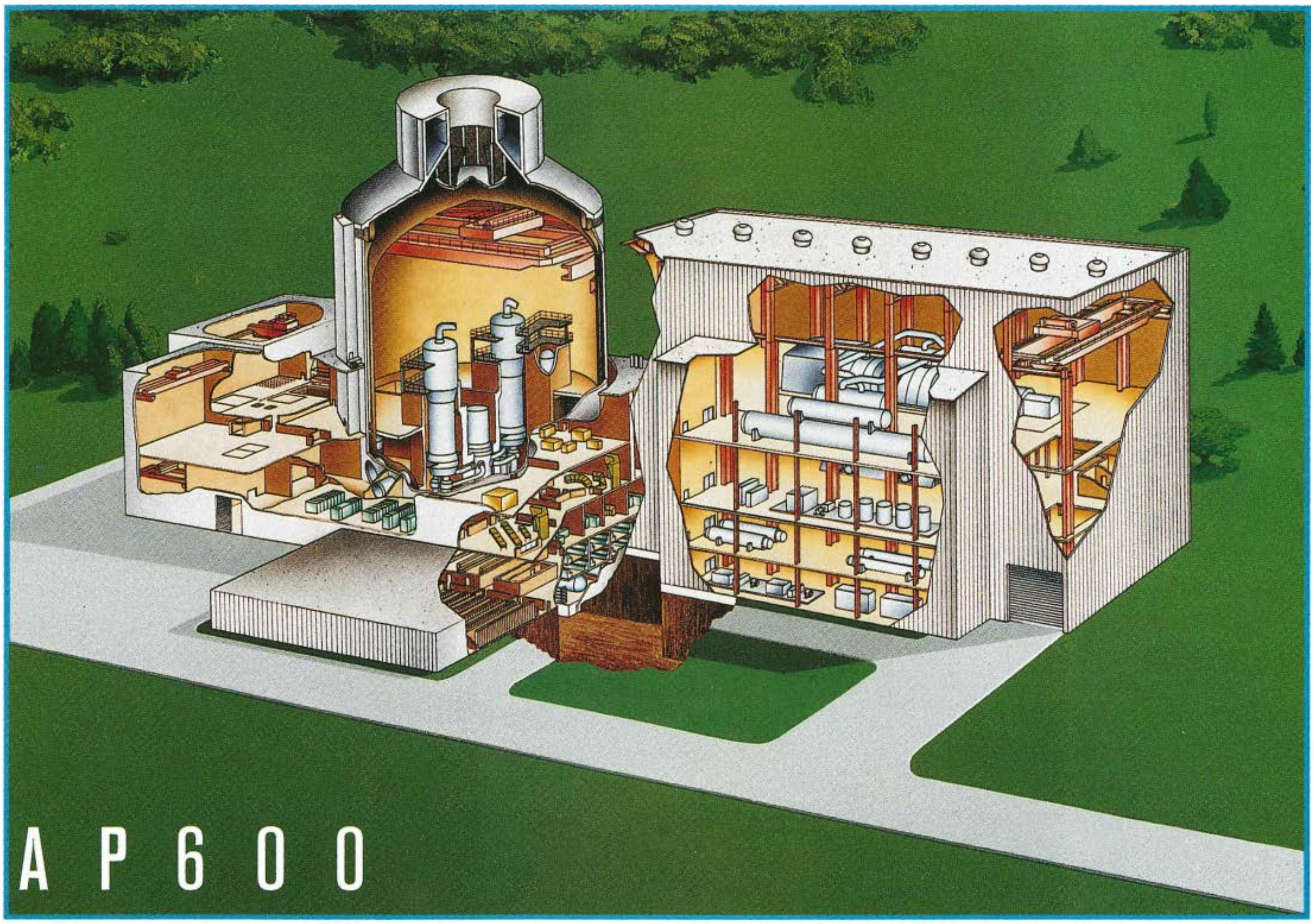
The SBWR design certification project is currently focusing on completing one of the most comprehensive testing and analysis programs ever undertaken for a commercial power plant. The testing activities are expected to be completed by mid-1995, and in early 1996 the NRC will commence review of the SBWR safety analysis report and related documentation, leading to issuance of final design approval and design certification.

Early siting permits

Beyond the FOAKE process, two further regulatory hurdles remain before an ALWR plant can be built and operated: first a siting permit must be obtained, and then the NRC must issue a combined construction and operating license. Just as new federal regulations enable the NRC to precertify ALWR reactor designs, early site permits (ESPs) can be issued to preapprove specific sites. Such permits allow the construction of a nuclear plant with a certified design on a particular property any time within 20 years. In other words, all siting issues, including environmental impact issues, can be resolved well before construction is scheduled to begin.

In order to provide utilities with the guidelines and analytical tools they need to obtain an ESP, a joint program cosponsored by EPRI, DOE, and other industry organizations was undertaken to help resolve siting issues and pave the way for a successful demonstration at an actual site. The first step was to review the extensive body of current regulations, regulatory guidelines, and acceptance criteria; most of these were found still to be applicable. Next, technical definitions were developed for all the parameters where an interface exists between the plant and the site. Conservative limiting values were then defined, such that any site that can accommodate these parameters can accept any of the four ALWR plant designs. Another aspect of this work was the development of an analytical process methodology for choosing a specific site from among comparable alternative sites that may be available to a utility.

Phase 2 of the ESP program, also completed, focused on the development or compilation of methodologies that an applicant will need in order to characterize



WESTINGHOUSE'S AP600 At 600 MW of capacity, the AP600 is a midsize pressurized water reactor expected to receive final design approval in 1996. The unit's simplified design and passive safety features allow the use of 50% fewer valves, 35% fewer pumps, 80% less safety-grade piping, and 70% less control cable than in today's PWRs.

and qualify a site (for example, to determine its hydrological and meteorological characteristics). One of the important techniques developed as part of this "toolkit" is a state-of-the-art, best-estimate approach for the seismic characterization of a specific site. The approach synthesizes more than a decade of extensive research on ground motion during earthquakes. Phase 2 of the ESP program also studied issues of public involvement and developed recommendations for future applicants.

The results to date indicate that the demonstration phase (Phase 3) will be very straightforward. The demonstration will apply the results of the previous phases to an actual site and support the preparation and submittal for NRC review of an actual application. Because the technical and licensing uncertainties associated with carrying out this phase of the project now appear to be low, this work has been scheduled to occur later in the overall development program.

International participation

From the beginning of the ALWR program, international participation and the international market have been critical factors. Unlike U.S. utilities, which have faced an unprecedented period of slow growth and generally have not placed orders for large new baseload plants in several years, utilities in other countries face supply shortages and are ordering new power plants at a rapid pace. In these markets, nuclear is—and is expected to continue to be—an important player. Uncertainties about energy supply sources and about the environmental costs of fossil fuel plants are also pushing the nuclear option to the forefront of consideration in rapidly developing nations. This trend is especially pronounced in the less-developed areas of Asia, where demand for electricity is soaring in response to a sustained high level of economic growth.

Nine international utilities are currently sponsoring participants in the ALWR program: Electricité de France, Ente Nazionale Energia Elettrica (Italy), GKN (the Netherlands), Japan Atomic Power Company, Korea Electric Power Company, Nuclear Electric (the United Kingdom), Tractebel (Belgium), Unidad Electrica SA (Spain), and

VDEW (Germany). Discussions with other utilities are ongoing. Recently, Electricité de France, already a program participant, agreed to expand its support to cover the ABWR FOAKE effort.

The level of international interest in the U.S. program is increasing. For example, China's National Nuclear Corporation recently signed a letter of intent with Westinghouse that, subject to government approvals, could lead to the construction of two AP600 plants. The System 80+ design is currently under evaluation by Taiwan for its next nuclear plant, and Korea Electric Power is also considering designs based on the System 80+ for its next generation of plants.

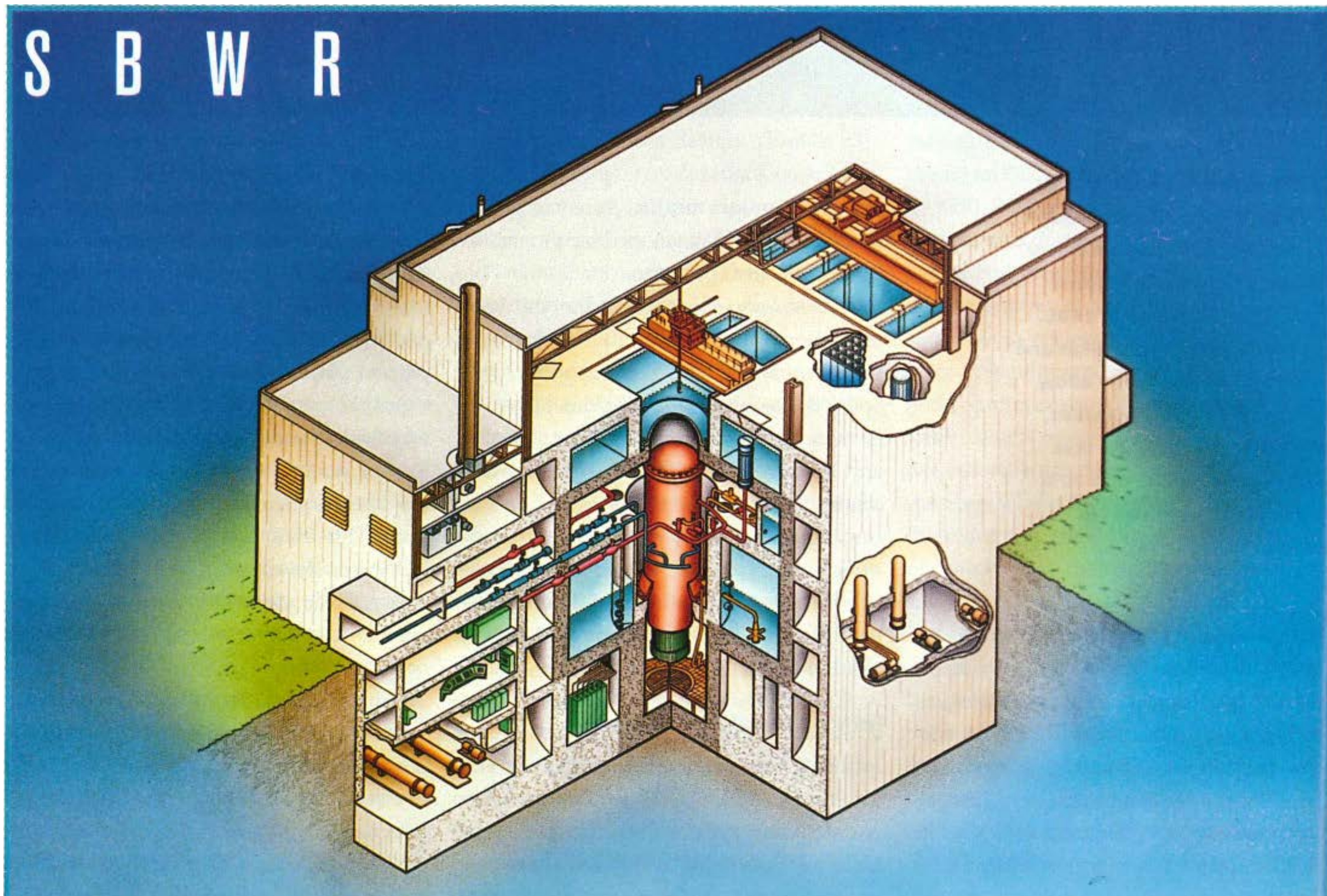
The first actual construction of an advanced light water reactor is currently under way in Japan, where two General Electric ABWR units are being built at Tokyo Electric Power Company's (TEPCO's) Kashiwazaki-Kariwa site, northwest of Tokyo. The design is being constructed under a joint venture agreement between GE, Hitachi, and Toshiba Corporation. The first 1356-MWe unit is expected to begin operation in 1996, only 58 months after groundbreaking. The second unit is scheduled for completion in 1997. Japanese utilities envision building over a dozen more plants of this type in the next few years. This effort represents a significant contribution to Japan's goal of generating 40% of its electricity from nuclear energy by 2010.

Five other Japanese utilities joined with TEPCO in sponsoring confirmation tests on key ABWR components, such as fine-motion control rod drives and internal pumps. These tests were conducted as part of a program by the Ministry of International Trade and Industry to improve and standardize light water reactor technology for use in Japan—a program that parallels and complements the ALWR program in the United States.

The future of the ALWR program

The ALWR design development efforts are well on their way. "The international character of the ALWR development program is helping to maintain America's nuclear industry through a difficult period," says EPRI's Santucci. "Domestic load growth is such that orders for new nuclear power plants in this country will not be justified

GENERAL ELECTRIC'S SBWR
A midsize boiling water reactor, the 600-MW SBWR employs natural water circulation for power generation and a wide array of passive safety features, including gravity-driven emergency core cooling from an elevated suppression pool. NRC design approval is expected in 1997.



Implementing ALWR Results in Today's Plants

In addition to creating the next generation of light water reactors, the ALWR program has developed technologies that could directly benefit currently operating nuclear plants. In January 1994, EPRI prepared a report identifying such technologies, which include improved analytical methods, retrofittable hardware, engineering guidelines, and licensing improvements. Some of these represent significant improvements on current practice; others are breakthrough innovations.

Some 25 items from the report are now being reviewed with member utilities for potential implementation at existing plants. Specific technologies usable now or in the near future include more-realistic estimates of probable radiation release (source term) for use in planning accident response, passive catalytic recombiners to reduce combustible gases after an accident, automated fuel transfer equipment that can reduce the time needed to refuel boiling water reactors, and in-core instrumentation to provide greater operating flexibility in pressurized water reactors.

An early technology transfer success was achieved recently in a project with Florida Power Corporation. During 1994, FPC worked with EPRI to implement at its Crystal River plant a methodology, first developed for the ALWR program, that demonstrates that certain high-energy "missile events" are not credible in PWRs. This methodology was developed by Westinghouse and reviewed by the NRC in the context of the AP600.

Most operating PWRs have a metal plate or concrete slab over the reactor or pressurizer cavity to protect the containment liner against the postulated ejection of high-energy missiles in the form of failed control rod drives, valve stems in high-pressure systems, or fractured bolts under tension. These missile shields must be removed and replaced during planned outages and can promote high temperatures within the cavities during operation. Manipulation of the shields during outages increases labor costs and personnel exposure to radiation and can affect outage schedules. Increased temperatures during operation can have a negative impact on performance and shorten the design life or qualified life of such equipment as motor-operated valves.

The AP600 missile evaluation methodology was applied at Crystal River during the spring refueling outage. When it showed that the cavity cover was not needed, operators were able to restart the plant without replacing the cover. From this single ALWR product, FPC estimates savings of more than $1 million over the remaining life of the plant. This experience is directly applicable to other utilities, which may realize equivalent savings by eliminating similar PWR missile shields.

Because of the significant potential to help reduce the operating costs of current plants, efforts to identify opportunities for implementing other ALWR spin-offs are being increased. □

before the turn of the century. Nevertheless, the ongoing development work is helping to bring U.S. industry to a state of readiness for deploying new nuclear plants in the United States. A few years from now, when the ALWR program is completed, ALWR designs will be competing in an aggressive power supply market.

"At the same time, utilities are facing unprecedented uncertainties: the full impact of the 1990 Clean Air Act Amendments, the impact of burning fossil fuels on climate change, the supply and price of natural gas, and so on. The ALWR offers many intrinsic advantages that directly address these uncertainties. The continued availability of the nuclear option can play a critical role in defining the optimal electricity supply mix for the future, and the ALWR is the industry's link to this future."

John Taylor, EPRI's vice president for nuclear power, agrees: "Through the ALWR program initiated by EPRI, the electric power industry is positioning itself technically to be able to build nuclear plants when the need for new baseload generation becomes apparent. That change could come suddenly, so we need to be able to react swiftly. By sticking with proven light water reactor technology, we've been able to avoid the need for going through an expensive, time-consuming prototype demonstration, while designing a new generation of reactors that are at least an order of magnitude safer than current plants. They will also be significantly simpler and more economical, and many of the technologies developed for them can be retrofitted for use in present reactors.

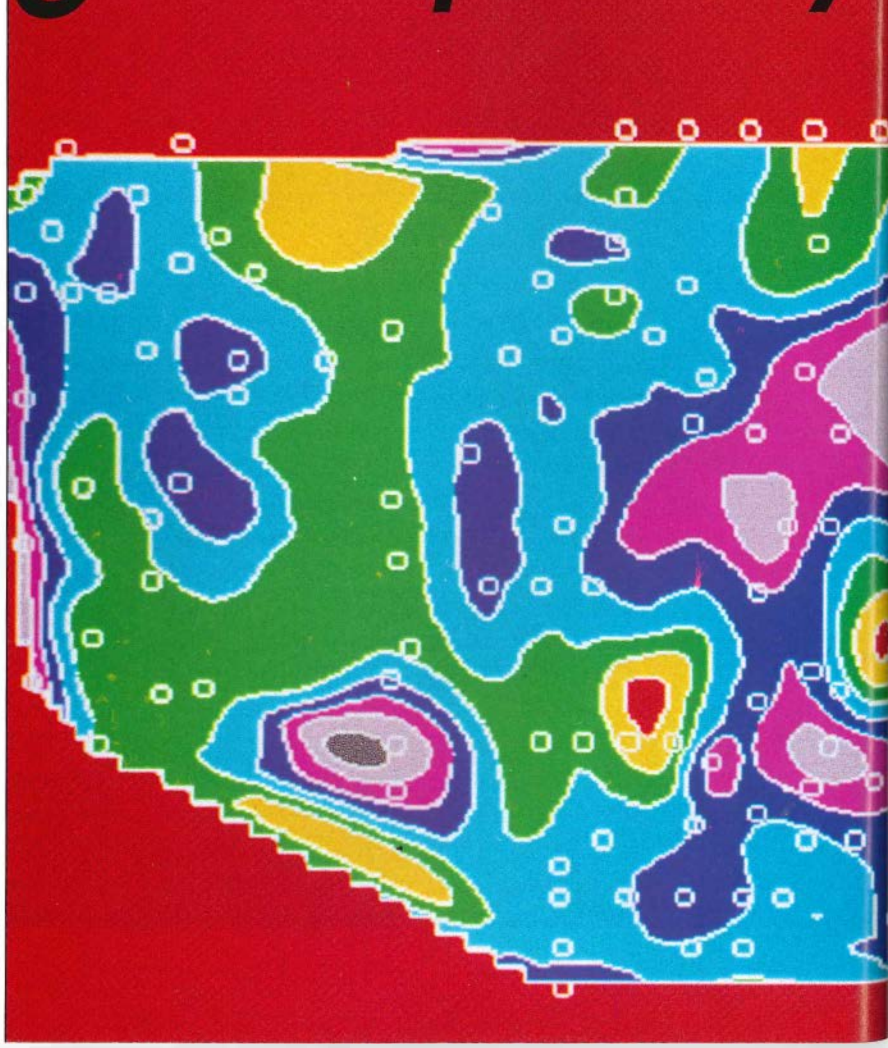
"The greatest remaining uncertainties are institutional, not technical. Already, ALWR designs are being accepted and built in other countries—a fact that could help reduce costs to American utilities when they order new plants. But this promise will be fulfilled only if industry and government keep working to overcome the remaining institutional hurdles and to convince a skeptical public of the environmental and economic advantages of nuclear power for a new era." ■

Background information for this article was provided by John Taylor and Joseph Santucci, Nuclear Power Group.

THE STORY IN BRIEF *The complexity of modern power systems has necessitated an increasing degree of computer assistance to ensure efficient and dependable operation. But while the machines are able to process and deliver more data more quickly than ever, the sheer bulk of numerical detail can be overwhelming for an operator trying to make the best decisions in a timely manner. Visualization techniques that help people see patterns and deviations can enable operators to grasp the big picture more intuitively and get to the nub of a problem quickly.*

by John Douglas

Visualizing Complex Sy



As the capability of computers to perform complex calculations and handle massive quantities of data continues to accelerate exponentially, the question of how humans can keep up with the flow of results becomes more pressing. The challenge is particularly acute in those applications—such as many electric utility operations—where critical decisions must be made quickly by correctly interpreting a flood of numerical information. At the root of this problem is a basic mismatch between the way computers "think" and the way humans do: computers zip blindly through details en masse; we look for the big picture embedded in the details. The emerging field of scientific visualization tries to bridge this communication gap by creating visual displays that help humans comprehend in more natural, intuitive ways the data pouring from computers.

"We're great at pattern recognition," says Martin Wildberger, who oversees scientific visualization research in EPRI's Strategic Development Group. "If you want a human to understand something, give him a break: Arrange the data so that he can recognize a pattern. Show relationships between variables. Omit things that aren't needed. Above all, don't overload him. At Three Mile Island, some 900 alarms went off during the first 90 seconds; there are much better ways to communicate complex information, and we're trying to make some of these available to utilities."

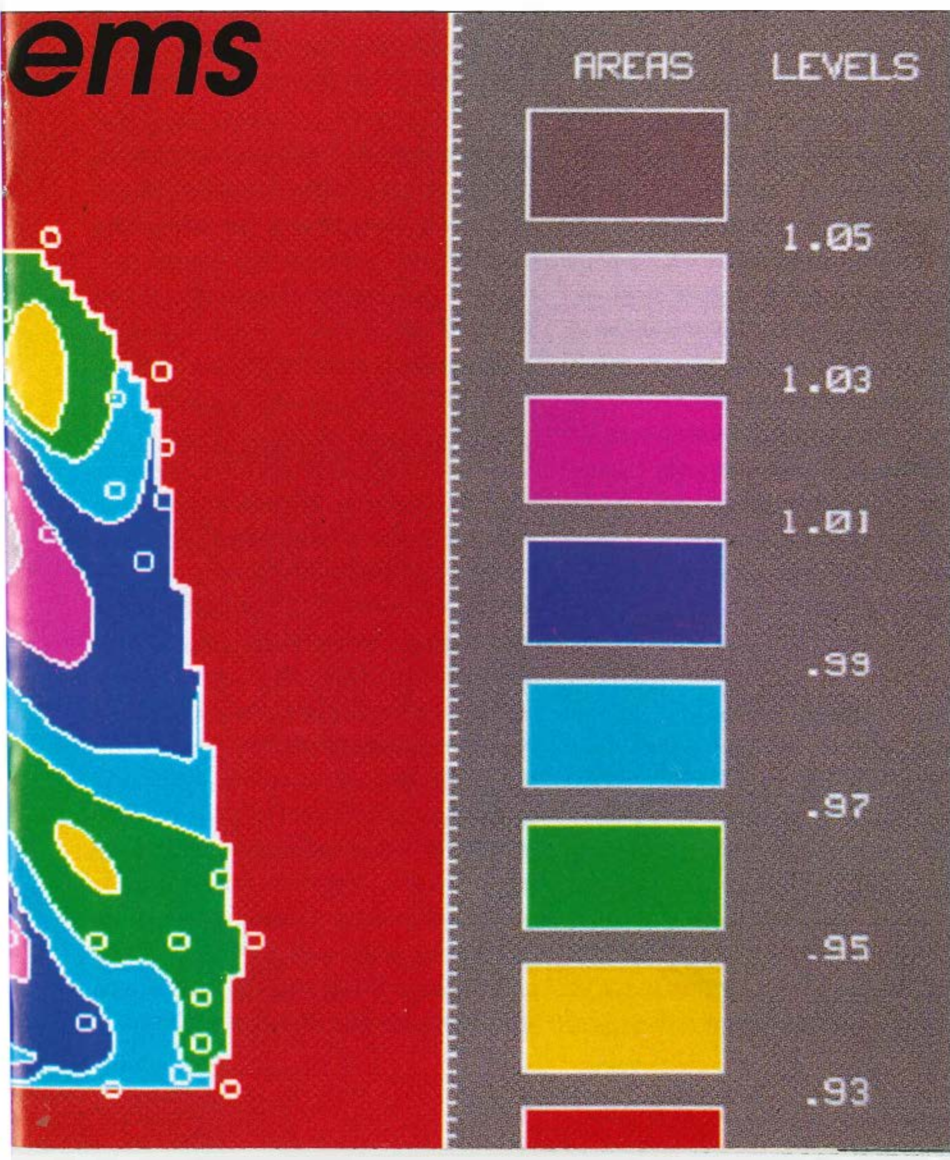
Icons and star plots

Intuitive understanding, Wildberger explains, is based on the creation of metaphors. Power system operators, for example, speak of their networks metaphorically as being "near the edge" or as "starting to sag up north." The presentation of messages in terms of such easily grasped metaphors is already helping to communicate abstract concepts in many applications. Icons, for instance, have been used successfully to make once-arcane computer instructions accessible to nonspecialists. Dragging a file folder icon across the screen of a Macintosh computer to a little wastebasket relates directly to the human metaphor of throwing something away and thus appeals to the intuition more than does the equivalent command, "Delete file."

It is a much more difficult challenge to visualize the interaction of multiple variables, such as the parameters that indicate the functional state of a complex physical system. Computers can easily deal with numerous independent variables by assigning each one its own dimension in an abstract "state space," where well-understood mathematical rules can be applied in the same way they are used to calculate interactions in ordinary, three-dimensional space. For most people, however, trying to visualize the goings-on in such an imaginary hyperspace is like trying to follow the plot line of a particularly convoluted *Star Trek* episode.

For applications with a relatively small number of independent variables, some success in visualizing multiple dimensions has been achieved through the use of so-called Kiviat diagrams, or star plots. In these diagrams, the axis for each variable radiates from a central point, and plotted values along the axes are connected by lines to form an enclosed figure. In one application, attempts have been made to visualize the operating state of a nuclear reactor with a star plot of the six most important parameters (core temperature, power level, coolant flow, and so on). Normal operation is indicated by a symmetrical hexagon formed by lines connecting the current parameter values. Reactor problems cause distortion of the figure in characteristic ways that can be easily recognized by an operator.

For systems with numerous critical parameters, however, Kiviat diagrams take



such complicated shapes that characteristic patterns indicating specific problems are hard to distinguish. Furthermore, like all visualization methods that reduce complexity by "projecting" multidimensional data onto a two-dimensional plane, they lose information that humans would often find useful.

Higher dimensions

One new method of visualizing multiple dimensions in a way that provides important opportunities for human pattern recognition—while retaining all the important mathematical information contained in the multidimensional space—has been developed by Alfred Inselberg and his colleagues at the IBM Scientific Center, Santa Monica, California. The method is based on the concept of parallel coordinates—vertical axes evenly spaced along a horizontal line, one axis for each variable. As values are plotted on each axis and connected by lines, a point in an n-dimensional state space becomes a broken line snaking along the n parallel axes. Other important n-space constructs, such as enclosed surfaces and intersecting trajectories, also have counterparts in parallel coordinates that can be recognized visually, although the correspondence may not be obvious at first.

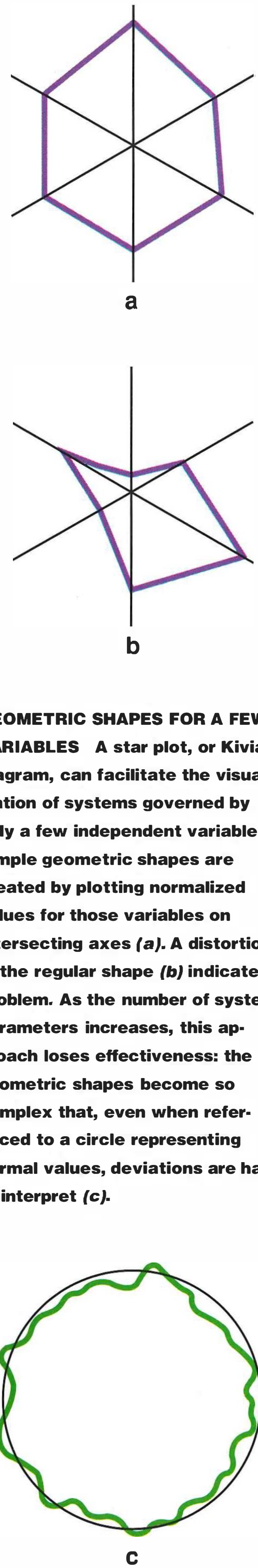
One easily grasped aspect of Inselberg's visualization scheme, which might be applied to the operation of complex utility systems, is the natural way it displays limits. If parallel axes are assigned to key system parameters—say, power flow at various buses of a transmission grid—each operational state of the system is represented by a line connecting the parameters' current values. Upper and lower limits can then be set for each parameter, and connecting these points forms an envelope for the line showing current operations. A shift in this line toward operating limits along certain axes can then be interpreted as indicating particular problems with the system. In the case of bus power flows, for example, readings that are too high on some axes and too low on others might indicate the presence of a faulted line.

Another way to visualize multidimensional data sets is to construct access "maps" that facilitate interaction between human and computer. Such maps are designed to guide user queries by reflecting the inherent logical structure of the data (which does not necessarily correspond to any physical structure). A system for constructing such data maps has been developed in EPRI-sponsored work by Richard Peskin and his colleagues at Rutgers University. Called SCENE (Scientific Computation Environment for Numerical Experimentation), this method allows scientists and engineers to create their own visualization tools for complex data sets without having to write complicated new computer programs.

So far, SCENE has been used primarily to support interactive numerical experiments involving fluid flow modeling in two or three dimensions—primarily as applied to the movement of gases and particulate matter released from a power plant. A user might, for example, use mouse clicks to view a contour plot of fluid density, to zoom in on the flow in a particular area, or to track a particular particle as it moves through the fluid. Since the SCENE system is designed to work with several different kinds of computers, including some that have extremely fast parallel processing capability, it can provide a convenient user interface for interpreting and directing computations in a variety of fields. Specific applications have included facilitating the visualization of results from the large computer models that are used to study global climate.

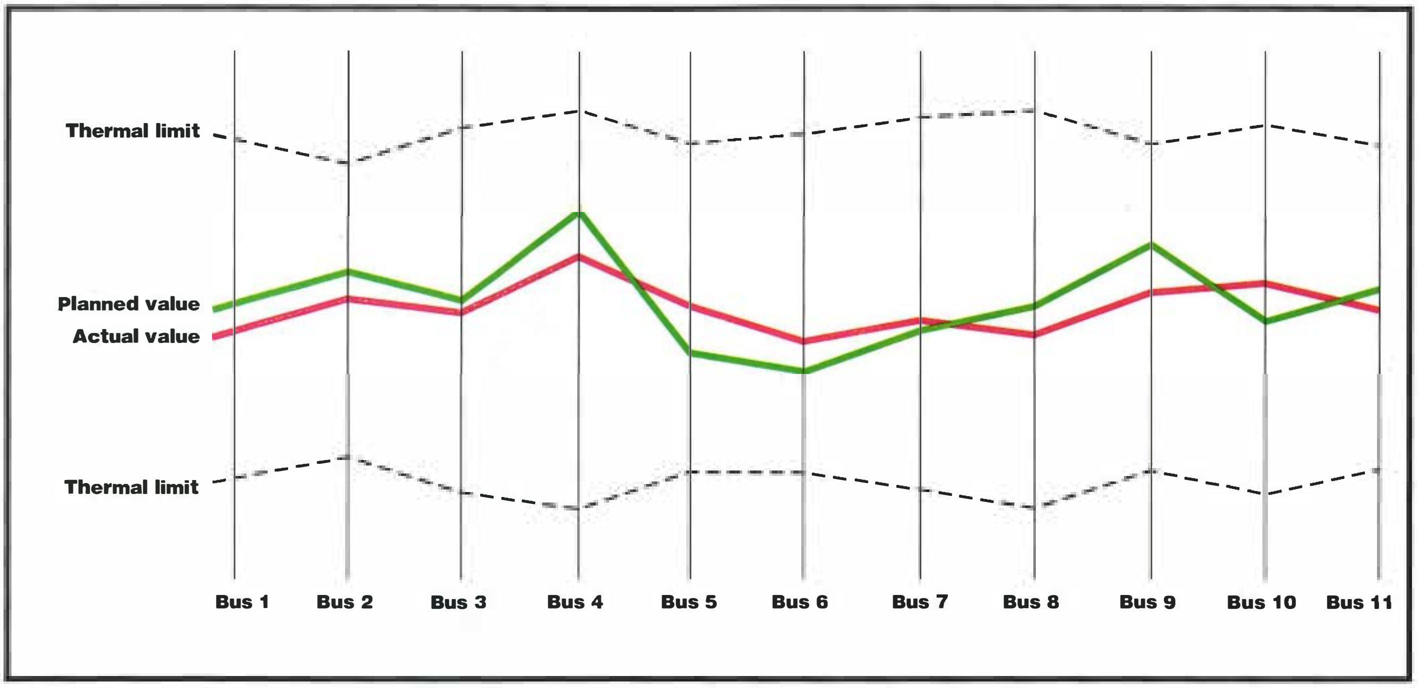
Toward utility applications

Most of the early attempts to apply advances from the field of scientific visualization to problems in the electric utility industry have focused on displaying power system data. The reason for this emphasis is that system operators now generally have access to full-graphics computer systems, but software that can take advantage of this power has not yet been fully developed. Most power system data are still presented in numerical form by the computerized energy management systems (EMSs) at utility control centers, thus limiting operator productivity. In response, EPRI has sponsored projects at the University of Washington and the University of Missouri, Rolla, to



GEOMETRIC SHAPES FOR A FEW VARIABLES **A star plot, or Kiviat diagram, can facilitate the visualization of systems governed by only a few independent variables. Simple geometric shapes are created by plotting normalized values for those variables on intersecting axes *(a)*. A distortion of the regular shape *(b)* indicates a problem. As the number of system parameters increases, this approach loses effectiveness: the geometric shapes become so complex that, even when referenced to a circle representing normal values, deviations are hard to interpret *(c)*.**

PARALLEL AXES FOR MANY VARIABLES **To visualize complex systems with many independent variables—such as a transmission network—values for the system parameters are plotted on parallel axes and then connected to form a zigzag line. In this example, each axis represents a bus on the transmission network, and the plotted lines connect values of power flow (MVA). Abnormal conditions are signaled when actual values extend beyond the thermal limit envelope indicated by lines at the top and bottom of the graph.**



develop advanced visualization methods that can shorten the time needed for power system operators to perform such functions as system restoration. The National Science Foundation (NSF) cofunded the University of Missouri research.

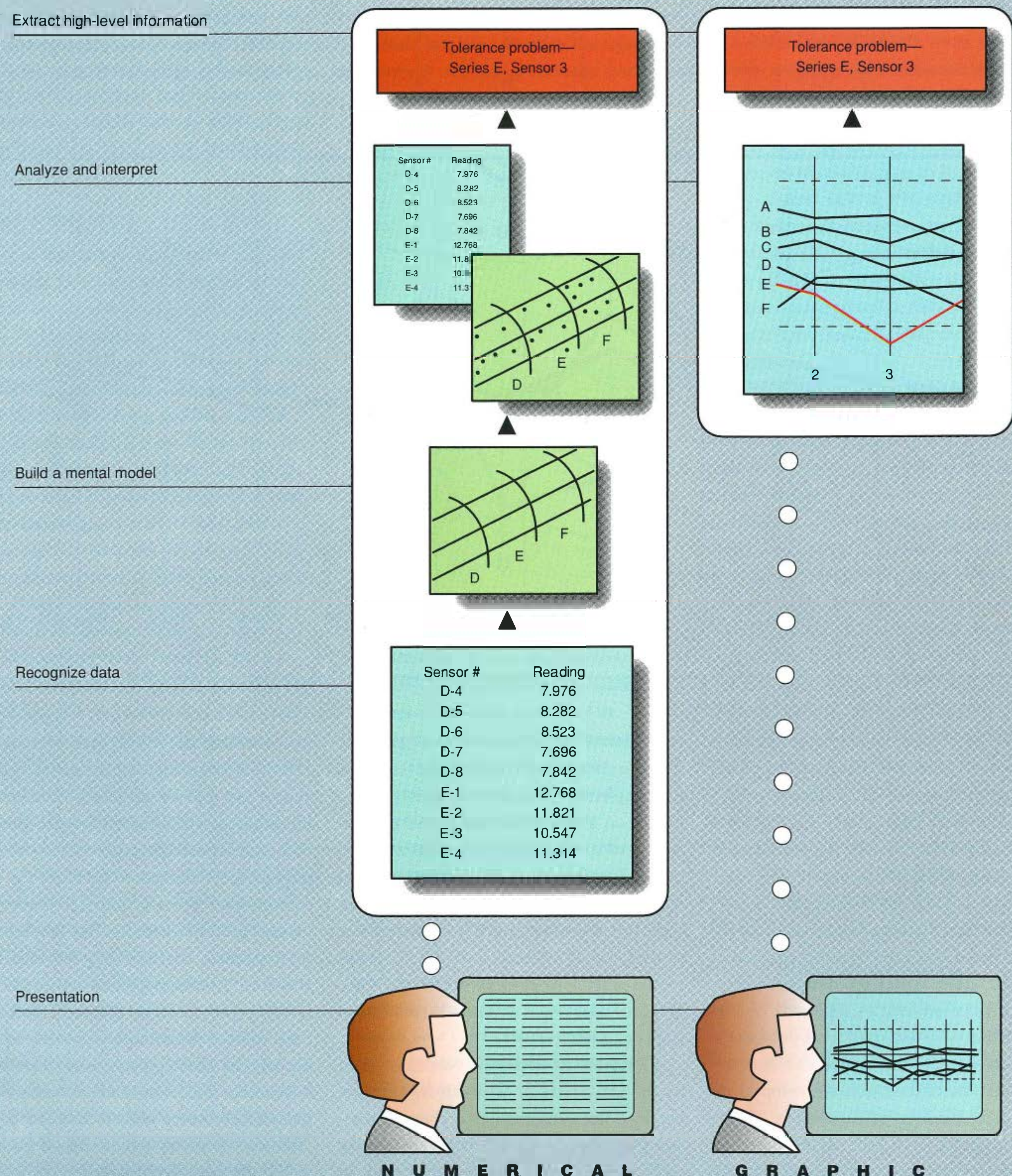
The University of Washington research, led by Richard Christie, addressed the problem of visualizing power system operations in broad terms, closely examining both current practice and future options. The researchers found that data from power systems are particularly difficult to comprehend because of their volume, complex interactions, and level of abstraction. "These three attributes work together to make communication of results the weakest link in the existing power system analysis process," the researchers concluded. "The problem in power system applications is no longer computation time—it is comprehension time."

The Washington team then developed a visualization system using a map with power flows encoded as line widths. Overloaded lines are displayed in a contrasting color. Small boxes with a two-color bar inside indicate bus voltages. This concept was implemented as an experimental prototype on a Sun workstation and used to represent an actual power system with 543 buses. The basic method was also modified to represent the static security of a system, with line and bus displays showing how severely certain events (such as a line fault) would affect the system and which elements of the system are most vulnerable to such contingencies.

A map-based approach was also taken by the University of Missouri researchers, led by Max Anderson, but they emphasized the use of a zoom function to display various levels of power system detail. In their method, different transmission voltage levels are distinguished by contrasting colors, and overloads are indicated by a change to a lighter shade. The zoom function not only makes it possible to select larger or smaller areas for display but also features "decluttering"—varying the amount of detail shown according to the scale. The system was implemented for a section of the Union Electric Company power system.

In this implementation, zoom level 0 shows only 345-kV generators and substations and no transmission lines. Zoom levels 1 and 2 focus on progressively smaller geographic areas but show all of the substations and lines. Finally, zoom level 3 focuses on a particular substation and superimposes a one-line diagram of its bus structure. A voltage profile across the system is represented by colored shading of certain areas. This method readily identifies regions where voltage is too high or too low, and in the event of an outage, distinctive shades can be used to indicate power "islands"—regions that are cut off from the rest of the grid. Eventually, the use of such displays could cut the time required for system restoration.

"This work is already having an impact on the EMS vendor community," says Rambabu Adapa of EPRI's Power Delivery Group, who managed the university research projects in Washington and Missouri. "We don't want to compete in the EMS market. Rather, we're interested in



BRIDGING THE COMMUNICATION GAP **As computers become capable of dealing rapidly with ever more complex problems, human operators face increasing difficulty trying to comprehend the calculated results. The old way to communicate results was essentially numerical, which required the human to build a mental model, analyze the data in light of the model, and extract critical information. Scientific visualization attempts to create graphic displays that emulate such models and, by highlighting critical information, enable humans to comprehend computer output in more intuitive ways.**

providing vendors with information to help them develop better commercial systems that can benefit utility operators. In this spirit we are also exploring the possibility of using tailored collaboration to demonstrate one of these advanced visualization systems at full scale on the power network of a member utility."

Other methods

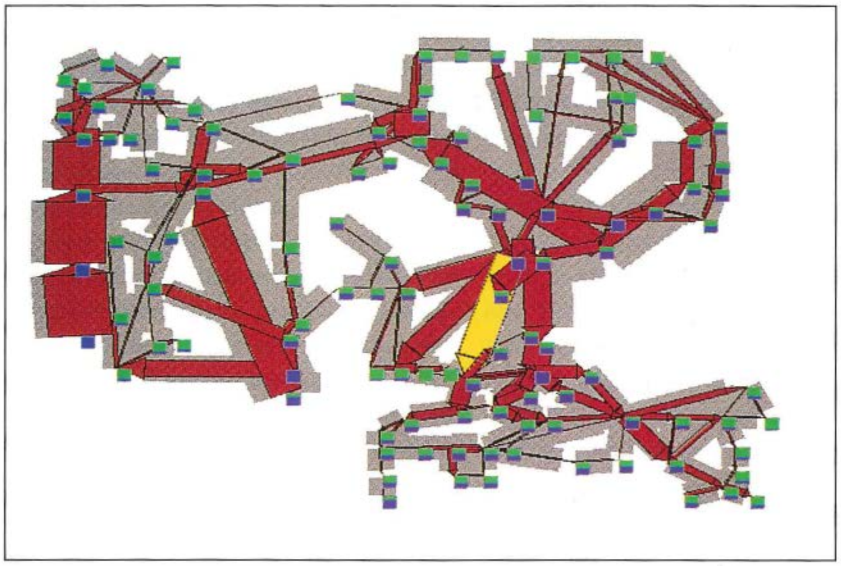
To examine other scientific visualization methods for possible application in the electric power industry, EPRI sponsored a workshop in October 1993 for researchers representing a variety of specialties.

A team from Southwest Research Institute described a visualization system designed to display objects modeled by means of high-speed parallel processors. A flexible data cache is used to accommodate newly computed data or on-line information from an ongoing experiment. The system has been applied to imaging the flow of liquid through porous media, providing real-time interactive viewing of an actual flow experiment.

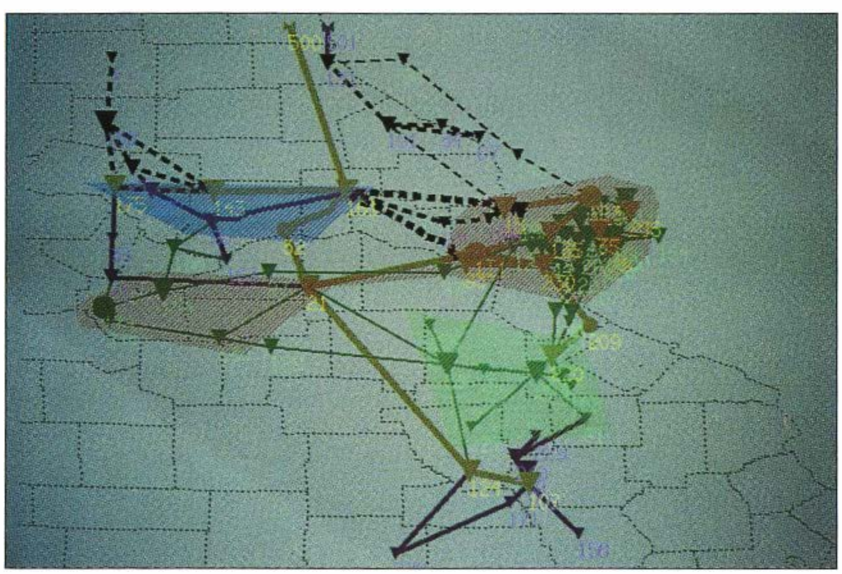
A new technique for displaying large quantities of electrical load and end-use data using the whole spectrum of colors was introduced by researchers from RLW Analytics. By using these colors, the yearly profile of load in a commercial building can be shown in great detail—with daily intervals on the horizontal axis and hourly intervals on the vertical axis—and yet be easily comprehensible. Periods of high demand show up as a yellow pattern dominating midday hours, while purple shows low demand at night. Seasonal variations are prominent as well.

Also described was EPRI- and NSF-sponsored research at the University of Wisconsin that focused on security displays for use with power system planning programs. For this application, it is possible to use a much simpler representation of the power system than the type used for online operations. Magnitudes of voltages or power flows on various buses are shown by vertical bars, which can readily be compared with those representing safe limits at different system conditions. "What if" exercises can be shown by animating the display to reveal how conditions vary in response to specified parameter changes.

"Although most of the techniques described at the workshop are still experimental, I believe that some of them have the potential to improve control efficiency for a variety of electric power applications, ranging from turbine startup to power plant optimization and power system security," concludes Wildberger. "On the basis of what we've seen, EPRI plans to explore several visualization techniques as candidates for demonstration by member utilities." ■



VISUALIZING POWER SYSTEM DATA **Maplike representations of power system states have been developed by researchers at the University of Washington (above) and the University of Missouri, Rolla (below). In the example above, power flow is indicated by the width of plotted lines, with an overloaded transmission line highlighted in yellow. Conditions during restoration after a voltage collapse are shown below, with dashed lines indicating lines out of service and colored areas showing energized "islands" within the network.**



Background information for this article was provided by Martin Wildberger of the Strategic R&D Business Unit, Strategic Development Group, and Rambabu Adapa of the Power System Operations Business Unit, Power Delivery Group.

A revolution is quietly spreading through the multisectored world of industrial inks and coatings. As air quality regulations become more stringent, there is growing pressure to eliminate emissions of volatile or reactive organic compounds from traditionally employed solvent-based inks and coating materials. In response, printers and manufacturers of all kinds are switching to new materials and technologies. These range from waterborne and high-solids products to hot melts and powder- and electrodeposited coatings.

The environment-friendly approaches also include ultraviolet (UV) and electron beam (EB) curing. These electrotechnologies use different forms of radiated energy to cause chemical reactions that convert a thin coating or ink into a solid. First introduced in the late 1960s, these curing techniques and the coating materials specially formulated for them were at first slow to spread beyond the graphic arts. In recent years, however, their growth rates have climbed into double digits.

The overall growth rate for sales of UV and EB coating equipment and chemicals is more than twice that for the general coatings industry, as printers and graphics firms of all kinds, vinyl-tile producers, makers of furniture and other wood products, and electronics manufacturers increasingly turn to the new techniques as a proven route to environmental compliance. And as various manufacturers and printing companies become more familiar with and confident in using UV and EB curing equipment and coatings, many are finding that the technologies can enhance the value of their products through improved quality or new and distinctive features of performance or durability.

In several areas of the country, electric utilities are collaborating with customers that are potential or current users of UV or EB systems. The utilities are serving as a source of information and contacts, conducting demonstrations, testing product samples, and providing customers with ongoing support and expertise in applying the technologies for competitive advantage. The Center for Materials Fabrication (CMF), an EPRI electrotechnology applications center, has supported such efforts by EPRI member utilities in UV and EB curing for several years. In cooperation with RadTech International North America, the industrywide association for the advancement of UV and EB curing technologies, EPRI and CMF expect to become more directly involved in the demonstration of innovative applications in new markets and product areas.

Getting the VOCs out

Generally formulated without the volatile organic compounds (VOCs) like aromatics, esters, and ketones that keep traditional inks and coatings in solution until vaporized in oil- or gas-fired convection curing ovens, UV and EB coatings are increasingly popular as a low-emission or pollution-free alternative. Fumes from conventional materials chemically combine in the atmosphere with nitrogen oxides from fossil fuel combustion and with energy from sunlight to produce ozone, the basic ingredient of smog.

Adding to the popularity of UV- and EB-curable coatings are the growing availabil-

Electrotechnologies Cure Ink

THE STORY IN BRIEF *The drive to reduce industrial emissions that contribute to air pollution is expanding markets and applications for ultraviolet and electron beam curing, using newly formulated inks and coatings. In many cases, these nonthermal electrotechnologies are replacing gas-fired convection drying ovens and are providing substantial gains in productivity as well as achieving environmental compliance. Their use is spreading beyond commercial printing to include all sorts of coatings for packaging, vinyl flooring, wood finishing, and electronics. Electric utilities in many parts of the country are already teaming up with commercial customers in various printing and manufacturing fields to help them understand and apply the productivity-leveraging power of ultraviolet and electron beam curing. EPRI is pursuing new opportunities with its member utilities and the radiation-curing industry to extend the applications experience base.*

by Taylor Moore

ity and affordability of improved curing equipment, analytical accessories, and curing and coating materials. Mercury-vapor UV lamps that can radiate 175–400 watts per square centimeter (and that use infrared-absorbing reflectors and active cooling to minimize product heating) are on the market, while lasers reliable enough to polymerize chemical coatings quickly are also now available at reasonable cost.

UV curing involves lower levels of applied energy than EB curing, so curing with UV at high speed requires the use of photoinitiator chemicals that quickly absorb the UV and start the chemical reaction. For the most part, however, the formulated coatings (largely acrylates) are the same for both UV and EB curing. "Generally speaking, UV or EB curing involves the application of some type of liquid that is then entirely converted into a solid coating or ink without any being vaporized as emissions," explains Alexander Ross, RadTech International's director of government affairs.

EB curing systems, which use an electron accelerator to generate high-intensity, collimated beams, are best suited to large-volume, high-speed flat production lines, where their higher capital cost can be justified. Electron beams are also able to penetrate into a substrate, such as wood, which offers certain advantages.

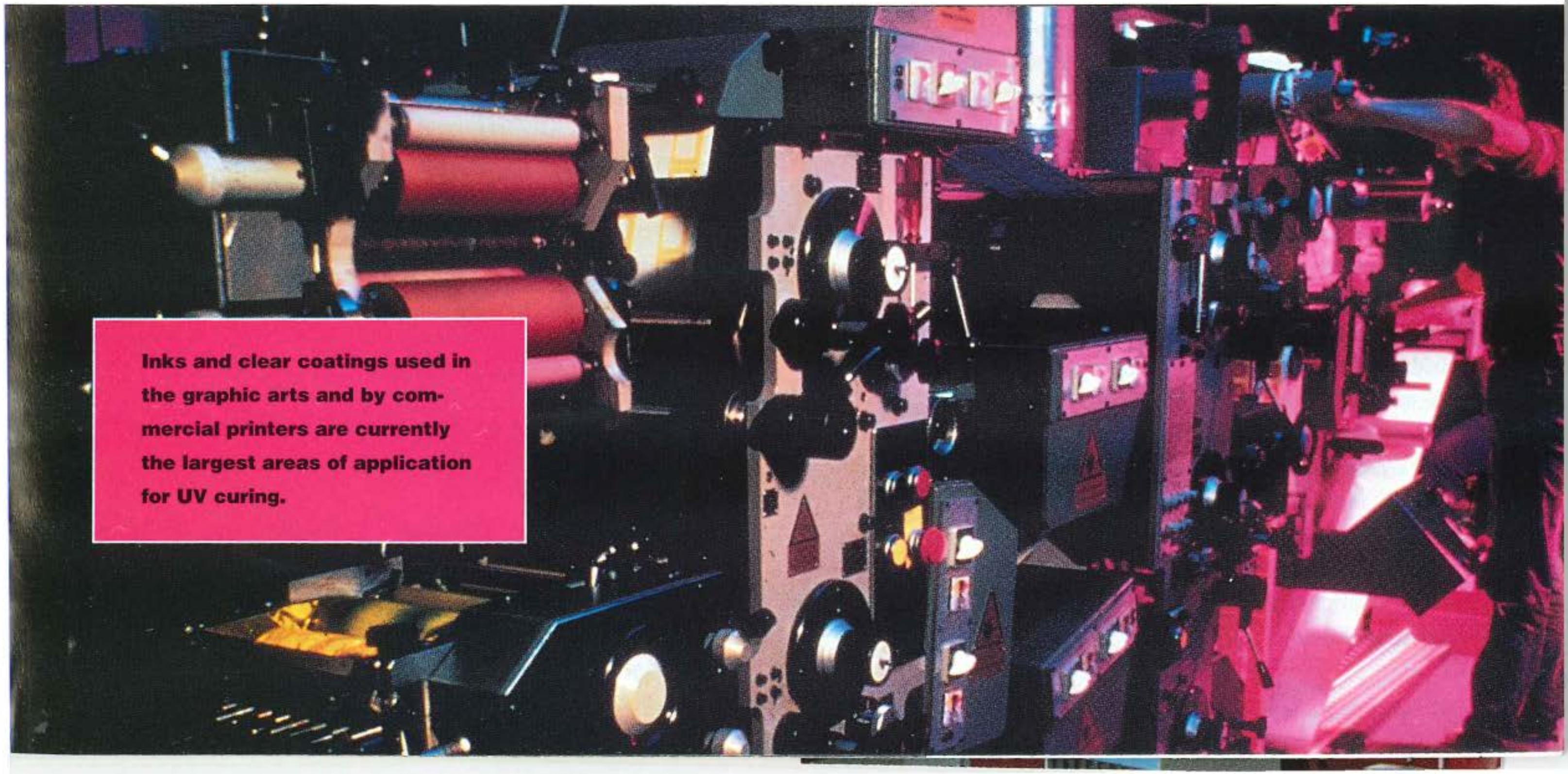
Industries that employ EB curing today include packaging converters that produce bulk quantities of cardboard or plastic wrapping from raw materials and also print manufacturers' labels on the packaging before delivering it. The printing on many cereal boxes and plastic bags is cured by EB, for example. Many specialty chemical producers also have EB curing installations for the bulk processing of a variety of polymers; several such installations are available for contract production.

Producers of specialty chemicals for curing applications, meanwhile, are turning out starting monomers of greater purity and quality than ever, chemical oligomers with a wider range of composition, and photoinitiator chemicals that are more efficient and even wavelength-specific. Experts say that the available variety of resin hybrids, copolymers, polymers, and monomer-oligomer blends is virtually unlimited.

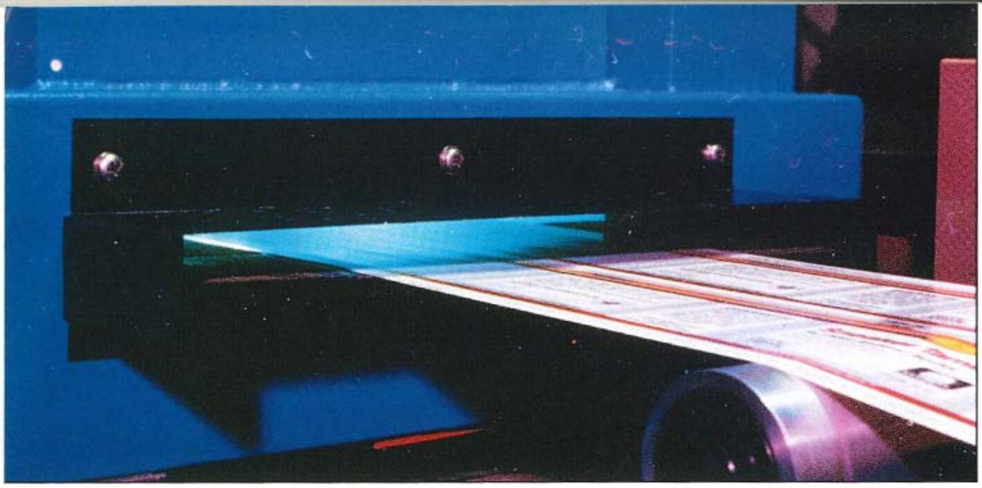
The UV and EB techniques are also more energy-efficient than convection curing, which typically requires oversized ovens to maintain the high temperatures necessary for fast, minimum-dwell-time curing. In some cases, the factory space required for curing operations can be reduced by 75–90% by changing to UV or EB curing.

Ross cites a well-known case study of UV curing—at Adolph Coors Company in Golden, Colorado. There UV lamps are used to cure in one step both the overprint varnish and the label inks on all Coors product cans, of which about 12 million are made daily. Ross says that the switch to UV curing, which began at Coors 20 years ago, has eliminated the use of fossil fuel for firing convection ovens; the additional electricity used by the UV lamps is about equal to that consumed by the no-longer-needed oven conveyor lines. According to information published by the U.S. Department of Energy's National Renewable Energy Laboratory (NREL), Coors estimates the annual energy savings from UV curing to be 62 billion Btu and credits the technology with reducing waste by more than 4500 tons.

and Coatings in a New Light



Inks and clear coatings used in the graphic arts and by commercial printers are currently the largest areas of application for UV curing.



ROLL THE PRESSES Graphic arts are expected to remain the major field in which UV curing is used. Emerging applications in commercial printing are focused on wide-web, high-speed flexographic presses.

According to RadTech International, curing inks and clear coatings in graphic arts applications and in various other types of printing continues to be the major use for the UV and EB techniques. Wood products, vinyl flooring, and electronics equipment round out the major areas of current use. The fastest-growing niche applications involve flexographic inks (as flexo and gravure printers develop low-viscosity, UV-curable inks and also press and applicator modifications for wide-web press installations); silicone coatings with a range of controlled-release properties and thicknesses; temporary corrosion-resistant coatings for steel pipe and tubing; protective, reflective acrylate coatings for optical fiber; and acrylate substitutes for the nitrocellulose-based lacquers and catalyzed alkyd amines used as coatings for wood cabinets and furniture.

UV and EB curing are being demonstrated in a widening array of automotive component applications, where the new approaches are just beginning to rival conventional methods in terms of consistent quality and performance. Pressure-sensitive adhesives are another area of projected growth in the application of UV and EB curing; development efforts by manufacturers are expected to lead soon to adhesives with improved resistance to heat and humidity. And a potentially important application of UV curing has been identified for rapid, low-temperature cross-linking of polymers that are applied as powder coatings and are now thermally cured. This application could lead the way to more-extensive use of UV and EB curing on metal surfaces, where commercial experience up to now has been limited.

Utilities promote the power of UV and EB

Several utilities that have proactive customer electrotechnology assistance programs are already familiar with UV and EB curing and have been helping their printing and manufacturing customers apply the technologies for some time. EPRI has supported a number of these utility efforts through CMF, serving as a source of information and referrals and facilitating technology transfer. Several utilities have installed their own UV curing lamps at electrotechnology demonstration centers to provide customers with sample tests, or will arrange for tests by a UV equipment manufacturer.

"We think utility demonstration centers where you can bring together equipment manufacturers and chemical suppliers to work with a company that may be interested in using UV curing are an excellent way to combine and leverage the resources of EPRI and RadTech," says Ross. A recent example of such collaboration is Pennsylvania Power & Light Company's Electrotechnology Application Center in Bethlehem, Pennsylvania. The center is supported by EPRI, with the participation of RadTech.

EPRI has also supported various electrotechnology demonstration efforts at Georgia Power Company's Technology Application Center. The Southern Company subsidiary estimates that of the roughly 1000 customer application projects it has assisted in, 5–10% involved UV curing. These projects have resulted in many UV curing installations in Georgia Power's service territory, which includes several air quality nonattainment areas in and around Atlanta and other metropolitan centers. The utility says that some customers have been able to reduce their energy bills as much as 90% by replacing thermal curing ovens with UV curing systems and eliminating the need for VOC emissions incinerators.

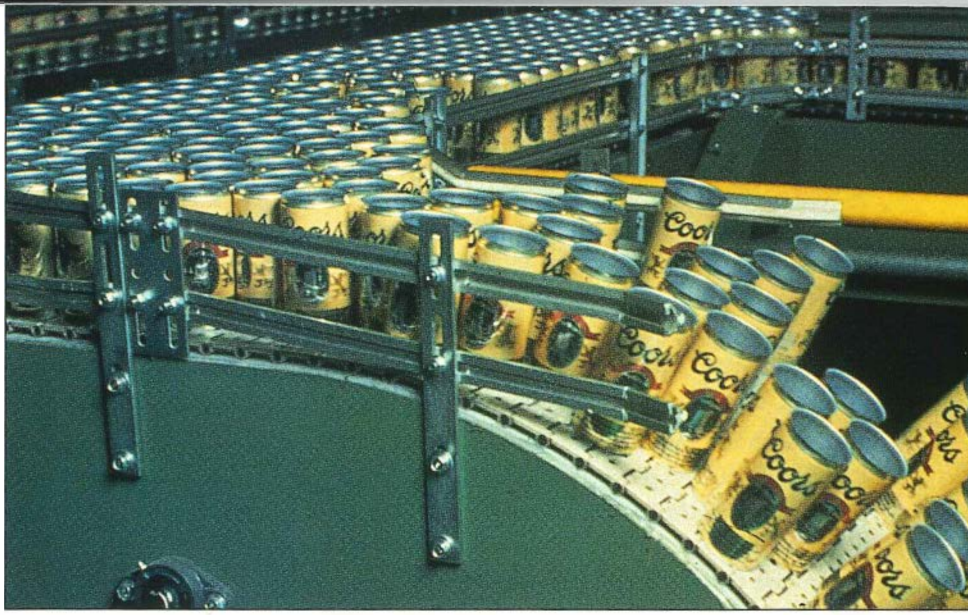
Wayne Pettyjohn, an applications engineer at the Georgia Power center, says that the coming era of open-access electricity marketing will make the emphasis on utility service all the more important. "The Technology Application Center is an added value that we can offer manufacturers as part of our service package to help us compete for those loads."

Southern California Edison Company and its manufacturing customers operate under the nation's toughest air quality regulations. Since 1990, SCE has conducted dozens of tests of UV curing applications for printers, metal decorators, and wood-furniture manufacturers at its Customer Technology Application Center. A couple of years ago, when Lockheed Aircraft Service Company began looking for a better corrosion-inhibiting coating for the circuit boards of digital flight recorders it builds for commercial and military aircraft, the company found an ally in SCE's Clean Air Coatings Technologies Program.

Together, SCE and Lockheed identified a solvent-free UV-cured coating that eliminates emissions and meets all military performance specifications. The new coating saved Lockheed more than $30,000 in the first month of use. Circuit boards that formerly took three to five days to dry by evaporation are now UV-cured and ready for the next assembly process in less than 5 minutes. The conveyor-fed, reciprocating UV system Lockheed installed for the job at its Chino manufacturing facility was up and running within 10 months of the company's first contact with SCE. "Without Edison's help, we'd still be doing it the old way," says Bill Ellis, Lockheed's senior manufacturing engineer at Chino.

Elsewhere, Public Service Electric and Gas Company is particularly proactive in demonstrating UV and EB curing applications to customers. Mike Perna, who oversees PSE&G's Electrotechnology Demonstration Facility in Edison, New Jersey, says that the utility realizes it must go the extra mile simply to retain manufacturing customers and deter them from relocating out of state. Citing environmental laws second in toughness only to California's, three-quarters of New Jersey's small chemical producers said in a recent survey that they would not build a new plant in the Garden State.

"UV and EB coatings are among half a dozen electrotechnologies we're promoting and demonstrating as a way to improve productivity while also achieving environmental compliance," says Perna. "It's definitely a business retention strategy for us," he adds, noting the large number of printing companies and plastics manufacturers in PSE&G's territory. "If we can help customers cut the cost of production, they're more likely to remain in the area and remain a customer.



COORS CANS GET THE UV CURE **Adolph Coors Company of Golden, Colorado, pioneered the use of UV systems to cure in one step the label inks and the overprint varnish on its entire daily production of about 12 million cans, eliminating fossil fuel combustion for thermal drying.**

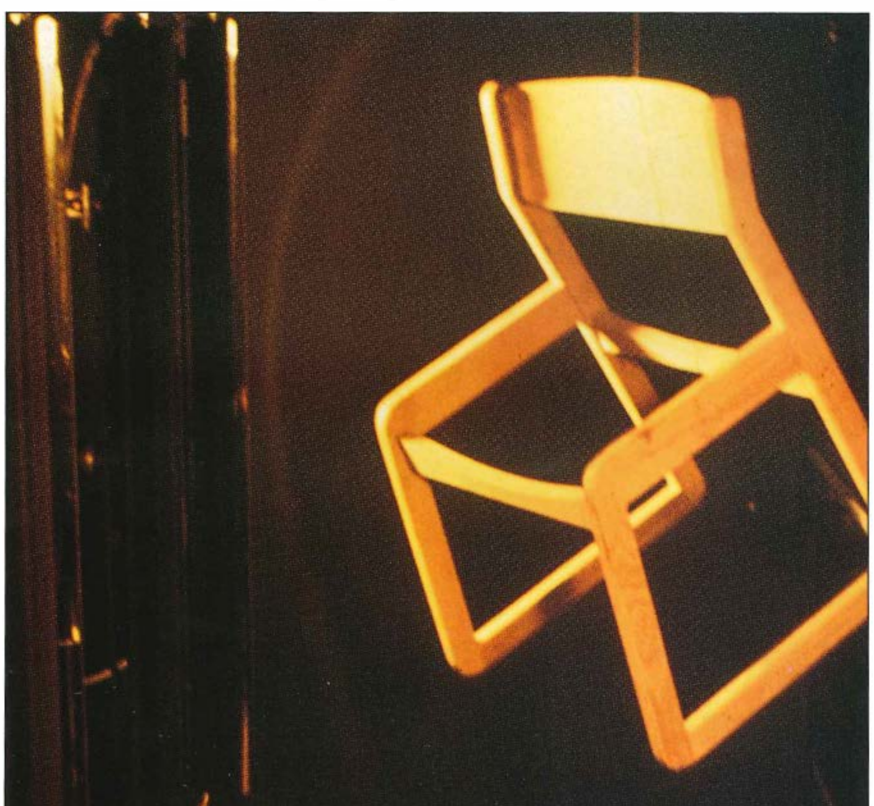
"Because of UV curing's applicability in a lot of product areas—from the plastic-bag manufacturer who wants to do printing to a wood-frame maker who just wants to get rid of VOCs—the technology cuts across a lot of SIC [Standard Industrial Classification] codes. It's also a technology that is truly within the realm of affordability for even the small or medium-size manufacturer. We can show customers with 30 employees how they can afford to put in a UV system for $25,000 that will have a major impact on their productivity.

"EB systems are more energy- and capital-intensive and are therefore a harder sell," notes Perna, "but we have a couple of chemical-manufacturing customers who use EB to apply a surface treatment to thin-film polymers and some high-end printers who like it for colorized coatings."

In a series of special reports, PSE&G has featured customers who are applying UV curing. Union Camp Corporation's Folding Carton Division, for example, expects a three-year payback on an investment in a UV curing system for varnish coatings that is saving it about $1 million a year by bringing the work in-house. Captive Plastics, a Piscataway-based manufacturer of pharmaceutical packaging, uses UV to cure screen-printed, high-gloss finishes and brightly colored inks, reporting increased productivity, improved quality control, and savings of 30% in required floor space for production. Pharmaceutical-label printer Plymouth Printing has cut startup time and spoilage by half through the use of four-, six-, and eight-color UV-equipped letterpresses that have tripled line speed while applying multiple layers of ink in continuous, roll-to-roll operation.

Perna calls EPRI's CMF "a great coordinator for putting you in touch with the

GOOD FOR WOOD **Makers of wood cabinets and furniture are increasingly turning to UV-cured acrylate coatings as alternatives to traditional solvent-based lacquers and other chemicals.**



right people. Although UV curing is not a new technology—it's been around for about 25 years—it is still unfamiliar to many manufacturers. What we have to do is convince companies that it represents a better way for them and provide them with the support they need to make a rational decision. So we're partnering with the people who have the knowledge to get it to our manufacturers who need it." Perna recently completed a one-year fellowship in EPRI's Industrial, Agricultural & Large Commercial Business Unit, where he worked on improving partnerships between utilities and university and government research and technology centers.

Perna suggests that, besides working with the staff at CMF, other utilities wanting to get involved with UV or EB curing should contact RadTech International at (708) 480-9576. RadTech can put them in touch with equipment manufacturers and chemical suppliers in their area that will be glad to work with them in developing UV and EB curing solutions for specific customer applications. "These kinds of alliances are invaluable, and the UV suppliers are very supportive," adds Perna.

Perna and Ross agree that once customers start using UV- or EB-cured coatings, they soon find unanticipated ways to take advantage of the technology's characteristics. Says Ross, "The benefits of high-speed production, reduced space requirements, and elimination of VOCs are what attract companies to these coatings. But when companies install a UV curing system and start to see for themselves what it will do, before long they're adding to it and making changes. Soon they're producing something new with it, and then they're ordering bigger UV units for more of their product line. Once customers get accustomed to the technology, they find more ways of using it that enhance the value of their products."

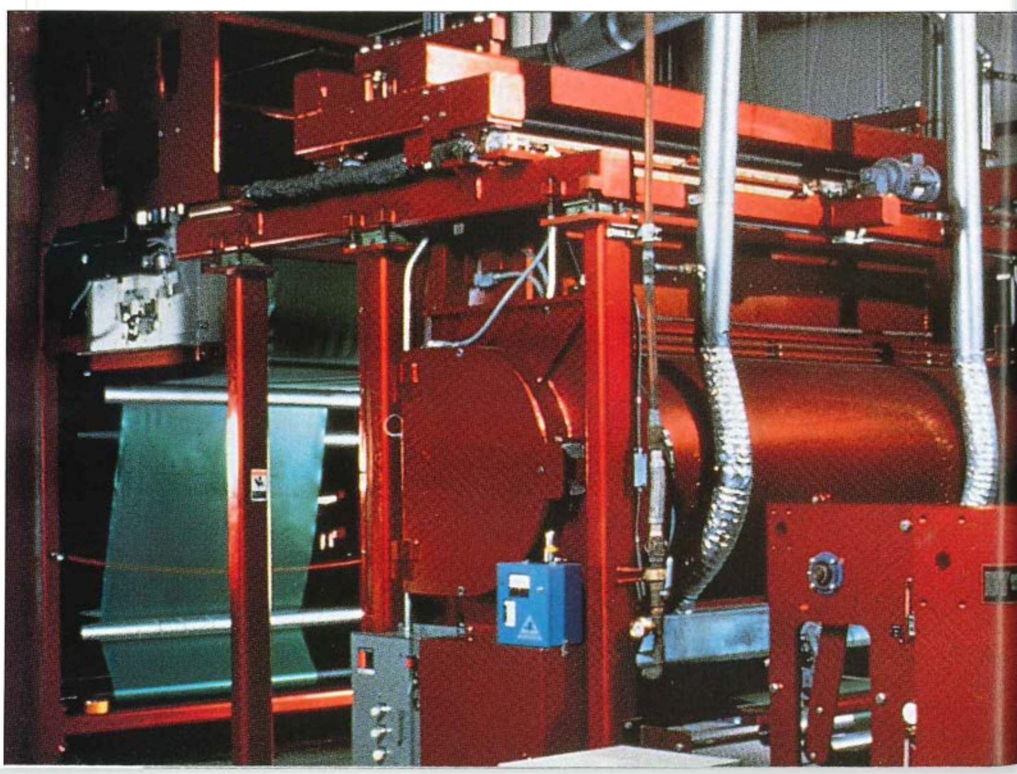
Demonstration plans taking shape

EPRI and RadTech are hopeful of even closer relations in the future if developing plans are realized for cooperating on several demonstrations of UV and EB curing applications in emerging new markets.

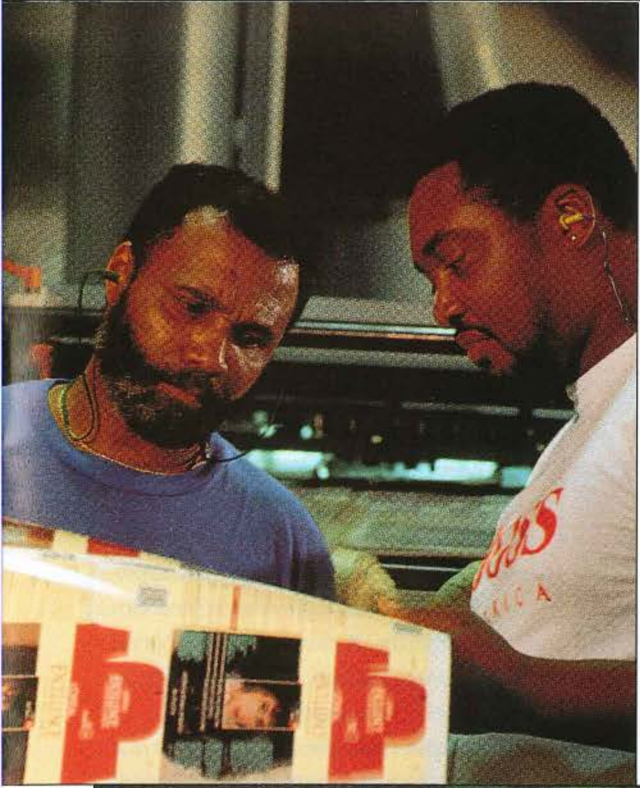
One of these markets is wide-web flexographic printing. Although UV and EB curing are already well established for narrow-web (18–24-inch) flexo presses, printers using wide-web presses of 60–70 inches across have been slow to adopt the technology because of concerns that the heat generated by UV lamps may distort or stretch the fast-moving plastic film. Ross says wide-web flexo printers in Europe have overcome these potential problems. Some solutions involve the addition of chilled rolls for heat removal and the use of infrared-absorbing reflectors in UV lamps.

COLLABORATING WITH CUSTOMERS Public Service Electric and Gas Company in New Jersey is active in demonstrating UV and EB curing to customers as part of a broader electrotechnology program aimed at helping them find ways to become more competitive. UV curing for small product samples is available at PSE&G's Electrotechnology Demonstration Facility in Edison, New Jersey. The utility also provides referrals to UV and EB equipment and coating suppliers and produces electrotechnology marketing materials that highlight successful customer applications.

CMF is organizing a demonstration of UV curing for wide-web flexo printing, having renewed the search for a host printer after one company that had recently installed a new wide-web press decided it could not delay commercial operation in order to develop and test a UV curing system. CMF is looking for a wide-web flexo printer that is already in commercial operation and is willing to accommodate the modification of its production line for UV system instal-

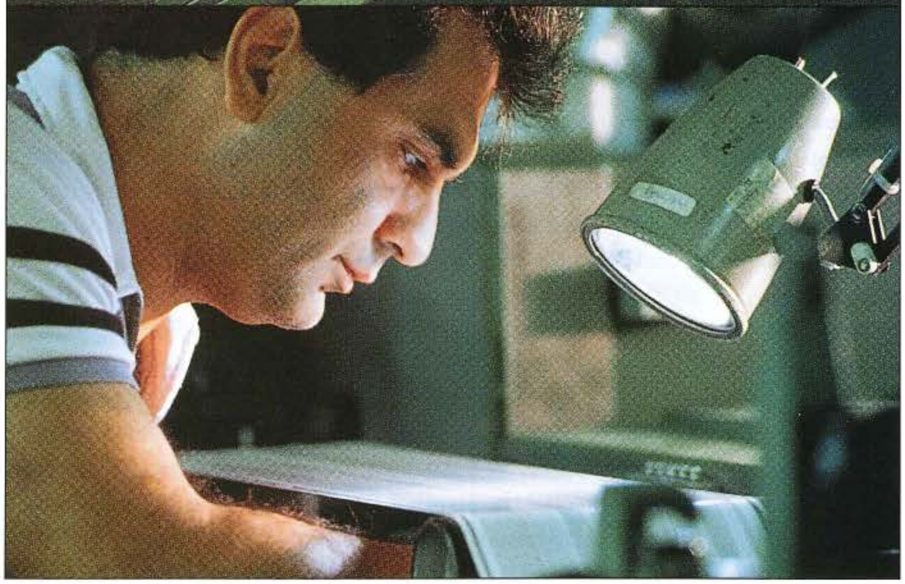


ELECTRON BEAMS USED FOR HIGH-VOLUME, FLAT-LINE PRODUCTION Web offset lithographic printing, particularly for food packaging, is by far the largest current market application for EB curing systems. But a potentially major growth market is the curing of silicone-release coatings that provide a range of functional characteristics. Douglas-Hanson Company of Hammond, Wisconsin, uses this EB unit from RPC Industries of Hayward, California, to polymerize a silicone-release chemical liner that is applied to the green polyester film.



Union Camp Corporation, Clifton, uses a UV system to cure varnish coatings on folding cartons.

Captive Plastics, Piscataway, installed screen printers with UV curing for the manufacture of pharmaceutical packaging.



Plymouth Printing, Cranford, uses UV lamps on rotary letterpresses to cure colored inks and high-gloss finishes on pharmaceutical labels.

lation, which is somewhat more complicated than incorporating UV curing in a new production line.

EPRI and RadTech are also pursuing demonstrations of UV and EB curing applications in wood finishing and metal finishing. One of the most attractive markets in metal finishing is that already demonstrated with support from CMF by Adolph Coors Company—beverage cans. Also attractive are three-piece food cans. Because food cans are printed and coated while flat (before being formed into cans), they may be a better bet for the application of EB curing.

Aluminum beverage cans, which are coated, printed, and cured after they become cans, represent a huge and barely tapped market for UV curing. The Coors plant in Colorado produces approximately 4% of all such cans in the country, meaning that all the other U.S. beverage producers are each day thermally curing approximately 300 million aluminum cans that could be cured more economically with UV. Coors and DOE's NREL estimate that industrywide implementation of UV curing over the next 15 years could yield overall savings of $10 million. Energy savings could total 2.2 trillion Btu a year.

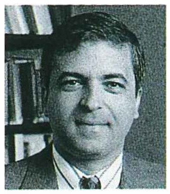
CMF will continue to pursue applications and demonstrations of UV curing of can coatings with member utilities and manufacturers that are ready to invest in a pilot UV curing line. "EPRI is increasingly being asked by its members to organize and participate in electrotechnology demonstration projects," says Gene Eckhart of the Industrial, Agricultural & Large Commercial Business Unit. "We look forward to working with RadTech International and with our utility members to forge new partnerships that will help bring UV and EB curing solutions into more applications and markets. Although environmental concerns originally spurred interest in these electrotechnologies, their use is certain to grow as manufacturers recognize the advantages they offer in improved productivity and enhanced product quality." ■

Background information for this article was provided by Gene Eckhart of the Customer Systems Group's Industrial, Agricultural & Large Commercial Business Unit.

CONTRIBUTORS

Technical sources for Journal feature articles

TAYLOR



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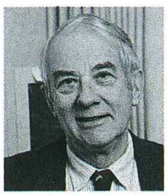


WILDBERGER

ADAPA

ECKHART

Reopening the Nuclear Option (page 6) was written by science writer John Douglas with technical information provided by members of EPRI's Nuclear Power Group.

John Taylor, vice president for nuclear power, joined the Institute in 1981. Previously he was at Westinghouse Electric Corporation for 31 years, managing nuclear power development for naval propulsion and electricity generation and eventually serving as vice president and general manager of Westinghouse's Water Reactor Business Unit. Earlier Taylor was a vice president at Bettis Atomic Power Laboratory and worked as a mathematician at Bendix Aviation Corporation and Kellex Corporation. He holds two degrees in mathematics—a BS from St. John's University (New York) and an MS from the University of Notre Dame.

Joseph Santucci is responsible for the Institute's programs on advanced reactors development and also serves as deputy executive director of the Advanced Reactor Corporation (ARC), a utility consortium sponsored by EPRI and DOE. Since coming to the Institute in 1982, he has held various management responsibilities in the Nuclear Power Group, including nuclear fuels and materials research, technology transfer, exploratory research, business development, and power plant siting. Santucci holds BS and MS degrees in nuclear engineering from the Polytechnic Institute of New York, a graduate degree in energy science and engineering from the same school, and an MBA from the University of California at Berkeley. ■

Visualizing Complex Systems (page 18) was written by science writer John Douglas with technical information provided by members of EPRI's Strategic Development and Power Delivery Groups.

Martin Wildberger of the Strategic R&D Business Unit manages exploratory research in applied mathematics and information science and provides Institutewide support in mathematical modeling and computer simulation. Before joining EPRI in 1992, he was chief computer scientist at General Physics Corporation for 11 years. Earlier he served for over 20 years as an officer in the U.S. Navy, specializing in aerospace engineering. He has also held teaching and research positions at Howard University and the University of Maryland. Wildberger holds a BS degree from Fordham University, an MS from the U.S. Naval Postgraduate School, and a PhD from the Catholic University of America.

Rambabu Adapa is manager for power system engineering in the Power System Operations Business Unit. He currently specializes in expert systems projects related to delivery system planning and operations. Before coming to EPRI in 1989, Adapa was an engineer at McGraw-Edison Power Systems (now Cooper Power Systems), where he was involved in digital and analog studies performed for electric utilities. He holds three degrees in electrical engineering: a BS from Jawaharlal Nehru Technological University (India), an MS from the Indian Institute of Technology, and a PhD from the University of Waterloo (Canada). ■

Electrotechnologies Cure Inks and Coatings in a New Light (page 24) was written by Taylor Moore, *Journal* senior feature writer, with background information from **Gene Eckhart,** manager for materials production and fabrication in the Customer Systems Group's Industrial, Agricultural & Large Commercial Business Unit. Eckhart joined EPRI in 1992 after 6 years as a program manager in DOE's Office of Industrial Technologies. In the 13 years before that, he held several engineering and technical positions with Armco, Inc.'s Specialty Steel Division. Eckhart received a BS in metallurgical engineering from Drexel University and an MBA from Loyola College (Maryland). ■

Stronger Links Forged With Department of Energy, World Bank

EPRI recently signed agreements in Washington, D.C., with the U.S. Department of Energy and the International Bank for Reconstruction and Development (the World Bank). The new agreements are expected to lead to expanded collaboration and to increased value for EPRI members.

On October 5, Energy Secretary Hazel O'Leary and EPRI President and CEO Dick Balzhiser signed a "Sustainable Electric Partnership" agreement to significantly expand collaboration and communication between their organizations. "This partnership highlights the Clinton administration's commitment to participate in a broad array of research and development activities with the private sector," said Secretary O'Leary. "Today's agreement brings the immediate benefit of enhanced value from shared research to address the complex technological and operational changes facing the electric utility industry. In the long term, I expect the work resulting from this agreement to bring cleaner and more economical electric service to the nation."

O'Leary and Balzhiser

Dick Balzhiser commented, "Electricity is clearly becoming a key vehicle for effectively coupling our energy and intellectual resources in assuring a clean, efficient, and sustainable energy future. EPRI looks forward to this partnership with DOE in assuring a sustainable electric future as we move into the twenty-first century."

DOE and EPRI agreed to brief each other annually on their R&D technology work, with the first briefing set for March 29, 1995. A provision taking effect immediately defines a standardized role for EPRI in the cost-shared work that DOE will manage, and the agreement establishes a firm schedule for completing model cooperative agreement terms for EPRI-managed collaborative efforts.

DOE and EPRI have a long history of cooperation in technology development. The agreement is intended to allow more closely focused R&D and to help use limited funds more effectively through improved prioritization, streamlined cost-sharing instruments, and more timely transfer and application of research results. Examples of current joint DOE-EPRI projects include R&D on advanced gas turbines, molten carbonate fuel cells, cost-effective electric vehicle batteries, and electric and magnetic fields, as well as efforts to verify advanced wind turbine performance and to increase utility experience with photovoltaics. DOE funds approximately $2.5 billion a year in utility-related research.

Also in October, Kurt Yeager, EPRI senior vice president for strategic development, and Jean-François Rischard, vice president of finance and private sector development of the World Bank, signed a memorandum of understanding (MOU) to enhance communication and cooperation. The MOU is intended to better link the bank's goals of improving the economies, quality of life, and environmental quality of developing countries with EPRI's broad utility technology expertise.

"This MOU signals the interest both organizations have in enhancing the quality of life in developing countries through the provision of electric services," remarked Yeager. "EPRI's systemwide technical expertise can serve as a valuable and objective asset to advancing the development of economically and environmentally sound systems for the production, distribution, and use of electricity."

Rischard responded that the World Bank attaches a high priority to improving the access to, and reducing the cost of, energy for people in the developing world: "Providing electricity and other infrastructure services to the poor will remain a key development challenge for the 1990s. We look forward to increasing collaboration with the Electric Power Research Institute in our effort to face this challenge."

Key points in the MOU include an annual executive conference, information exchange and cooperation, strategic planning, and development of a framework for conducting joint initiative programs. The first executive conference is scheduled for March 30, 1995, in Washington, D.C.

Both agreements are viewed as important vehicles for enhancing the value of EPRI membership. Leveraging information and research dollars on behalf of members through strategic partnerships will continue to be a high priority. ■

Fuel Cells

Tapping the Energy Potential of Landfills

In one of the first demonstrations of its kind in the world, EPRI is about to test the feasibility of using a carbonate fuel cell to generate electricity from landfill gas.

Landfills produce a substantial quantity of methane gas, a natural by-product of decaying organic wastes. Currently, only a small amount of electricity—some 300 MW—is generated from the methane in U.S. landfills. More commonly, the gas simply leaks into the atmosphere, where it is believed to contribute to the global warming phenomenon and possibly even to ozone depletion. In some areas, where local environmental laws require a reduction in methane emissions, landfill operators install flares to combust the gas without recovering any of the resulting energy.

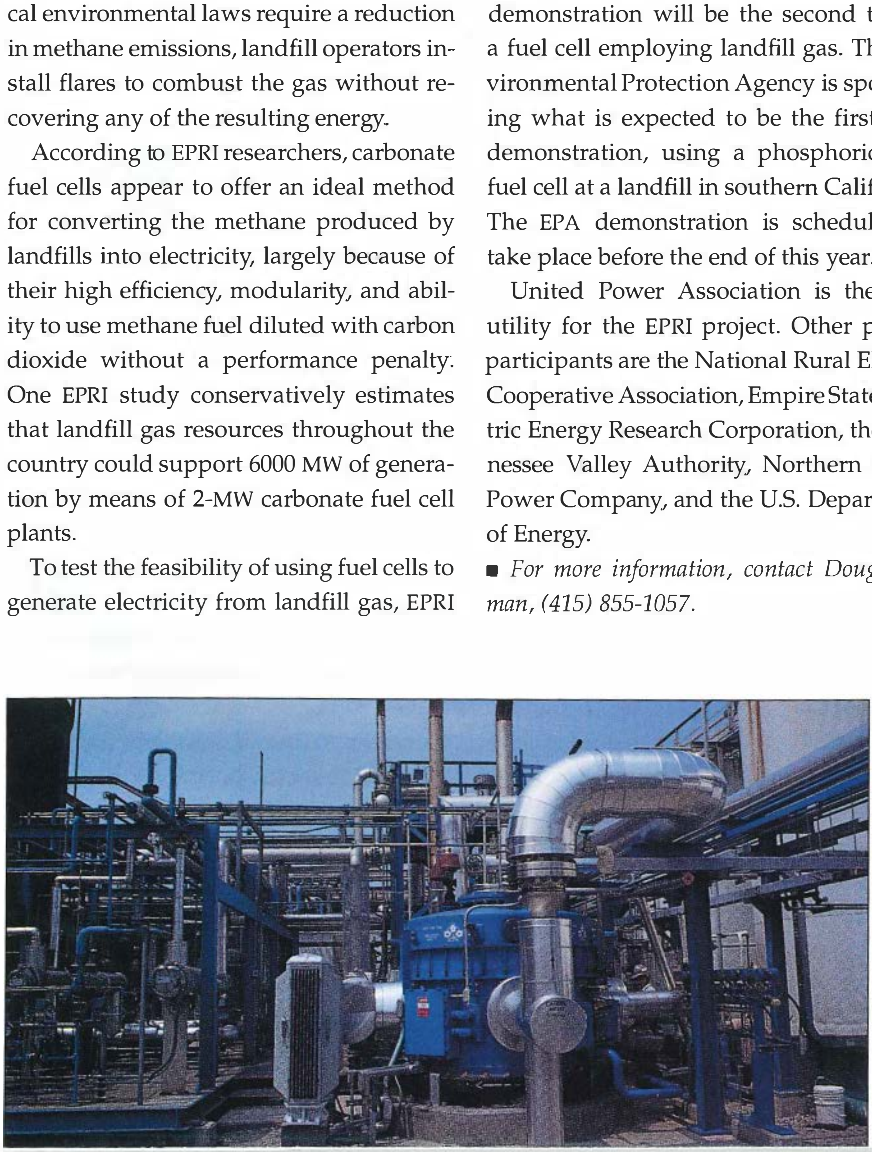
According to EPRI researchers, carbonate fuel cells appear to offer an ideal method for converting the methane produced by landfills into electricity, largely because of their high efficiency, modularity, and ability to use methane fuel diluted with carbon dioxide without a performance penalty. One EPRI study conservatively estimates that landfill gas resources throughout the country could support 6000 MW of generation by means of 2-MW carbonate fuel cell plants.

To test the feasibility of using fuel cells to generate electricity from landfill gas, EPRI has transferred a 100-kW modular fuel cell test facility from Destec's coal gasification plant in Plaquemine, Louisiana, to a landfill in Anoka County, Minnesota, near Minneapolis. The plant has been reassembled and is currently undergoing design modifications and preoperational checkouts.

The actual testing of the fuel cell is scheduled to begin late next year. Operators will run the unit for a few thousand hours to determine whether the concept is economically feasible. As Doug Herman, EPRI's manager for the project, points out, "Landfill gas is cheap, if not free, but it's not clean. So the challenge is to clean the gas well enough to be used by the fuel cell without making the process prohibitively expensive." According to Herman, EPRI's demonstration will be the second test of a fuel cell employing landfill gas. The Environmental Protection Agency is sponsoring what is expected to be the first such demonstration, using a phosphoric acid fuel cell at a landfill in southern California. The EPA demonstration is scheduled to take place before the end of this year.

United Power Association is the host utility for the EPRI project. Other project participants are the National Rural Electric Cooperative Association, Empire State Electric Energy Research Corporation, the Tennessee Valley Authority, Northern States Power Company, and the U.S. Department of Energy.

■ *For more information, contact Doug Herman, (415) 855-1057.*



EPRI's modular fuel cell pilot plant at Destec's coal gasification test facility in Plaquemine, Louisiana

Drinking-Water Treatment

Making Ozonation More Efficient

Disinfecting drinking water with ozone is far more effective than conventional chlorination. For instance, ozonation can effectively kill cryptosporidium, a pathogenic cyst, whereas chlorine is ineffective against such contamination. Last year, cryptosporidium caused over 40 deaths when it got into Milwaukee's drinking-water supply.

Today more than 100 water treatment plants in the United States employ ozonation, and the number is growing rapidly because of the increasing stringency of drinking-water regulations. In fact, experts anticipate that in 10 years about 25% of the drinking water supplied in the country will be treated with ozone.

Ozonation has one drawback, however; it is a big user of electricity, making it more expensive than chlorination. Ozonation consumes an average of 170 kWh for every million gallons of water treated—the amount typically needed to supply a community of 5000 people for one day.

Through a joint project with the American Water Works Association Research Foundation, EPRI-sponsored engineers are working to reduce the operating costs of ozonation by making the process more efficient. The goal is to develop an operating manual that will enable water treatment plants to employ ozonation up to 15% more efficiently while maintaining high water quality.

The first phase of the project involves the evaluation of plants in the San Francisco Bay Area, home of the country's highest concentration of drinking-water plants that use ozone. The engineers will work with plant operators to make the ozonation process more efficient and will incorporate the knowledge gained into the operating manual they're developing for water treatment facilities. So far, one of five planned plant evaluations has been completed.

The second phase of the project will demonstrate the improved ozonation process at several of the largest water treatment plants in the country. In the third and final phase, modifications to conventional equipment and process designs will be implemented to enable more-efficient production and use of ozone in water treatment. The entire project is expected to be completed in 1997.

"By optimizing ozone systems, we're removing some of the barriers to their use while improving the quality of the drinking water supplied," says Keith Carns, EPRI's manager for the project. "We expect this project to encourage more water utilities to install ozone treatment."

■ *For more information, contact Keith Carns, (314) 935-8598.*

Superconducting Cable

Researchers Aim to Deliver More Power With One Line

EPRI has initiated a project to develop a high-temperature superconducting underground transmission cable that will deliver twice as much power as conventional cables. The implication for cost savings in the utility industry is significant; such a cable would require a smaller right-of-way than conventional cables delivering the same amount of power and would cost less to install. Excavation and installation can account for up to 70% of the total capital cost of an underground cable.

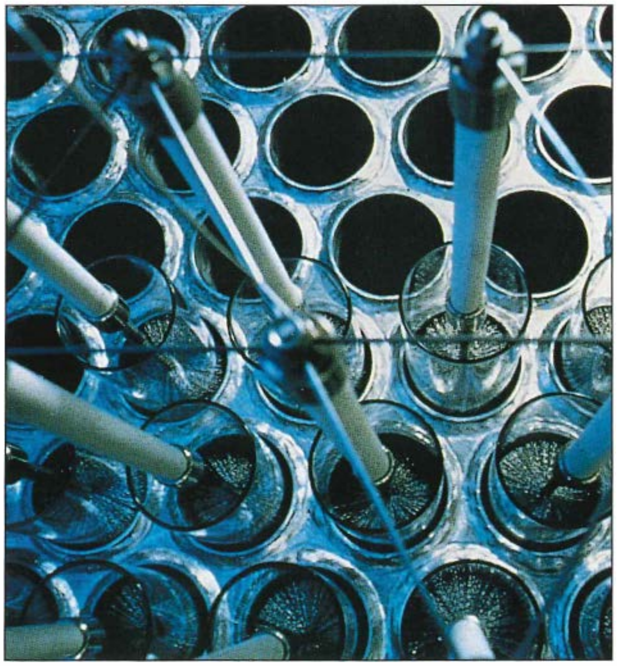
As EPRI's Don Von Dollen, who is managing the project, explains, the new cable will employ high-temperature superconductors but will rely heavily on conventional cable technology. In fact, everything about the cable will be conventional except its conductor. Whereas conventional cable has copper in the center, EPRI's new cable will have a hollow core—through which refrigerant is circulated—surrounded by layers of superconducting tape.

Von Dollen explains that the high-temperature superconducting material, made of bismuth, strontium, calcium, and copper oxide, is able to operate at about −321°F, compared with −452°F for conventional superconductors. This higher operating temperature allows the refrigerant to be liquid nitrogen, which is less expensive and easier to use than the liquid helium required for lower temperatures. Refrigeration units to maintain the low temperature and pumps to circulate the liquid nitrogen through the cable will have to be established at regular intervals in manholes along the cable route.

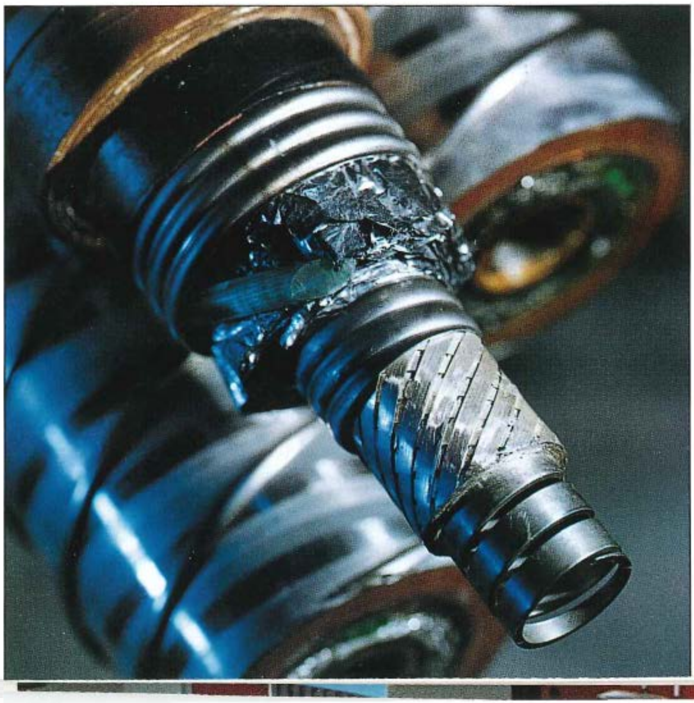
Pirelli Cable Corporation is the prime contractor for the project and will be engineering the entire cable system. American Superconductor Corporation will make the superconducting tape that will be incorporated into the system. The project is expected to result in a prototype cable that will undergo qualification testing sometime in 1998. Researchers will then subject the cable to accelerated life testing. Commercialization is anticipated by 2001.

■ *For more information, contact Don Von Dollen, (415) 855-2679.*

A glimpse inside an ozone generator



Model of high-temperature superconducting cable under development



Advanced Aeration Technology Tested for Wastewater Treatment

EPRI has sponsored a series of tests of a new high-efficiency aeration system that holds promise for a variety of municipal and industrial wastewater treatment applications. Tests of Biomixer Corporation's floating aeration machine were successfully conducted last summer at the Palo Alto Municipal Water Treatment Plant by EPRI contractor Air and Water Technologies, a division of Metcalf and Eddy. Additional tests of the machine were performed earlier in the year at a site in Tennessee. A commercial-scale demonstration is planned in Colorado.

The Biomixer system employs an innovative design to produce very high oxygen transfer and mixing of wastewater in lagoons and secondary-treatment facilities. Twin float tanks suspend a motorized, rotating six-bladed diffuser below the water's surface. As the helicopter-like blades rotate, pores in the blades diffuse a continuous, fine-bubble stream of air that puts more oxygen into the water more quickly.

The oxygen supports aerobic bacteria that feed on organic material in the wastewater, thereby improving the effectiveness of treatment. The system's major appeal is its energy efficiency, which is up to twice that of existing aeration technologies. Electricity for pumping and aeration can account for over half the cost of wastewater treatment, and the Biomixer system may reduce electricity use for that operation by half.

Biomixer offers a line of self-contained, stand-alone systems in sizes from 10 to 100 hp. The retractable, self-cleaning diffuser is engineered for high reliability and easy maintenance. The company can be reached at (310) 577-6554.

■ *For more information, contact Keith Carns at the EPRI Community Environmental Center, (314) 935-8598.*

Selective Noncatalytic Reduction of NO_x Emissions

An alternative to combustion modifications for controlling emissions of nitrogen oxides from fossil power plants, selective noncatalytic reduction (SNCR) has been demonstrated at industrial- and utility-scale installations worldwide, and several U.S. utility units now have commercial SNCR systems. Recently published EPRI guidelines enable utilities to evaluate the feasibility of implementing SNCR on specific units, determine site-appropriate system characteristics, predict performance, and estimate costs.

The guidelines—*SNCR Feasibility and Economic Evaluation Guidelines for Fossil-Fired Utility Boilers* (TR-103885)—are based on data from utility-scale commercial applications and demonstrations described in EPRI's 1993 *State-of-the-Art Assessment of SNCR Technology* (TR-102414). They provide utility engineers with a methodology for taking site-specific factors into account when assessing the suitability of SNCR for any boiler, preparing vendor requests, or evaluating SNCR system designs in-house.

EPRI recently teamed up with two utilities to demonstrate the use of SNCR on two units where combustion occurs at high temperatures (over 3000°F) and NO_x emissions are relatively high. One of these hot units is a 130-MW cyclone-equipped boiler; the other is a 320-MW wet-bottom, split-furnace boiler. To date, SNCR has yielded NO_x reductions of 30% to 40% at these sites, with ammonia levels of 5–10 ppm. EPRI is also exploring the use of SNCR in conjunction with selective catalytic reduction (SCR). If SNCR removes enough NO_x in these hybrid applications, utilities could use SNCR to reduce the required size of SCR installations, thereby potentially avoiding the installation of a separate reactor vessel.

■ *For more information, contact Jeff Stallings, (415) 855-2427, or EPRI's Environmental Assistance Center, (800) 322-3774.*

NYSEG Builds on EPRI Research to Develop Fossil Thermal Performance Advisor


NYSEG

Utilities everywhere recognize the need to improve thermal performance at fossil power plants. But engineers at New York State Electric & Gas Corporation (NYSEG) wanted to reduce plant maintenance costs as well as improve thermal performance. To meet these twin goals, the utility needed the ability to assess the on-line condition of its generating units.

EPRI has been sponsoring fundamental research on advanced algorithms for on-line performance monitoring tools since the 1980s and has worked with various utilities on performance monitoring and improvement projects. Building on EPRI's work and benefiting from the exchange of information at EPRI conferences and meetings of advisory committees on which it served, NYSEG developed a real-time, on-line performance monitoring tool with an expert system for diagnostic capabilities—the Fossil Thermal Performance Advisor, or FTPA™.

FTPA helps plant operators by displaying and diagnosing thermal losses, providing target values for all parameters, organizing the data graphically, and providing advice for problem correction. NYSEG engineers make use of FTPA's ability to perform trending analyses of archived plant data. The system also provides detailed performance reports, helps improve maintenance and outage planning, ensures consistency between operator shifts, and provides remote access to plant data.

NYSEG has already used FTPA to reduce heat rate at its Kintigh station, for estimated savings of $160,000 a year over the next 15 years, and to avoid forced outages at its Homer City Unit 3, for one-time savings of $546,000. The utility estimates total present-value savings of over $2.5 million through the use of FTPA to improve plant performance and avoid forced outages.

FTPA is available from DHR Technologies, Inc., (410) 992-4000.

■ *For more information, contact Ellen Petrill, (415) 855-8939.*

Land and Water Quality

Cofiring MGP Site Remediation Wastes in Utility Boilers

by Ishwar Murarka and Adda Quinn, Environment & Vital Issues Business Unit

ABSTRACT *One strategy for the management of tar and tar-contaminated soils (remediation wastes) from former manufactured gas plant (MGP) sites is to burn them with coal in utility boilers. Both nonhazardous MGP remediation wastes and MGP remediation wastes that have been rendered nonhazardous are candidates for such cofiring. However, test data on cofiring in utility boilers are limited. Through tailored collaboration agreements with member utilities, EPRI is carrying out tests of cofiring to assess its environmental soundness. The preliminary findings of the first two test series—one in a cyclone boiler and one in a pulverized-coal boiler—indicate that cofiring is an environmentally viable option for managing MGP site remediation wastes.*

Utilities need cost-effective methods for the remediation of former manufactured gas plant (MGP) sites contaminated with by-product tars. One possibility is to cofire tar-contaminated soil with coal in utility boilers. However, only nonhazardous solid wastes can be cofired in industrial boilers without extensive regulatory permits. Thus this option can be considered only for tar-contaminated material determined to be nonhazardous upon excavation from an MGP site or for excavated material that can be rendered nonhazardous on-site within a 90-day accumulation period (as required by U.S. Environmental Protection Agency regulations).

According to previous research by EPRI and testing by individual utilities, a high benzene concentration is the primary reason that MGP site remediation wastes exhibit a hazardous characteristic in TCLP (toxicity characteristic leaching procedure) testing. Tarry MGP wastes seldom fail TCLP testing for any other parameter. If excavated MGP material can be managed on-site to reduce its TCLP benzene concentration, then the material is a candidate for cofiring in a utility or similar boiler. (Such cofiring has the additional benefit of utilizing the tar's high Btu value.)

A number of important issues remain to be resolved concerning the cofiring of tar or tar-contaminated soil in utility or similar boilers. More work is needed, for example, in understanding materials-handling problems, selecting methods for rendering tar or tarry soil nonhazardous, determining how well boilers destroy a variety of tar constituents, examining the impact of the material on plant equipment, and assessing possible health, safety, and environmental impacts.

This article presents the preliminary results of two studies in which MGP tar or tar-contaminated soil was cofired with coal in tests in utility boilers. In the first study, the cofired soil was only lightly contaminated with tar and was found to be nonhazardous in TCLP testing. The second study involves the cofiring of MGP materials rendered nonhazardous before cofiring—either tar or highly contaminated tarry soil.

Cofiring lightly contaminated soil

The first study took place in March 1994. In this study, 2100 tons of a clay-rich, cohesive soil that was lightly contaminated with tarry residue from former MGP operations was cofired in a cyclone boiler located near the MGP site. The contaminated soil was transported from the site to the power plant in trucks; the route between the two locations was selected to minimize exposure of the general population. Air monitoring was carried out hourly during staging, using a photoionization detector (PID). Although slight tarry odors were noted in the immediate vicinity of the soil, the PID typically did not detect volatile organic compounds (VOCs) in the air. The only detectable levels of VOCs were indicated by occasional PID readings of less than 0.5 ppm.

The contaminated soil was processed in two stages. In the first stage, a front-end loader on the containment pad was used to mechanically mix contaminated soil and coal to improve materials handling; the result was a 50:50 (by volume) soil-coal mixture. The second stage consisted of several steps carried out in a mobile unit capable of processing up to 25 tons of material each hour. The soil-coal mixture was passed through a clay shearer, a metal separator, and a vibrating machine to remove any material greater than 2 inches in diameter. Large material was crushed in a hammer mill and placed back in the processing stream. During materials processing, the air was monitored hourly, and PID readings typically were less than 0.1 ppm.

After the processing was completed, the soil-coal mixture was ready for blending with coal for the cofiring test. This step, carried out on the coal-handling conveyors, produced a fuel blend containing 4% soil by weight. (The blend was approximately 12:1 by volume of coal to soil-coal mixture.) The final 4%-soil mixture was sized in coal conditioners and loaded into the fuel bunkers of the cyclone boiler. During the fuel-loading process, air monitoring was carried out at several locations every 2 hours. Although some of the locations had detectable levels of VOCs, none of the PID readings were above the action level of 5.0 ppm, and there were no reports from plant personnel of any nuisance odors during the process.

Before each cofiring test, samples of the contaminated soil and the initial and final soil-coal mixtures were collected for analysis. After each test, samples of bottom ash, fly ash, and sluice water were collected and analyzed for a variety of chemical and physical parameters, TCLP metals, and polycyclic aromatic hydrocarbons (PAHs). In addition, baseline conditions were determined before the tests by analyzing samples of the fuel coal, then firing the coal and analyzing its residual products. The results of the analyses were used to assess the efficiency of cofiring in destroying PAHs in the contaminated soil and to determine if physical or chemical parameters changed as a result of the addition of MGP site remediation wastes.

Before cofiring, the physical parameters of the soil-coal mixture were similar to those of the coal. For example, the average heat content was 8230 Btu/lb for the coal and 9400 Btu/lb for the soil-coal mixture; the moisture content was 12% for the coal and 15% for the soil-coal mixture; and the combustible matter (at 550°C) was 87% for the coal and 86% for the soil-coal mixture.

TABLE 1
Total PAH Content
(mg/kg)

	Before Firing				*After Firing*		
	Excavated Soil	*Initial Soil-Coal Mixture**	*Final Soil-Coal Mixture†*	*Coal Only*	*Bottom Ash*	*Fly Ash*	*Sluice Water*
Baseline tests (avg. of three)	—	—	—	2.5	BDL	BDL	BDL
Cofiring test 1	—	74	30	—	BDL	BDL	BDL
Cofiring test 2	—	20	3	—	BDL	BDL	BDL
Cofiring test 3	—	39	6.3	—	BDL	BDL	BDL
Cofiring test 4	325	—	4	—	BDL	BDL	BDL

Note: BDL = below detection limit.
*50:50 mixture by volume.
†4% soil by weight.

The preliminary results indicate that the PAH levels in the residues from the cofiring tests were below the analytical detection limit of 0.008 mg/kg (ppm). Table 1 summarizes the preliminary results on total PAH content for the baseline (coal only) tests and the four cofiring tests; it shows that no PAHs were detected in any cofiring residues. Table 2 shows the concentration ranges of TCLP metals in fly ash samples from the baseline and cofiring tests; for most metals, the baseline and cofiring ranges were similar. Bottom ash samples had no detectable TCLP metals except barium. Thus the preliminary data indicate that in terms of chemical constituents and physical/chemical parameters, the residues from cofiring lightly contaminated MGP site soil were similar to those from burning coal alone.

Cofiring tar and highly contaminated soil

The second cofiring study is nearing completion. Although similar to the first study in many respects, it differed in that it involved the cofiring of heavily contaminated soil as well as tar with TCLP benzene levels above the regulatory limit of 0.5 mg/L. As a result of the higher levels of contamination, an additional stage of materials handling was needed before cofiring. To design this stage of operations, researchers conducted a laboratory study to determine the ratio of tar and coal necessary to render the tarry material nonhazardous according to TCLP testing.

In the laboratory study, coal and tar were mixed in various proportions, and the mixtures were analyzed for total benzene and TCLP benzene. An initial experiment used 10 mixtures containing from 1.5% to 27% tar by weight. A second experiment, carried out to confirm the results, was confined to ratios of tar and coal that, as observed in the initial experiment, yielded TCLP results below the regulatory level. The study findings, shown in Figure 1, indicate that a mixture containing 4.45% tar would have a 97.5% probability of being found nonhazardous in TCLP testing.

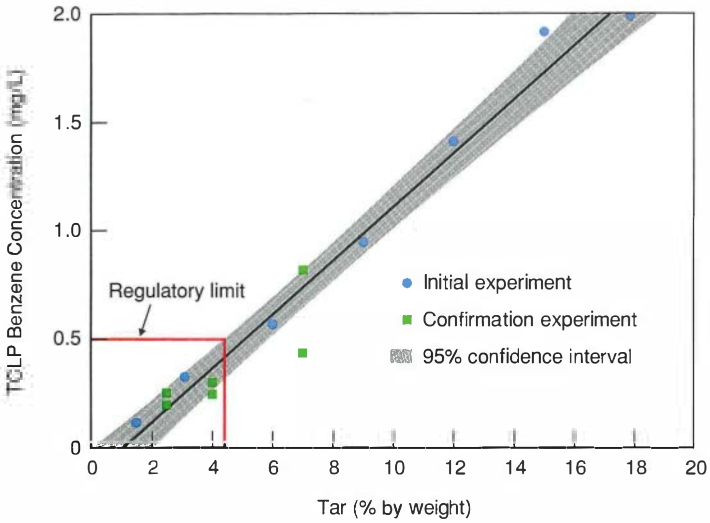
TABLE 2
Metal Concentration Ranges in TCLP Extracts From Fly Ash
(mg/L)

Metal	*Baseline Tests*	*Cofiring Tests*
Arsenic	0.19–0.28	0.52–0.91
Barium	1.3–1.4	BDL–0.65
Cadmium	0.23–0.26	0.2–0.27
Chromium	1.6–2.0	1.6–2.0
Lead	0.29–0.41	BDL–0.42
Mercury	BDL	BDL
Selenium	0.022–0.069	0.077–0.17
Silver	BDL	BDL

Note: BDL = below detection limit.

Furthermore, the study data showed that a rapid-turnaround (2-hour) method for total benzene analysis, previously developed for EPRI by Meta Environmental, could be used to confidently predict a material's TCLP benzene concentration. Using this method, samples were screened quickly and inexpensively for potential TCLP failure. In addition, two new methods were designed and tested as alternative screening techniques for TCLP benzene. One method is a mini-TCLP test that takes about 24 hours to perform, and the other is a headspace benzene test that takes about 1 hour. The results indicate that both methods are promising alternatives for rapid, cost-effective, and reliable predictions of TCLP benzene levels and can be performed on-site. Thus the methods can provide essential information during excavation and materials handling for future cofiring operations.

Figure 1 In connection with cofiring tests of MGP site remediation wastes, researchers analyzed various mixtures of tar and crushed coal for TCLP benzene. Shown here are the results for the mixtures with less than 20% tar. They indicate that a mixture containing 4.45% tar has a 97.5% probability of testing nonhazardous for TCLP benzene.



The laboratory mixing study was completed last May. Cofiring tests at a utility power plant using a pulverized-coal boiler were completed in August. The tests examined four fuel mixtures—two composed of tar (2% or 4% by weight) and crushed coal, and two composed of tarry soil (2.5% or 5% by weight) and crushed coal. For the first two mixtures, tar was combined with crushed coal in a mixing box to the desired composition. Then the mixture was screened, processed in a hammer mill, and screened again (using 1.5-inch and 0.75-inch screens). Oversized materials were rejected and, when time allowed, sent through the process a second time. The final mixture was carried on the power plant conveyor belt to the fuel bunker to await burning. (The bunker feeds three mills that pulverize the material; 95% of the material leaving the mills is less than 200 mesh. Each mill feeds one ring of the boiler.)

For the mixtures of tarry soil and coal, the same procedure was followed, with an additional step. The soil was first mixed with crushed coal to an initial composition of about 26% soil by weight, and more coal was added at the power plant fuel feed hopper until a final mixture consisting of 2.5% or 5% soil was obtained.

About 53 tons of a mixture containing 2.5% tarry soil was used in the initial cofiring test to evaluate flow characteristics, identify processing challenges, and determine how much material is rejected during the screening step. No problems were encountered in this test. A second test was carried out with 67 tons of a mixture containing 5% tarry soil, and again no significant problems were encountered.

As in the first cofiring study, baseline tests using only coal were conducted. Also, extensive monitoring of the materials processing and the cofiring tests was carried out. For example, air was monitored throughout the materials-processing operations; samples of bottom ash, fly ash, and wastewater were collected and analyzed; and stack gas testing was performed. The data analysis will be completed by the end of 1994. The preliminary results show no detectable PAH levels in the ash produced in cofiring.

A viable option

These two cofiring studies indicate that cofiring MGP site remediation wastes with coal in high-efficiency utility boilers is a viable option for the management of these wastes. Preliminary information suggests that cofiring the wastes in boilers can be operationally feasible, financially reasonable, and environmentally sound.

Similar cofiring tests are being carried out with three more utilities. Through these and other cofiring studies, including some involving extended operations, more data on the process's environmental effectiveness will be developed, along with engineering and economic assessments—information that will enable utilities to adopt cofiring as an option for managing MGP site remediation wastes.

Electric Compressors for Gas Pipelines

by Ammi Amarnath, Industrial, Agricultural & Large Commercial Business Unit

Compressors are used on natural gas pipelines to move gas from the fields to the marketplace. Traditionally, most U.S. pipeline compressors have been driven by reciprocating gas engines. Gas turbines have been the second-most-used option, and electric motors have been used only on a limited basis.

A few years ago, the notion of electrically driven compressors would have been unthinkable to most natural gas executives. But today more and more of them are looking at advanced-design, adjustable-speed electric motors to drive compressors for new or expanded pipelines or to replace aging gas-fired units.

Why the electric option?

Three factors are motivating gas pipeline firms to consider the electric option. The first is environmental regulations. Title I of the 1990 Clean Air Act Amendments (CAAA) identified 98 areas of the country, primarily urban, that had not met ambient air quality standards for ozone. These ozone nonattainment areas—many of which are located in the Northeast and in central and southern California—are required to bring ozone levels into compliance by certain dates by reducing emissions of nitrogen oxides and volatile organic compounds. The main NO_x emissions requirements applying to reciprocating gas engines in these areas are as follows:

- Existing sources: Annual NO_x emissions greater than 25 tons must be reported to the state environmental agency.
- New sources: New or upgraded reciprocating engines at existing compressor stations require emissions offsets.
- Offset provisions: Between 1.1 and 1.5 tons of NO_x emissions allowances are required for each ton of new or excess emissions, depending on an area's ozone classification.
- Trading: Companies that "overcontrol" their emissions, thus achieving reductions greater than required, may be able to sell the excess to others as credits.
- Increasing restrictions: For the 24 most-severe ozone nonattainment areas, states will require a reduction of 3% per year in NO_x emissions.

Most pipeline compressor stations are a major source of NO_x emissions—particularly stations with reciprocating gas engines. Reciprocating engines installed before 1955 usually cannot comply with the new standards, requiring substantial capital expenditure for upgrading. Because electrically driven compressors emit no NO_x, their installation as new units or as replacement units for aging gas-driven compressors is an attractive alternative for gas transmission and storage companies.

New economic realities are a second factor in the growing interest in electric compressors. When interstate pipeline firms were regulated, the cost of the fuel used to drive compressors was simply passed on to ratepayers. Unbundling transmission from other gas industry segments (as required by the Federal Energy Regulatory Commission in Order 636), however, means that gas pipeline companies must track fuel in their overall system costs. Electricity often emerges as the most economical option when all costs are considered.

Within individual ozone nonattainment areas, those companies whose NO_x emissions are below the regulatory level may be able to sell credits to companies whose emissions are above the regulatory level. Since electrically driven compressors emit no NO_x, companies that use electricity will maximize their opportunities for selling emissions credits rather than having to buy them.

A third factor leading pipeline companies to weigh their compressor options is the availability of new technology for reducing emissions. The CAAA refer to three categories of control technology:

- Reasonably achievable control tech-

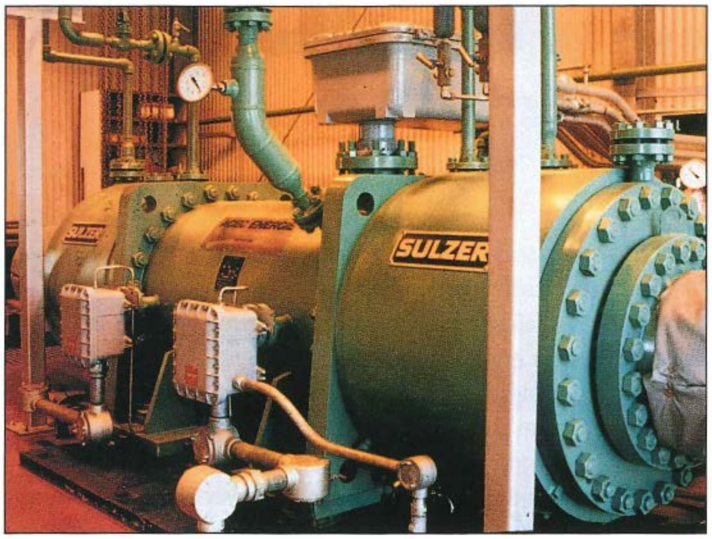
ABSTRACT *Three factors—environmental regulations, economics, and new technology—are motivating gas pipeline companies to consider using electric motors instead of reciprocating gas engines in current and future compressor stations. Recent EPRI research indicates that the use of electrically driven compressors is often an economically attractive option for complying with regulations on emissions of nitrogen oxides. By promoting this option, electric utilities have an opportunity to increase their market while reducing NO_x emissions in their service territories.*

nology (RACT). For compressor NO_x emissions, the major examples are air/fuel control equipment and spark/ignition retardation systems. These technologies can reduce NO_x emissions from reciprocating gas engines by 10–40%.

□ Best available control technology (BACT). The major examples are catalytic converters for reciprocating engines and new gas-turbine-driven compressors that employ dry low-NO_x combustors.

□ Lowest achievable emission rate (LAER) technology. The primary example is electric motors, which produce no emissions.

Figure 1 In Mopico's advanced electric unit, a compressor is located at each end of the motor. The motor can operate at variable speed, requires no external cooling, is virtually maintenance free, and emits no NO_x.



Mopico, a unit of Pipeline Compressor Systems, Inc., has developed a new adjustable-speed LAER electric motor/compressor (Figure 1) that is as much as 65% more efficient than some gas-driven compressors. Mopico's compressor is also cheaper to build and is virtually maintenance free. Electromagnets suspend its only moving part, the motor shaft, eliminating the need for lubrication oil.

In 1991, Transcontinental Gas Pipe Line Company and Transco Energy Ventures Company replaced four inefficient reciprocating-engine-driven compressors at a station in Billingsley, Alabama, with a single 8000-hp Mopico unit. The installed cost of the unit was $4.5 million, or 20–30% less than for new gas-driven units. The added load poses little problem for Alabama Power Company, which built a transmission line to serve the station.

Until four years ago, no interstate gas pipeline companies had asked Mopico to bid when they needed new compressors. Now, according to Mopico vice president John Fagg, 70–80% of them solicit electric compressor bids for expansion or replacement projects.

Analysis of compliance options

Recently EPRI's Chemicals & Petroleum Office completed a marketing study for a utility in the Southwest. The study identified favorable opportunities for advanced electric compressors—not only on interstate pipelines but also on shorter, intrastate lines and even on lines in natural gas fields and storage caverns.

As part of this study, the researchers performed an economic analysis of five NO_x emissions compliance options for reciprocating gas engines. In order to ensure a broad base of site-specific, realistic operating information for this analysis, the researchers surveyed the emissions of 200 reciprocating engines—representing 325,000 hp—at 50 pipeline compressor stations. The results of the analysis are presented in the forthcoming report *Electric Motors for Gas Pipeline Compressors, Vol. 1: NO_x Compliance Options for Reciprocating Gas Engines* (TR-104692), available to member utilities through EPRIAMP, (800) 4320-AMP.

The following compliance options were analyzed:

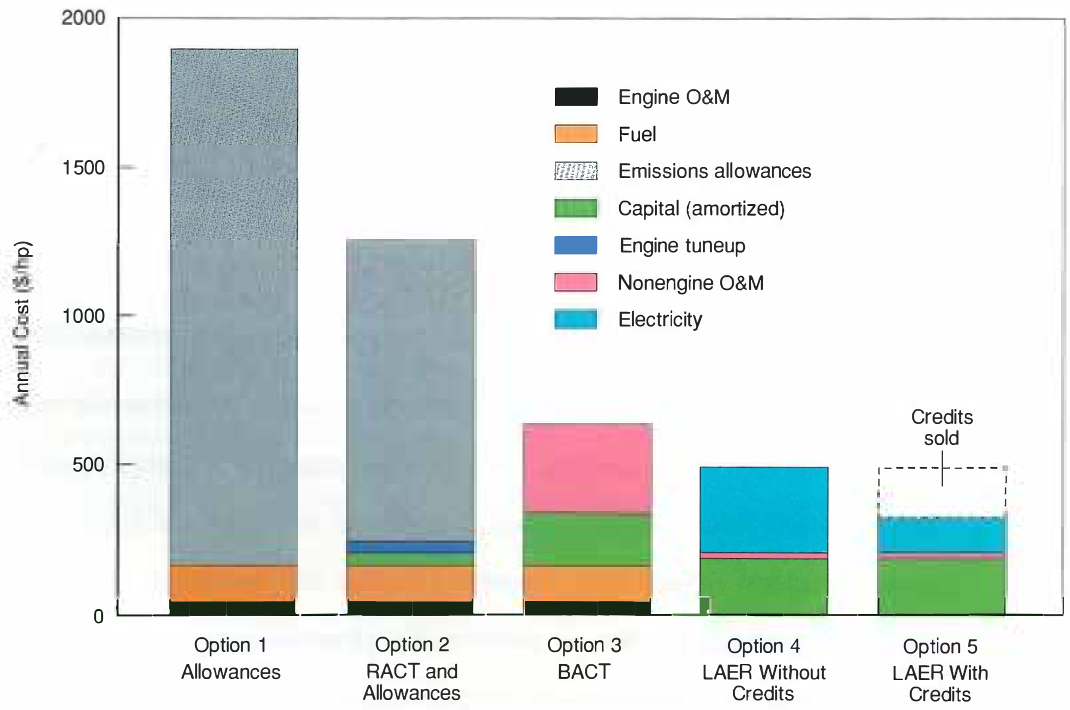
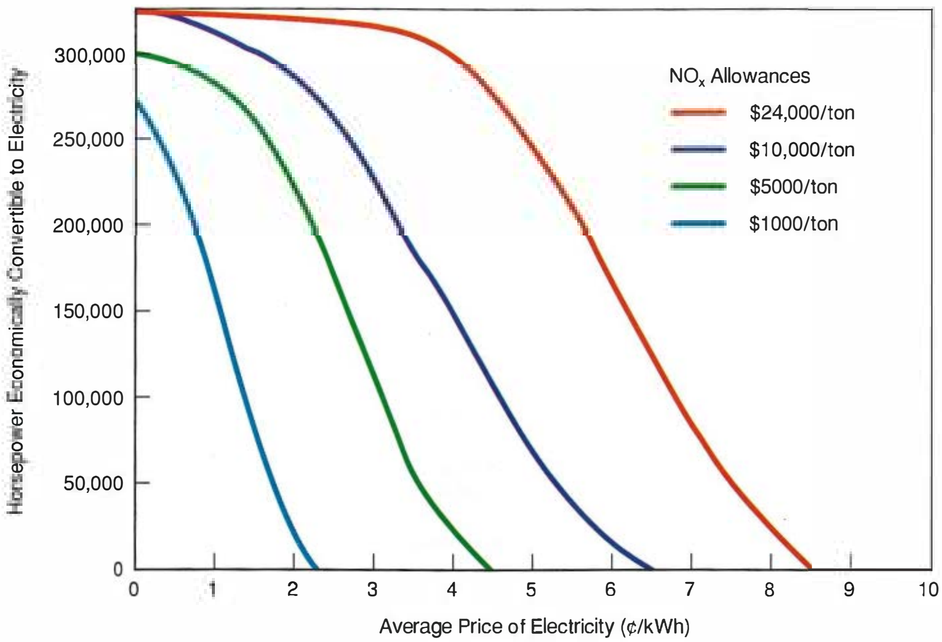


Figure 2 Economic analysis of five NO_x compliance options for a compressor run by a 500-hp, lean-burn, integral reciprocating gas engine at full load. The options involve various compliance measures: the purchase of emissions allowances; the use of RACT, BACT (catalytic reduction), or LAER (electric motor) technology; and the selling of credits resulting from overcompliance. Given the study assumptions ($10,000/ton for NO_x allowances, 3¢/kWh for electricity, and $2/million Btu for natural gas), options 4 and 5—which involve replacing the reciprocating engine with an electric unit—are the most attractive.

Figure 3 According to an EPRI survey of 50 pipeline compressor stations, two critical variables—the market value of NO_x allowances and the price of electricity—affect the economics of converting from gas-driven to electrically driven compressors. Plotting these variables, this graph shows the gas-driven compressor horsepower (out of a total of 325,000 hp surveyed) that can be economically converted to electricity.



□ Option 1: Purchase NO_x emissions allowances.

□ Option 2: Install technology classified as RACT, and purchase NO_x emissions allowances as required.

□ Option 3: Install technology classified as BACT (minimal purchase of emissions allowances required).

□ Option 4: Replace engine with LAER technology (i.e., electric motor) without credits for overcompliance.

□ Option 5: Replace engine with LAER technology, and sell credits generated by overcompliance.

Figure 2 shows the results of the analysis for a 500-hp unit at full load. For the first two options, the largest expense is the cost of NO_x emissions allowances; for the third option, it is the nonengine operating and maintenance cost; and for the fourth and fifth options, it is the cost of electricity.

The researchers found that two variables have a critical impact on the economics of compliance options—the market value of NO_x emissions allowances and the price of electricity. For example, at $10,000/ton for NO_x emissions allowances and 3¢/kWh, electrification would be less costly than the use of reciprocating engines for nearly 250,000 hp (77%) of the 325,000 hp surveyed. At the same market value for allowances but at 5¢/kWh, 60,000 hp (18%) would benefit from electrification. Figure 3 shows the effects of these variables.

To sum up

The owners of reciprocating-gas-engine-driven compressors who find that their systems cannot comply with the new NO_x requirements have a number of options. They can do nothing and purchase NO_x allowances, implement combustion controls, invest in postcombustion controls, or replace reciprocating engines with electric units.

In the past, gas pipeline companies and gas producers have been reluctant to use a power source other than gas-driven reciprocating engines or turbines for compressor applications. This situation appears to be changing, particularly among the major pipeline companies.

Although NO_x emissions limitations do not apply to areas that now meet ozone requirements, such limitations may well be imposed in the future. In fact, many pipeline operators believe that more emissions restrictions, even in current ozone attainment areas, are a certainty. Given this situation, electric utilities are urged to communicate to their customers the economic and environmental benefits of the electric option.

EPRI's industrial activities to identify utility-specific market opportunities for advanced electric compressors on gas pipelines are ongoing. Utilities interested in participating should contact Richard Schmeal at the EPRI Chemicals & Petroleum Office, (713) 963-9307.

New Contracts

Project	Funding/ Duration	Contractor/EPRI Project Manager
Customer Systems		
Development of Commercial-Sector Applications of the Nonintrusive Load-Monitoring System (RP2568-36)	$99,700 24 months	Massachusetts Institute of Technology/*L. Carmichael*
Electric Vehicle Development (RP2664-28)	$250,300 4 months	Renaissance Cars/ *J. Guy*
Development, Demonstration, and Field Testing of Active Power Line Conditioners (RP2935-29)	$225,000 17 months	Power Quality & Electrical Systems/*M. Samotyj*
Power Quality Database (RP2935-31)	$474,000 16 months	Electrotek Concepts/ *M. Samotyj*
State-of-the-Practice Handbook: Impact Evaluation of Nonresidential Demand-Side Management Programs (RP3269-32)	$120,000 6 months	Xenergy/*R. Gillman*
Design and Fabrication of Electric Vehicle Charging-Station Prototypes (RP3304-19)	$497,000 11 months	Square D Co./*G. Purcell*
Application of Performance Measurement and Management System to Power Generation, Maintenance, and Operations (RP3716-1)	$525,000 8 months	Venture Associates/ *P. Sioshansi*
Residential End-Use Data Development Project (RP3819-17)	$65,000 4 months	Quantum Consulting/ *R. Gillman*
EPRI Partnership for Industrial Competitiveness: Industrial Market Assessment and Strategic Analysis (RP3829-14)	$147,000 10 months	Resource Dynamics Corp./*W. Smith*
Performance of Rooftop Packaged HVAC Systems (RP3831-1)	$358,100 17 months	Energy Simulation Specialists/*W. Krill*
Stock Characterization and Energy Savings Potential of Forced-Air Systems in Frostbelt Homes (RP3841-2)	$250,000 19 months	Synertech Systems Corp./ *S. Kondepudi*
Quality New-Construction HVAC Program (RP3841-3)	$125,000 6 months	Proctor Engineering Group/*S. Kondepudi*
Evaluation and Analysis of Restaurant Subsystems (RP3851-1)	$454,200 20 months	Pennsylvania State University/*W. Krill*
Industrial Efficiency Optimization Using Pinch Analysis: Kelco Plant (RP3879-8)	$63,800 15 months	TENSA Services/ *A. Amarnath*
Ground-Source Heat Pump Grouting Research (RP3881-1)	$413,000 20 months	South Dakota State University/*C. Hiller*
Performance of Residential Air Conditioners at High Outdoor Ambient Temperatures (RP3884-1)	$112,800 12 months	Texas Engineering Experiment Station/ *S. Kondepudi*
Combustion Turbine Inlet Air Cooling (RP3890-2)	$80,000 30 months	University of Wisconsin, Madison/*M. Khattar*
Partnerships With Regional/Local Centers and Member Utilities for Industrial Electrotechnology Development and Deployment (RP3901-1)	$2,215,100 60 months	Northampton Community College/*W. Smith*
Spatial (Geographic-Information-System-Based) Decision Support System for Utility Marketing Departments (RP3904-1)	$135,000 5 months	Argonne National Laboratory/*P. Meagher*
Assessment of Alternative Iron-Making Technologies (RP4810-1)	$60,000 5 months	Julian Szekely and Associates/*E. Eckhart*
Advanced Communication Network and Controls for Residential Customers (RP4817-1)	$594,900 19 months	Southern California Edison Co./*L. Carmichael*
Development of Improved Methods for Integrating Demand-Side Options Into Resource Planning (RP4819-1)	$624,700 35 months	Synergic Resources Corp./*G. Heffner*

Project	Funding/ Duration	Contractor/EPRI Project Manager
Environment & Vital Issues		
Epidemiologic Study of Electric Utility Employees Exposed to Magnetic Fields (RP2964-27)	$246,300 12 months	University of North Carolina/*L. Kheifets*
Transient Responses of Grasslands and Forests to Climate Change (RP3316-7)	$210,400 12 months	Colorado State University/ *L. Pitelka*
Magnetic Field Shielding (RP3959-3)	$1,603,500 24 months	Electric Research & Management/*R. Lordan*
EMF Workstation (RP3959-4)	$250,100 12 months	Enertech Consultants/ *R. Lordan*
Superparamagnetic Polymeric Shielding Materials for Magnetic Fields (RP3959-5)	$198,700 13 months	SRI International/*R. Lordan*
MYGRT, MOSES, and ROAM Models (RP9015-15)	$150,600 17 months	Tetra Tech/*I. Murarka*
Remediation of Pentachlorophenol/Heavy Polycyclic Aromatic Hydrocarbon Contamination in a Pole Yard (RP9024-6)	$299,300 4 months	ESU Inc./*I. Murarka*
SARMAP Ozone Modeling Extension (RP9052-1)	$190,000 14 months	Pacific Gas and Electric Co./*A. Hansen*
Coal Tar Distribution in a River Downstream of a Former Manufactured Gas Plant Site (RP9054-3)	$252,300 9 months	Metcalf & Eddy/*I. Murarka*
Evaluation of Soil Vapor Extraction at a Manufactured Gas Plant Site (RP9054-4)	$403,500 16 months	Atlantic Environmental Services/*I. Murarka*
Survey of Utility Combustion Waste Management Practices (RP9055-1)	$118,200 6 months	Science & Technology Management/*I. Murarka*
Management Options for Pyrites and Mill Rejects (RP9055-2)	$109,700 7 months	Tetra Tech/*I. Murarka*
Risk Analysis Case Studies (RP9064-1)	$474,000 14 months	Decision Focus/ *R. Goldstein*
Northeast Air Quality Study: Coordination (RP9072-1)	$376,600 8 months	Sonoma Technology/ *P. Mueller*
Northeast Air Quality Study: Quality Assurance and Auditing (RP9072-2)	$66,000 3 months	Desert Research Institute/ *P. Mueller*
Northeast Air Quality Study: Sampling Sites, Connecticut and New York (RP9072-6)	$105,600 3 months	Radian Corp./*P. Mueller*
Generation		
Development of the Object-Oriented Coal Quality Software CQIM++ (RP1400-30)	$157,700 18 months	Black & Veatch/ *D. O'Connor*
Advanced Display Technology for Hard-Panel Emulation (RP3384-6)	$993,500 40 months	TRAX Corp./*R. Fray*
Compact Simulator Hard-Copy Panel Interface and Advanced Model Development (RP3384-21)	$1,025,000 17 months	GP International Engineering & Simulation/ *R. Fray*
Solid-Oxide Fuel Cell System Definition for Distributed Power Applications (RP3608-2)	$93,800 9 months	Technology Management/ *D. Rastler*
Wind Turbine Performance Verification (RP3691-2)	$8,552,400 65 months	Central and South West Services/*E. Davis*
Photovoltaic Systems at Dallas Energy Park (RP3779-2)	$3,087,800 48 months	TU Electric/*F. Goodman*
Houston Photovoltaic System Application Experiments (RP3779-4)	$137,800 22 months	Houston Lighting & Power Co./*F. Goodman*
O&M Workstation Development: Consolidated Edison (RP3782-1)	$62,000 9 months	Bogan/*R. Colsher*
Management and Technical Support: O&M Workstation Project (RP3782-3)	$60,000 5 months	Woyshner Instrument Service Co./*R. Colsher*
Electric Motor Predictive Maintenance (RP3834-1)	$150,000 6 months	Bogan/*R. Colsher*

Project	Funding/ Duration	Contractor/EPRI Project Manager
Electric Motor Predictive Maintenance Program: Machine and Lubricant Analysis (RP3834-2)	$204,100 44 months	Predict Technologies/ *R. Colsher*
Dish–Stirling Engine Utility Evaluation (RP3842-1)	$400,000 24 months	Cummins Power Generation/*D. Morris*
GEMS (Generator Expert Monitoring System) Commercialization (RP3868-1)	$1,019,800 22 months	General Electric Co./ *J. Stein*
Development of a High-Accuracy, High-Resistance Temperature Detector for High-Temperature Applications (RP3876-4)	$618,000 30 months	Martin Marietta Energy Systems/*J. Weiss*
Control Maintenance Workstation: Development and Demonstration (RP3891-1)	$225,300 24 months	Automation Technology/ *M. Perakis*
Chlorine Dioxide Treatment of Zebra Mussels (RP3894-3)	$120,600 10 months	PSI Energy/*J. Tsou*
Fabrication and Testing of IMHEX Fuel Cell Stack for 250-kW Demonstration Power Plant (RP3932-1)	$502,400 16 months	M-C Power Corp./ *R. Goldstein*
Building Code Approval for Autoclaved Cellular Concrete (RP9040-2)	$99,600 16 months	GAI Consultants/ *D. Golden*

Nuclear Power

Project	Funding/ Duration	Contractor/EPRI Project Manager
Knowledge-Assisted Tagout System (RP3341-1)	$1,119,700 42 months	General Physics Corp./ *J. Gisclon*
Programmable Logic Controller Safety-Grade System (RP3410-4)	$184,000 17 months	Southern Company Services/*J. Naser*
Dissolved Oxygen Control to Minimize Corrosion-Product Formation and Transport (RP3419-2)	$160,700 18 months	CENTEC-21/*H. Ocken*
Electrochemical Noise Monitoring (RP3468-7)	$150,000 15 months	Empire State Electric Energy Research Corp./ *R. Pathania*
Low-Level-Waste Vitrification (RP3500-29)	$200,000 20 months	Vectra Technologies/ *C. Wood*
Main Feedwater Pump Maintenance Guide (RP3814-4)	$143,600 11 months	QES, Inc./*K. Barry*
Nondestructive Evaluation Technology for Vessel Internals Applications (RPB201-1)	$216,900 5 months	J. A. Jones Applied Research Co./*J. Lance*
Verification of General Electric TRACQ Shroud Load Calculations (RPB301-4)	$53,100 4 months	S. Levy/*R. Carter*
Fuel-Cladding Integrity at High Burnups (Part 2) (RPX103-5)	$177,600 27 months	Institute of Nuclear Energy Research/*S. Yagnik*

Power Delivery

Project	Funding/ Duration	Contractor/EPRI Project Manager
Power Transformer Insulation Behavior During Overload (RP1289-8)	$249,700 18 months	Monash University/ *S. Lindgren*
In-Service Performance Evaluation of Distribution Cables (RP2436-2)	$1,597,100 88 months	Orange and Rockland Utilities/*B. Bernstein*
Advanced Concepts in Energy Resource Scheduling and Generation Control: Constrained Dynamic Dispatch (RP3555-5)	$444,800 21 months	ESCA Corp./*D. Sobajic*
Support of C-Criteria for Interconnected Power System Operation (RP3555-10)	$258,000 10 months	Priority-Based Control Engineering Co./ *D. Maratukulam*
Nonconductive Tower Evaluation (RP3748-5)	$98,800 7 months	General Electric Co./ *A. Hirany*
Evaluation of Post Insulators Coated With Room Temperature Vulcanized Silicone Rubber (RP3787-6)	$162,500 12 months	General Electric Co./ *A. Hirany*
Substation Reliability-Centered Maintenance (RP3882-1)	$168,300 20 months	Halliburton NUS Corp./ *M. Hammam*
Chronological Cost Simulation of Demand-Side Programs (RP3902-1)	$540,000 36 months	University of Oklahoma/ *R. Adapa*
SMALLTALK Demonstration (RP3928-7)	$100,000 1 month	Dev Team One/*A. Kader*
New Applications Program for Distribution Engineering Workstation (RP3952-1)	$318,100 15 months	Electric Distribution Design/*H. Ng*
Transformer Load and Fault Gas Analyzer (RP3970-1)	$337,600 17 months	Micromonitors/ *S. Lindgren*
Framework for Strategic Asset Management (RP7678-4)	$170,000 5 months	Strategic Decisions Group/ *L. Rubin*
Superconducting Cable Construction and Testing (RP7921-6)	$3,359,000 51 months	Pirelli Cable Corp./ *D. Von Dollen*

Strategic R&D

Project	Funding/ Duration	Contractor/EPRI Project Manager
Constraint Processing for Electric Power Problems (RP8014-6)	$112,500 36 months	University of California, Irvine/*D. Sobajic*
Application of Parallel Computing to Power Plant Simulation (RP8014-7)	$200,300 28 months	Computer Simulation Technologies/*L. Agee*
Fracture Analysis of Composite Insulators (RP8019-6)	$345,200 36 months	Oregon Graduate Institute of Science and Technology/*J. Stringer*
Polymeric Ultrathin Films as Bonded Lubricants, Coat'ngs, and Membranes (RP8019-7)	$79,100 17 months	Colorado State University/ *B. Bernstein*
Response of Grasslands to Elevated CO_2 (RP8020-3)	$121,000 16 months	CSIRO/*L. Pitelka*
Whitings: A Potential Model for CO_2 Abatement (RP8020-5)	$54,000 12 months	University of South Florida/ *R. Goldstein*
Iron Deficiency in Marine Phytoplankton (RP8021-5)	$257,600 28 months	Woods Hole Oceanographic Institution/ *D. Porcella*
Genetic Ecology: Pentachlorophenol and Polycyclic Aromatic Hydrocarbon Degradation (RP8021-6)	$125,000 12 months	Rutgers University/ *R. Goldstein*
Quantitative Imaging of Frost (RP8034-7)	$50,000 14 months	University of Illinois, Urbana/*S. Kondepudi*
Ultralow-Frequency Magnetic Field Measurements Along the Hayward Fault (RP8035-2)	$75,000 7 months	Stanford University/ *H. Tang*
Enhancement of a Real-Time Monitoring System for San Francisco Bay Area Earthquakes (RP8035-4)	$65,000 7 months	University of California, Berkeley/*J. Schneider*
Spallation Resistance of Thermally Grown Oxide Films (RP8041-5)	$146,000 9 months	DOE/*J. Stringer*
Mechanistic Studies of Chloridization of Iron- and Nickel-Base Alloys (RP8041-6)	$122,200 12 months	Ohio State University Research Foundation/ *J. Stringer*
Anode Materials for Low-Temperature (700–900°C) Solid-Oxide Fuel Cells (RP8062-5)	$150,300 25 months	Massachusetts Institute of Technology/*R. Goldstein*
Radial-Flow Solid-Oxide Fuel Cell Development (RP8062-7)	$152,500 24 months	Technology Management/ *R. Goldstein*
Ion-Beam-Assisted Deposition Process for High-Current High Temperature Superconductors (RP8065-7)	$494,900 36 months	Stanford University/ *D. Von Dollen*
Exploratory Synthesis at High Pressures: Routes to New Oxide and Sulfide Superconductors (RP8066-3)	$155,000 36 months	IBM Corp./*P. Grant*
Technical Assistance in High-Temperature Corrosion (RP9000-28)	$381,300 21 months	Battelle Memorial Institute/ *J. Stringer*
Behavior of Chlor'ne During Coal Combustion in Atmospheric Fluidized-Bed Combustion Systems (RP9002-13)	$115,000 11 months	Western Kentucky University/*A. Mehta*

New Technical Reports

Requests for copies of reports should be directed to the EPRI Distribution Center, 207 Coggins Drive, P.O. Box 23205, Pleasant Hill, California 94523; (510) 934-4212. There is no charge for reports requested by EPRI member utilities. Reports will be provided to others in the United States for the price listed or, in some cases, under the terms of a license agreement. Those outside the United States should contact the Distribution Center for price information.

CUSTOMER SYSTEMS

Electric Utility Survey of Residential Ventilation Issues
TR-103802 Final Report (RP2417-22); $200
Contractor: Energy International, Inc.
EPRI Project Manager: J. Kesselring

Uncertainty Analysis of the Measured Performance Rating Method
TR-103804 Final Report (RP2417-16); $200
Contractor: NAHB Research Center, Inc.
EPRI Project Manager: J. Kesselring

New Service Opportunities for Electric Utilities
TR-104345 Final Report (RP3557-2); $200
Contractor: Synergic Resources Corp.
EPRI Project Manager: I. Bran

ENVIRONMENT & VITAL ISSUES

Health Risks Associated With Low Doses of Radiation
TR-104070 Final Report (RP2920-11); $200
Contractors: S. Cohen and Associates, Inc.; ICF Kaiser Engineers
EPRI Project Manager: L. Kheifets

Sites A to Z: A Reference Manual for Site Risk Analysis
TR-104168 Topical Report (RP3372-1); $200
Contractor: Decision Focus Inc.
EPRI Project Manager: R. Goldstein

Key Issues in the Design of NO_x Emission Trading Programs to Reduce Ground-Level Ozone
TR-104245 Final Report (RP3835); $200
Contractor: National Economic Research Associates, Inc.
EPRI Project Manager: G. Hester

Investigation of the Effects of Magnetic Field Exposure on Human Melatonin
TR-104278 Interim Report (RP2964-15); $25
Contractor: Midwest Research Institute
EPRI Project Managers: R. Kavet, R. Black

GENERATION

Predictive Maintenance Guidelines
TR-103374 Final Report (RP2817-1); $200
Contractor: EPRI Monitoring & Diagnostic Center
EPRI Project Manager: R. Colsher

Thermal and Stress Analysis of High-Temperature Tier Filters for GCC and PFBC Power Plants
TR-103866 Final Report (RP3160-1); $200
Contractor: Rheinisch-Westfälische Technische Hochschule Aachen
EPRI Project Manager: M. Epstein

Coal Quality Field Test at Salem Harbor Unit 3 of New England Power Company
TR-104067 Final Report (RP1891-4); $5000
Contractors: Electric Power Technologies, Inc.; Fossil Energy Research Corp.; Southern Research Institute; Southern Company Services; Energy and Environmental Research Corp.
EPRI Project Manager: A. Mehta

Proceedings: 1994 EPRI Workshop on NO_x Controls for Utility Boilers
TR-104284 Proceedings (RP2916); call for price
EPRI Project Manager: K. Zammit

Proceedings: Second International Conference on Managing Hazardous Air Pollutants, 1993
TR-104295 Proceedings (RP2933); $200
Contractor: Decision Focus Inc.
EPRI Project Managers: W. Chow, L. Levin

Unit Commitment DYNAMICS 3.0 User's Manual
TR-104411 Final Report (RP3116-2); $200
Contractor: Decision Focus Inc.
EPRI Project Manager: R. Schainker

NUCLEAR POWER

Review of Technical Issues Related to the Failure of Rosemount Pressure Transmitters Due to Fill Oil Loss
TR-102908 Final Report (RP2409-27); $500
Contractor: ERIN Engineering and Research, Inc.
EPRI Project Manager: R. James

Supplemental Reactor Vessel Surveillance Program Guidelines: Joint EPRI-CRIEPI RPV Embrittlement Studies
TR-103086 Final Report (RP2975-4); $200
Contractor: ABB Combustion Engineering
EPRI Project Managers: T. Griesbach, R. Carter

Statistical Analysis of Steam Generator Tube Degradation: Additional Topics
TR-103566 Final Report (RPS405-9); $500
Contractor: Dominion Engineering, Inc.
EPRI Project Manager: P. Paine

Guidelines for the Selection, Procurement, and Acceptance of Nuclear Safety-Related Mild Environment Motor Insulation for Rewinds
TR-103585 Final Report (RP3186-15); $200
Contractor: Strategic Technology and Resources, Inc.
EPRI Project Manager: F. Rosch

Nuclear Plant Life Cycle Management Information Systems
TR-103858 Final Report (RP2643-35); $200
Contractors: Baltimore Gas and Electric Co.; Grove Engineering, Inc.
EPRI Project Managers: J. Carey, M. Lapides

Sodium Leakage From Condensate Polishers Under Alternate Amine Chemistry
TR-104299 Final Report (RP2977-1); $500
Contractors: Pedro Point Technology, Inc.; CENTEC-21
EPRI Project Manager: P. Millett

POWER DELIVERY

Integrated Graphic Display of Distribution Automation
TR-103600 Final Report (RP2949-13); $5000
Contractor: Power System Engineering, Inc.
EPRI Project Manager: W. Blair

Design Concepts for a Superconducting Cable
TR-103631 Final Report (RP7911-10); $5000
Contractor: Underground Systems, Inc.
EPRI Project Manager: D. Von Dollen

The Value of Transmission Security
TR-103634 Final Report (RP4000-14); $5000
Contractor: University of Wisconsin, Madison
EPRI Project Manager: R. Adapa

UCA and DAIS Information Security Analysis
TR-103773 Final Report (RP2949-4); $5000
Contractor: Computer Sciences Corp.
EPRI Project Manager: W. Blair

Dynamic Brake Control to Reduce Turbine Shaft Transient Torque
TR-103902 Final Report (RP2473-39); $5000
Contractor: Montana State University
EPRI Project Manager: R. Adapa

Analytical Methods for Contingency Selection and Ranking for Dynamic Security Analysis
TR-104352 Final Report (RP3103-3); $5000
Contractor: Siemens Energy & Automation, Inc.
EPRI Project Managers: G. Cauley, P. Hirsch

Proceedings: Disaster Preparedness Conference III
TR-104368 Proceedings (RP3225); $400
EPRI Project Managers: B. Damsky, T. Kendrew

STRATEGIC R&D

Turbine Steam, Chemistry, and Corrosion
TR-103738 Final Report (RP9002-1); $200
Contractors: Stress Technology, Inc.; Jonas, Inc.
EPRI Project Manager: B. Dooley

Effects of Moisture on the Life of Power Plant Cables, Parts 1 and 2
TR-103834-P1–P2 Final Report (RP9001-3); $200
Contractors: Ogden Environmental and Energy Services Co.; Strategic Technology and Resources, Inc.
EPRI Project Managers: B. Bernstein, G. Sliter, R. Viswanathan

Study to Reduce the Cost of Bimetallic Boiler Tubes
TR-104118 Final Report (RP2742-2); $200
Contractor: ERIM
EPRI Project Manager: W. Bakker

EPRI Weld-Related Research Activities
TR-104307 Final Report (RP9002-5); $200
Contractor: Structural Integrity Associates
EPRI Project Managers: W. Childs, R. Viswanathan

Power Quality Market Assessment
TR-104372 Final Report (RP3273-9, -10); $200
Contractor: Arthur D. Little, Inc.
EPRI Project Manager: V. Longo

EPRI Events

JANUARY 1995

30–February 3
Fireside Performance of Coal-Fired Boilers for Optimized Performance and Emissions Control
Irving, Texas
Contact: Ellen Petrill, (415) 855-8939

31–February 2
Infrared Thermography
Charlotte, North Carolina
Contact: Linda Suddreth, (704) 547-6141

FEBRUARY

8–9
Energy Efficiency and the Global Environment
Newport Beach, California
Contact: June Appel, (610) 667-2160

MARCH

2–3
EPRI Partnership for Industrial Competitiveness
Phoenix, Arizona
Contact: Bill Smith, (415) 855-2415

7–9
Retail Market Management: Analytical Systems for Evolving Electricity Markets
San Francisco, California
Contact: Valerie Goodell, (415) 855-2951

13–16
5th NMAC Annual Conference
Amelia Island, Florida
Contact: Linda Suddreth, (704) 547-6141

14–15
Tools for Ecological Risk Assessment
Dallas, Texas
Contact: Bob Goldstein, (415) 855-2593

19–22
EMF Science and Communication Seminar
Santa Clara, California
Contact: Banks & Associates, (612) 623-4600

22–24
Verification and Validation of Digital Systems
Nashville, Tennessee
Contact: Linda Nelson, (415) 855-2127

28–31
1995 SO_2 Control Symposium
Miami, Florida
Contact: Pam Turner, (415) 855-2010

APRIL

5–6
Decision Analysis for Environmental Risk Management
Washington, D.C.
Contact: Bob Goldstein, (415) 855-2593

10–13
1995 International Fossil Simulator Users Group Meeting
Phoenix, Arizona
Contact: Ron Griebenow, (704) 547-6168

MAY

3–5
Continuous Emissions Monitoring Users Group Meeting
Atlanta, Georgia
Contact: Linda Nelson, (415) 855-2127

8–10
13th International Conference on Fluidized-Bed Combustion
Orlando, Florida
Contact: Rich Brown, (415) 855-2216

8–11
4th International Conference on Power Quality: Applications and Perspectives—PQA '95
New York, New York
Contact: Lori Adams, (415) 855-8763

15–19
Joint Symposium on Stationary Combustion NO_x Control
Kansas City, Missouri
Contact: Susan Bisetti, (415) 855-7919

25
Risk Assessment of Power Plant Releases to Surface Waters
Dallas, Texas
Contact: Bob Goldstein, (415) 855-2593

JUNE

1–2
Analysis of Regional Ozone and Visibility Issues in a Risk Framework
Dallas, Texas
Contact: Bob Goldstein, (415) 855-2593

6–7
Decision Analysis for Environmental Risk Management
Dallas, Texas
Contact: Bob Goldstein, (415) 855-2593

13–15
5th EPRI Valve Symposium
Albuquerque, New Mexico
Contact: Susan Otto, (704) 547-6072

19–21
ISA POWID/EPRI Controls and Instrumentation Conference
San Diego, California
Contact: Lori Adams, (415) 855-8763

22–23
EPRI Partnership for Industrial Competitiveness
San Francisco, California
Contact: Bill Smith, (415) 855-2415

28–30
7th National Demand-Side Management Conference
Dallas, Texas
Contact: Pam Turner, (415) 855-8900

JULY

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

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

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

AUGUST

15–18
Particulate Control/Managing Hazardous Air Pollutants
Toronto, Canada
Contact: Lori Adams, (415) 855-8763

22–23
Tools for Ecological Risk Assessment
Dallas, Texas
Contact: Bob Goldstein, (415) 855-2593

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

SEPTEMBER

28
Risk Assessment of Power Plant Releases to Surface Waters
Palo Alto, California
Contact: Bob Goldstein, (415) 855-2593

OCTOBER

4–6
Biodiversity and Ecosystem Health
Jackson Hole, Wyoming
Contact: Pam Turner, (415) 855-2010

5–6
Decision Analysis for Environmental Risk Management
Palo Alto, California
Contact: Bob Goldstein, (415) 855-2593

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

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

NOVEMBER

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

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

Index to 1994 EPRI Journal

EPRI JOURNAL

December 1994

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